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Rebuilding of marine fisheries Part 2: Case studies



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by

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Preparation of this document

This document on rebuilding of marine fisheries has been prepared jointly by the FAO Fisheries and Aquaculture Department and the Fisheries Expert Group of the IUCN Commission on Ecosystem Management (IUCN-CEM-FEG), with the coordination of the European Bureau of Conservation and Development (EBCD) and with contributions from many experts in the field. The document consists of two parts.

Part 1 contains a global extensive review of the literature regarding: the emergence of the concept of fishery rebuilding at stock, multispecies assemblages and ecosystem levels; the evidence available for depletion and rebuilding; the scientific foundations; the natural, and human dimensions of the challenge; the governance framework; and the rebuilding strategies, with their objectives, plans, tools, and performance assessment. Part 1 has been prepared by Serge M. Garcia, Yimin Ye, Jake Rice and Tony Charles.

Part 2 contains a series of case studies of fisheries rebuilding initiatives and processes on different types of resources, in various areas of the world, describing the resources and the fisheries, the depletion process, the rebuilding process and measures, drawing some lessons for the future. The case studies were elaborated by various experts, many of which members of IUCN-CEM-FEG and edited by Serge M. Garcia and Yimin Ye.

FAO extends its appreciation to all authors for their contributions to both Parts.

The graphics were finalized by Genuine Roman Art snc, Rome, Italy. The cover-page was designed by Emanuela D'Antoni. The final formatting and proof-editing were done by Edoardo Mostarda with much skill and patience. Grateful thanks to them.

Abstract

This Part 2 of the global review of “Rebuilding of marine fisheries” provides 13 case studies of fisheries on which rebuilding initiatives were undertaken, in various parts of the world and under different circumstances. A 14th analysis considers specifically the role of closures (MPAs and fishery closures) in rebuilding. The case studies relate to the fisheries on: Northeast Atlantic and Mediterranean Bluefin tuna; Norwegian spring spawning herring and Northeast-Atlantic cod; Southeast Australia multispecies (scalefish and sharks); Japanese sardine, anchovy and chub mackerel; Western Australia snapper, multispecies demersal resources and scallop; South African hakes, sardine and rock lobster; and the emblematic Canadian (Newfoundland) cod. The MPA analysis considers many examples of MPAs and fishery closures, including the Great Barrier Reef. This small number of cases illustrates nonetheless a number of contrasting situations and the multiple dimensions of the rebuilding challenge regarding: the nature of the resources; types of governance; types of fisheries; environmental and socioeconomic contexts; causes of depletion; information richness; and outcomes. A number of lessons are learned regarding: the triggering factors; the likelihood of success in rebuilding; the importance of reactivity, timeliness and clarity of objectives; the weakly predictable nature of the process; the uncertainty inherent in rebuilding trajectories; the needed improvements in the legal, policy, governance and management frameworks; the rebuilding and post-rebuilding regimes; economic and social considerations; science & policy issues; environmental issues; enabling and limiting factors and challenges.

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Abbreviations and acronyms

B	Biomass
B_{lim}	Minimum (Safe) Biological Limit
B_{MSY}	Biomass at the MSY level
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DFO	Department of Fisheries and Oceans (Canada)
EAF	Ecosystem Approach to Fisheries
EEZ	Exclusive Economic Zone
F	Fishing mortality
FAO	Food and Agriculture Organization of the United Nations
F_{MSY}	Fishing mortality at the MSY level
HRC	Harvest Control Rule
ICCAT	International Commission for the Conservation of Atlantic Tuna
ITQ	Individual Transferable Quota
IUCN	International Union for Conservation of Nature
LOSC	United Nations Law of the Sea Convention
LRP	Limit Reference Point
MCS	Monitoring, Control and Surveillance.
MPA	Marine Protected Area
MSE	Management Strategy Evaluation
MSY	Maximum Sustainable Yield
NAFO	Northwest Atlantic Fisheries Organization
NEAFC	Northeast Atlantic Fisheries Commission
ICSEAF	International Commission for Southeast Atlantic Fisheries
NEA	Northeast Atlantic
NGO	Non-Governmental Organization
OECD	Organisation for Economic Co-operation and Development
OMP	Operational Management Procedure
RFMO	Regional Fishery Management Organisation
SARA	Species At Risk Act (Canada)
SSB	Spawning Stock Biomass
SESSF	Southern and Eastern Scalefish and Shark Fishery (Australia)
TAC	Total Allowable Catch
TRP	Target Reference Point
TURF	Territorial Use Right in Fisheries
UNCED	United Nations Conference on Environment and Development
UNCHE	United Nations Conference on the Human Environment
UNCLOS	United Nations Law of the Sea Conference
UNEP	United Nations Environment Programme
UNFSA	United Nations Fish Stock Agreement
UNGA	United Nations General Assembly

The Eastern Atlantic and Mediterranean bluefin tuna: an archetype of overfishing and rebuilding?

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Abstract

The overexploitation of East Atlantic and Mediterranean bluefin tuna (ABFTE) stock has been considered as an archetype of overfishing and general mismanagement of national and international fisheries bodies. The crisis highlighted, among other things, the fact that uncertainties that are inherent to any scientific advice can be used in lobbying to attempt to discredit science-based management. It also showed how interactions between science and management can change through time according to public awareness and opinion. This long and highly publicized crisis finally came to an end, in 2009, when ICCAT, under the pressure of NGOs and public opinion, fully endorsed the scientific advice within a rebuilding plan. Nowadays, the ABFTE stock is recovering, even more quickly than expected, although uncertainties involved in current scientific advice do not allow the precise quantification of the level of this recovery. Despite this, the case of the ABFTE stock clearly demonstrates that the effective management of international fisheries that exploit highly valuable species and have been overexploited for decades is still possible when there is strong political will.

1. INTRODUCTION: DESCRIPTION OF THE FISHERY

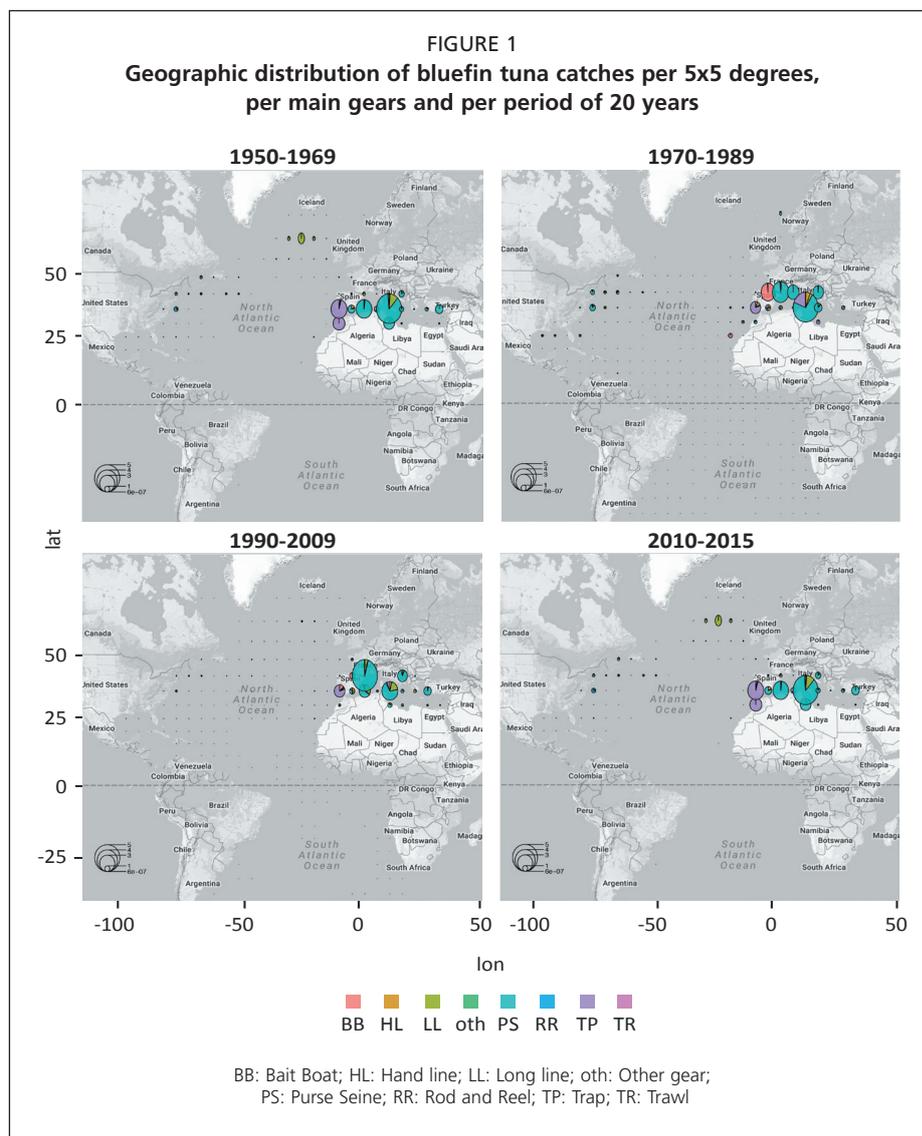
1.1 History

The tuna trap is one of the most ancient fishing systems targeting bluefin tuna in the Atlantic and the Mediterranean, particularly along the Spanish, Italian, Portuguese and Moroccan coasts (Ravier and Fromentin, 2001). Trap uses passive nets placed in the migratory path of bluefin tuna and was the most important fishing gear for centuries. Despite conspicuous long-term fluctuations, traps caught, in average, up to 15,000 tonnes/year (Ravier and Fromentin, 2002). After 1950, this gear was gradually replaced by longline and purse seine, but after a drop in the 1970s to the 1990s trap catches have increased again and represent up to 10% of the total catches (Figures 1 and 2).

Purse seiners became a major fishery catching ABFTE in the northeast Atlantic during the 1950s and then in the Mediterranean Sea since the 1970s (Fromentin, 2009, Figure 1). This fishery comprised vessels from France, Spain, Italy, Tunisia, Turkey and Croatia and its catch represents more than 50% of the reported ABFTE catches since 2000 (Figure 2). Initially, this fishery operated near the coast, on small young schooling bluefin tuna. In the mid-1980s, some fleets started exploring spawners

aggregations in the Balearic Islands area, the Ionian Sea around Malta and later (Fromentin and Powers, 2005). By the early 2000s, the purse seine fishery expanded its fishing area to Libya and Egypt in the Levantine Basin and became the main provider of live fish to tuna fattening farms.

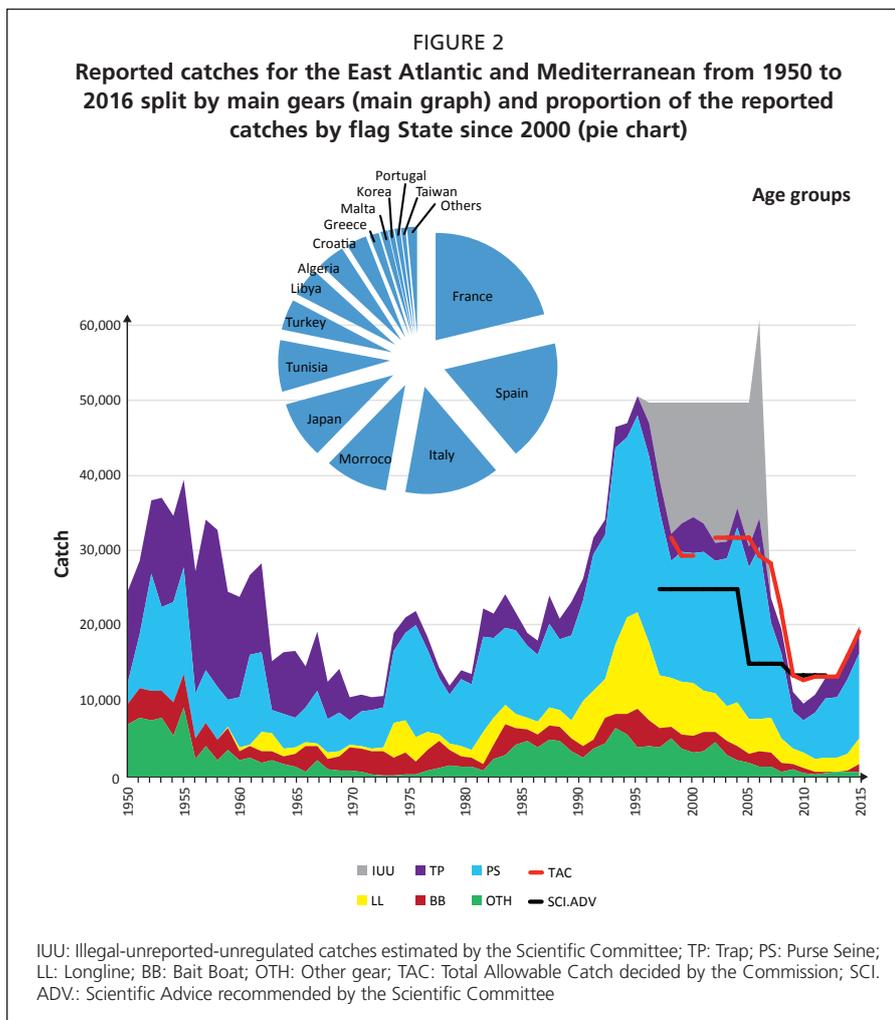
The Japanese longliners had operated in the Eastern Atlantic since the late 1950s and in the Mediterranean since the 1970s, targeting large fish and making substantial catches in the Mediterranean until the 1990s (Mather et al., 1995). Since then it has relocated in the Northeast Atlantic within waters under the Gulf Stream influence (**Figure 1**). Small scale longliners from various coastal countries also operate along the coasts of the Mediterranean, mostly on small- to medium-size bluefin tuna.



The bait-boat fishery (i.e. a pole and line fishery using live bait) was introduced in the Basque country in 1948. Traditionally, the bluefin tuna fishery operated in the south-eastern area of the Bay of Biscay and lasted from June to October (**Figure 1**). Most of the catches are composed by juveniles (1-4 years) and are usually concentrated in a very limited area (Cort and Abaunza, 2015). This fishery made its higher catches in the 1950s and 1960s and operated at a lower level since the 1970s.

1.2 The market

ABFTE was traditionally canned or sold to the Mediterranean fresh market at a rather low value until the rise of the sashimi market in the 1980s, which deeply transformed the market (Fromentin and Powers, 2005). This new and strong demand for fresh ABFTE came from Japan because of increasing domestic demand, but also because of overfishing of the southern bluefin tuna, which used to be the main source of fresh tuna for the Japanese market (Polacheck, 2002). Consequently, the value of ABFTE increased in the following decades and bluefin tuna became, in the media, the fish that was worth its own weight in gold when quoting the New Year auctions on the Tsukiji fish market in Tokyo. Unfortunately but, not surprisingly according to the “race-for-fish” strategy (see Hilborn et al.,2003), the growing value of ABFTE induced a sharp increase in the fishing efficiency and capacity of various fleets during the 1990s and 2000s, especially in the Mediterranean Sea. In addition, new storage technologies and farming practices introduced in the late 1990s strongly reinforced the “race-for-fish”, which finally led to a severe and uncontrolled overcapacity that in turn generated a critical overexploitation of the resource (Fromentin and Powers, 2005).



Consequently, ABFTE fisheries crystallised most of the problems found in many fisheries, i.e. severe overcapacity, open access in international waters, geographical expansion of the fisheries, high market value and deficient governance at both international and national levels (Garcia and Grainger, 2005; Hilborn, 2007; Pauly et al., 2002). Therefore, Non-Governmental Organisations (NGOs) publicised Atlantic bluefin tuna (ABFT), especially the East Atlantic and Mediterranean stock (ABFTE) that supports the bulk of ABFT catches, as the archetype of overfishing and general mismanagement of the world fisheries (e.g. Greenpeace, 2006; WWF, 2008).

2. FISHERIES MANAGEMENT HISTORY

The International Commission for the Conservation of Atlantic Tunas (ICCAT) is the Regional Fisheries Management Organisation (RFMO) established in 1969 to monitor and manage ABFT and other tuna and tuna-like species of the Atlantic Ocean. As all five RFMOs responsible for tuna fisheries, ICCAT includes: (i) a scientific body that aims at collecting and analysing fisheries data to evaluate stock status and propose management recommendations; (ii) a management body that endorses conservation and management measures and decides the budget of the RFMO; and (iii) a secretariat that performs administration and coordination functions. Decisions (i.e. recommendations) taken by ICCAT are by consensus among the 48 members and five Cooperating Parties. When consensus cannot be reached, decisions are made by voting, which remains rare. Conservation and management measures for tuna stocks are first elaborated by panels and then moved to the Commission to be approved. The decisions are mandatory for all contracting parties. However, there is a well-defined system in the ICCAT constitution allowing members to object to such decisions within a timeframe in order not to be bound by them.

ICCAT scientific body raised serious concern about ABFTE stock status since the early 1990s. This stock was estimated to be overexploited in 1996, about 15 years after the overexploitation diagnosis of the Western Atlantic stock (ICCAT, 1999). From 1998 onwards, a Total Allowable Catch (TAC) system was implemented while size limit regulations and time/area closures were progressively reinforced (see Fromentin et al., 2014 for more details). This TAC is not transferable or tradable among contracting parties, but some countries have operated joint-ventures and thus used a boat operated by another fishing country to catch its own quota¹. Nonetheless, the TAC did not improve the situation because the ICCAT management body: (i) did not implement an efficient compliance and control procedure and (ii) did not follow the advice of its own scientific body and kept recommending TACs that exceeded the scientific recommendations (**Figure 2**).

This management failure was partly due to the multilateral nature of ICCAT and to a decision-making process based on consensus, as noted above. Conflicts of interests between the numerous countries that fished ABFTE (**Figure 2**) impeded strong decision-making, especially to limit catches. In addition, the ABFTE market was highly profitable and economic interests took precedence over conservation-based ones. This is an unfortunate but quite common situation for many exploited stocks, even of lower economic value (Aps et al., 2007).

¹ Note that the TAC is decided every year by ICCAT and allocated among different contracting Parties according to an allocation scheme based on historical landings. The quota allocated to a Party, is allocated by that Party to its national fishery operators and may be transferable among them.

Management regulations were thus ineffective, at that time, in limiting ABFTE catches, especially in the Mediterranean Sea. The lack of compliance and control noted above further induced increasing levels of Illegal Unreported and Unregulated (IUU) fishing under flags of convenience (**Figure 2**). IUU catches were well documented by ICCAT scientific body (ICCAT, 2007; 2009) and several NGOs inquiries (e.g. Greenpeace 2006; WWF 2008), but were apparently complacently ignored by ICCAT management body which took little action to curtail them until 2008. While the implementation of a TAC in 1998 was expected to decrease fishing mortality, the overall mismanagement finally led to an opposite outcome characterized by greater overexploitation and higher catches. ABFTE catches were probably at or above 50 000 tonnes per year during the 2000s, while ICCAT scientific body had recommended a TAC between 15,000 and 25,000 tonnes in the same period (**Figure 2**).

The ICCAT scientific body had alerted the ICCAT management body since the late 1990s and gave explicit statements in its 2006 report: *“Our evaluation of the current regulatory scheme is that, unless it is adjusted to impose greater control over the fisheries by improving compliance and to reduce fishing mortality rates, it will lead to further reduction in spawning stock biomass with a possibility of stock collapse”* (ICCAT, 2007). However, the scientific advice had little weight against fisheries lobbies, which were most influential at maintaining high catch levels. Using the argument of uncertainty in the scientific advice (inherent to any scientific diagnosis), stakeholders pushed managers to obtain higher TACs than those reflected in the scientific advice and avoided the recommended reduction in effort. During the 2000s, the environmental NGOs became, however, more and more powerful and very efficiently used communication tools to call the attention of the public to the poor stock status of ABFTE. To do so, unlike scientific bodies, NGOs sometimes used dramatic and scientifically incorrect terms and expressions such as “extinction” or “Race for the last bluefin” to describe ABFTE status and were also selective in communicating the scientific advice. Although such a strategy can undermine science-based management in the long-term, it was beneficial for ABFTE management because it raised public awareness of ABFTE stock status and, in turn, obliged ICCAT commission to really pay attention to the scientific advice and its Parties to more fully complying with their Flag States duties.

3. THE REBUILDING PLAN

Finally, the ICCAT management body implemented a first rebuilding plan in 2007, which included more restrictive management regulations, such as the reduction of the fishing season for the main fleets (purse seiners), an increase in the minimum size (from 10 kg to 30 kg) and new tools to monitor and control fishing activities. However, two key issues were not tackled: overly high catches and overcapacity (ICCAT, 2009). Under the NGOs pressure and scientific advice, the plan was reinforced in 2008, by strengthening the control measures and planning a reduction of fishing capacity over 5 years, but again the TAC remained 2 to 3 times higher than scientifically advised. The procrastination of ICCAT led, in 2009, to the demand by Monaco (with the support of most NGOs) to list ABFT under Appendix 1 of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES), introducing international trade controls. ABFTE was pointed as an archetypal example of mismanagement by its responsible body (ICCAT) and the intervention of CITES in the process was advocated by some parties to improve the situation (Fromentin, 2010a, b; Losada et al., 2010). This crisis clearly pushed

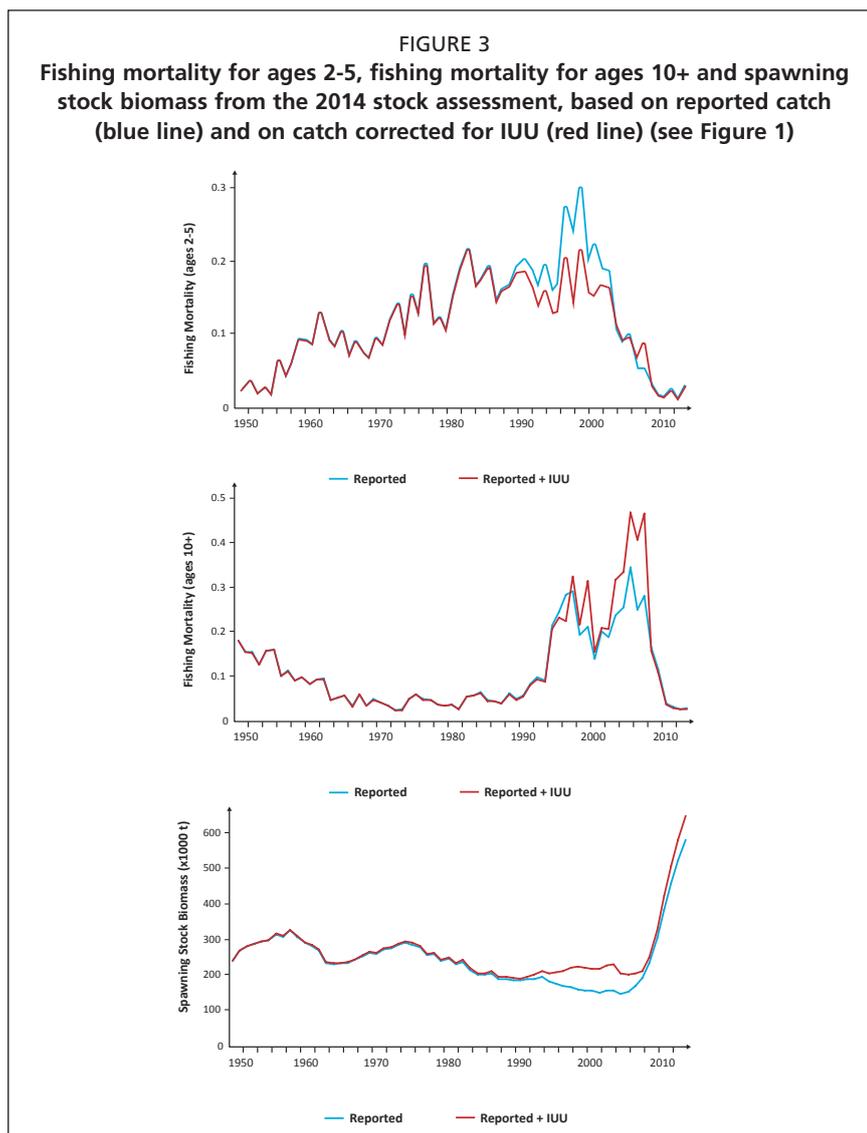
ICCAT management body to fully endorse the scientific advice and it recommended a low TAC for the three following years, at about 13 000 tonnes (a level that was recommended by ICCAT scientific body to reach the reference targets, i.e. F_{MSY} and B_{MSY} , within the 15 years of the rebuilding plan). Undoubtedly, such a drastic change in ICCAT management would not have happened without the strong NGOs' pressure.

The reduction of fishing capacity and the strong reduction of the TAC since 2010, led to substantial reduction in the purse seine fleet size. For instance, the French purse-seine fleet decreased from 36 boats in 2007 to 23 boats nowadays, of which only 10-17 boats have been actually fishing since 2010. This reduction also led to ownership concentration at national levels. Similarly, the number of Japanese longline vessels had been significantly reduced and this fleet is not a major fishery for ABFTE anymore. The rebuilding plan also affected the area covered by most fisheries. The purse seine fishery increased its focus on the exploitation of spawning areas over May-June and targets the size classes favoured by the farms and the market. The Japanese longline fishery has concentrated in the Northeast Atlantic, especially in the southern waters off Iceland. EU small-scale longline fisheries (mostly from Spain, France, Italy and Malta) have benefited from the rebuilding plan, as lower TAC also translates into higher value, so that they have become more profitable on local/regional markets than before.

4. PERFORMANCE ASSESSMENT

One of the most spectacular effects of the rebuilding plan since 2010 was the drastic decrease in total catches of ABFTE. From 1998 to 2007, reported catches were about 30 000 to 35 000 tonnes, but, as mentioned before, ICCAT Scientific Committee estimated that actual catches were rather in the order of 50 000 t per year during this period (**Figure 2**; ICCAT, 2007). Since 2008, the ICCAT Scientific Committee did not detect any large quantity of unreported catches and concluded that a substantial decrease in the IUU catches had occurred following the reinforcement of the controls. In 2011 and 2012, reported catches were around 12 000 tonnes, i.e. the lowest catches recorded since 1950 and about four to five times less than four years before (**Figure 2**).

In contrast to the mid-2000s, all CPUE indices used for the 2012 and 2014 ABFTE stock assessments displayed positive trends in recent years. Fisheries-independent information from the aerial surveys performed on the juvenile fish in the north-western Mediterranean Sea provide similar indications, showing a four-fold increase in juveniles abundance in 2009-2012 compared to 2000-2003 (Bauer et al., 2015). In contrast to the 2006 and 2008 stock assessments, which detected a rapid and strong decline in the spawning stock biomass (SSB), the last stock assessments showed clear signs of increase in recent years in all the runs that have been investigated (**Figure 3**; ICCAT, 2013; 2015). Trends in fishing mortality (F) for the younger ages (ages 2-5) and for oldest fish (ages 10+) decreased sharply since the late 2000s, after 20 years or more of increase and reach the lowest historical levels (**Figure 3**). The general trend in F for the oldest fish is consistent with fisheries expert knowledge, especially the shift in targeting towards larger individuals destined for fattening and/or farming during the 1990s.



The perception of stock status derived from the last assessments has thus greatly improved relative to past assessments. F_{2013} was significantly below the reference target level ($F_{0.1}$)² in all scenarios ($F_{2013}/F_{0.1} < 0.5$). If F_{2013} seems to be consistent with ICCAT Convention objectives, current biomass is most likely to be below the level expected at $F_{0.1}$ (i.e. $SSBF_{0.1}$) in the high-recruitment scenario, but above the expected level in the low- and medium-recruitment scenario (ICCAT, 2015). Note that the last SSB value is among the highest values of the time series, which is rather intriguing for a recently overfished stock, especially for a long-lived species such as ABFT. Nonetheless, absolute values of SSB can hardly be compared between each other because $SSBF_{0.1}$ changed considerably over time due to changes in recruitment levels and/or selectivity patterns. Most importantly, past and/or recent SSB estimates are likely to be heavily biased because of unquantified uncertainties (see below).

Projections of SSB from last stocks assessments for a range of TACs are consequently optimistic, in contrast with past stocks assessments, and they indicate that ABFTE rebuilding to the $SSBF_{0.1}$ level, as presently defined, could be achieved by the end of

² $F_{0.1}$ has been selected by ICCAT scientific committee as the proxy for the fishing mortality that would provide the maximum sustainable yield, so that $SSBF_{0.1}$ corresponds to the SSB that is expected under maximum sustainable yield strategy.

the rebuilding plan (in 2022) for catch levels equal or below 26 000 tonnes. Based on current knowledge and modelling assumptions, ABFTE could thus be fully rebuilt by 2022, or before. Following the 2014 scientific advice, an increase of 20% per year in the TAC was then applied from 2015 to 2017, so that the TAC reached about 23 000 t in 2017. Based on last projections carried out during the 2017 stock assessment, the scientific committee recommended a progressive increase of the TAC up to 36 0000 tonnes by 2020 (ICCAT 2018), which has been recently endorsed by the Commission.

However, and as noted before, the scientific advice assumes that the outcomes of the stock assessment model (VPA-ADAPT) are not strongly impaired by current unquantified uncertainties. This is very unlikely according to Fromentin and Kell (2007) who showed how long-term fluctuations in ABFT abundance can severely bias the perception of stock status. Such uncertainties arise from three major sources: (i) process errors, or our understanding of ABFTE biology and population dynamics (i.e. population structure, natural mortality, age structure, population growth rate and recruitment), (ii) observation errors, or the quality/quantity of the data used (mostly catch data and CPUE indices) and (iii) model errors, or the ability of assessment models to correctly reproduce key population dynamics patterns (Fromentin et al., 2014). For such reasons, the last stock assessments outcomes may be over-optimistic, as they were possibly over-pessimistic in the early 2000s, and for the same reasons. Such a situation is worrying, as it could break the virtuous circle that was painfully instigated 10 years ago with the implementation of the rebuilding plan. One way to avoid such a deleterious process would be to agree on management measures that would be evaluated with respect to agreed objectives, in other words, to implement a harvest control rule within the frame of a Management Strategy Evaluation (MSE; Kell et al., 2005; Froese et al., 2011). Note that such an approach has been successfully implemented by the Commission for the Conservation of Southern bluefin Tuna (CCSBT) to unravel the long southern bluefin tuna dispute (Kolody et al., 2008; Kurota et al., 2010).

This rebuilding initiative has also highlighted the tensions between science, policy and civil society that might be exacerbated during processes of collapse and rebuilding. When the first signs of ABFTE rebuilding were mentioned, some NGOs (but not all) had the same strategy as the fishery lobbies in the past and attempted to discredit the scientific advice by exploiting the various sources of uncertainty to get more conservative management measures. The risk to the stock is nonetheless not symmetric, as high catches when overfishing occurs increase the risk of stock collapse while low catch when overfishing does not occur translate into lower profits for the fisheries. Furthermore, it is rational to advocate for low catches when there is high uncertainty in the scientific advice (Mäntyniemi et al., 2009). Nowadays, all the NGOs have recognized the ABFTE rebuilding and the relations between economic interests and the sustainable use of resources were more balanced until very recently.

Questioning the scientific advice through the issue of uncertainty has been commonly used by different lobbies that wished to push their own agendas. Uncertainty is also a source of misunderstanding between scientists and managers for whom uncertainty often means poor advice. However, uncertainty is inherent to any scientific advice. Like in all scientific fields, fisheries scientists cannot provide certainties, but only probabilities and sometimes a consensual interpretation. In some cases, those probabilities can be seriously biased because of unquantified uncertainties. Some sources of uncertainties in the ABFTE stock assessment can be reduced by improving scientific knowledge and models, but stochastic uncertainty (i.e. variability in the population dynamics caused by natural variations in biotic and abiotic factors) will remain. It is up to fisheries scientists to actively communicate with managers, stakeholders and NGOs about the

various sources of uncertainty, firstly to better inform about the scientific process and then to investigate alternative management strategies more robust to uncertainty. It is also crucial to identify those unquantified uncertainties and to evaluate their impact on the outcomes of the assessment, i.e. how different the true risk might be (EFSA, 2013). Such an approach is not trivial and implies to agree upon which of the known but unquantified uncertainties should be included in the evaluations. Some authors suggested that scientists and stakeholders debate a limited number of scenarios, which can be first identified in a qualitative way, as being areas of concern (Punt and Donovan 2007).

From a social and economic perspective, the rebuilding has noticeably modified fishermen viewpoint on governmental scientists and in general on the scientific approach. Formerly, fisheries scientists were mostly seen as the ones who brought bad news and were often accused to be biased towards a conservationist approach. The scientific debate around the CITES episode and the scientific documentation of ABFTE stock rebuilding have changed this perception, as fishermen have seen that scientists could also bring and endorse good news. Consequently, the dialogue between scientists and fishermen has improved and cooperation has restarted.

5. CONCLUSION

The recent history of ABFTE management demonstrated that improving stock status of a heavily overexploited and valuable stock can be achieved when there is real political will. However, the history of ABFTE management, as those of many other fish stock, showed that political factors firstly respond to economic interests. Without the strong NGOs pressure during the 2000s, ICCAT Commission would have probably continued doing “business as usual”, i.e. paying little attention to the scientific advice and being reluctant to endorse efficient measures to stop overfishing. Nowadays, managers seem to really pay more attention to the scientific advice, so that the main challenge is to develop a scientific framework with clear management objectives that is robust to various sources of uncertainties. More science, less uncertainty and better management recommendations should finally translate into lower risks of fisheries and population collapse, mid- and long-term sustainable management and finally increased revenues of the fisheries.

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Management and rebuilding of herring and cod in the Northeast Atlantic

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Abstract

For centuries, Norwegian spring-spawning (NSS) Herring and Northeast Arctic (NEA) Cod, hereinafter referred to as herring and cod, have been the backbone of Norwegian fisheries, securing livelihood along the coast both as sources of food and monetary income. The depletion of herring in the late 1960s, and the overfishing of cod culminating 20 years later, were the two single most decisive incidents that led to an ongoing process shaping the framework and measures of modern Norwegian fisheries management. Although different regarding biological parameters, harvesting and the degree to which the stocks were depleted, the overall management measures needed for restoration and implementation of sustainable management of these two stocks, as well as for other stocks, are of the same general nature. The detailed measures depend obviously on stocks, fleets and fisheries concerned but all within a common political, legal and management framework, the general elements of which are:

- International agreement on the management and sharing of transboundary stocks;
- Improving exploitation patterns and the reduction of discards and waste;
- Reducing fishing mortality and the introduction of Harvest Control Rules (HCR);
- Measures to increase profitability in the fishing fleet;
- Sharing of resources nationally between fleet groups and individual vessels;
- Establishment of sufficient fisheries control and enforcement capacities; and
- Ongoing development and adaption of the management system.

1. INTRODUCTION: BACKGROUND ON THE STOCKS AND FISHERIES

This case-study tells the story about management and rebuilding of two fish stocks of the Northeast Atlantic Ocean: a herring stock and a cod stock. Both are transboundary, in that they have a distribution that extends in the exclusive economic zone of more than one coastal State. This feature implies that management actions need to be based on decisions arrived at through fisheries agreements by the relevant States. A summary timeline of some key events is given in **Annex 1**.

Both stocks can be considered as target stocks of the fleets exploiting them. The fishery for herring has generally little bycatch of other species, whereas there will often be bycatch of other whitefish species in the cod fishery. The dominant gears in

the fishery for herring are purse seine and pelagic trawl. In the international fishery for cod, trawl takes most of the catch while gill net, long line and Danish seine are also important gears in the Norwegian fishery. The vessels harvesting these species vary considerably in size and by the gear they use, but as the coastal states fishing these stocks are Nations with highly developed economies, it is fair to say that in a global perspective, the fleets are technologically advanced. The productivity measured as catch per fisherman is therefore high. The income from the fishery is shared between the crew and the owner, where the latter uses part of the income to acquire and maintain the vessel. In the coastal communities from where the fleets operate, the income generated from the fisheries is important, both directly and through multiplier effects.

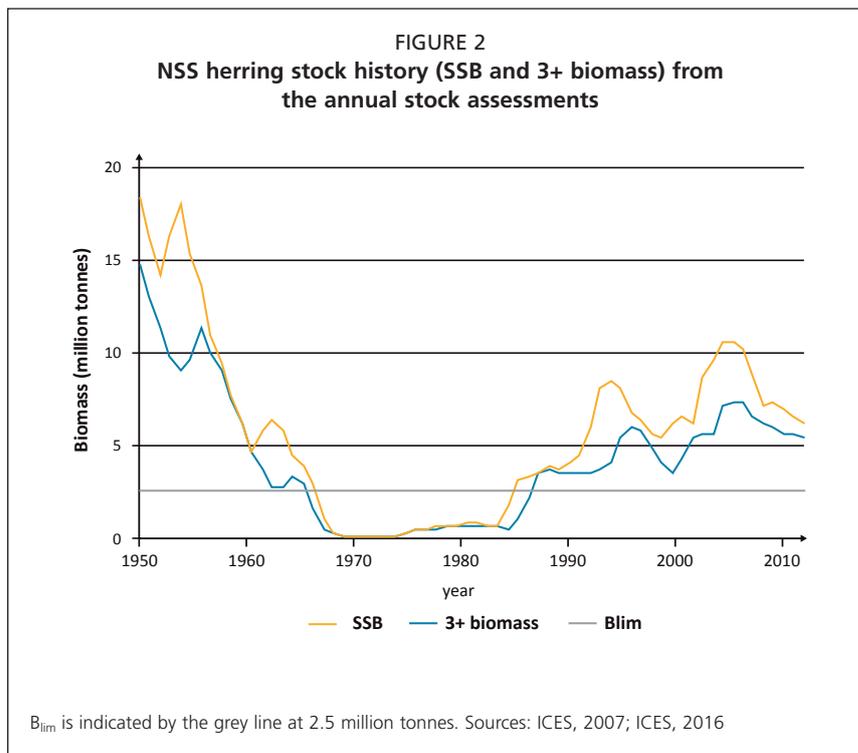
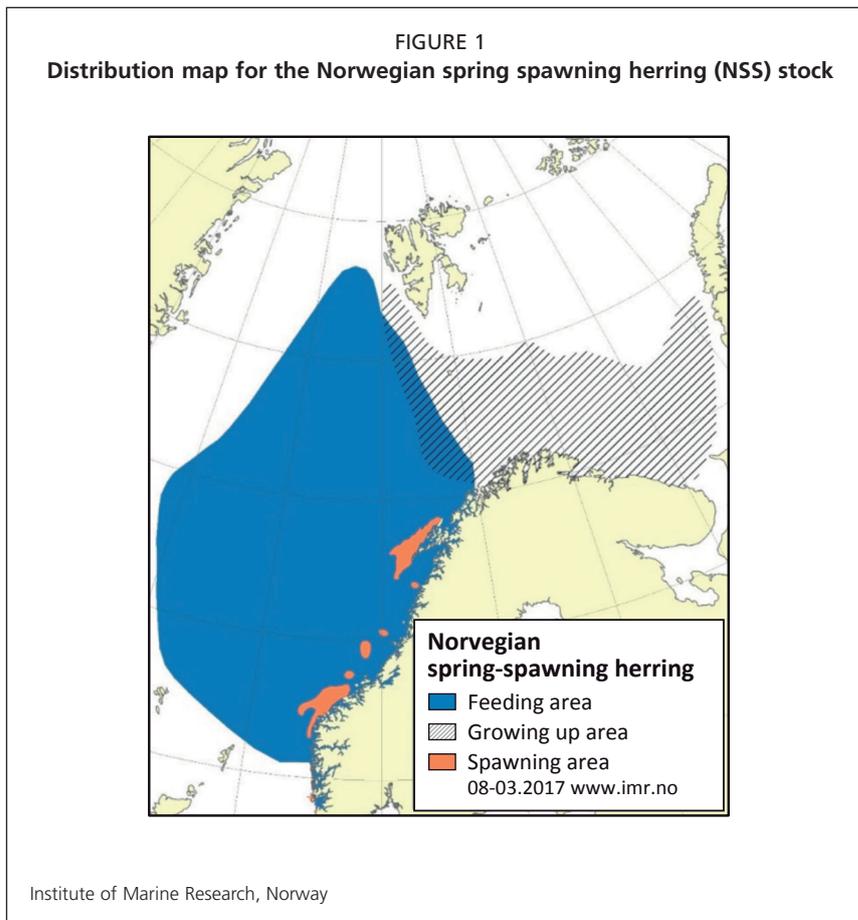
Below, we will start by describing the biology, stock and fishery for the two species. We will thereafter put on our Norwegian spectacles and explain the national and international management measures that have been important to rebuild the two fish stocks, as well as laying the foundation for increased profitability in the fishing fleet. In contrast to studies that focus on specific measures applied to rebuild one fish stock, this document describes the development of measures over a period to sustainably and profitably manage, as well as to rebuild, two important fish stocks and their fisheries. The management measures introduced during the period of rebuilding have to a large extent come to be seen as vital for ongoing successful management after rebuilding had been completed.

1.1 Biology, stock and fishery development of Norwegian spring-spawning herring

Norwegian spring-spawning herring (NSSH, *Clupea harengus*) is the largest herring stock in the world with recorded levels of spawning stock biomass (SSB) estimated at 16 million tonnes at its highest in 1945 (Toresen and Østvedt, 2000). The stock distribution is shown in **Figure 1** and the history of the SSB and the biomass of fish over 3 years of age (thereafter 3+) in **Figure 2**.

It is widely distributed in the Northeast Atlantic where it is a key species both as a major consumer of zooplankton and as prey for predatory fish and marine mammals. It is also a highly important commercial resource. The adults spawn in spring on coastal banks off the Norwegian coast and the main nursery areas are found in the Barents Sea. After spawning, the NSSH migrates to the Norwegian Sea where it feeds on zooplankton during summer. The feeding migrations are extensive and feeding takes place throughout the Norwegian Sea. During this period, the NSSH mixes with other pelagic species such as Atlantic mackerel and blue whiting. After feeding, it assembles in wintering areas until the next spawning season.

Biological data for the NSSH stock extends back to 1907, and it is therefore possible to construct a time series of SSB for a long time-period (Toresen and Østvedt, 2000). These data show that there have been large fluctuations in recruitment to the stock, and even at high stock levels, there have been periods of reduced recruitment. This has led to fluctuations in abundance even before the fishery became an important factor (Dragesund et al., 1997; Toresen and Østvedt, 2000).



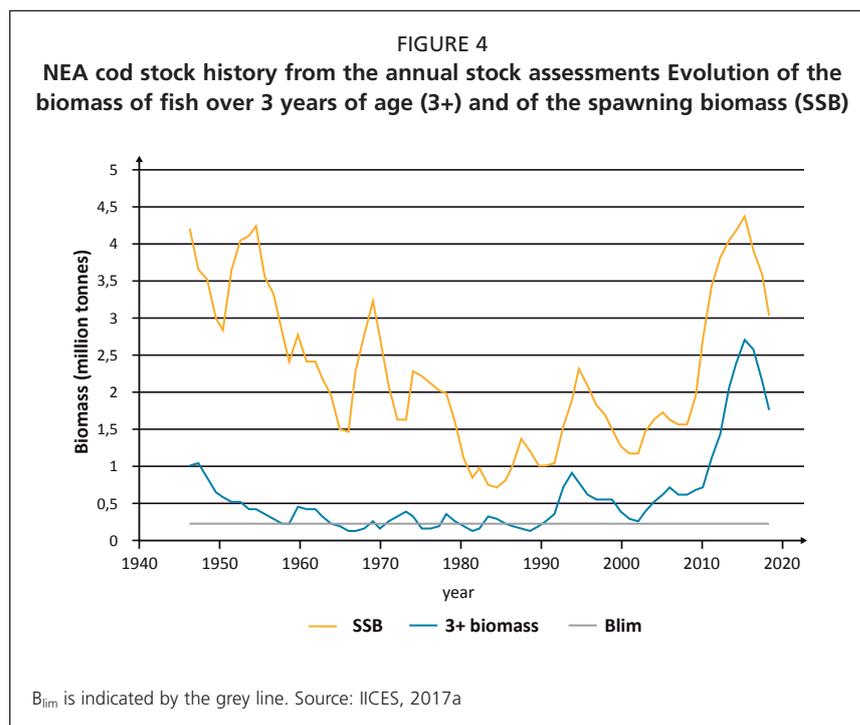
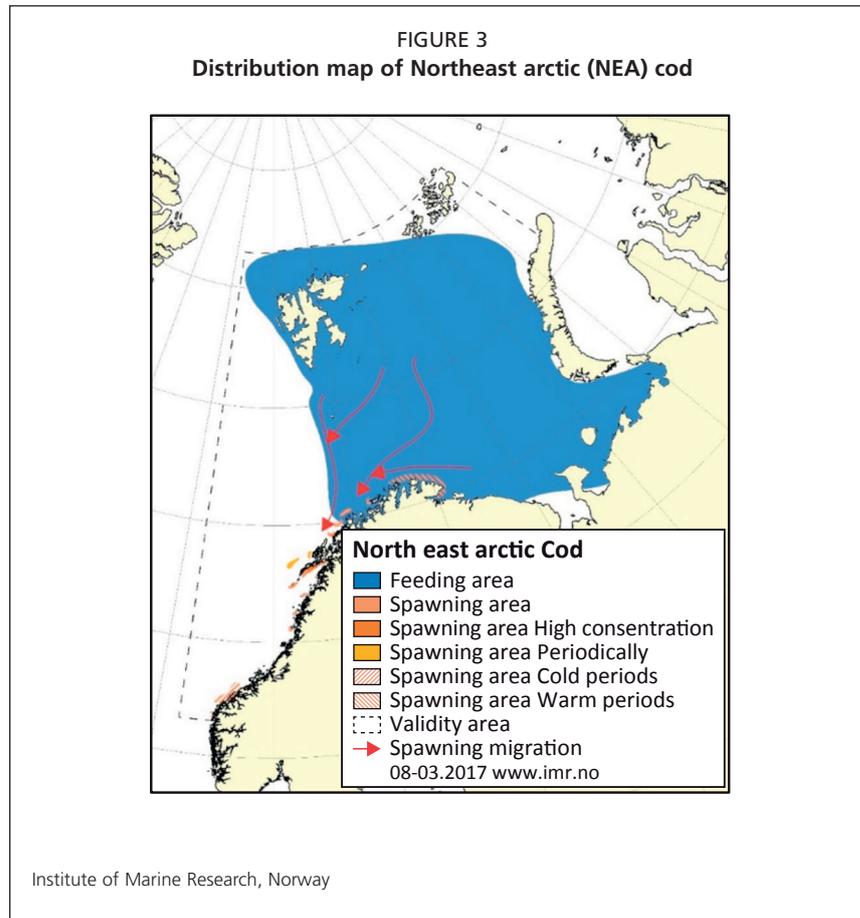
The NSSH stock collapsed in the 1960s from a SSB of 12 million tonnes in 1956 to less than 100 thousand tonnes in 1969 (Toresen and Østvedt, 2000). The fishery of the stock changed dramatically during the years prior to the collapse. Particularly during the 1960s there was a steep increase in landings until a top level of 2 million tonnes in 1966, after which the fishery collapsed along with the collapse in the stock (Dragesund et al., 2008). This huge increase in catch was made possible by a fundamental development in fishing gear technology combined with a total lack of stock assessment and management during that period (Dragesund et al., 2008). Particularly the introduction of echo-sounders, lighter nylon nets and power blocks for hauling the nets enabled fishermen to handle much larger nets and to expand the fishery into offshore areas which had previously been out of range due to the dependency of small boats for setting and hauling the nets. The International Council for the Exploration of the Sea (ICES) working group on Atlanto-Scandian herring stocks (which includes NSSH) met several times during the collapse period, but it was only in 1971 that the working group recommended a reduction in the catch (Dragesund et al., 1980). The collapse of the stock was followed by a period of very low abundance until 1987 when the strong 1983 year-class started to recruit to the spawning stock. After that, several strong year-classes followed which, combined with an internationally agreed harvest control rule, contributed to the recovery of the stock to levels well above the precautionary biomass level (B_{pa}). The stock has been declining again since 2009 due to several weak year-classes entering the stock, and the spawning stock in 2017 is below B_{pa} . However, the coastal States have continued implementing the harvest control rule and taken substantial reductions in annual catch. The fishing mortality has therefore been below F_{pa} (precautionary fishing mortality) in recent years.

The dramatic decline in abundance during the 1960s was followed by additional changes in stock parameters such as migration pattern (Dragesund et al., 1997). Migration pattern of NSSH is dynamic with frequent shifts often associated with the recruitment of abundant year classes to the spawning stock (Huse et al., 2010), although climate variability is also known to affect the migration (Dragesund et al., 1997). After the collapse, the stock abandoned its extensive feeding and wintering migration into the Norwegian Sea and remained distributed along the Norwegian coast throughout the year (Dragesund et al., 1997). Changes in stock composition and growth accompanied the collapse. Although Ndjaula et al. (2010) found no correlation between condition factor and SSB in the time series, Torsen (1990) reported increased individual growth and consequently decrease of the age of 50% maturity during the collapse period (Engelhard and Heino, 2004). Age distribution also changed. Ndjaula et al. (2010) found that age diversity in the stock declined during the period of the collapse. The mean age of the spawning stock did not change much until after the collapse and the decline observed was mostly due to earlier maturation caused by faster individual growth (Rouyer et al., 2011).

1.2 Biology, stock and fishery development of Northeast Arctic Cod

The Northeast Arctic cod stock (NEA Cod, *Gadbus morhua*) is currently the largest cod stock in the world. The stock has its main spawning grounds around the Lofoten Islands off Northwest Norway, and nursery and feeding areas in the Barents Sea (Figure 3). In a global context, this is at the northern extreme of the range for a cod stock and warmer than average waters (observed in the 1930s-1950s, and since 2000) can be considered favorable for it. The stock has a long history of economic importance for Norway with export fisheries stretching back over 1000 years (Anon c. 1240). The stock has, since 2010, supported sustainable catches of between 610,000 tonnes and 986,000 tonnes (ICES, 2017a). Research has been ongoing on NEA cod for over 100 years, and the assessment time series starts in 1946.

The drastic reduction in fishing during World War II, combined with a period of warmer temperatures, led to a relatively high abundance of the stock in 1946, when the assessment series begins (Figure 4).



The stock was then somewhat fished down and varied around B_{lim} for several decades, but never completely collapsed in the way NSSH did, and the stock was able to recover when fishing pressure was reduced. In addition to a reduction in the SSB, the stock experienced a marked truncation of the age structure, and reduced age at maturity. The rise in SSB in the early 1990s followed a short period of reduced fishing pressure, but the fishing pressure increased and the SSB was again reduced. The subsequent progressive introduction of more sustainable management (as described below) coincided with two good year classes in 2003 and 2004. As a result, first the whole stock, and then the SSB increased dramatically, with SSB reaching a high of almost 2.7 million tonnes in 2013, the highest recorded in an assessment series reaching back to 1946. Although this has reduced somewhat as the year-classes aged, the SSB was still at 1.77 million tonnes in 2016. The age structure is continuing to improve because of high survival in these year-classes resulting from an extended period of moderate fishing pressure, to the extent that the assessment methodology has recently been altered to account for the more diverse age structure (ICES, 2017b). The increase in, first, the stock size and, subsequently, the age structure, can be attributed to a range of factors. Kjesbu et al. (2014) argue that it was the combination of good fishing practices, favorable climate and two good year-classes that led to the favorable outcome for this stock.

An additional factor affecting the cod has been the abundance of capelin (*Mallotus villosus*). This short-lived (3-4 years) forage fish is an important food source for cod which cannibalism appears to increase in years with poor capelin stock. The capelin stock varies dramatically and keeping a high capelin biomass is important for the health of the cod stock, while ongoing decrease in sea-ice cover may be making capelin more available to cod, and hence changing the carrying capacity for cod (Howell and Filin, 2013). Since 1992, the capelin has been managed with an escapement strategy allowing fishing only on the spawning stock remaining after the cod predation needs have been satisfied. The two stocks are linked through predation, and as such have required coordinated management.

The ongoing recovery of the age structure leaves open the question of whether or to what extent the stock –which has shown changes in population parameters under decades of high fishing pressure– will revert to its earlier dynamics, or whether these changes will persist in the long term. For example, a trend towards younger age at maturity was recorded during this period, and modelling suggested that Fishery-Induced Evolution (FIE) may have occurred (e.g. Heino et al., 2002). The age at maturity has been increasing in recent years (e.g. ICES 2017a), but whether it will return to the levels seen prior to intense exploitation, or whether long term FIE changes have occurred remains an open question. Another issue is that although the main spawning area is in the Lofoten Islands, there were historically many smaller spawning grounds further south along the coast of Norway which have been mostly abandoned during the period of heavy fishing. Again, it is an open question as to if, or when, these will be recolonized.

2. THE LEGAL FRAMEWORK OF NORWEGIAN FISHERIES MANAGEMENT

Until 1970, the fishing of herring, and most other Norwegian fisheries except those using trawls, had been operating under open access. Fishing with trawl had been restricted by law, since the 1930s, not for biological reasons but to protect traditional coastal fisheries from competition from capital-intensive fishing. The herring stock collapse, in the late 1960s, provoked, as an emergency measure, a temporary stop in the registration of new purse-seine vessels into the national register of fishing vessels. The temporary stop was followed-up in 1972 by Parliament passing a new Act on

Participation in Fisheries. The law gave government authorities a mandate to limit access to fisheries when deemed necessary to protect fish resources. In accordance with the new law, the temporary stop on registration was replaced in 1973 by a permanent regulation restricting access for new, offshore purse-seine vessels above 28 meters in length. The law, subject to amendments in following years and to a major revision in 1999, has been instrumental in the subsequent limitation of access and reduction of excess capacity in Norwegian fisheries.

In 1977, Norway, as well as numerous other coastal States, extended national jurisdiction to 200 nautical miles from the baselines. The Act relating to the economic zone of Norway of December 1976, empowered Norway to manage the resources in its Exclusive Economic Zone (EEZ) and provided a basis for closer management cooperation with neighboring coastal states on transboundary resources, including herring and cod. The extension to 200 nm economic zones by coastal States soon became customary law, later codified by the 1982 United Nations Law of the Sea Convention (LOSC).

The LOSC was supplemented in 1995 by the United Nations Fish Stock Agreement (UNFSA) pertaining to the management of high sea resources as well as stocks straddling between EEZs and the high sea. Norway has ratified both instruments.

Pressure on fish stocks from overfishing triggered the need for strengthening national legal instruments to regulate the exercise of fishing. In 1983, the Parliament passed the Act Related to Seawater Fisheries, summarizing existing pieces of legislation and improving government authorities' competence to regulate the exercise of fishing. The law, with later amendments, was replaced in 2009 by The Marine Resources Act. The former act focused mainly on the commercially exploited marine resources, whereas the new act applies to all living marine resources and thus incorporates an ecosystem approach to fisheries management as a guiding principle. For more details on practical efforts to include an ecosystem approach in Norwegian fisheries management, see Gullestad et al. (2017).

The LOSC, the UNFSA and the three mentioned national laws in force, supported by other national legislation, such as The Coast Guard Act and the Fishermen's Sales Organization Act, constitute the legal foundation on which modern Norwegian fisheries management rest. It is important to note that, over the years, the national legislation has been amended on multiple occasions in response to emerging challenges on the road towards sustainable fisheries management, including to tackle IUU issues and introduce port State measures.

3. INTERNATIONAL COOPERATION IN MANAGING HERRING AND COD – SHARING OF RESOURCES

Most stocks important to Norwegian fisheries are shared with neighboring coastal States: Russia in the Barents Sea, several countries in the Norwegian Sea, and the EU (including Great Britain) in the North Sea/Skagerrak. Some of these stocks also straddle into the high sea, where the Northeast Atlantic Fisheries Commission (NEAFC) manages stocks or their international components, as appropriate. Successful joint management and sharing of stocks is therefore of vital importance to Norway and its fishery sector since 90 % of the value of Norwegian catches comes from shared resources.

In the following sections, we will look at the implications for herring and cod fisheries management and stock rebuilding.

Herring

The collapse of herring meant that the minuscule stock remaining in the 1970s was confined to Norwegian coastal waters only, both throughout the year and during its course of life. This only changed when the strong 1983-year class recruited to the stock and extended again its living area at the juvenile stage into the Barents Sea, including the Russian Economic Zone. It took two years of negotiation, including a Russian fishery of 25 000 tons of juveniles in 1985, to reach an understanding in autumn 1986, according to which Norway would grant Russia, annually, a quota of adult herring in Norwegian waters in exchange for not fishing juveniles in Russian waters. This partnership is still functioning. New strong year classes were born in 1991 and 1992, forming the basis for a permanent stock recovery.

By 1990, the 1983-year class had left the Barents Sea and taken up previous migration patterns, spawning in spring off the Norwegian coast and feeding in summer throughout the Norwegian Sea. This meant that the stock was again available for fishing in summer both in international waters and possibly in the economic zones of several Norwegian Sea coastal states. In December 1996, the five coastal states Norway, Russia, Iceland, the Faroe Islands and the EU agreed on a quota allocation key, which lasted until 2002. A characteristic feature of this stock is an extensive, flexible and varying migration pattern. The migration may be relatively stable for periods while large changes occur occasionally at varying time intervals. The allocation key was once again thoroughly discussed during the period 2002-2006, and a new key adopted as from 2007. It lasted until 2013, after which the coastal States have (so far) not reached a consensus on a new allocation key. These States have, however, cooperated on control since the late 1990s, and continue to do so despite the disagreement on allocation.

Cod

As early as 1975, Norway and the USSR (from 1991, Russia), in preparation of extended jurisdiction from 1977, agreed to cooperate on the management of fishery resources in the Barents Sea by establishing the Joint Norwegian-Russian Fisheries Commission (JNRFC). At the same time, the parties reached a political agreement to share quotas of cod and haddock evenly between them, with provisions for fishery from third parties according to bilateral agreements. The sharing between the two coastal states has been stable since then, a fact that has provided contributed to an environment for productive cooperation also on other management issues, sharing of resources normally being the single most contentious one in fisheries negotiations.

The examples of herring and cod illustrate that the number of shareholders, as well as possible variation or shift in migration patterns or distribution area are central parameters when it comes to creating favorable conditions for long term international agreement on sustainable management (including rebuilding) of shared resources. Generally, climate change will undoubtedly lead to many changes in distribution of fish stocks in the future, increasing the need for robust allocation systems.

Article 63 of the LOSC imposes coastal states to cooperate when managing straddling stocks, including non-coastal fishing nations in the case of stocks straddling the High Sea. However, the Convention does not provide any detail the content of this cooperation and on how to share quotas of straddling stocks. Article 7 of the UNFSA does however indicate that the extent to which a stock occurs in the different jurisdictions, should be an important element when it comes to the sharing of quotas between coastal States, as well as between them and high sea fishing States. Starting

with the herring negotiations in 1995, the concept of Zonal Attachment developed as the foundation for a principal Norwegian position when it comes to sharing of joint stocks. Professor Johannes Hamre, at the Institute of Marine Research, developed a model mapping the geographical distribution of a year class of herring throughout its lifetime. He suggested that summing up of quarterly data on the zonal distribution of a representative year class through its lifetime would provide a fair indicator of how the entire stock is distributed between zones. Such calculations can be done for any stock for which fishery-independent age-distributed acoustic data exist (Hamre, 1993). For more information on how sharing of stocks straddling Norwegian waters developed in the period 1975-1993, see Engesæter (1993).

4. EXPLOITATION PATTERNS AND EXPLOITATION RATES

Fisheries affect the productivity of fish stocks through their exploitation pattern and exploitation rate. The exploitation pattern can be regulated by minimum legal sizes of fish, gear restrictions etc., whereas the exploitation rate can be regulated through input or output restrictions (the former often by licenses and the latter by catch quotas). What follows is a description of how these regulatory measures have been implemented in the herring and cod fisheries.

4.1 Measures to regulate exploitation pattern

Herring

Prior to the collapse, the Norwegian fisheries for herring was conducted on the adult part of the stock as well as in a coastal fishery directed on juveniles, and no legal minimum size was set. The international fishery on herring took place in the Norwegian Sea on the adult part of the stock only, and Russia and Iceland had, at least by 1970, introduced minimum legal sizes of 26 and 25 cm respectively (Sandberg, 2010).

The fishery for juveniles turned out to be particularly damaging in a period of diminishing stock due to overfishing and less favorable natural conditions for recruitment and growth. In 1970, Norway introduced a minimum legal size of 20 cm which somewhat reduced the fishing of juveniles. The politically difficult move to close this coastal fishery entirely was only taken in 1977 by increasing the legal minimum size to 25 cm to allow the fish to spawn at least once before capture. As part of the negotiations with Russia in 1986, agreement on 25 cm as minimum legal size was confirmed, in exchange for Russian fishing opportunities of adult herring in Norwegian waters. This has also been the case in the subsequent multilateral agreements.

Cod

Juveniles and other young immature individuals of cod have an easterly distribution into Russian waters of the Barents Sea. The mature fish, spawning on the Norwegian coast, tends to have a westerly distribution. This is reflected in a difference in exploitation pattern between Russian and Norwegian fishermen, the former traditionally fishing, on average, younger fish than the latter. Seen from the perspective of solely maximizing the output in tonnes or firsthand value from the stock, it is a fact that a large mesh size and minimum landing size of fish would be beneficial, and consequently this has been an issue of long time difference of opinion between the two parties regarding the optimal exploitation pattern. To reduce this difference, Norway, already since 1977, allowed Russian fishing vessels to fish their quotas of cod in Norwegian waters outside 12 nautical miles.

When the EEZ's were established, Norway and Russia had “inherited” an earlier NEAFC regulation of a minimum trawl mesh size of 120 mm. In 1979, the Parties agreed on an increase to 125 mm. After several years of continued negotiations attempting to agree to a further increase, Norway unilaterally increased the mesh size to 135 mm in its waters in 1983.

The continued negative state of the cod stock led, in the late 1980s, to renewed efforts to improve exploitation patterns. An important element was the successful development of a sorting grid, the “Nordmore grate” originally developed by a fisherman, to reduce bycatches of juvenile cod and other whitefish in shrimp trawling. From 1993, the grid, with 19 mm spacing between bars, became mandatory both in Norwegian and Russian waters. The positive results from the introduction of grid technology in shrimp trawling led the parties to join scientific efforts to develop similar grid systems that could improve also the selectivity of the whitefish trawl. The efforts were successful, and in 1997, a sorting grid for whitefish trawls with a spacing between bars of 55 mm became mandatory in Norway and Russia.

In 2009, Norway and Russia finally succeeded in agreeing on a compromise of 130 mm minimum mesh size, and minimum legal sizes of cod and haddock of 44 and 40 cm respectively, to be effective from 2011 throughout the Barents Sea.

Mesh size regulations alone do not prevent intermixture of juvenile fish in the catches and discarding of smaller fish. In 1983, the first strong year-class of cod since 1975 was born. To protect this precious year-class from decimation in its early years, Norway in 1984 established a program for Real Time Closure of fishing areas (RTCs). Under this program fishing grounds with a too high proportion of young fish are temporarily closed. The program served well in protecting the juveniles in their first, vulnerable years. In 1987, most of the year-class had reached the legal minimum size and the basis for closures was no longer present. However, another problem surfaced: high-grading. At an extensive scale, fishing vessels would fill their quotas with the largest, best-paid fish and discard the smaller sizes. At the time, the practice of discarding was legal. The situation called for immediate political intervention, and a ban on discarding of cod and haddock was introduced in 1987. RTCs and discard bans were later extended to other fisheries and species, including herring. See Gullestad et al. (2015) for more detailed information on the Norwegian discard policy and its effects.

4.2 Measures to regulate the exploitation rate

Since the introduction of the EEZs in Europe in 1976-1977, ICES has issued annual advice on quotas for commercially important fish stocks to coastal states in the Northeast Atlantic. In the period 1976–1986, the focus was to reduce “growth overfishing”, and the advice was based mainly on fishing mortality reference points derived from calculation of yield-per-recruit (F_{\max} , $F_{0.1}$). From 1987, additional fishing mortality reference points derived from stock–recruitment relationships (SSRs) were used for the advice. This change reflected concerns about reduced reproduction capacity (i.e. spawning stock size) caused by overfishing. In the period, 1992–1997, clear and specific advice about catch levels was given only in cases when the spawning stock was below *Minimum Biological Acceptable Level* (MBAL). When the stock was “within safe biological limits”, that is above MBAL, no specific recommendation on catch level was given. Rather, options for various catch levels and the consequences of these levels for the remaining spawning stock were presented. Phrases like “*the stock sustains current fishing*” were used when the situation appeared rather stable, or “*no long-term gain in increasing F*” in cases when F was well above F_{\max} .

The precautionary approach, stating that lack of full scientific certainty shall not be used as an excuse for postponing measures to prevent environmental degradation, was one of the main outcomes of the 1992 United Nations Conference on Sustainable Development (UNCED). For fisheries, UNCED was followed up, in 1995, by the UNFSA and the FAO Code of Conduct for Responsible Fisheries. In subsequent years, ICES through its various working groups developed limit reference points for the major fish stocks in the Northeast Atlantic. Limit reference points refer to stock-specific, minimum levels of spawning stock biomass (B_{lim}) and maximum fishing mortality levels (F_{lim}), that should be avoided. To take care of the uncertainty in data and assessment models, precautionary reference points (B_{pa} , F_{pa}) respectively higher and lower than B_{lim} and F_{lim} were defined, at which action would need to be taken to limit the risk to reach B_{lim} or F_{lim} . Considering the uncertainty in the assessment of the stock, an annual catch level corresponding to F_{pa} or lower should imply an acceptable probability that such catch level is in fact set at F_{lim} or lower.

These reference points formed the basis for introducing the Precautionary Approach (PA) and subsequently Harvest Control Rules (HCR) into ICES' advisory process. Norway and the States with which it has shared fishery resources were quite early to develop and implement HCRs based on the Precautionary Approach. As the fishing mortality (F) in these HCRs implies a low risk of stock collapse, they in effect also secure fish stocks with sufficient reproductive capacity, while fishing at levels which can provide long term yields close to what can be expected as "maximum yields". Having these established, Norway has seen less benefit in adopting explicit F_{msy} levels in these HCRs.

While the limit reference points are strictly determined on scientific grounds, in principle, the precautionary reference points and the target fishing mortality are for management to decide, reflecting the acceptable degree of risk it is willing to take in managing a stock. Management bodies in the Northeast Atlantic, based on guidance from science, seem to have accepted and adopted precautionary levels generally reflecting the objective of keeping spawning stocks above B_{lim} and fishing mortality rates below F_{lim} with a probability of 95 %.

In this manner, uncertainty has become an argument for exercising greater caution in fisheries management. Earlier uncertainty had very often been used, not least by industry, as an argument for increasing quotas, the argument being that the stock might be larger than assessed by scientists. Evidently, the very existence of accepted precautionary limits in combination with a general growing environmental awareness has over time led to increased "political costs" for non-precautious or unsustainable fisheries management practices (Gullestad et al., 2014).

Development and construction of HCRs based on reference points proposed by ICES followed for major commercial fish stocks in the Northeast Atlantic. The first one was for Norwegian spring-spawning herring, on which the coastal States agreed in 1999.

Herring

In 1999 EU, Faroe Islands, Iceland, Norway, and Russia agreed to implement a long-term management plan for herring. The plan consists of the following elements:

1. Every effort shall be made to maintain a level of Spawning Stock Biomass (SSB) greater than the critical level (B_{lim}) of 2.5 million tonnes;

2. For the year 2001 and subsequent years, the Parties agreed to restrict their fishing on the basis of a TAC consistent with a fishing mortality rate of less than 0.125 for appropriate age groups as defined by ICES, unless future scientific advice requires modification of this fishing mortality rate;
3. Should the SSB fall below a reference point of 5.0 million tonnes (B_{pa}), the fishing mortality rate, referred to under paragraph 2, shall be adapted in the light of scientific estimates of the conditions to ensure a safe and rapid recovery of the SSB to a level over 5.0 million tonnes. The basis for such an adaptation should be at least a linear reduction in the fishing mortality rate from 0.125 at B_{pa} (5.0 million tonnes) to 0.05 at B_{lim} (2.5 million tonnes);
4. The Parties shall, as appropriate, review and revise these management measures and strategies on the basis of any new advice provided by ICES.

ICES endorsed the objectives of the plan as consistent with the precautionary approach and has since then presented its annual management advice to coastal states based on the plan. Coastal states undertook a review of the plan in 2013 and decided to continue implementing it. They annually inform NEAFC on their decision on TAC and its allocation, and NEAFC subsequently adopts a recommendation allowing coastal states to fish their quotas wholly or in part in the NEAFC Regulatory Area (international waters).

Although the allocation key has been periodically subject to debate, the coastal states have kept the HCR established in 1999 unchanged.

Cod and, indirectly, capelin

For Barents Sea species such as cod, haddock and capelin, the process developing Harvest Control Rules started in 1997 when the JNRFC decided that the theme of the 8th Norwegian-Russian Symposium, to be convened in Bergen in 1999, should be “Management Strategies for Barents Sea fish stocks.” The symposium, with high-level representation from both Norway and Russia, revealed no basic disagreement between the parties, the industries included, on long-term policy objectives for the management of Barents Sea stocks. For cod, there was a broad consensus that a management strategy should include:

- A goal to maximize the long-term output of the stock;
- A mechanism curbing annual changes in the quota; and
- Annual update and inclusion of new information in assessment and advice.

It took another three years before the Commission finally agreed, in 2002, on a Harvest Control Rule for cod, as well as for haddock and capelin. The rule for cod, with an amendment (shown **in bold** below) agreed in 2009 and applied until 2017 reads:

- Estimate the average TAC level for the coming 3 years based on F_{pa} . The TAC for the next year will be set to this level as a starting value for the 3-year period;
- The year after, the TAC calculation for the next 3 years is repeated based on the updated information about the stock development; however, the TAC should not be changed by more than +/- 10% compared with the previous year's TAC. *If the TAC, by following such a rule, corresponds to a fishing mortality (F) lower than 0.30 the TAC should be increased to a level corresponding to a fishing mortality of 0.30;*

- If the spawning stock falls below B_{pa} , the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{pa} at B_{pa} , to $F=0$ at SSB equal to zero. At SSB levels below B_{pa} in any of the operational years (current year, a year before and 3 years of prediction), there should be no limitations on the year-to-year variations in TAC;
- Reference points: $B_{lim} = 220\ 000\ t.$, $B_{pa} = 460\ 000\ t.$, $F_{lim} = 0.74$, $F_{pa} = F_{msy} = 0.40$.

One of the most important prey species for cod in the Barents Sea is capelin, a short-lived species spawning in spring at the age 2-4. After spawning, it dies. The proper management of capelin is therefore of utmost importance to the well-being of cod. In October each year, Norwegian and Russian research vessels jointly measure acoustically the spawning stock of capelin. Cod's expected predation of capelin in the period October – April is estimated and deducted (set aside) before calculating the capelin TAC. The HCR for capelin is an escapement rule whereby the TAC for a possible winter fishery is set to allow, with a certainty of 95 %, a minimum spawning biomass of 200 000 t. The choice of HCR for capelin reflect its value as prey for cod, was agreed by Norway and Russia in 2002 and prolonged in 2016 and has functioned well.

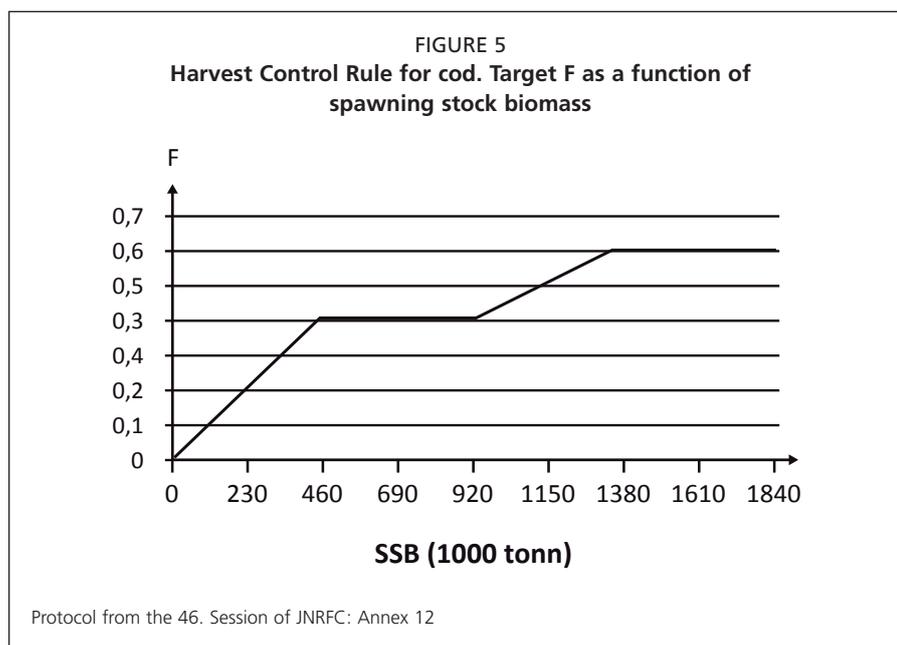
It is fair to consider the agreement on HCRs as one of the greater achievements in the development of the Barents Sea fisheries cooperation between Norway and Russia. The very short-term needs and perspectives that until then had been guiding the setting of TACs, resulted in unquestionable and well-documented detrimental effects both for stocks and not least for all the people and communities whose livelihood depend on fisheries from these stocks.

Quota setting based on predetermined HCRs with a long-term perspective, scientifically tested for robustness by ICES, has obvious advantages compared with the previous short-term, ad hoc arrangements:

- Focus on maximizing the long-term output for the industry;
- Address ecological sustainability;
- Address uncertainty in assessment and advice; and
- Reduce annual variation in catches and create predictability in quota setting; beneficial for market planning, prices and economic result.

Not only in theory but also in practical terms is it fair, in addition to favorable environmental conditions for Barents Sea stocks, to pay credit to the HCRs being a major contributor to the remarkable positive results obtained in recent years. For cod, the average spawning stocks in the last ten years has been 2.6 times higher than in the previous 20-year period, while average annual catches increased by 35 %.

In 2015-2016, the HCR for cod was subject to a major revision process. The outcome of the process was that JNRFC decided to prolong the existing rule for a new five-years period, but with two amendments. The first, based on input from industry, was that the possible annual variation in TAC was increased from 10 to 20 %. The second was of a more fundamental character. In 2002 when the first HCR for cod was agreed, the stock was at a low level. No one imagined at that time that the spawning stock could increase five times within a period of 15 years, opening a discussion about whether the cod stock could actually become “too big”. Cod is, after all, a heavy predator on important commercial species such as capelin and herring, as well as being cannibalistic. JNRFC therefore, including multispecies considerations in their deliberations, decided to amend the target fishing mortality (F) of the HCR as indicated in **Figure 5**.



The amended rule states that when SSB is higher than $2x B_{pa}$ (920 000 tons), the target F of the HCR shall increase gradually from 0,40 to reach 0,60 when SSB is at or above $3x B_{pa}$ (1 380 000 tons).

Before the adoption of long term Harvest Control Rules, the annual setting of TACs was subject to *ad hoc* decisions. Although based on scientific advice, the decisions would often be vulnerable to political pressure to meet short-term industry needs, leading to higher quotas than considered precautionary or beneficial in the long term. In general, the introduction of predetermined Harvest Control Rules has considerably reduced this problem.

5. MEASURES TO INCREASE PROFITABILITY IN THE FISHING FLEET

Any fishery can be considered an economic activity. When the resource base (the fish stock) is secured through a sustainable exploitation pattern and exploitation rate giving high long-term yields, and the fishery is conducted in accordance with these regulations (see Section 6), the question related to optimal fleet size remains to be solved. What can be considered the best answer to such a question will likely vary between fishing nations, depending upon costs and alternative employment opportunities for its fishermen.

Norway is a society, which during the recent history has had a low level of unemployment, and the reduction in number of fishermen during recent decades has not led to an increase in the unemployment rate, at least on a national scale. This may partly be caused by a fortunate discovery and development of petroleum fields in the Norwegian economic zone. During the decades where the number of fishermen decreased, these found new employment opportunities in other industries. Consequently, using fisheries as a buffer sector against widespread unemployment has not been a prevalent objective during the last years. Rather, objectives related to profitability to ensure safe and good employment opportunities for those still in the fishery have gained weight. This change in objectives has implied less focus on question of what the optimal fishing capacity is, and a search for measures to secure a sustainable level of profitability for the still active fishing vessels. While the number of vessels

has still been regulated, the technical fishing capacity, for example in terms of engine power, has not.

The measures applied to increase profitability in the Norwegian fishing fleet include limiting access, abolition of subsidies, scrapping as well as license aggregation schemes, and the introduction of individual vessel quotas. For a more detailed description, see Gullestad et al. (2014).

5.1 Limiting access

The overfishing and collapse of the Norwegian spring-spawning herring stock gave impetus to the process of limiting access to Norwegian offshore fisheries. The new law regulating participation in fisheries entered into force in 1972 and over subsequent years, offshore fisheries were gradually closed to new entrants. In parallel, the extension of exclusive economic zones to 200 nautical miles limited foreign fleets' access to Norwegian waters.

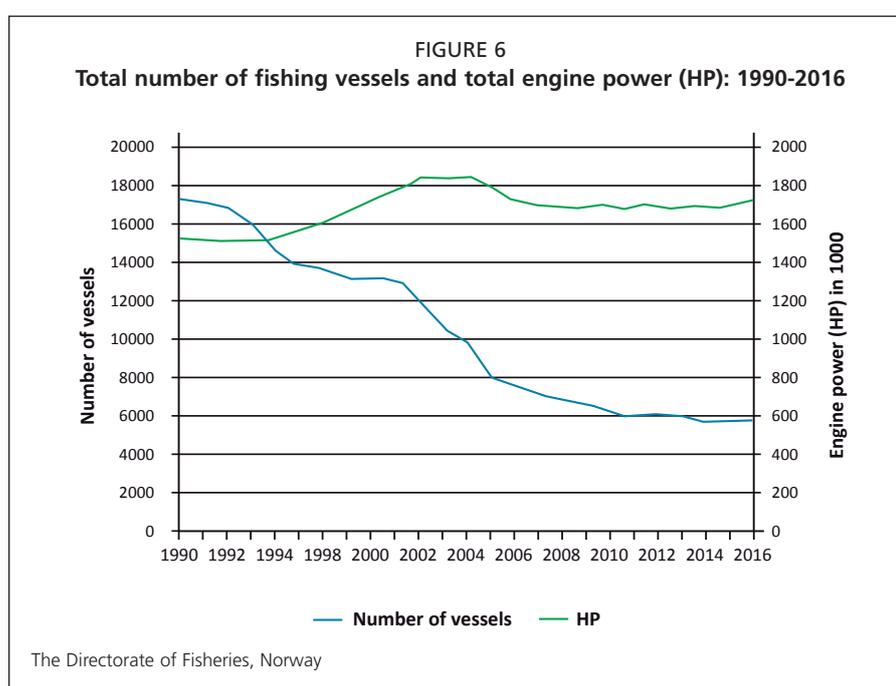
Nevertheless, by 1990 the situation for the cod stock had become critical because of overfishing. As a major part of Norwegian fisheries for cod is conducted by coastal vessels, Norwegian authorities saw it as necessary to limit access for most of Norway's coastal fleet fishing for cod. This was a draconian step, in a country where open access to coastal fishing had been regarded as a sort of human right since time immemorial. At the time, this first comprehensive access regulation of a coastal fishery was explained and defended politically as a pure emergency measure which would be repealed as soon as the stock situation would have improved. With time, however, it was gradually but reluctantly accepted that this was not merely an emergency measure, but one of the permanent steps necessary to curb overfishing and as well as to ensure an acceptable level of income for those fishermen most dependent upon this fishery, regardless of the stock situation. In the late 1990s and early 2000s, many additional coastal fisheries became subject to access regulations, including in 2002 the coastal fishery for herring. Since 2004, the remaining open access opportunities in coastal fisheries are all small-scale and, in many cases, regulated by overall quotas, and thus in general have only a minor impact on fish stocks and should not encourage fishers to make new investments.

5.2 Abolition of subsidies

Starting in the 1960s, a strong political commitment to increase the wages for fishermen as well as to protect employment and settlement in vulnerable rural coastal communities had led the government to grant annual financial support to the fisheries sector. The subsidies peaked around 1980 when they amounted to about one third of the first-hand value of fish, and where the bulk constituted support to increase revenues and decrease expenses. The subsidies were gradually reduced in the 1980s, increased temporarily during the cod crisis, but have been negligible since the mid-1990s. Although the phasing-out of subsidies were not welcomed among the fishermen, they occurred at the same time as the rapid increase in productivity (measured as catch/fisherman), as shown in **Figure 7**. Consequently, increased income counteracted reduced subsidies. Besides the intended positive effect of maintaining (artificially) a high level of employment in the fisheries sector, the subsidies had several negative effects. The most obvious one was that it helped preserve fleet overcapacity, and even contributed to its increase, putting stocks under permanent pressure and threat of overfishing.

5.3 Scrapping and license aggregation schemes

Limiting access and eliminating subsidies in fisheries were, however, not sufficient to reduce the risk of overfishing and secure profitability in the fishing fleet. During the 1980s, some of the above-mentioned subsidies to the sector was utilized to finance scrapping schemes to reduce fleet capacity. From the 1990s, such schemes were gradually replaced by voluntary license aggregation schemes, e.g. voluntary scrapping of one vessel entitles the owner to transfer the old vessel's fishing licenses to another existing vessel for a period of 20 years. Limits are set on how many licenses one may aggregate onto one vessel or by one owner. This policy succeeded in reducing the number of fishing vessels and increasing fleet profitability although fishing capacity, as measured in technical terms by the fleet aggregate horsepower, has not decreased (Figure 6).



5.4 Distribution of annual fishing opportunities: stakeholder participation

The national distribution of quotas between fleet groups and between vessels within each group has been a contentious and time-consuming issue, particularly in the period from 1990 to around 2005. Since then, however, the most important distributional issues are settled, and durable, long-term solutions seem to persist. In this process the Norwegian Fishermen's Association (NFA), which organizes fishers and vessel owners from most fleet segments, played a vital role in the delicate task of negotiating relatively robust compromises between its members. Recent catch history of fleet groups was one of the more important components in reaching solutions. The intensive efforts of the NFA in this context have been appreciated and the compromises have largely been respected in practical politics by Parliament and changing governments. This has contributed to relative political stability on these often very sensitive issues. The general experience is that consultation and stakeholder participation in the regulatory process has contributed significantly to the development of sustainable fisheries management and to the industry's acceptance of regulatory measures. Specifically, NFA's involvement and influence on distributional issues have been considerable and, gradually, the large majority of stakeholders is embracing the long-term sustainability perspective on fisheries management.

6. MONITORING, CONTROL AND ENFORCEMENT

6.1 The establishment of a control organization

One of the lessons learnt over the last decades is that robust science and regulatory measures are necessary, but not sufficient conditions for curbing overfishing. During the 1980s it became clear that prudent control and enforcement, both at sea and in harbor, were essential elements in rebuilding stocks and an essential part of successful fisheries management, and that an entirely new field and profession had to be established and developed to perform the task.

The Norwegian Coast Guard, a separate branch of the Royal Navy, was established in 1977 with its main task to exercise fisheries inspection and control in the extended waters that had now come under Norwegian jurisdiction.

Very soon, it became evident that control could not be limited only to the inspection of mesh sizes and other gear-related issues and that the monitoring of catch quantities in relation to quotas and by-catch regulations had become increasingly important. While the Coast Guard conducts such controls at sea, the Directorate of Fisheries, during the 1980s, extended gradually its traditional task of quality control to include the quantitative control of landings, in addition to coordinating the overall Norwegian control activity related to fish resources.

The industry also got an important role to play. Six fishermen's sales organizations share a legal monopoly, dating back to the 1930s, on all firsthand sales of fish in Norway. They set minimum prizes and act as an intermediary between fishermen and fish buyers, including accounting for the financial settlement of sales. The sales note is a legal document, both in relation to the commercial aspects and in relation to catch reporting, particularly for quota accounting purposes. It is signed by the fisherman and the buyer and, immediately after signing electronically, transmitted to the sales organization which forward it automatically to the Directorate of Fisheries. In addition to serving as a commercial document, it is also the basis for fisheries statistics and analysis, and for the monitoring and control of fisheries and quotas. The sales organizations are legally responsible for settling of catches against vessel quotas, and for retention of the sales value of quota overruns.

6.2 Consistency of historical series: when is a kilo not a kilo

Before the introduction of quotas, government's incentive to focus on possible incorrect catch statistics was limited because there was no cheating on quotas. However, in situations with strong supply of fish in the white fish sector, minimum prices set (too high) by the fishermen's sales organizations, combined with one or few local fish buyers, fishermen could be "persuaded" to deliver more kilos than reported, to be able to sell the catch (at the legal minimum price). This phenomenon has even its own name among fishermen; "storhundra", or "big hundred" in English, implying that a "hundred kilos" may sometimes be more than this.

In the pelagic sector, other practices leading to under-reporting had evolved. In that sector, in Norway, catches were landed onto a conveyor belt and were traditionally only weighed or counted after being boxed in the processing plant. Business practices, including the deduction for (allegedly) damaged or low-quality fish and the tolerance of 10-20 percent overweight in the boxes, underestimating landings, turned out not to

be unusual. Similarly, in other European countries where pelagic fish are landed and weighed in containers, generous deduction for “water content” was revealed.

Conversion factors for onboard processed fish into live weight equivalent have also turned out to be a difficult and complex issue. Existing conversion factors, at least in Europe, were/are old, undocumented and not reflecting very well the actual production. A country may for example only have one conversion factor for filets, regardless of actual production; with or without skin, pin bone etc.

The development of modern resource control has therefore also meant “to clean up in old sins”, challenging some deeply threaded traditions in buying and selling of fish. Compulsory and correct weighing of catches at the quayside and a program for updating and documentation of conversion factors have become central elements of modern fisheries management. The introduction of new processing technologies and fish products will require, for example, continuous revision of conversion factors.

The implications, for the analysis of a rebuilding program is that the level of recovery estimated by comparison with historical biomass or catch data may be overestimated.

6.3 IUU-fishing for cod

Depending on stock size and climatic conditions, cod may at times be available for fishing in international waters in the Northeastern part of the Barents Sea (the Loophole). In the early 1990s, an unregulated fishery by European flagged vessels as well as vessels under flag of convenience, developed in the area. This experience had a huge influence on developing Norwegian policies and measures against IUU-fishing. One useful measure was the blacklisting of vessels participating in IUU-activities from any future fishing in Norwegian waters, regardless of future flag or ownership. After nearly a decade of joint efforts, Russia and Norway, through trilateral or bilateral consultations and agreements, were finally able to largely halt the unregulated fishing in the Loophole.

In the late 1990s, the Coast Guard revealed another IUU challenge. Russian vessels licensed for fishing in Norwegian waters were transshipping catches of cod to reefer vessels, without notifying catches to Russian authorities. For 2001 alone, it was revealed that half the number of transshipments, estimated to include 100 000 tons of fish, had not been reported. The reefer vessels subsequently unloaded their cargo in European ports. Norway had already bilateral agreements on cooperation on fisheries control with several European countries, and based on this cooperation the reefer vessels were eventually prevented from landing such catches in European ports, finally bringing the illegal activity to a stop around 2005. These positive experiences were important when NEAFC, in 2007, introduced Port State Control measures in the Northeast Atlantic, followed, in 2009, by the adoption of FAO's *Agreement on Port State Measures to Prevent, Deter and Eliminate IUU Fishing*.

IUU fishing from foreign, as well as Norwegian vessels put the rebuilding of stocks at risk, and a substantial and sustained effort has been necessary to reduce this problem to a manageable level and to keep it under control. To this end, a range of new control methods, and data tools such as satellite tracking and electronic logbook reporting has been developed and introduced. The legal basis for control and sanctions is also expanded to include, not only fishermen, but also the processing industry and other parts of the supply chain.

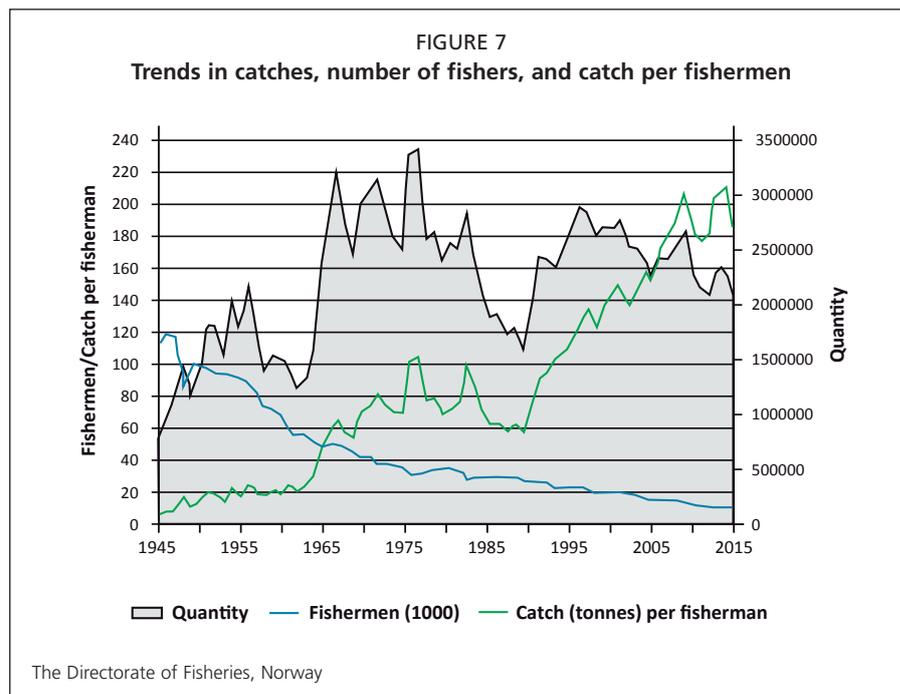
Over time, reduced number of fishing vessels and increased stakeholder participation in management has and will continue to ease the control tasks. Nevertheless, the common nature of fish resources requires a sustained effort in this respect.

7. OUTCOMES OF STOCKS REBUILDING

As in many other coastal states, Norwegian fisheries developed rapidly after 1945 (Figure 7). The broad picture is a fisheries development phase up to the 1960s, then a rather unmistakable overfishing phase with reduced yield that came to a head in the latter part of the 1980s. Then followed the rebuilding of major stocks, giving room for increased yield.

Management strategies and harvest control rules based on the Precautionary Approach, along with improved technical measures and an extensive enforcement regime, have contributed to the rebuilding of depleted stocks, including herring and cod, and laid the foundation for improved profitability in the fishery.

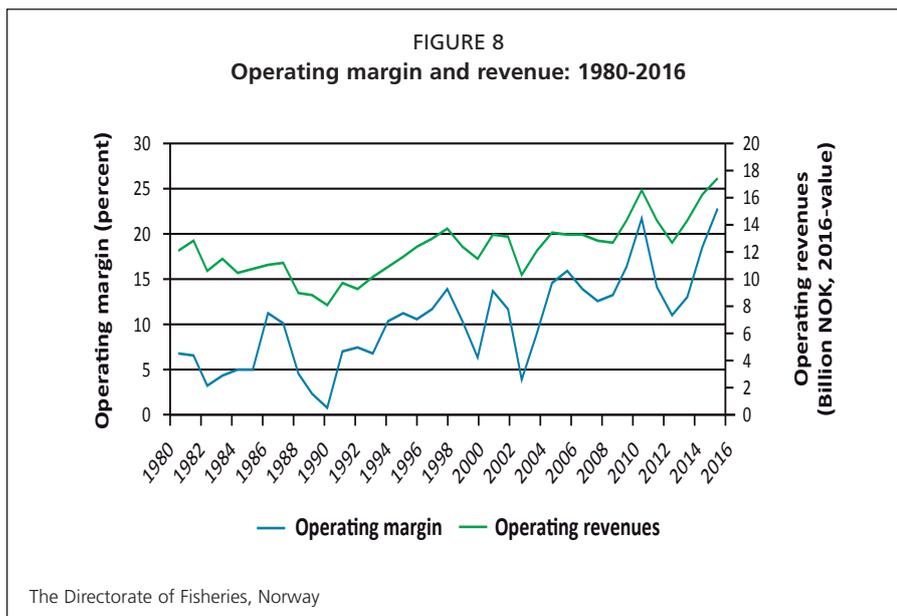
Ecological sustainability is radically improved. The spawning and total biomasses of herring as well as cod show radical improvement since the 1990s (Figures 2 and 4). This is also the case for other stocks economically important for Norwegian fisheries. Aggregate spawning stock of herring and cod have more than tripled since the second half of the 1980s, which, together with the good stock status for the other eight economically most important fish stocks (Arctic cod, haddock and saithe, Greenland halibut, North Sea saithe and herring, mackerel, blue whiting, NSSH and Barents Sea capelin), are so far contributing to a sustainable long-term annual aggregate Norwegian catch level of around 2-2,5 million tonnes (Figure 7). Not surprisingly, this level is lower than during the unsustainable peak-years of the 1960s and 1970s, but it still represents a 40% increase in aggregate catches over those in the second half of the 1980s.



The ambition expressed in the Johannesburg Plan of Implementation (JOI) is “to maintain or restore stocks to levels that can produce the MSY, with the aim of achieving these goals for depleted stocks on an urgent basis and where possible not later than 2015”. Note that while the JOI sets out clear ambitions in restoring stocks to levels that can produce MSY in line with the UNFSA, it does not stipulate how stocks should be managed, as long as they are rebuilt and kept at or above such levels. Objectives of management and rebuilding strategies, target Fs and details of HCRs can thus be stock specific within this framework, and cod and herring are within the ranges identified in the HCRs as producing good yield.

Mainly due to reduced stocks and catches, aggregate real income from fisheries decreased throughout the 1980s. From 1990, this trend was reversed because of the rebuilding of stocks and the possibility of gradually increasing sustainable catch levels (Figures 2 and 4). In combination with structural policy measures reducing the number of vessels, this has improved the profitability of the remaining fleet considerably. Profitability is often measured as “operating margin” which is simply operating profit divided on income, expressed in terms of a percentage. A positive operating margin indicates that the firm has profits after paying its operating expenses (including wages to the crew). In recent years, the average operating margin in Norwegian fisheries has fluctuated between 12% and 23%, indicating a profitability comparable to other sectors of the Norwegian economy (Figure 8). This is in stark contrast to the 1980s when the industry failed to achieve satisfactory profitability, despite receiving substantial amounts in the form of subsidies.

Figure 6 indicates that despite severe reduction in the fleet size, the total fleet horse power (and hence probably the fleet’s potential fishing capacity) did not decrease. Figures 2 and 4, show that stocks have been rebuilt, nonetheless, and Figure 8 shows that economic profitability was significantly increased (increasing landings and reducing operating costs). It is possible that there is still an overcapacity in the fisheries sector in technical terms, but this is clearly not incompatible with resource sustainability and the sector’s viability.



The reduction in numbers of fishers, and vessels have facilitated increased productivity and profitability for those remaining in the industry (Figures 7 and 8). However, the decrease in the number of vessels and fishers have reduced the industry’s

traditional role as the main contributor to employment and settlement in rural coastal communities. Fortunately, this departure from fishing, which largely has been a natural market-driven process, occurred during a period with low unemployment rates and many alternative employment opportunities in Norway. This is likely to have been instrumental in enabling broad political consensus on the necessity of measures to close fisheries to possible new entrants. In this regard, the situation in Norway has been favorable to the needed fisheries reform, giving room for long-term sustainability considerations in management.

In the face of declining participation in fisheries, counter-measures have been introduced to meet policy objectives with respect to regional stability and diversified ownership. Such counter-measures include regulations limiting ownership concentration and the transferability of fishing rights between geographical regions and between fleet groups. This has to some extent mitigated the adverse effects of fewer vessels and fishers in rural coastal areas.

8. CONCLUSION

In both the NEA cod and the NSS herring stocks described here, actual recovery occurred following good recruitment events. The management measures in place allowed SSB to slowly increase, making such events possible, and then protected those good year classes to enable them to mature gradually into both the fishery and the stock. One can put in place the management preconditions for a recovery to occur, but the actual outcome will also depend on the variability of the natural ecosystem. As such, outcomes are always uncertain – in our examples, it would clearly not have been possible to predict in advance when such good year-classes would occur. We would also stress that the successful recovery of these stocks has not been based on special short-term “recovery plans”, but on long term management evolving to allow the stocks to recover and thrive. The fact that the stock structure and dynamics of the cod are continuing to change after the overall SSB has recovered, even though in this case the stock never experienced full collapse, also highlights that recovery is dynamic and long-term process, affecting more than simply overall biomass. Consequently, full recovery following a collapse is likely to take longer than simple projections of stock biomass may indicate.

The emergence of sustainable management of cod and herring in Norway has taken time. In both cases, this is because the introduction of strict and unpopular measures often requires a period of political maturation before they can be realized, and because the expected period, within which positive results of the measures can be expected are uncertain, relying on future recruitment and growth. Furthermore, for the industry to survive during rebuilding, a stepwise approach may often be necessary, which also means prolonging the rebuilding period.

Sustainability rest on three pillars that must be kept in dynamic balance. The fundamental lesson learnt is that ecological sustainability must have supremacy, treated as a prerequisite for achieving any social or economic sustainability. How one should balance the last two pillars is a political issue, which may differ from country to country, fishery to fishery, and over time. Within the Norwegian economy, which over the last 25 years has been characterized by near full employment and high labor costs, economic forces have tilted the balance in favor of economic sustainability. The balance is however not stable and to some extent still open for political debate. Measures to control the fleet size and how these are aligned have been at the core of this debate.

One contentious social issue when establishing Individual Vessel Quotas (IVQs) is the barrier that acquisition of an IVQ may pose to newcomers. If holding an IVQ is profitable, i.e. that the income from the fishery exceeds the cost of fishing, no newcomer will be able to acquire an IVQ without compensating those fishermen who are willing to give up their IVQs. For valuable fisheries on cod and herring (among other stocks), the price of an IVQ will be high and constitute a barrier against newcomers. The contentious issue is whether it is legitimate that exiting fishermen get a compensation for giving up an IVQ which, at the outset, they got from society for free. This issue has in its turn spurred a debate on whether super-profit or resource rent generated from exploiting a natural resource like fish should be subject to taxation.

Sound fisheries management is based on laws and regulations. The legal framework for Norwegian fisheries management has been, and still is, under continuous development. There is no single date, no one piece of regulation, that one could point at as being “the key” in rebuilding these stocks. Rather, the stepwise ongoing process has underpinned the stock recoveries. An important prerequisite for developing good fisheries management has proven to be the capacity and ability to quickly investigate and propose necessary changes in fisheries legislation as new and pressing issues arised. Successful management is clearly not a short-term exercise, limited to a rebuilding timeframe or the lifespan of a HCR, but an ongoing process. Norway has proved successful in having a continuity of incremental management adjustments, partly based on a continuity among the managers which gives them time to become experts in their fields, which has helped shape a long-term perspective on management. We would also stress that “management” in this context is far more than simply setting quotas. Without the complex array of technical measures previously described, to guide fisheries towards improved sustainability (e.g. measures to combat black landings, spatial and temporal closures, gear restrictions, capacity management and so on), it is doubtful that the recovery strategies would have been as successful.

Many economic important fish stocks around the world are transboundary stocks shared between jurisdictions but far fewer are however actually managed jointly. To achieve sustainable stock management, the examples of cod and herring illustrate the necessity as well as the complexity in developing joint management arrangements. Long-time scientific cooperation has proven to be a good start and basis for building confidence between parties, and achieving possible agreements on measures regarding exploitation patterns, HCRs, resources sharing and control issues. The success of the NEA cod fishery has relied heavily on close cooperation between Russian and Norwegian scientists and management bodies, whereas for NSS herring the cooperating partners also include EU, Faroe Islands and Iceland. For both species, joint management has evolved over time to meet emerging issues as they arose.

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ANNEX 1 – TIMELINE OF FISHERIES MANAGEMENT KEY EVENTS

Period	General events	Situations or events relevant for herring fisheries	Situations or events relevant for cod fisheries
1945-1949		<ul style="list-style-type: none"> Spawning stock at high level 	<ul style="list-style-type: none"> Spawning stock at high level
1950-1959		<ul style="list-style-type: none"> Spawning stock declining 	<ul style="list-style-type: none"> Spawning stock declining
1960-1969	<ul style="list-style-type: none"> Agreement to start subsidizing the Norwegian fishing fleet 	<ul style="list-style-type: none"> Total catch increases sharply Spawning stock collapses 	
1970-1979	<ul style="list-style-type: none"> The Act on participation in fisheries is adopted Establishment of The Joint Norwegian-Russian Fisheries Commission Establishment of 200 nm economic zone Establishment of The Norwegian Coast Guard ICES provides advice on fishing opportunities based on reference points like F_{max} or $F_{0.1}$. The first scrapping schemes are introduced 	<ul style="list-style-type: none"> Temporary limited access for new offshore purse seine vessels Minimum legal fish size of 25 cm established Remaining stock confined to Norwegian waters Permanent limited access for new offshore purse seine vessels Close to complete moratorium on fishery (only very limited amount for coastal vessels) 	<ul style="list-style-type: none"> Norway and Russia establish Total Allowable Catch (TAC) Norway and Russia agree on allocation keys for cod as well as for haddock and capelin Norway and Russia agree to increase mesh size in trawl
1980-1989	<ul style="list-style-type: none"> The Act related to seawater fisheries is adopted Subsidies to the sector are declining Directorate of Fisheries increases its focus on catch control Six sales organizations are given the responsibility to control catch against individual vessel quotas (IVQ) Measures to reduce discarding practices are introduced 	<ul style="list-style-type: none"> Strong year class (1983), migrates to the Barents Sea, including Russian waters, as juveniles TAC for herring set according to a fishing mortality (F) of 0.05. Russia is granted quota of adult herring in the Norwegian Economic Zone 	<ul style="list-style-type: none"> Strong year class (1983) Further (unilateral) increase in mesh size by Norway Program of Real Time Closures implemented to protect juvenile cod Discard ban for cod and haddock introduced Overfishing and the need to limit access in coastal fisheries for cod becomes evident

1990-1999	<ul style="list-style-type: none"> • Focus on correct weighing of catches and the need for correct and harmonized conversion factors • Voluntary scrapping schemes are gradually replaced by license aggregation schemes • Fisheries subsidies are phased out 	<ul style="list-style-type: none"> • Strong year classes (1991 and 1992) • Increase in biomass and distribution of adult stock beyond Norwegian waters. • Total catch increases • Workshop to determine the distribution of stock on High Seas and EEZ of coastal states • Negotiations and agreement on allocation key for sharing of TAC among coastal states • Compromise reached on national sharing between fleet groups • Harvest Control Rule agreed between coastal states • Cooperation on control between coastal states 	<ul style="list-style-type: none"> • Limited access to coastal fishery and introduction of individual vessel quotas (IVQ) • Mandatory sorting grid in shrimp trawl to avoid bycatch of juveniles of demersal species • Mandatory sorting grid in cod trawl to avoid catch of cod below minimum legal size • An unregulated international fishery for cod in the Loophole develops, finally brought to an end through joint efforts by Norway and Russia • Joint Norwegian Russian Fishery Commission arrange symposium on Management Strategies and work to establish HCR for cod starts
2000-2009	<ul style="list-style-type: none"> • Vessel monitoring systems and electronic logbooks become mandatory • Port state control measures introduced in the Northeast Atlantic • The Marine Resources Act is adopted 	<ul style="list-style-type: none"> • Negotiations on international allocation key reopened, Agreement on new allocation key 	<ul style="list-style-type: none"> • Illegal fishery for cod by Russian vessels detected, and work is undertaken to assess its magnitude as well as to end it. • HCR for cod, haddock and capelin adopted
2010---	<ul style="list-style-type: none"> • Fisheries management is moving towards an ecosystem based approach 	<ul style="list-style-type: none"> • Negotiations on allocation key again reopened 	<ul style="list-style-type: none"> • Harmonization of minimum mesh size and minimum legal fish sizes in Norway and Russia • HCR for cod amended, allowing an increase in F when SSB is high

Decline and partial recovery of a trawl fishery in South-eastern Australia

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Abstract

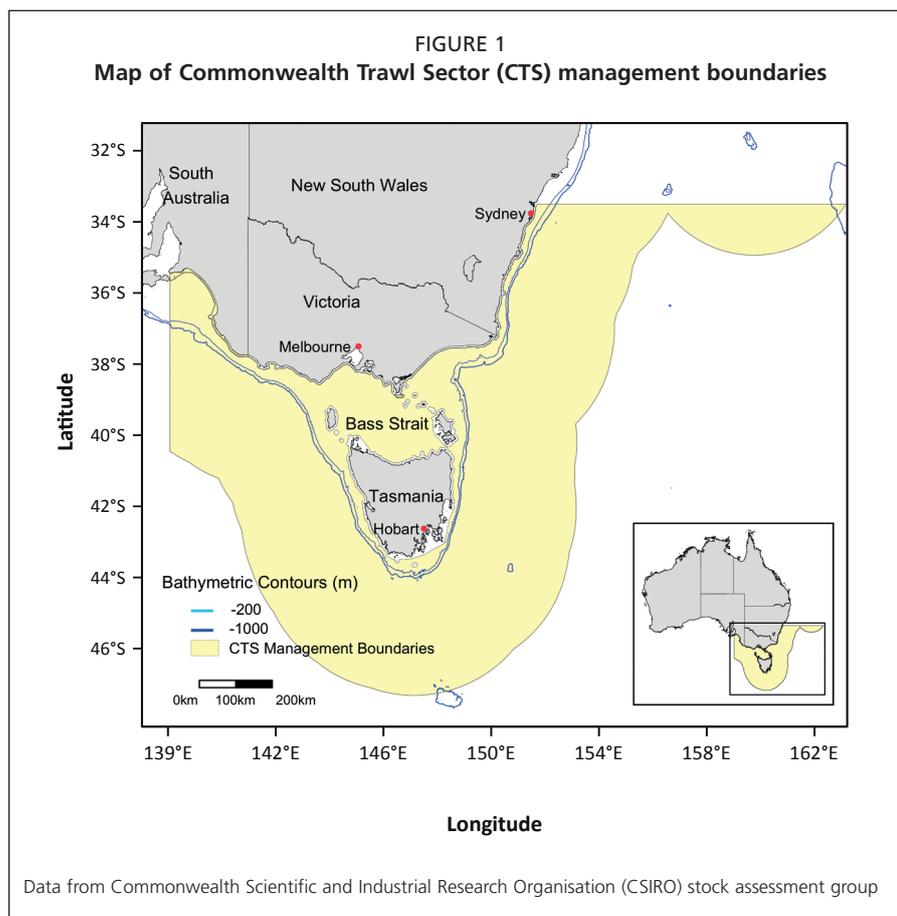
This chapter describes the management history of a complex multispecies trawl fishery in south eastern Australia, particularly over the past three decades. Substantial declines in stock status and economic performance of the fishery in the early 2000s resulted in several initiatives to deal with this situation, including the development of a strategic evaluation of the overall management arrangements for the fishery, the introduction of a formal harvest strategy framework to address overfishing, and the buyout of half the fishing fleet in the mid-2000s. Although a few overfished stocks have so far failed to recover, overfishing (fishing mortality rates above F_{MSY}) has ceased and the fishery has returned to positive profitability. Broader improvements in environmental performance have also been achieved, particularly in managing impacts of fishing on protected species and benthic habitat. This case study illustrates the complexities of recovery in multispecies fisheries, and the combination of political, scientific and management efforts needed to move towards recovery.

1. INTRODUCTION

A commercial trawl fishery has existed around south-eastern Australia since the early part of the 20th century (Novaglio 2016). It has changed considerably over the past 100 years, both in the size and nature of the fishing fleet, the spatial extent of the fishery, the species targeted, and particularly in management of the fishery. For most of its history it consisted of several separate fisheries developed and managed under the jurisdiction of four different states of Australia in a relationship that could be characterised as competitive development. The Commonwealth government began taking a stronger coordination and management role in the 1980s and, by the early 1990s, provided the primary management for the fishery (Grieve & Richardson, 2001). The present trawl fishery, known as the Commonwealth Trawl Sector (CTS), is part of a larger fishery management unit called the Southern and Eastern Scalefish and Shark Fishery (SESSF), comprising a variety of fishing gears and demersal target species, and managed by the Australian Fisheries Management Authority (AFMA). In 2016 the CTS landed 8057 tonnes of fish valued at about AU\$40 million, representing about two thirds of the overall value of the SESSF (Georgeson et al., 2016). The CTS targets about 10 species but lands over one hundred species and captures a further five hundred (mostly in small quantities) which are of no commercial value and are discarded. It has been the main supplier of fresh fish to the Melbourne and Sydney fish markets for most of its history. It is geographically large (**Figure 1**), covering an area larger than the landmass of Italy,

and it encompasses a wide range of marine habitats (the continental shelf, slope and seamounts that rise from abyssal depths) (Smith & Smith, 2001).

This chapter first describes the historical development of the fishery in the 20th century, and more recent changes since 2000. The second section focuses on fisheries management, particularly the significant changes in the mid-2000s following a period of very poor economic and biological performance, and the recovery strategies put in place at that time. The final section discusses the outcomes of these recovery strategies, including the reasons for both successes and failures, set in the context of the assessment and management of this complex multi-species fishery.



2. HISTORICAL DEVELOPMENTS

2.1 The South-East Trawl fishery in the 20th century

The history of trawling in south-eastern Australia is well-described in several publications (Klaer, 2001; Novaglio, 2016). Following exploratory trawl surveys in the early 1900s along the New South Wales (NSW) coast, the NSW government imported three steam trawlers which fished the continental shelf close to Sydney. Important target species in this early phase of the fishery included several species that still remain important in the fishery – tiger flathead (*Platycephalus richardsoni*), jackass morwong (*Nemadactylus macropterus*), redfish (*Centroberyx affinis*) and John dory (*Zeus faber*). The government vessels were sold to private interests and the fleet quickly expanded, reaching 17 vessels by 1929. The trawl fleet then declined over

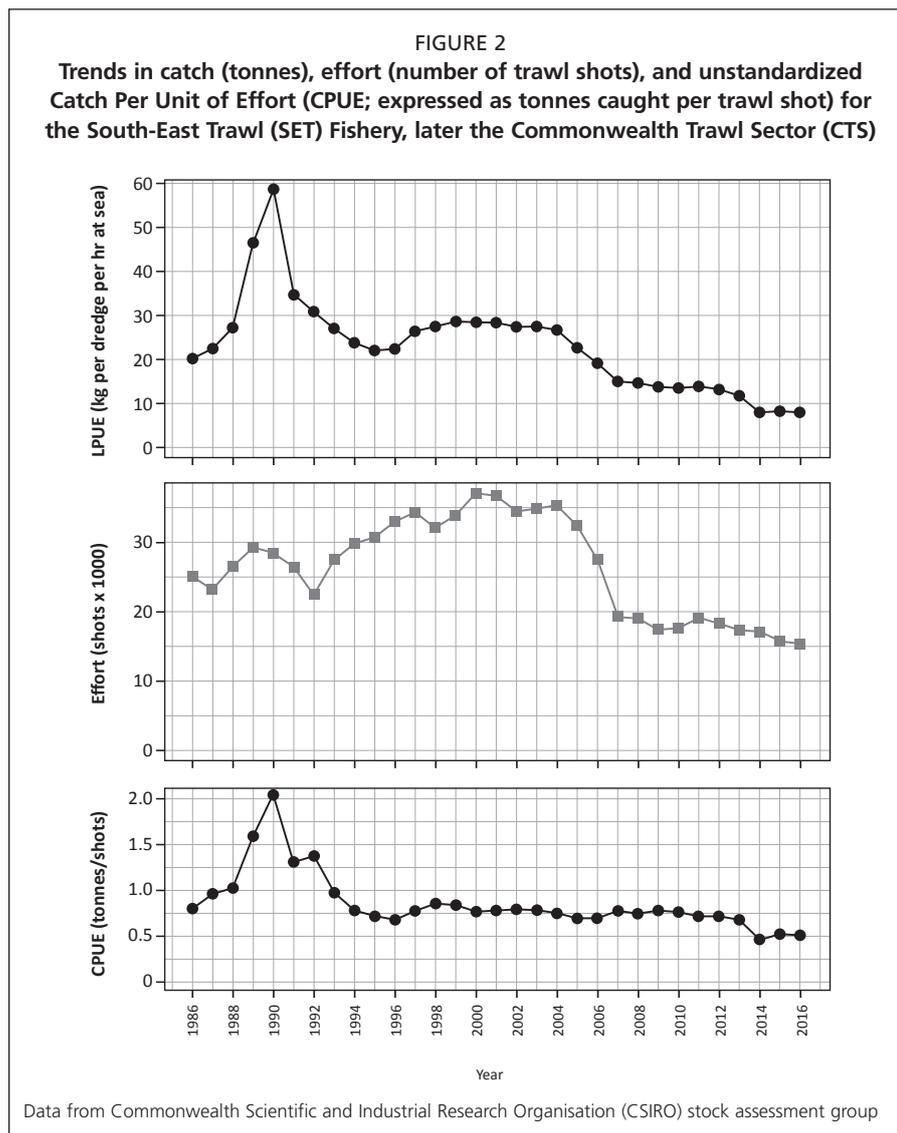
the next 30 years, with the final steam trawler ceasing operations in 1961. During this period and into the early 1970s, the fleet was replaced with Danish seiners (bottom purse seiners), which continued to target many of the same shelf species, particularly tiger flathead.

The introduction of diesel powered otter trawlers in the early 1970s saw the rapid re-emergence of trawling coincident with a major extension of trawl grounds into deeper waters (upper continental slope) and more southerly grounds. The main species driving this expansion was gemfish (*Rexea solandri*), with winter spawning aggregations targeted at 300-400 m depth along the southern NSW coast. By 1976, gemfish had become the major commercial species in the southeast trawl (SET) fishery and the fleet expanded rapidly to 180 vessels by 1982 (Tilzey & Rowling, 2001). This rapid expansion was facilitated by the absence of significant management restrictions, which were then under State rather than federal control, with management limited to a few input regulations on nets, minimum legal lengths on some species, and vessel size (Grieve & Richardson, 2001).

A major change in management of the fishery came in 1985 when the federal government began to actively manage the SET, at first with management through a federal government department and then, in 1991, through a federal Statutory Authority (Grieve & Richardson, 2001). This resulted in a division of the fishery into spatial sectors, with entry criteria for each sector that limited the number of vessels per sector, and later the introduction of tradable catch quotas (Tilzey, 1994). This was of some importance in limiting further fleet expansion when large new resources of blue grenadier (*Macruronus novaezelandiae*) and orange roughy (*Hoplostethus atlanticus*) were found at deeper levels of the continental slope, and in the most southerly sector close to Tasmania. The discovery and exploitation of large aggregations of orange roughy around Tasmania in the late 1980s saw SET catches rise to unprecedented levels, then decrease again just as quickly, continuing to decline with some oscillations until 2016 (Figure 2).

A key change that came with federal management from the mid-1980s was a greater focus on monitoring, research and assessment for the fishery. Compulsory logbooks were introduced in 1985, and quantitative stock assessments of key species began in the late 1980s. These led to the first output controls being implemented for SET species, with catch quotas introduced for gemfish in 1988 and for orange roughy in 1990. A management advisory committee, SETMAC, was implemented in 1986 and a research and assessment group for orange roughy was established in 1989.

A further important change in Commonwealth (federal) management occurred in 1991 with the establishment of the Australian Fisheries Management Authority (AFMA). This transferred day to day management responsibility for Commonwealth fisheries, such as the SET, from a federal government department to a separate statutory authority with its own expertise-based board. The AFMA "model" for fisheries management has been described elsewhere (e.g. Smith et al., 1999), with a key feature being a widely consultative and participatory approach to fisheries management with stakeholder involvement at multiple levels in the management process.



Several important management changes quickly followed from AFMA taking control of the SET. Quota management for 16 SET species was introduced in 1992, allocated as individual transferable quotas (ITQs). To support quota management, a stock assessment group, the South-East Fishery Assessment Group (SEFAG), was set up in 1993 to report annually on the status of quota species. This umbrella group was supplemented later in the 1990s by species-specific assessment groups such as the Eastern Gemfish Assessment Group, the Orange Roughy Assessment Group, and the Blue Grenadier Assessment Group, each comprising representatives from science, management and industry. AFMA also established the Integrated Scientific Monitoring Program (ISMP) for the fishery in the mid-1990s, which collected data on the size structure of retained and discarded fish and provided otoliths to the newly established Central Aging Facility (Morison et al., 1998). These initiatives, together with fishery independent surveys for blue grenadier and orange roughy, contributed to a greatly enhanced ability to assess the status of key quota species in the SET fishery. A management plan was introduced for the SET in 1998.

The introduction of quotas and the focus on stock status and assessment during the 1990s highlighted that the SET did not exist independent of other fisheries in the region. Some of the same species were also caught by non-trawl methods,

including gillnets, hooks and traps, often targeting non-SET species such as sharks, but sometimes targeting the same species such as ling (*Genypterus blacodes*) and blue warehou (*Serirolella brama*). In addition, fisheries under state jurisdiction also caught some SET species, particularly shelf species. These catches needed to be accounted for in stock assessments, and compatible management arrangements implemented where possible. Quotas were introduced for the AFMA-managed non-trawl fisheries in 1997, leading later (2003) to the establishment of a broader fishery management unit, the Southern and Eastern Scalefish and Shark Fishery (SESSF) that encompassed all fisheries targeting demersal fish resources in the region, except for the state-based fisheries.

Two other management changes occurred in the late 1990s that, while outside AFMA's jurisdiction and control, greatly influenced management of the SET. The first of these was the introduction of the Environmental Protection and Biodiversity Conservation Act in 1999. This was federal legislation that provided oversight of fishery management performance through the Department of Environment, and both reinforced the need for sustainability of target stocks and greatly strengthened the focus on the impacts of fishing on bycatch and protected species, both of importance to a trawl fishery. The second was the Australian Oceans Policy in 1998, with a focus on the establishment of a national representative system of marine protected areas (Vince et al 2015). The first area of application of this Policy was in the waters around south-eastern Australia, encompassing much of the area of the SET.

The history of the SET in the 20th century, recounted briefly above, is described in more detail in a special issue of the scientific journal Marine and Freshwater Research (Smith & Smith, 2001).

2.2 The South-East Trawl fishery in the 21st century

Benchmarking the SET at the end of the 20th century, the ABARE Fishery Status Report for 2000-2001 provides a useful summary of the status of the fishery entering the 21st century (Caton, 2002). Landings of trawl-caught quota species in 2000 were 26 157 tonnes, while trawl-caught non-quota landings were of 4 061 t, with a combined value of AUD 68 million. Four species were classified as overfished – eastern gemfish, eastern and southern orange roughy, blue warehou and redfish. Four species (tiger flathead, blue grenadier, jackass morwong and ocean perch) were assessed to be fully fished, and the status of a further nine species was uncertain. The number of active trawlers had decreased since 1992, but total fleet capacity (gross tonnes) had increased and the total effort (hours trawled) had almost doubled since the early 1990s, despite a government-funded buyout of 27 licenses in 1997. The available trawl TAC in 2000 of 35 510 tonnes was significantly higher than the landings of 26 157 tonnes, a consistent feature of the fishery. Highly targeted species such as orange roughy, blue grenadier and tiger flathead tended to have TACs close to fully caught, but landings of many “minor” species were less than 50 percent of the TACs.

By 2003, effort had stabilized (**Figure 2**) but landings had declined (Caton et al., 2004). Landings of trawl TAC species were 23 727 tonnes and 4 491 tonnes of non-quota species, with a combined value of AUD 66 million. Five species were by that time classified as overfished, with silver trevally added to the list from 2000. Five species were assessed as not overfished, with a further seven classified as uncertain. Of concern was the status of the “uncertain” group, with catch rates (CPUE) for most of these at their lowest levels since 1986. Without formal decision rules in place, this situation did not (generally) lead to reductions in TACs.

Of concern to license holders in the fishery was the marked deterioration in profitability in the early to mid-2000s. Net economic returns (total revenue from first landings less fixed and variable costs) for the SET were close to zero in 2002 and deteriorated significantly in 2003 with costs exceeding revenue for the fleet. This, as much as concerns about the biological status of stocks, resulted in calls to undertake a broad evaluation of the current state and direction of the fishery. The outcome was a research project, funded in 2004, to evaluate alternative management options, not just for the CTS but for the whole SESSF. This project came to be known as the Alternative Management Strategies (AMS) project. Its aims and outcomes are described in the next section of this chapter.

3. MANAGEMENT STRATEGIES

3.1 The Alternative Management Strategies (AMS) project 2004 to 2007

The AMS project was developed in 2004 to examine options to reverse the decline in the economic and ecological status of several parts of the SESSF, particularly the trawl sector. The project was conceived as a management strategy evaluation (MSE) analysis at a whole of fishery level. MSE is a method to compare alternative management strategies or options. The comparison is based on predicting their likely performance in terms of performance indicators that reflect (potentially conflicting) management objectives, while explicitly taking into account uncertainties in making those predictions (Smith et al., 1999). MSE is a method that is widely used to evaluate the expected performance of single species harvest strategies and had been used previously in the SESSF for that purpose (e.g. Punt & Smith 1999; Punt et al., 2001). The MSE undertaken for the AMS project was much broader in scope:

1. It focused simultaneously on all sectors and components of the multi-species, multi-gear, multi-region SESSF;
2. It focused on a very broad range of management objectives and performance indicators, including those associated with economics, social outcomes, and governance, as well as the (more usual) biological/ecological outcomes;
3. It considered a broad range of management tools, including quota management, gear and effort controls, spatial management and bycatch mitigation; these were grouped into comprehensive “management strategies” that in some cases went well beyond the existing form of management arrangements in the fishery.

A novel feature of the project was the use of two entirely different methods to predict and evaluate the consequences of the alternative management actions. MSE studies usually use quantitative models to encompass uncertainties and predict the consequences of different management strategies, and because the focus is usually on single species harvest strategies almost all MSE application are based on single species stock assessment models. The AMS project took a different approach to both these usual features of MSE. In a first phase, the MSE methodology was applied qualitatively, with stakeholder, management and scientific expert judgement being used to predict the consequences of alternative management strategies, separately and in addition to the usual quantitative and model-based predictions. In this the formal structure of an MSE approach was maintained, so that a set of well described alternative harvest strategies were systematically compared using pre-identified performance indicators. In a second phase, the quantitative MSE assessment was conducted using a bioeconomic systems model that included broad representation of the ecosystem, fleet and some

other fishery operational dynamics (e.g. discard practices) and economics (including employment and social indicators).

This combination of approaches was designed to help reduce the scientific “black box” reactions that model-based evaluations can engender among non-scientists and to provide a reality check on the complex ecosystem model. Several members of the project team were apprehensive about stakeholder acceptance of a complex quantitative ecosystem model to make the reliable predictions, particularly given wide scepticism among the same set of stakeholders about the reliability of much simpler single species stock assessment models.

The project team included fishery managers and scientists (covering both biology and economics) with over 150 years collective experience in the fishery. The project was also overseen by a group of stakeholders including fishers from each of the main sectors in the SESSF fishery, plus representatives from environmental organizations with an interest and history of involvement in the fishery. A broader set of fishers was actively involved throughout the life of the project, including in a series of workshops, port meetings, and one on one discussions, particularly focused on eliciting ideas for alternative management strategies – “how would you manage this fishery?”.

Phase one: qualitative assessment

The qualitative phase was undertaken during 2004 and 2005 and focused initially on four alternative strategies – (1) a biologically and economically relatively optimistic variation of the *status quo*; (2) a biologically and economically pessimistic variation of the *status quo* (3) an “enhanced TAC” strategy involving more species in the quota management system; and (4) a “blue skies” strategy involving an integrated mix of input and output controls including enhanced spatial management (Smith et al., 2004). The fourth strategy was called blue skies because at the time it was deemed very unlikely to be adopted but was included to encourage stakeholders to think outside the box. Following an initial qualitative assessment of these strategies, a second round of still qualitative assessments was undertaken in 2005 to evaluate new strategies that had been suggested by stakeholders during discussions of the initial strategies considered. Five additional strategies were considered, including three developed by different sections of the fishing industry, one by the AFMA fishery managers, and one by conservation interests. Some of these new strategies were radically different from the first four, such as very widespread use of spatial closures in the “conservation” strategy, and removal of TAC management and reversion to input controls in one of the “industry” strategies. The “managers” strategy was a more practical and pragmatic variation of the original “blue skies” strategy.

The assessment for each of the nine strategies involved qualitatively predicting the time series for 24 separate indicators using the expert judgement of the project team, supported by detailed description of reasoning and assumptions. The qualitative predictions took the form of sketched graphs of the expected change in indicators through time. The indicators covered aspects of fishery performance such as economic performance by fleet, management costs, public image, interactions with protected species, habitat impacts, and status of key resources. The assumed interrelationships of these indicators were also documented and used to ensure consistency of thinking across scenarios, to help guard against some of the known potential weaknesses of expert-based scenario projections.

An interesting feature of phase one was the way in which it served as an agent of change in the fishery. The “blue skies” strategy was included by the project team as a deliberate attempt to get stakeholders to “think outside the box” about what was wrong with the fishery and how that might be resolved. It was not initially intended as a management strategy that could be realistically adopted, but rather to show that alternatives to the status quo existed and might lead to better outcomes. However, after some initial concern by stakeholders at the implications of the strategy, they quite quickly embraced it as a realistic possibility. The stakeholder group quickly realised that the project was an opportunity to propose and consider new solutions. This led to an outpouring of ideas, particularly by fishers, about better ways to manage their fishery. This was an opportunity for fishers to propose alternatives, rather than simply complain about current arrangements. It also led to more careful consideration by stakeholders about the difficulties and challenges of managing such a complex fishery (“how would you manage it better?”). This is what led to the nine proposals for alternative management strategies outlined above, which were then subject to both qualitative assessment in the first phase and quantitative assessment in the second phase of the AMS project.

Phase two: quantitative assessment

The second phase of the AMS project used a quantitative ecosystem model for south eastern Australia. It encompassed key ecological, fisher and socioeconomic aspects of all the fisheries in the region, including aspects of fleet dynamics and fisher behavioural responses to management changes. This was the first practical implementation of the Atlantis model (Fulton et al., 2011), later designated as Atlantis SE. The results of the second phase of the project were reported to stakeholders in 2007 (Fulton et al., 2007) and the model and project results are given in Fulton et al. (2014).

Two aspects of the second and quantitative phase of the project are worth emphasising. The first aspect was the very positive engagement and response of stakeholders. Phase one had introduced them to the idea of MSE at a whole of fishery level and had involved wide stakeholder participation including close oversight of the project through a stakeholder steering group, active participation in workshops and port meetings, proposing new management options, and the ability to comment on and modify the expert judgement predictions made by the project team. It had also made the concept of MSE easy to understand. The second aspect was that the project team’s earlier apprehension about stakeholder acceptance of a complex “black box” quantitative ecosystem model to make the predictions proved to be largely unfounded. Most stakeholders understood and liked the additional complexity of the ecosystem model, compared to stock assessment models, as better representing the actual complexity of the fishery and ecosystem. They also valued the ability of the model to address specific concerns and questions that arose. For the scientists involved, the model provided a more objective approach to dealing with uncertainty.

Both the qualitative and quantitative analyses predicted future trajectories for the same set of key performance indicators and, despite overlap by some project team members, they were developed largely independently. This substantial independence of the qualitative and quantitative assessments allows comparison of the two approaches across strategies that were in common to both phases. There was good agreement in the predictions of the two approaches across most indicators. A clear difference, discussed further below, was that the qualitative analysis was generally more optimistic about the speed and nature of the recovery dynamics for a few key species and groups.

A final point to emphasize about the AMS project was that it did not just focus on evaluating harvest strategies for stock recovery. While this was an important focus given the deteriorating stock status and economic performance of the fishery at the time, the management strategies evaluated also focused on broader environmental performance of the fishery, including impacts on bycatch species, protected species and benthic habitat, as required both in fisheries management legislation, and as further emphasized in the policy changes reflected in the EPBC Act and in Australia's Oceans Policy in the late 1990s. An important outcome of the study was also to start to embed the principles and practice of ecosystem-based fisheries management in the management of the SESSF (Smith et al., 2007).

3.2 Management changes in the fishery (2005 to 2007)

The qualitative AMS report (Smith et al., 2004) pointed to the possibility of considerably improved fishery performance (both biological and economic) for the SESSF generally, and for the trawl sector in particular, by adopting significant changes to the management arrangements. However, the analysis of likely economic trajectories also demonstrated that there was a considerable short term economic cost to be born in implementing the new arrangements. This realization by stakeholders, and parallel discussions with AFMA and between several government agencies, resulted in a delegation of stakeholders approaching the then minister of fisheries in 2005 to point out the opportunities and costs of change, and to seek government assistance. The AMS report giving the results of the qualitative MSE comparisons was used to support this call for assistance.

At the same time, a process was initiated through AFMA to develop a formal harvest strategy framework for the fishery. This process was led by several of the same scientists involved in the AMS project and was driven initially through AFMA's assessment group for the fishery. A report in mid-2005 (Smith & Smith, 2005) outlined a possible framework that could be applied to all quota species in the fishery, using a tiered approach to account for the different types of information and indicators available for each stock, and the different levels of uncertainty at each level. The framework proposed was reviewed by the assessment group, formally recommended by the management advisory committee, and adopted by the AFMA Board towards the end of 2005. Details of the harvest strategy framework and its implementation are provided by Smith et al. (2008).

Several key policy announcements and directions were made by the federal minister for fisheries late in 2005. These were informed by the developments in the SESSF (i.e. the results of the AMS project, the stakeholder delegation to the minister and adoption of the SESSF harvest strategy framework), along with policy evaluation within various parts of government and the development of harvest strategy concepts in various national and international fisheries. The announcements and directions applied to all Commonwealth fisheries (i.e. all fisheries managed by AFMA). These initiatives included:

1. A Ministerial Direction to AFMA to take immediate steps to cease overfishing and recover overfished stocks. This was to be achieved by developing and applying a Commonwealth Harvest Strategy Policy (CHSP) with features very similar to the framework already adopted in the SESSF. Specific policy settings in the CHSP included defining overfishing as a fishing mortality rate over that at MSY, a target biomass level at 40 percent of unfished levels (later linked explicitly to maximum economic yield MEY), a limit biomass level at 20 percent of unfished levels, and at least an 80 percent chance of avoiding the biomass limit in the face of uncertainty.

The rebuilding time was determined to be the minimum of the mean generation time plus 10 years or 3 times the mean generation time;

2. In conjunction with this Ministerial Direction, the government announced a \$220 million structural adjustment package called Securing Our Fishing Future (SOFF) to support those who agreed to leave the industry. The explanation accompanying the announcement of the package provided explicit description of the expected future management regime to support informed response by industry to the structural adjustment options available. This noted that there would be reductions in TAC levels in the SESSF in 2006 and beyond, in some cases reduction to zero catch;
3. The government also announced the future establishment of a network of marine protected areas in south eastern Australia, as part of the development of Australia's Oceans Policy, noting that the structural adjustment package in SOFF would also help to compensate for the loss of fishing grounds.

In parallel with these management measures there was additional funding provided for research to develop and apply methods for assessment of 'data poor' fisheries, and for development and testing of harvest strategies that could be applied to such fisheries. This was to address the relatively large number of species that were unassessed previously because of limited information, and to identify management strategies that could be applied to these fisheries and have a high chance of meeting the policy specifications.

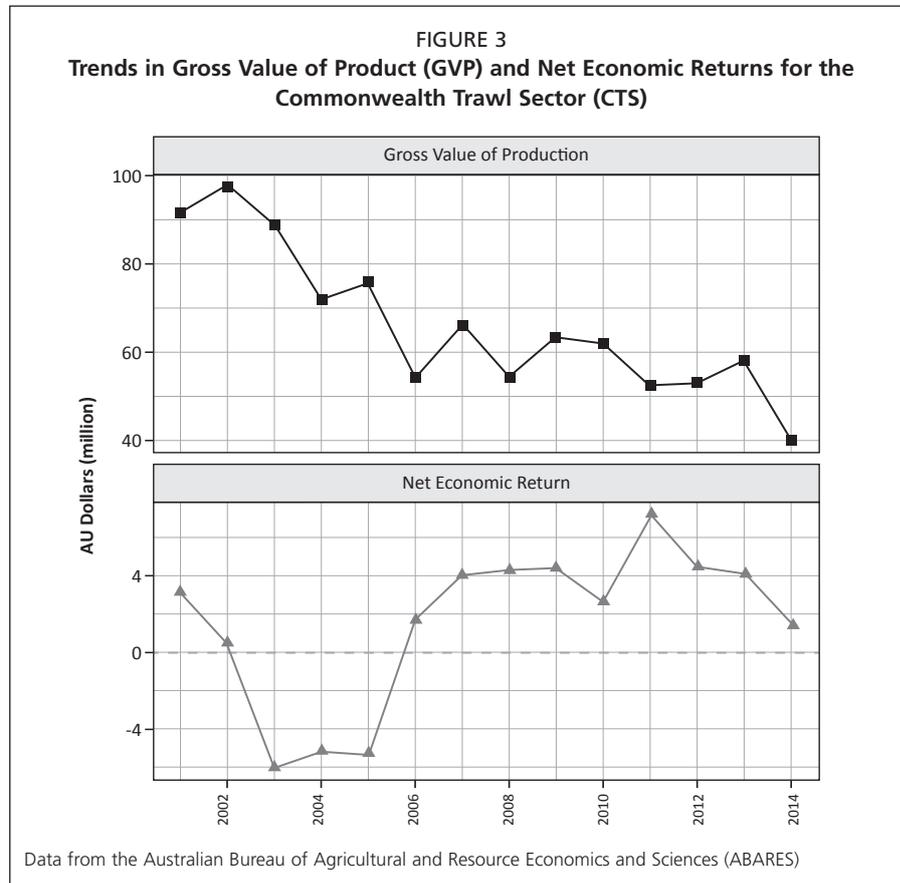
The Ministerial Direction regarding harvest strategies took immediate effect in the SESSF, though the Commonwealth Harvest Strategy Policy was not fully implemented in all Commonwealth fisheries until 2007 (Rayns, 2007). The structural adjustment also took a year and a half to implement in the SESSF. The structural adjustment decreased vessel numbers from 118 to 59 in the trawl sector of the SESSF. Implementation of the harvest strategy framework in the SESSF resulted in rapid reductions in TACs over about the same period. From 2006 to 2007 the total TACs in the SESSF reduced by 17.5 percent, with significant reductions in key target species for the trawl fishery including blue grenadier (by 33%), tiger flathead (23%), and silver warehou (25%). Reductions were particularly large in the deep water (mid-slope) fishery, including through the introduction of large areas closed to fishing (over and above closures due to implementation of MPAs), with orange roughy catch reduced by 87 percent and catch of both deep water oreos and deep-water sharks reduced by 100 percent.

3.3 Main management outcomes: post 2007

Economic outcomes

Despite the reductions in many of the TACs following the introduction of the harvest strategy framework in the SESSF, and a consequent decrease in the Gross Value of Product (GVP) for the trawl sector, the Net Economic Returns of the sector improved markedly following the structural adjustment (**Figure 3**). This improvement was due mainly to the large reduction in number of vessels and effort and is not adjusted for the costs of the buyback, which amounted to AUD 47.6 million for the SESSF as a whole (the majority for the CTS). The economic effect was almost immediate, due to improvements in economic productivity as less efficient operators left the fishery through the structural adjustment package (Vieira et al., 2010). The GVP was about constant from the time of the adjustment until 2013, after which it abruptly decreased by almost a third. This decrease, seen also in the catch (**Figure 2**), is explained by some

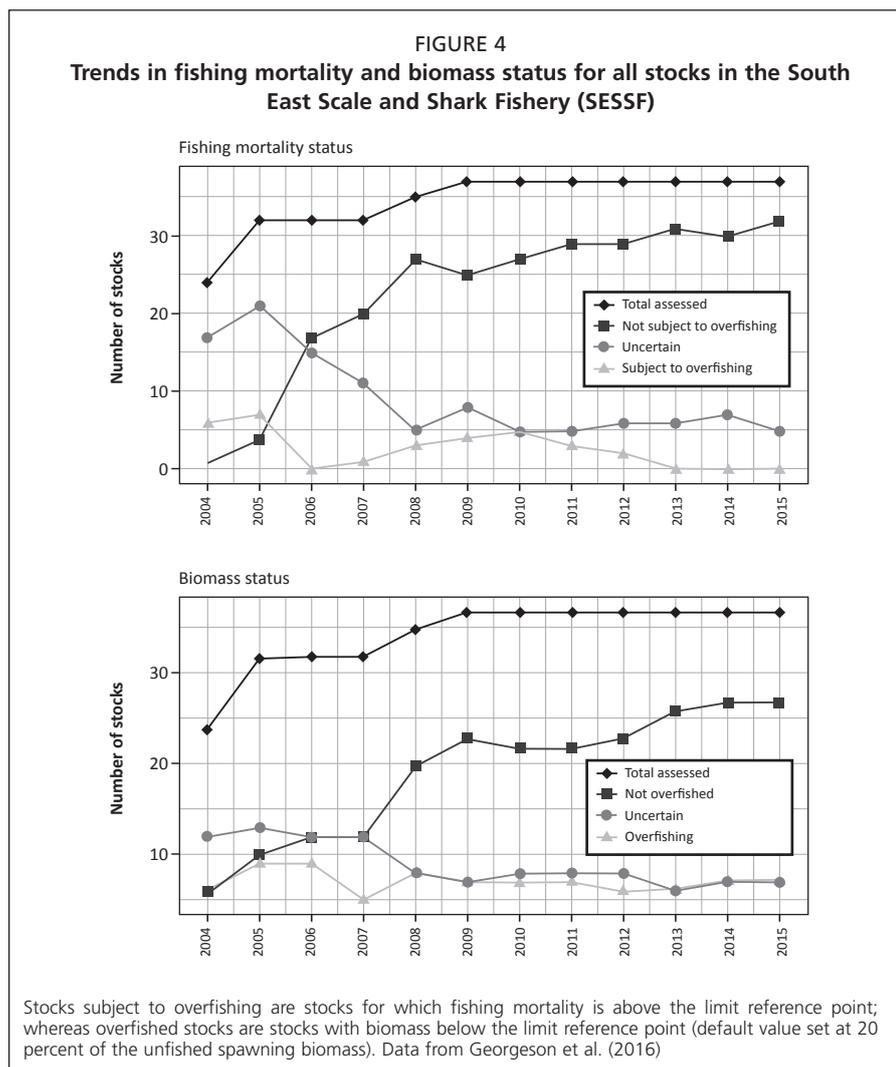
specific operational constraints, as discussed further below. The Net Economic Return from the fishery remained positive and approximately constant after the structural adjustment, peaking somewhat in 2011 and then, like GVP, decreasing rapidly in 2014 (Figure 3). Unpublished data suggest that it has improved again since then.



Biological outcomes

Biological recovery of the fishery can be viewed in various ways. A first view comes from fishery-wide catch rates (CPUE), aggregating all species, shown in Figure 2. Other than the period to 1994, which reflects the rapid rise and decline of the highly targeted orange roughy fishery, the CPUE has been remarkably steady until 2013, when it declined to a new level. There was a slight increase from 2006, following the structural adjustment. This reflects the effect of removing half of the fleet in that year, but the effect is quite small, compared with the much larger impact on Net Economic Returns (Figure 3). This suggests that the main effect of the restructure was the removal of less economically efficient operators.

The federal government independently reports on the status of all AFMA managed fisheries. This identifies whether stocks are overfished (biomass below the limit reference point) and whether overfishing is taking place (fishing mortality above the limit reference point). A second view on biological recovery is seen in trends in these metrics for the main stocks in the SESSF from 2004 to 2015 as shown in Figure 4. Following introduction of the SESSF harvest strategy in 2005, with many TACs reduced, there was a rapid reduction in the incidence of overfishing (defined as $F > F_{MSY}$) between 2005 and 2006. The reduction was short-lived and between 2006 to 2010 there was a steady increase in the number of stocks classified as experiencing overfishing, and an even greater increase in the number of stocks assessed.



This is the effect of the additional research to assess data-poor stocks, since all stocks subject to TACs had to be assessed under the harvest strategy from 2005. As more stocks were assessed, some were found to be experiencing overfishing, and although management measures were being put in place through the harvest strategy to address this, the increase in stocks with overfishing through that time reflected the detection of past situations of overfishing, not recognised until then (Smith et al., 2013). After 2010 the continued introduction of management measures to address overfishing reduced the number of stocks with that classification, and since 2013, no stock in the SESSF has been classified as subject to overfishing. There has been less response in overfished status.

The number of stocks classified as overfished did not increase greatly as a result of the research focused on data poor stocks because relatively few of these were found to be overfished, a finding at odds with Costello et al. (2012) who found that unassessed stocks were generally in a worse state than assessed stocks. However, the reduction in overfished stocks (i.e. the rebuilding to Blim) overall has been slow. Overfishing is under direct management control and can be reduced quickly, but recovery from overfished status (biological rebuilding and recovery) also depends on the ecological characteristics of the stock and ecosystem and takes longer. Caddy and Agnew (2004) found that most stocks recover when F is reduced appropriately, and at about the expected rate, but this may not be the case in a multi-species

fishery. Several of the overfished SESSF stocks are showing trends toward recovery, but an additional element complicates some interpretations. For several stocks the management measures introduced for recovery also disrupt, or even prevent, the observations previously used for assessing stock status (in the SESSF these are often fishery dependent data such as CPUE) and consequently the assessment becomes more uncertain.

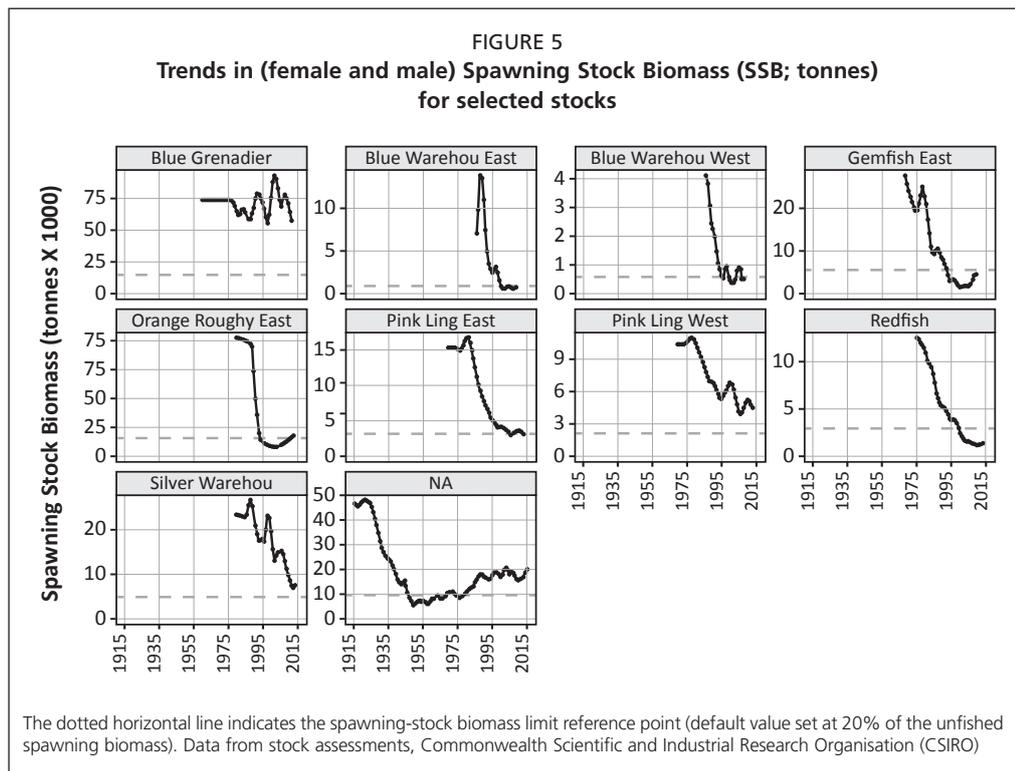
Of primary trawl-caught species, four are currently designated as overfished. These are eastern gemfish, orange roughy (eastern stock), blue warehou, and redfish. These species are subject to explicit stock recovery strategies (**Table 1**) to meet the rebuilding requirements of the Harvest Strategy Policy and legislation, which resulted in zero commercial TAC for orange roughy until 2015 and low TACs for the other species (see **Table 1** for TACs by species and year). In addition, incidental TACs are set to allow some bycatch of these depleted species when other species are targeted. The low level of incidental TACs and their stepwise reduction is intended to discourage targeting of depleted species and encourage more selective fishing with less bycatch of such species. A [third view](#) on the biological response to the restructure can be seen in the spawning biomass trends for the four overfished stocks (eastern gemfish, orange roughy (eastern stock), blue warehou, and redfish), shown in **Figure 5**. For comparison, this figure also shows biomass trends for several other key trawl-caught stocks that are not overfished – blue grenadier, tiger flathead, pink ling, and silver warehou. These are still only a subset of all the stocks and species subject to TAC management in the fishery.

TABLE 1
Recovery strategy objective and specific management actions for blue warehou, eastern gemfish, orange roughy and redfish (AFMA 2017)

Species	Strategy year	Primary objective	Recent outcomes	Management actions
Blue Warehou	2008; revised in 2014	To rebuild stocks to B_{LIM} by 2024 (one mean generation time of 6 years plus 10 years, since 2008)	In 2013, standardised catch rates below B_{LIM}	* Catch limits: zero commercial TAC; incidental TAC of 118 t, decreased since 2008
Eastern gemfish	2008; revised in 2015	To rebuild the stock to B_{LIM} by 2027 (one mean generation time of 9 years plus 10 years, since 2008)	In 2010, stock assessed below B_{LIM} (at 15.6% of unfished biomass) and considered as still recovering in 2015	* Catch limits: zero commercial TAC; incidental TAC of 100 t implemented since 2002 and decreased since 2008 * Trip limits: commercial NSW state fishers are restricted to a 50 kg trip limit to prevent targeting of eastern gemfish * Compulsory pre-reporting: AFMA introduced compulsory pre-reporting arrangements in 2015-16 for fishers landing eastern gemfish during the species annual spawning migration to support data collection for stock assessment * State and recreational arrangements: AFMA is discussing complementary management measures to protect stocks outside AFMA jurisdiction

Redfish	2016	To rebuild the stock to B_{LIM} by 2043 (one mean generation time of 17 years plus 10 years, since 2016)	In 2014, stock assessed below B_{LIM} (at 11.7% of unfished biomass)	* Catch limits: zero commercial TAC; incidental TAC of 100 t implemented in 2015
Orange roughy East	2006 (Orange Roughy Conservation Program);	To rebuild the stock to B_{MSY}	In 2014, stock assessed above B_{LIM} (at 25% of unfished biomass)	* Catch limits: commercial TAC at 465 t * Additional monitoring: Acoustic Optical Surveys; real time, 100% monitoring of fishing on aggregations
Orange roughy South, West and South Tasman Rise	2006; revised in 2014	To rebuild the stock to B_{LIM} by 2072 (one mean generation time of 56 years plus 10 years, since 2006)	* In 2000, South stock assessed below B_{LIM} , with 2006 updates indicating that rebuilding may be occurring. In 2014, stock considered overfished * In 2002, West stock assessed below 30% B_{LIM} with 50% certainty. In 2014, stock considered overfished * In 2003, South Tasman Rise stock assessed as being reduced though no biomass trends are available. In 2014, stock considered overfished	* Catch limits: zero commercial TAC; incidental TAC of 31 t for the South stock and of 60 t for the West stock * Additional monitoring: Acoustic Optical Surveys * Additional fishery closures: South Tasman Rise zone
Orange roughy Cascade	2006; revised in 2014	To rebuild the stock to B_{MSY}	In 2009, stock assessed above B_{LIM} (at 63% of unfished biomass)	* Catch limits: commercial TAC at 500 t * Additional monitoring: Acoustic Optical Surveys
Orange roughy Great Australian Bight	2006; revised in 2014	To rebuild the stock to B_{LIM} by 2072 (one mean generation time of 56 years plus 10 years, since 2006)	There is no formal stock assessment for this stock as catches and data are sporadic. In 2014, stock considered as uncertain if overfished	* Catch limits: zero commercial TAC; incidental TAC of 50 t * Additional monitoring: Acoustic Optical Surveys * Additional fishery closures: nine spatial closures over recognised Orange Roughy seamounts * Incidental catch trigger: trigger limits of 10 t for areas outside Albany and Esperance and the seamounts fishery closures. If trigger limits or incidental catch are reached, all catches of orange roughy will be ceased

Additional management controls in place for the whole SESSF are listed in each strategy and include limited entry, gear requirements, catch and discard monitoring strategies, and fishery closures. B_{LIM} is the biomass limit reference point (default value set at 20% of the unfished spawning biomass), and B_{MSY} is the maximum sustainable yield biomass (default value set at 40% of the unfished spawning biomass).

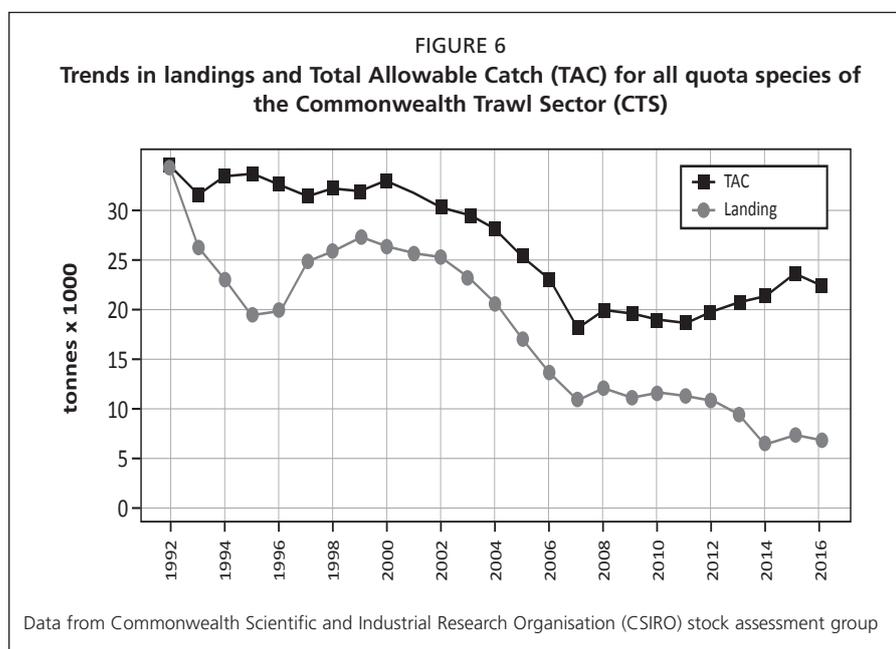


The figure shows that the four overfished stocks had all fallen below limit reference levels (B_{Lim}) by the mid-1990s. Blue warehou stocks are fluctuating close to limit reference levels, while both eastern gemfish and eastern orange roughy are showing recovery, with the latest assessment for orange roughy placing it above the limit reference level. The possible recovery in eastern gemfish is uncertain based on available data, however, illustrating the point that management measures brought in to aid recovery can cause problems in interpreting fishery dependent data, thus increasing uncertainty in assessments. Redfish shows no signs of recovery despite low TACs and catches. Thus, the only overfished stock to show clear signs of recovery is eastern orange roughy.

Trends in several of the non-overfished species illustrate some of the complexities of this multi-species fishery. Tiger flathead is a key shelf species that has been targeted from the inception of the trawl fishery in the early 1900s. It was overfished by the late 1940s but had recovered by the mid-1980s, well before quota management was introduced. In recent years it has remained close to target levels (B_{MEY} assumed to be 48% of unfished levels) and is the most valuable shelf species in the fishery. Blue grenadier, a key upper slope species, has fluctuated in abundance well above limit reference levels since exploitation began in the late 1970s. Pink ling is also a key upper slope species, which is also heavily targeted by the non-trawl sector of the SESSF (particularly by longlines). Both the eastern and western stocks have declined, with the eastern stock just above limit biomass levels. Silver warehou has also shown a substantial decline in recent years. Not shown here, other species have shown various trends in abundance, with some relatively stable, and some increasing. Given this variability in response, it is perhaps not surprising that overall CPUE (**Figure 2**), which includes all landings, including non-TAC species, remained relatively unchanged over a long period of time.

A fourth view of biological recovery considers landings in relation to TACs. As noted above, landings of quota species have been substantially below TACs since the inception

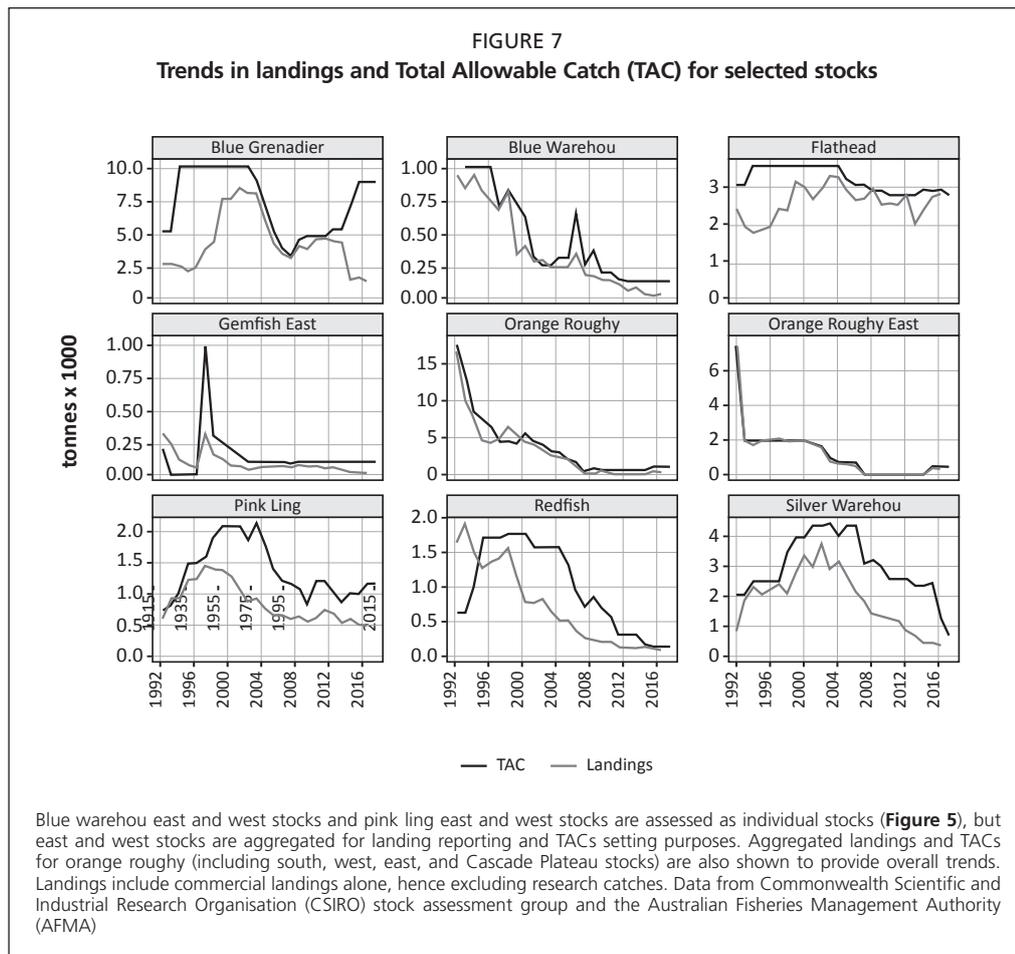
of the quota management system in 1992 (**Figure 6**). This was regarded as a problem in the 1990s, with concerns that some TACs may have been set too high (in the absence of stock assessment information, initial TACs for some species were set at historical catch levels). However overall reductions in TACs from 2000 to 2006, set with much greater confidence in the reliability of the stock assessments and the appropriateness of the TAC levels following improvements in monitoring and assessments during the 1990s, and implementation of the harvest strategy in 2005, resulted in much the same proportion of the overall TAC being caught until about 2010. This most likely reflects the multi-species nature of the fishery, with the fleet only able to target, or interested in targeting, a few species or a mix of species. For the trawl fishery in the SESSF, the primary target species are tiger flathead, school whiting and redfish on the shelf; gemfish, blue grenadier and ling on the upper slope; and orange roughy at mid-slope depths. The TACs for these species strongly determine fishing patterns and while other quota species are occasionally targeted, most are taken as an incidental (but valued) by-product of targeting the primary species.



Notwithstanding this general multispecies feature of the fishery, **Figure 6** also shows increasing divergence of landings compared to TACs since about 2010. The reason for this is more evident in **Figure 7**, which compares landings and TACs for several individual species. The East and West stocks of Blue warehou and pink ling are assessed as individual stocks (**Figure 5**), but east and west stocks of each species are aggregated for landing reporting and TAC setting purposes, and so **Figure 7** shows aggregated values for these species. Also, landings shown in **Figure 7** are commercial landings alone, excluding research catches (i.e. tonnes caught as part of research programs; see **Table 1**), which are accounted for in stock assessments. This allows direct comparison of commercial landings with commercial TAC. The most notable divergence in landings and TAC is for blue grenadier, where landings were very close to the TAC from 2000 to 2013 but dropped dramatically in 2014 and 2015.

There is a fishery operational explanation for this. Since the mid-1990s, most of the blue grenadier catch has been taken by New Zealand factory trawlers brought in by SESSF quota owners to target a spawning aggregation off the West coast of Tasmania. These vessels relocated from New Zealand for a few weeks each winter and have access to most of the blue grenadier TAC. They did not fish in 2014 and 2015, for reasons

that are not entirely clear, but that appear to be associated with both price and better opportunities to fish the same species (as hoki) in New Zealand. While the Australian trawl fleet also targets blue grenadier, they are not equipped to process large catches in short periods of time and so they have not compensated for the absence of the New Zealand factory trawlers. Given the large TAC for blue grenadier, the decline in catch for this species alone accounts for much of the decrease in landings (Figure 6) and GVP for the entire SESSF fishery (Figure 3), and also probably for the drop in overall CPUE since 2014 (Figure 2). Figure 7 also shows that landings have been similar to the TAC for flathead, blue warehou, and orange roughy, with more notable divergences for ling, redfish and silver warehou.



4. DISCUSSION

The notable events that structured the evolution of the management framework for the fishery are summarized in Table 2. The trawl fishery in south eastern Australia is a multi-species fishery with a long and complex history of expansion and management (Smith and Smith 2001). For most of its history it was developed and managed on a day to day basis as several separate fisheries by several Australian states, and it became a single fishery managed under Commonwealth jurisdiction through a process that occurred mainly in the 1980s. Stock rebuilding and fishery restructuring efforts began in the 1990s with the introduction of an individually transferable quota management system. This later led to a more ambitious stock rebuilding program that began in 2005. That program included (1) significant change in the management regime (especially development and adoption of formal harvest strategies that resulted in

reduced catch quotas, and increased use of spatial management and gear controls to deal with impacts on bycatch, protected species and benthic habitat), (2) a government funded restructuring package that removed half of the trawl fleet, with some additional support to those remaining in the fishery, and (3) increased investment in research to assess more stocks and develop improved harvest strategies (especially approaches for data poor stocks and improved quota setting decision rules).

TABLE 2

Timeline of notable events in the SESSF fishery

Year	Events
1985	Fishery comes under Federal management
1988	Catch quota for eastern gemfish
1990	Catch quota for eastern orange roughy
1991	Australian Fisheries Management Authority formed
1992	Catch quotas and ITQs for 16 species
1997	First government buyout Quotas for AFMA-managed non-trawl fisheries
1998	First SET management plan Australian Oceans Policy adopted
1999	Environmental Protection and Biodiversity Conservation (EPBC) Act
2002	Assessments show eastern gemfish, eastern and southern orange roughy, blue warehou and redfish overfished
2003	Silver trevally added to list of overfished stocks First year of negative Net Economic Returns for the SE trawl fishery, lasting to 2005
2004	Alternative Management Strategies (AMS) project initiated Qualitative phase 1 of AMS used to argue for structural assistance Ecological Risk Assessments (ERA) initiated for bycatch, protected species and habitat
2005	\$220M Securing Our Fishing Future (SOFF) announced by Federal government Introduction of first formal Harvest Strategy Framework for SESSF to set TACs Announcement of network of MPAs in SE Australia under Ocean Policy
2006-07	Second government buyout as part of SOFF - \$46M buys out half the SET fleet Quantitative phase 2 of AMS project
2008	Formal stock recovery strategies for eastern gemfish, orange roughy, blue warehou and redfish initiated by AFMA in line with both harvest strategy and EPBC requirements
2009-13	Development of various EBFM initiatives in the SESSF building on ERAs and focused on bycatch and protected species management
2014	Formal Environmental Management Plan adopted by AFMA for the SE trawl fishery

The development and implementation of this rebuilding program involved significant actions and engagement across the political, policy, management, scientific (including economics) and industry realms. At the operational level the partnership approach used by AFMA, with inclusive science and stakeholder advisory groups and projects (see Smith et al., 1999), was instrumental in developing and evaluating harvest strategy options. And within this, the Alternative Management Strategy (AMS) project was particularly important in developing and evaluating harvest strategy options that were consistent with the policy aims and had both scientific rigor and stakeholder support. This project took a unique approach. In addition to a quantitative MSE evaluation, in which bioeconomic ecosystem models were used to predict the performance of

alternative harvest strategies, there was a separate qualitative evaluation in which performance predictions were made through expert judgement by a group of managers and scientists, with major input from (primarily industry, but also conservation NGO) stakeholders. This combination proved to be very constructive and successful. First, both approaches gave very similar evaluations which increased confidence in both. Second, the qualitative process engendered considerable mutual understanding of issues and evidence among the diverse participants, additional (and some radically different) management options were identified and evaluated by the participants, and the process resulted in strong support for the final conclusions from all stakeholders. From an initially sceptical position, the industry participants suggested several new management strategy options and used the project results as a part of their support for the whole stock rebuilding program. It was important that all the participants (managers, scientists and stakeholders) had considerable experience with the fishery and its ecosystem. They were all experts in their domain and had considerable exposure to, and a basic understanding of the other domains. This facilitated respectful and evidence-based evaluation based on different kinds and sources of evidence and avoided obscure or simply 'strong opinion' based justifications that are a common problem of Delphic assessment approaches. From this experience the overall approach of using parallel qualitative and quantitative MSE analysis, with active stakeholder engagement particularly in the qualitative analysis, warrants more widespread application.

The stock and fishery rebuilding program had various outcomes for the fishery and its ecological and biological performance (**Table 3**). The buyout of effort halved the number of trawlers in the fleet and resulted in a very substantial reduction in fishing effort, though it did not decline by the full 50% (**Figure 2**) due to removal of less efficient effort. This reduction in effort also resulted in a corresponding reduction in catch, also partly driven by reductions in TACs with the introduction of harvest strategies in 2005 (**Figure 6**). Despite these changes, fleet level CPUE hardly altered between 1995 and about 2012 (**Figure 2**).

TABLE 3
Key outcomes for the SE trawl fishery associated with the buyout and the introduction of harvest strategies in the mid-2000s

Year	Outcomes
	<i>Fishery</i>
2006-07	Number of trawlers halved from 118 to 59
Post 2005	Substantial decline in effort
Post 2005	Substantial decline in catches
Post 2005	Little change in CPUE over all species
	<i>Economic</i>
2003-05	Negative net economic returns
2006-13	Positive net economic returns
2002-06	Decline in GVP
2007-13	GVP stable
	<i>Biological</i>
2013-15	No stocks subject to overfishing
2008-15	Several stocks continue to be overfished
2016	Eastern orange roughy recovers to above LRP

The most notable success of the restructure was a substantial improvement in economic performance (**Table 3**, **Figure 3**). Notwithstanding the decline in GVP associated with the overall reduction in catches, the Net Economic Returns for the fishery improved substantially and quickly, from negative returns prior to 2006 (costs

exceeding revenue), to positive and sustained returns since 2006. A formal analysis of these economic benefits relative to the cost of the buyout (\$46 million, paid for by government) has not been undertaken, but discounted over the subsequent decade, would appear to be at least break even. Although this could be seen as private benefit from a public subsidy, this also needs to be considered against any environmental and governance improvements from the buyout and rebuilding program.

At first glance, the biological outcomes of rebuilding are less evident. Only one of four stocks that have been the focus of formal rebuilding programs has so far recovered to above its limit reference biomass. Orange roughy achieved this outcome in 2016, but eastern gemfish, redfish and blue warehou are yet to recover to this level. Orange roughy has several features that perhaps make its recovery more likely, despite being a very long-lived species with a low overall productivity. First, the fact that it is very long-lived and does not recruit to the fishery until age 30 meant that the age classes entering the fishery since the mid-2000s (i.e. during the recovery period) were produced by a spawning stock that was unfished (the fishery did not develop until the mid-1980s). Second, the species is highly aggregated, and the fishery targets these aggregations, so that there is little bycatch and no other important quota species are caught with orange roughy. This contrasts with the other species in the formal rebuilding program, where even zero targeted TACs do not remove all fishing mortality, due to incidental catches arising from targeting other species. Third, due in part to its aggregating nature as well as its economic value, orange roughy has been the focus of an active program of fishery independent surveys right since its inception, which continued during the period of its decline and recovery. This again contrasts with the other three species, whose assessments and therefore information about stock status rely heavily on trends in commercial CPUE, which have been impacted by the restrictions put in place in the rebuilding programs themselves.

Despite the failure of three stocks to recover so far, it is likely that the reduction in effort and catch associated with the buyout has prevented the decline of further stocks. **Figure 5** presents a possibly misleading impression as it focuses mainly on species and stocks that have been overfished. Considering all stocks in the quota management system, there continue to be increases and decreases in abundance over time, but without a continuation of the general decline seen for many stocks in the early 2000s (Haddon and Sporcic, 2017). It is also likely that the reduction in effort has reduced the “ecological footprint” of the trawl fishery, including its impacts on benthic habitat (Smith et al., 2011).

The governance benefits of the buyout and rebuilding should also be considered. Although not immediate, the introduction of the harvest strategy framework has resulted in a cessation of overfishing (fishing mortality rates for all stocks are now below F_{MSY}) (**Figure 4, Table 3**). Of equal or perhaps greater importance, the removal of effort and the consequent improvement in economic performance arising from the buyout made easier the introduction of new management measures in the fishery. These included measures to reduce impacts of fishing on protected species such as seabirds and marine mammals, and on bycatch species such as many species of sharks and rays. These measures included various forms of gear controls, including adoption of bycatch mitigation measures, as well as a considerable expansion in the use of closed areas for bycatch protection. Although requirements to address such issues were mandated in both fisheries and environmental legislation and policies, there is no doubt that the ability to implement the measures taken was enhanced by the funding made available through the SOFF program announced in 2005 and implemented over the next several years. The adoption of this broader EBFM approach to management of the fishery was

reflected in the adoption and implementation of the comprehensive Environmental Management Plan for the fishery in 2014 (**Table 2**).

The rebuilding program provided more challenges than expected to the scientific assessment of some species. Assessment of many of the species that are subject to very limiting catch controls has become more uncertain because these controls change fishing behaviour and complicate interpretation of fishery dependent data (especially catch rates and size composition). Recognising this, a Fishery Independent Survey program was established as part of the overall fishery restructure and rebuilding program. However, this has not proven to be adequately precise for some species, and even for well sampled species only recently has the time series of observations been long enough for meaningful interpretation. This additional research and management attention is also costly and, because AFMA operates under a cost recovery policy which recovers a substantial amount of the monitoring and management costs for the fishery through levies on the fishing industry, these costs are challenging to meet in this diverse and geographically large fishery with relatively small total landings.

Two economically-related responses to the restructuring were surprising. The first was the continued under-catch of quotas, despite these being reasonably well estimated biologically and achievable if targeted by the available fleet. Some of this under-catch is easily explained by operational constraints, such as the recent unavailability of the specialised vessels needed to take the quota of blue grenadier. But this still leaves a substantial under-catch unexplained. The causes of this are currently being examined, but it is likely that economic constraints acting through the multi-species nature of the fishery are at least part of the explanation (the fishery mainly targets a handful of key commercial species, with landings of other species representing a useful by-product of these targeted catches). The second is the reduction in economic performance around 2014, almost a decade after the rebuilding program began. This has been attributed to changes in both prices and input costs in 2014 and may also reflect overall changes in catch levels (Patterson et al., 2016).

Overall the fishery rebuilding program has provided substantial and demonstrable benefits to the status of some fish stocks, to the economic profitability of the fishery, and to the rigor of the management system. It has been a pivotal event in the history of the fishery and made a significant contribution to the biological and ecological sustainability of the fishery. Of course, there can be no long-term guarantees of biological or economic sustainability but the formal use of harvest strategies that can evolve to meet new requirements provides a clear mechanism for adaptation. The rebuilding program has not solved all challenges, and indeed it has created some new ones, but it has been a very positive step.

While the economic and governance benefits of the rebuilding program have been significant, and environmental benefits have also been substantial despite the failure of several stocks to rebuild so far, this required considerable focus, and commitment of resources at political, policy, management and scientific levels. Constructive engagement by the fishing industry stakeholders was also critical. It is easy to imagine a much-reduced outcome if any of these parties had not been as focused and committed as they were. The results of this rebuilding program also illustrate some of the complexities of managing complex multispecies fisheries, with outcomes driven not only by management actions undertaken, but also by the vagaries and complexities of the ecosystems and fisheries involved.

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Rebuilding and full utilization of alternating pelagic species around Japan: a social-ecological approach

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Abstract

As the result from complex interactions between social and ecological systems in Japan, the catch of mackerel, sardine, and anchovy have shown successive, out-of-phase fluctuations of about 50-60 years. In the late 1960s and 1970s, good catch of mackerel provided a lot of profits to purse seiners and the fish processing sector. In the late 1970s and 1980s, sardine biomass increased greatly but its' price was very low. Therefore, purse seiners invested to build big fleets for catching a lot of cheap raw material for the processing into fish meal and fish oil. In the late 1980s, sardine collapsed and an "anchovy regime" began. However, fishing ground location, meat quality and price were not good enough for both the processing sector and consumers, and the catch of the very abundant anchovy was not increased. During this period, several strong year classes of mackerel appeared. Purse seiners, who were economically suffering from the over-investment in the late 1980s, intensively harvested them because the price of juvenile mackerel was higher than that of anchovy. This inevitably resulted in mackerel overfishing, which prevented the full development of that species biomass. To deal with this situation, a national TAC system and Resource Recovery Plan for mackerel were introduced in 1997 and 2004, and the biomass of that species is now steadily increasing. On the other hand, since around the 2010s, sardine has been quickly increasing again. However, this new peak in resources cannot be fully used because the infrastructure (fleets, processing factories, workers) have shrank below the capacity needed. To fully utilize the expected big increase of the sardine biomass in the near future, first the mackerel stock should be recovered quickly. Then, the profit from the sustainable mackerel catch would be invested to fish processing facilities (freezers, meal/oil plants, etc.). In the long term, catch combination with demersal species (walleye pollock, pacific cod, etc.) and the development of new food culture are important for sustainably utilize the fluctuating pelagic species, avoiding depletions and rebuilding problems.

1. INTRODUCTION

In this document, I will discuss the Japanese depletion and rebuilding experiences following a Social-Ecological Systems (SES) Approach (Berkes et al., 2003; Ostrom, 2009; Omar et al., 2011), i.e., discussing the complex interaction between alternating pelagic species in the North-West Pacific (ecosystem dynamics) and the adaptive utilization strategy adopted by the Japanese fishery sector (social dynamics) for sustainable social, economic and ecological benefits. Species alternation results from the out-of-phase quasi-cyclic fluctuations of mackerels, sardine and anchovy stocks. For more than a half century, the large-scale purse seiners have been harvesting these species sequentially and processing them for human consumption, fish meal, fish oil, etc. During this period,

there were “boom and bust” fishing periods and also initiatives for the “rebuilding” of depleted stocks that are detailed in the document.

Section 2 of this document introduces the species alternation phenomena of pelagic fish species and their uses in Japan during the last 50 years, from stock dynamics and economic perspectives, ending with overfishing in the 1990s. **Section 3** reviews the mackerel stock recovery experiences since 2004, and discusses the short-term and long-term strategies to adopt to maintain the fishery system social and economic sustainability despite the species alternation phenomena, avoiding the too common “boom and bust” exploitation syndrome. **Section 4** provides a summary of the paper and a discussion of future perspectives towards more resilient fisheries.

2. PELAGIC SPECIES AND PURSE-SEINE FISHERIES IN JAPAN

2.1 Species alternation and purse seine fisheries

Pelagic fish fluctuate greatly in response to changes in ocean conditions (Lluch-Belda et al., 1992; Kawasaki, 2002). In the North-Western Pacific around Japan, the catch of mackerels (a mix of chub mackerel, *Scomber japonicus*, and spotted chub mackerel, *Scomber australasicus*), sardine (*Sardinops melanostictus*) and anchovy (*Engraulis japonicus*) have shown successive, out-of-phase fluctuations of about 50-60 years at least since the early 1900s (**Figure 1**) – a phenomenon referred to as “species alternation” (Saito et al., 2010). Each species has its price and uses. Mackerels fetch a high market price and are used mainly for human consumption (fresh or processed) while sardines and anchovies are cheap and mainly used both for human consumption (processed) or reduction into animal feeds. These species are generally short-lived, and have a high productivity and biomass, and an early reproduction. These biological characteristics interact with the environmental conditions (temperature, feeding environment, etc.) to generate resources fluctuations to which the fishery system, in turn, reacts, reflecting the complex interactions between the ecological and social sub-system.

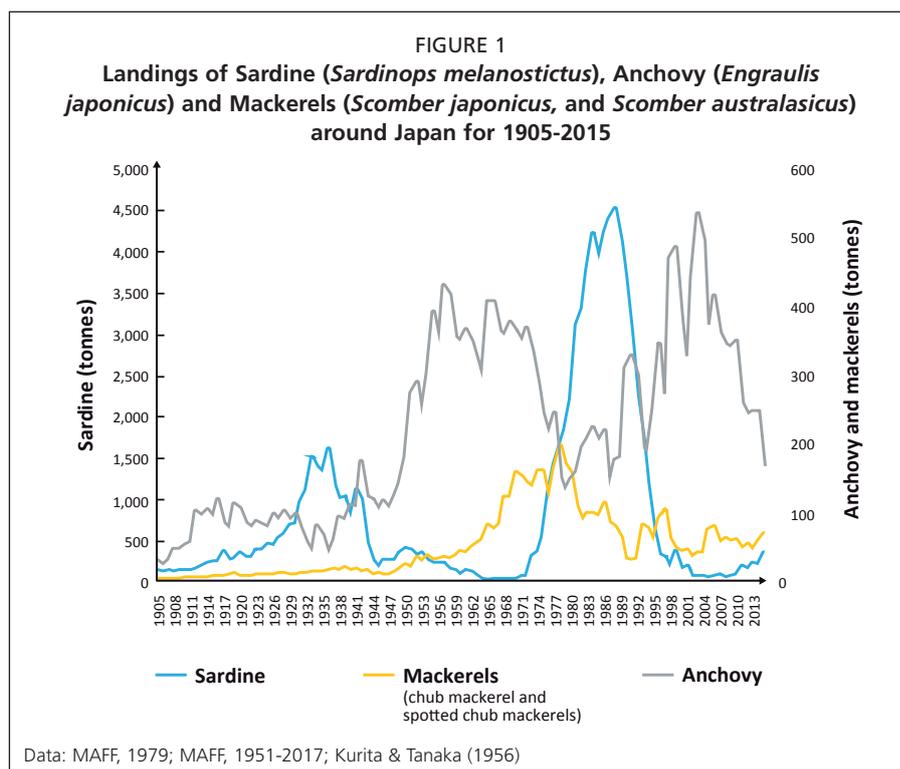
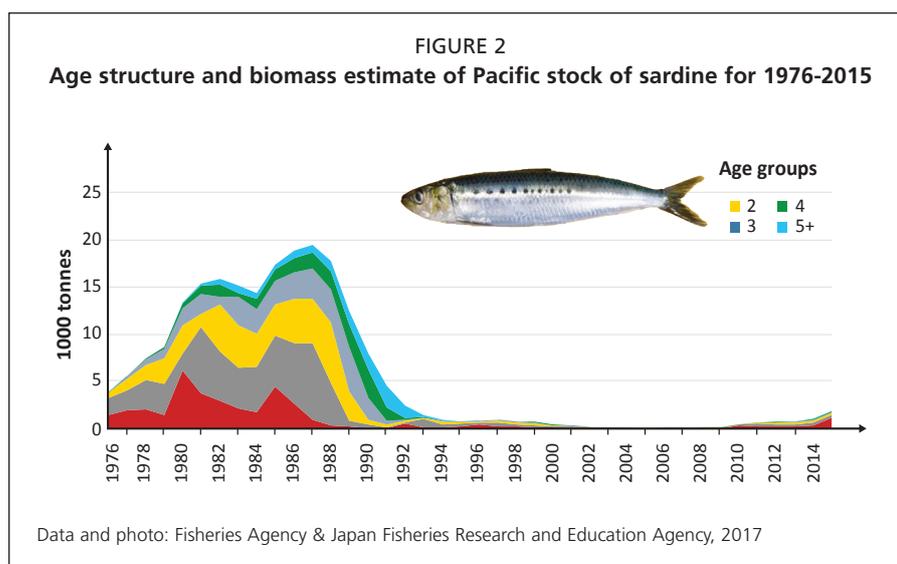


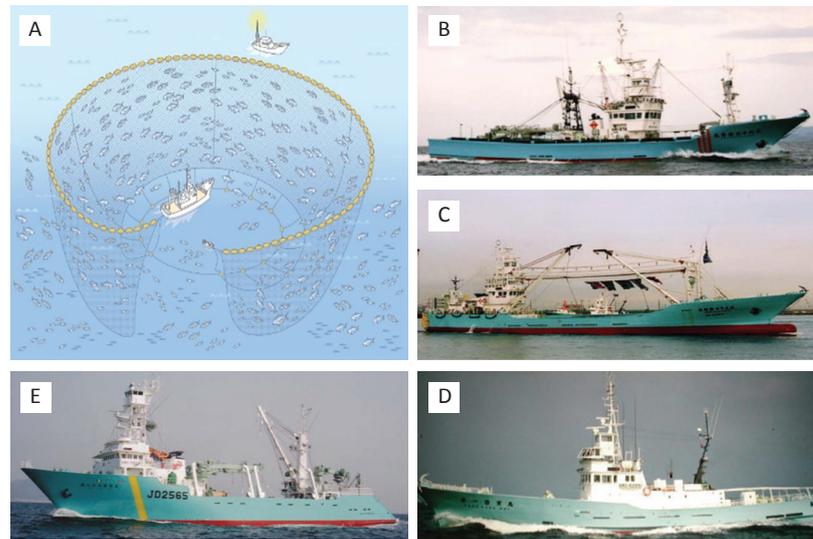
Figure 1 shows the changes in landings of sardine, anchovy and mackerels for 1905-2015. In the late 1960s and 1970s, mackerels were abundant around Japan, and intensively harvested by large-scale purse seiners. In the 1980s, the sardine stock level increased, and the purse-seiner's catch hit a record of about 4.5 million tonnes per year while catches of anchovy and mackerel decreased. Around 1989-1990, the sardine catches suddenly dropped and the catches of anchovy slightly increased in the 1990s and the 2000s. Since the 2000s, the catch of mackerels has been gradually increasing while that of sardine showed a small but continuous increase in the 2010s.

One of the typical understandings of ecological mechanism behind such fluctuations, especially in the 1980s and 1990s, is as follows (Saito et al., 2010, 2012). In the early 1980s, a weak wind created positive sea surface anomaly (SSA) in the Central-Eastern Pacific. This positive SSA moved west as the Rossby Wave and arrived in the Japanese area in the late 80s, increasing temperature and reducing the mixed layer depth in the area. Each pelagic species has its own preferendum for sea temperature range for the survival of juveniles (Wada & Jacobson, 1998; Yatsu et al., 2005; Takasuka et al., 2008) and the depth of the mixed layer correlates to the success rate of the sardine reproduction (Nishikawa & Yasuda 2008). As a result, such changes in oceanographic conditions triggered the decline of the sardine stock but the increase of anchovy stock in the 1990s (Figure 2).



The large-scale purse seine fishery is the main harvester of sardine, anchovy, and mackerel and the biggest fishery in the Japanese EEZ in terms of production volume, along with the offshore bottom trawling. Usually, it operates in “small-fleets”, each of which consists of one main fishing boat of about 135 gross tons (holding the net), two transportation boats of about 330 gross tons each, and one searching boat of about 100 gross tons, operated by 50 to 60 crews (Figure 3 a-d). The total number of “small-fleets” is managed using 5-year licenses from the Minister (Makino 2011). Recently, however, to save fuel and reduce personnel costs, so called “mini-fleets” consisting of one bigger main fishing boat of about 300 gross tons and one bigger transportation boat of about 330 gross tons, are becoming more common.

FIGURE 3
Fishing operations and types of vessels used in the small pelagic fisheries



Fishing operation with a purse-seine (A). "Small-fleet" conventional fishing boat of 135 gross tons (B), Transporting boat of 330 gross tons (C) and Searching boat of 99 gross tons (D). "Mini-fleet" main boat of 300 gross tons (E). Image (A) Courtesy of Ministry of Agriculture Forestry and Fisheries, Japan. (http://www.maff.go.jp/tokei/census/gyocen_illust2.html). Photos B to E, by courtesy of Fukushima Fisheries Co., Ltd.

2.2 Fleets growth and stocks collapse

As shown in **Figure 1**, in the late 1960s and 1970s, there was a good catch of mackerels, which delivered raw material (whole fish) to processing factories generating products, mainly for human consumption (Ohunabara 1980, **Figure 4**).

FIGURE 4
Typical processed products from mackerels



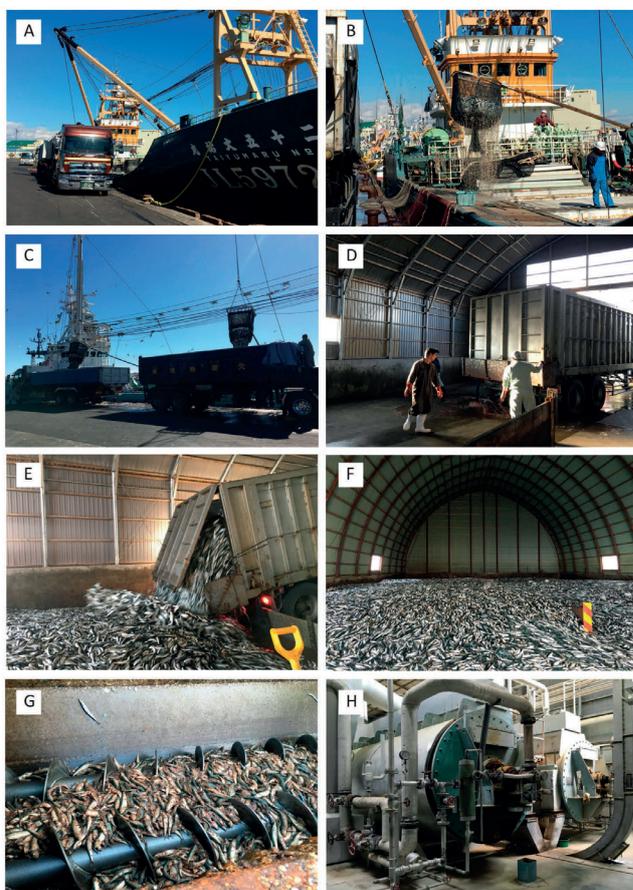
- A: Marinated
- B: Fermented and dried
- C: Canned products
- D: Tasted by kelp
- E: Sushi

All photos provided by the Hachinohe Chamber of Commerce

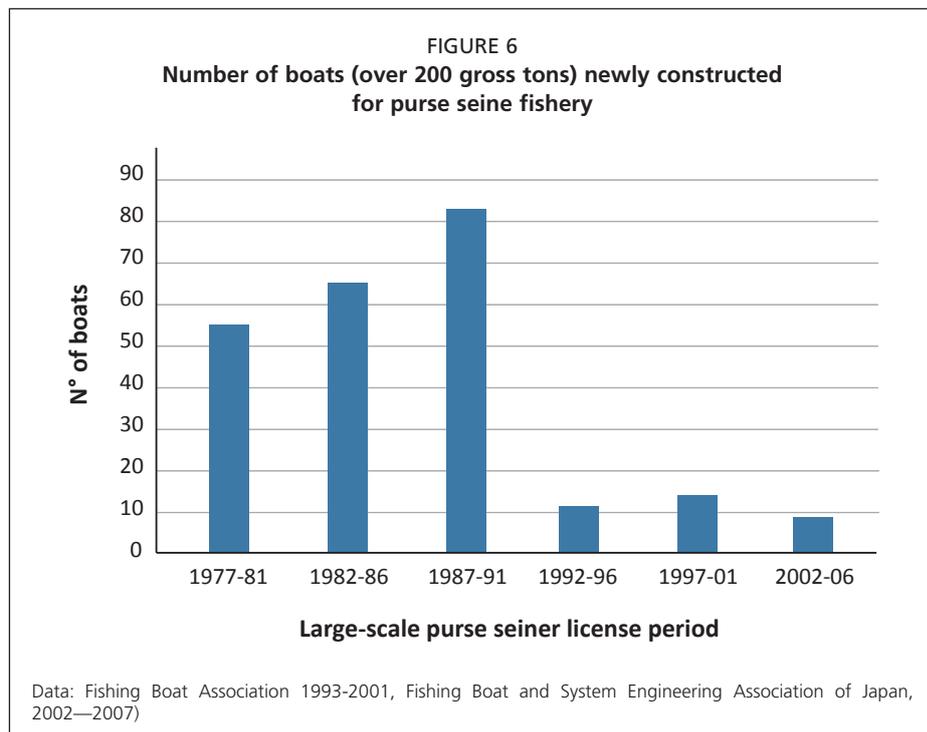
A lot of unused residuals generated from such processing factories were collected and processed into fish oil and fishmeal. During this period, therefore, the fish processing sector accumulated profits and invested largely in infrastructure to support pelagic fisheries such as big fish freezers, processing plants, and fish-meal/oil plants.

In the mid-1980s, as shown in **Figure 1**, the catch of sardine increased greatly, up to 4.5 million tonnes per year). With its low price and rate of return, the sardine is not a money-making species. However, by the mid-1980s, fisheries infrastructures constructed with the profits made from fishing on mackerels had been fully depreciated. Therefore, on the one hand, the fish processing sector could economically process over 90 percent of total catch of sardines as cheap raw material into fish oil and fishmeal, with only a small amount used for human consumptions (**Figure 5**). On the other hand, the harvesting sector (the large-scale purse seiners) could only obtain a very low unit-price for sardine (about JPY 12-17/Kg in the late 1980s) compared to the price they obtained before for mackerels (about JPY 40-68/Kg). This problem was compensated by the fact that the sardine stock biomass and hence the catch rates were very high. A former purse seiner skipper told the author that, at that time, excessive catches often caused the rupture of the purse seine. Therefore, in the late 1980s, many of purse-seiners owners invested to construct large transporting vessels (over 300 gross tons, at a construction cost of about JPY 500-600 million/vessel) (**Figure 6**) expecting to maximize catches and profits. By the 1990s, however, the sardine stock collapsed, and purse seiners owners stopped building new boats.

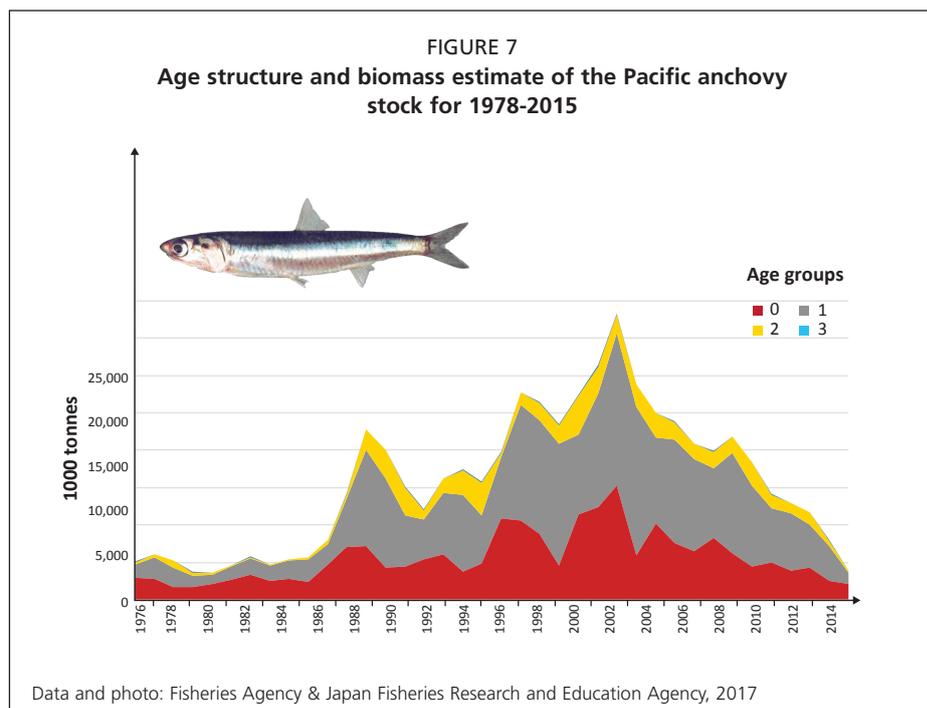
FIGURE 5
Images of fish meal/oil plant operation



A-C: Landings of sardine from a transporting vessel to a truck. D-F: Unloading and storage of raw fish in the fishmeal/oil plant. G-H: Processing sardine into fishmeal and fish oil. Photos by T. Kaneko



As explained in the previous section, towards the end of 1980s, ocean conditions changed, sardines collapsed and the “anchovy regime” started. According to the official stock assessment (Fisheries Agency & Japan Fisheries Research and Education Agency, 2017), the anchovy landings were relatively high in the 1990s and 2000s (**Figure 7**). But the main fishing ground was located far in the South, implying high operating costs. In addition, the quality and price of anchovy were not good for the fish processing sector and consumers in Japan. Therefore, the catch of anchovy did not show as big an increase as the sardine did earlier, as shown in the **Figure 1**.

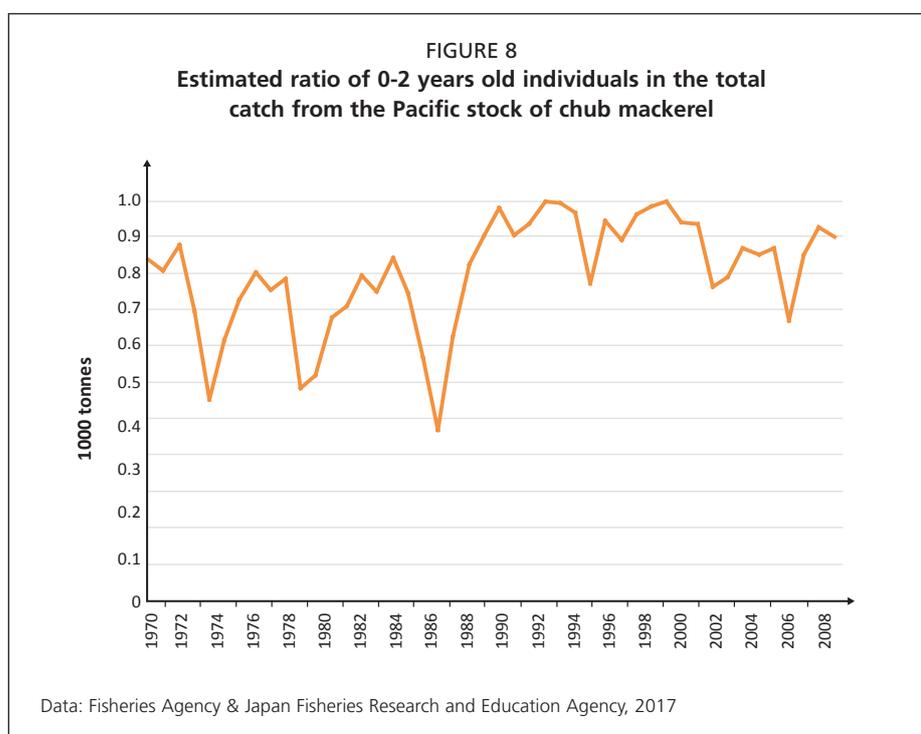


2.3 The dynamics of mackerel overfishing

The year-class strength of alternating species may vary significantly between years. Strong year class of Chub mackerel occurred in 1992 and 1996. However, the expected boom in the fishery did not happen for two reasons.

First, in the 90s, the price of juvenile chub mackerel was higher than that of anchovy and fishers were preferably targeting them at their early life stages (**Figure 8**). In the 1990s and early 2000s, about 90 percent of catch was made of fish below three-years old (i.e. immature fish of less than 300 grams) which inevitably resulted in growth overfishing (Makino, 2011, Fisheries Agency & Japan Fisheries Research and Education Agency, 2017).

Second, as shown in **Figure 6**, a large amount of new transporting boats had been built for the sardine fishery in the late 1980s. However, the sardine stock collapse in 1989-1990 left an overcapitalized fishing fleet with transporting boats that could not be depreciated by fishing on depleted sardines in the 1990s. So, to avoid bankruptcy, purse-seiners owners had strong incentives to catch highly valuable juvenile chub mackerels without considering the risk of overfishing which, as one would have expected, occurred. The real triggering cause was the decision made in the 1980s to invest massively when the sardine stock was booming. According to bio-economic modeling, the mackerel catch would have recovered to more than one million tonnes by the 2000s if the transporting vessel construction in the late 1980s had been 10 percent lower and the strong mackerel year classes had been properly protected in the 1990s (Makino & Mitani, 2010).



In the 2010s, the sardine stock started increasing again (**Figure 2**), and a new ecological “sardine regime” might be coming before the boom of mackerels. This is a big issue from the social system perspectives because almost all the fish-meal/oil plants built in the late 1970s and 1980s have already closed down. For example, in Kushiro city (the largest landing port for sardine in the 1980s), the number of plants decreased from 25 in

the booming times to only 2 today (Kaneko et al., 2013). As mentioned earlier, sardine is not profitable enough to finance the building of new plants and if sardine biomass increases again significantly, Japan will not have the processing infrastructure needed to generate the potential societal benefits.

Obviously, sardine does not represent the same resource opportunity for the current Japanese society as it did in the 1980s. The present balance between the social and ecological systems is different. The infrastructure supporting fisheries in the social system that was first developed for the highly profitable mackerel boom, was then used to exploit the less profitable sardine boom and, following its collapse, to overfish the new mackerel boom, aborting its development through overfishing. This infrastructure has now aged and shrunk and needs to be rebuilt and refunded to face the new low value sardine boom (if it materializes).

3. SOCIAL STRATEGY TO SUPPORT STOCK RECOVERY

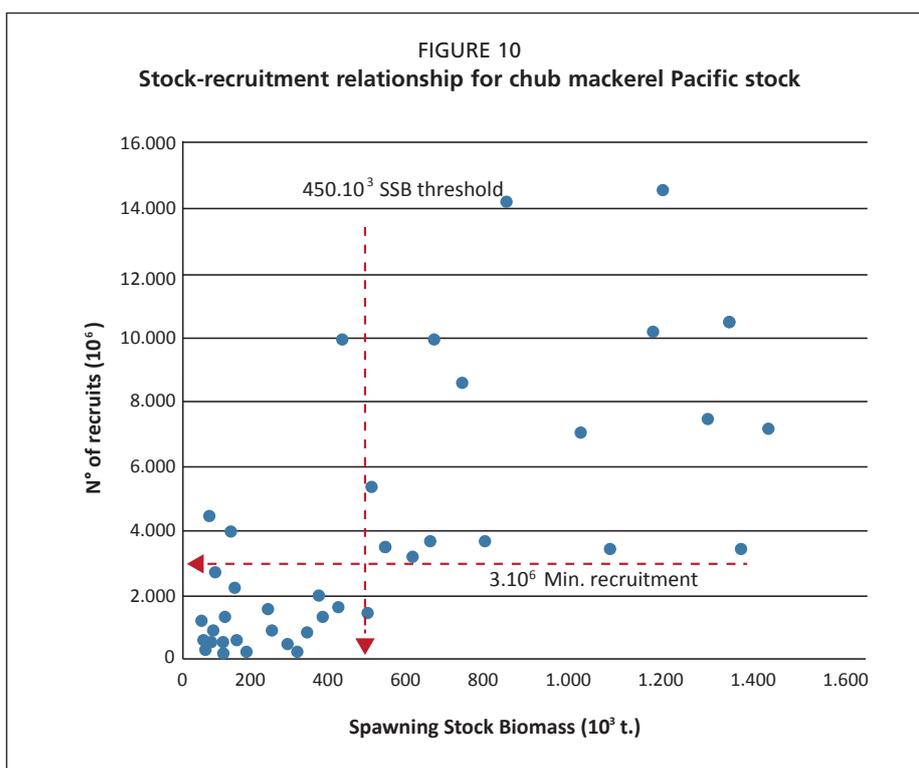
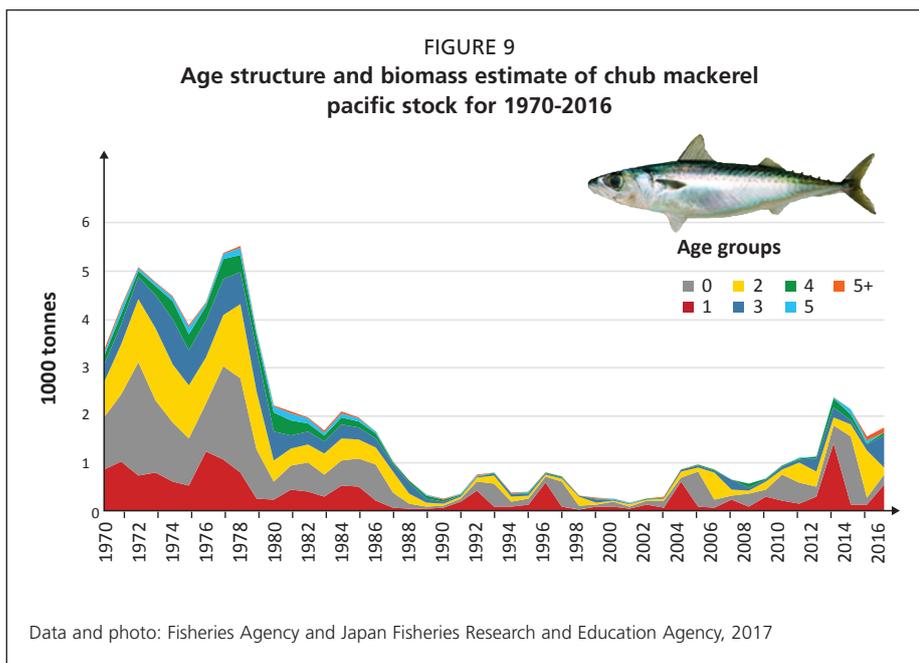
3.1 Stock recovery plan for chub mackerel

In 1996, Japan ratified the United Nations Convention on the Law of Sea (UNCLOS). Accordingly, since 1997, the government of Japan has complemented its licensing system (input control) introducing in addition, a Total Allowable Catch (TAC) regulation system (output control) for 8 species (Pacific saury, walleye pollock, Japanese jack mackerel, sardine, chub and spotted chub mackerel, Japanese common squid, and snow crab). Since 2001, the government of Japan has further introduced the Resource Recovery Plan (RRP) system, based essentially on the Japanese fisheries co-management concept (Makino, 2011). With the help from researchers, fishers drafted the RRP with detailed strategies for the recovery process and its management. Then, the government authorized the RRP, and implemented it in cooperation with fishers. In this process, the government could provide subsidies to compensate for the economic losses incurred because of implementing the RRP (to correct the investment errors made in the 1980s!). The RRP has clear recovery targets (see below), and the execution of the plan is officially monitored by the government. Such a RRP for the Pacific chub mackerel, in addition to the TAC, has been implemented in 2003 jointly by the large-scale purse seiners federation and the government of Japan. In this plan, one of the main recovery strategy is the adaptive protection of strong year classes by controlling fishing pressure on the stock. The interim target was set at 180 000 tonnes of spawning stock biomass (SSB), a six-fold increase from the SSB in 2003. However, based on the past relationship between SSB and recruitment, the full rebuilding target was set at 450 000 tonnes of SSB, a level historically expected to achieve a relatively stable recruitment every year (Fisheries Agency, 2003).

Implementing this plan, the purse seiners owners reduced fishing pressure, in terms of operating days (days at sea) as a form of adaptive strategy, with several reduction scenarios made contingent on the actual observation of strong year classes in the fishing ground. If a strong year class occurs, current fishing pressure on the whole stock is to be cut further by about 25-30 percent. If a year class is average, the reduction of fishing pressure is more moderate (for example, by 10 percent). Also, since 2007, the purse seine owners autonomously allocated TAC to each mini-fleet (or “small-fleet”), as a sort of Individual Quota (IQ) system with the objective to ensure that accumulated landings by all the fleets would not exceed the total catch limit.

In 2004 and 2009, strong year classes of chub mackerel occurred, followed up by a very strong year class in 2013. All strong year classes were effectively protected (**Figure 8**).

According to the latest stock assessment report (Fisheries Agency & Japan Fisheries Research and Education Agency, 2017), SSB reached 516 000 tonnes in 2015 and 670 000 tonnes in 2016, exceeding the full rebuilding target SSB of 450 000 tonnes (Figure 9). According to the historical relationships of recruitment and SSB (Figure 10), at least more than three billion individual recruits can be expected if the SSB is above 4.5 million tonnes. Therefore, it seems that the stock has recovered to the relatively stable level (Fisheries Agency & Japan Fisheries Research and Education Agency, 2017). If the ocean conditions remain favourable to mackerel, the next strong year class would be a very big one, leading to a total biomass up to about 3 million tonnes.



3.2 The way forward for the full utilization of alternating species

The overfishing of mackerel in the 1990s and the early 2000s was due, in part, to investment decisions made on sardine exploitation, unrelated to the state of the mackerel stock when they were made. The successful recovery of the chub mackerel since the mid-2000s would be the results from the combination of various management measures such as licensing, TAC, adaptive control of fishing pressure on juveniles, etc., together with favourable climatic conditions. The relative contribution of each of these measures to the recovery is not known. A combination of various measures, adapted to the social and ecological conditions of the target resources and fisheries system were applied to bring successful results. Then, based on the SES approach, how can we fully utilize the fluctuating pelagic species without jeopardizing the resource sustainability? Some elements of response are provided below.

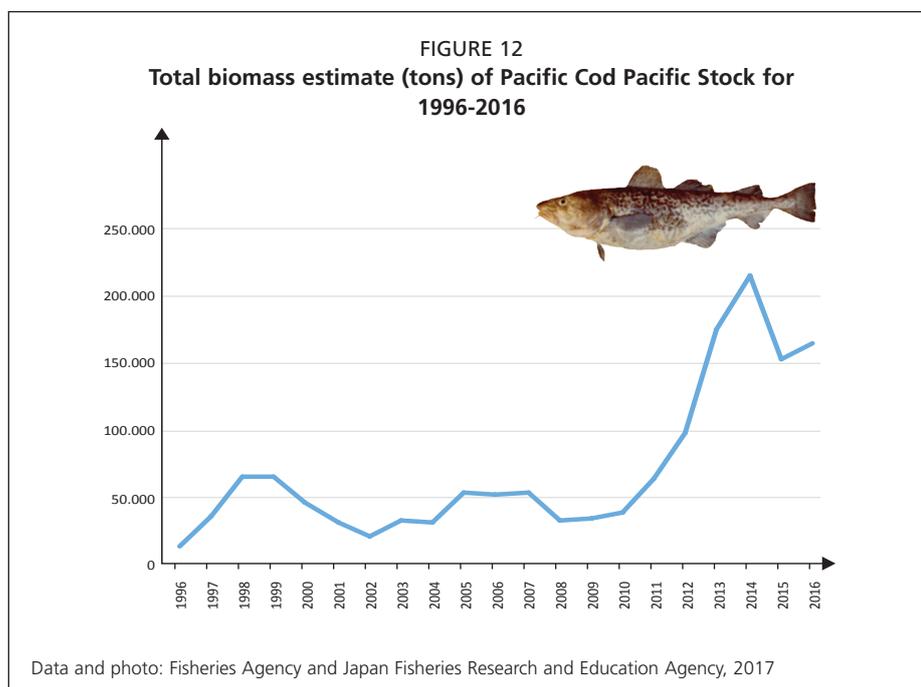
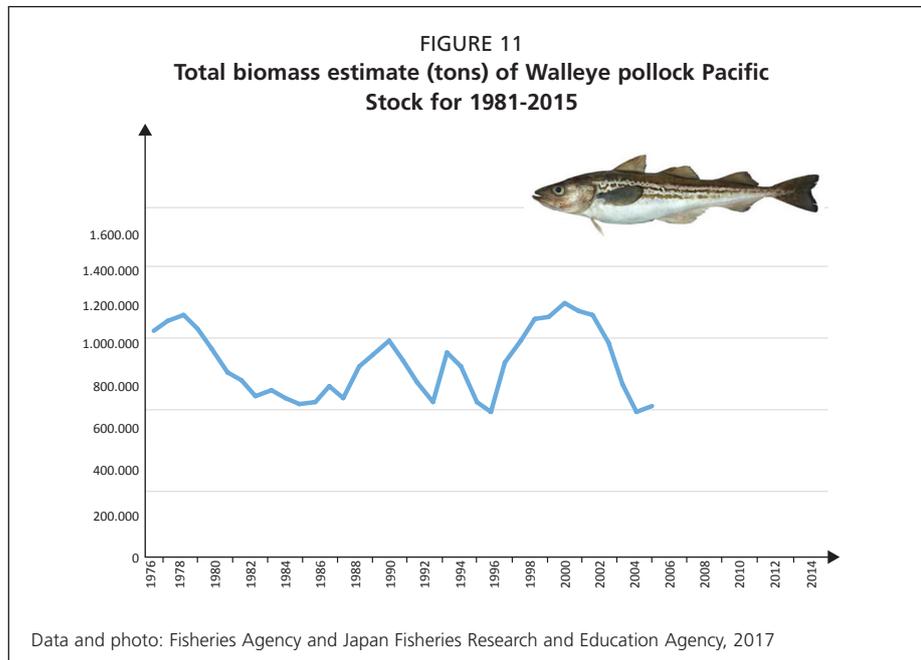
First, as seen in **Section 2**, a rising biomass (like that of sardine) might not be fully used as a resource if the social system (fishing fleets, processing factories, workers) has shrank below the capacity needed. Therefore, to fully exploit eventual increases in sardine stocks in the future, we need, first, to have fisheries catching and processing infrastructure available. To do that, the most urgent and critical thing is to increase the highly valuable chub mackerel stock biomass to a high enough level, for example, to 3 million tons (as an investment in natural assets). Then, we can harvest it in a sustainable way and accumulate the profits, investing them in fisheries infrastructure (freezers, fish meal/oil plants, etc.), just as we did in the 1970s and the early 1980s to optimally use the mackerel boom, avoiding overinvestment this time, and, when the boom will be over, to exploit the alternating species (sardines) when they return. This would be a short-term SES strategy for the next 10 years or so. In addition, nowadays, the chub mackerel, as well as Pacific saury, is becoming an international stock shared with China, Taiwan, Russia, Korea, etc. The role of the regional fisheries management organizations such as the North Pacific Fisheries Commission (NPFC¹) and the transparency of their management framework is getting more and more essential.

As a long-term SES strategy for the next 20-30 years, and to avoid overinvestments, we should make more efforts to combine the exploitation of alternating pelagic species and less fluctuating demersal species, e.g., Walleye Pollock (*Gadus chalcogrammus*) or Pacific Cod (*Gadus microcephalus*). Fortunately, their stock levels around Japan are currently at good level (**Figures 11 and 12**). These species could be used as raw materials for processed products such as surimi, mientai (tasted roe), etc. Of course, the fish residuals can be used for fishmeal/oil production. The profits from these species should be used to stabilize the overall profit of the fishery and keep the plants running and renewing. Also, around Japan, we have a lot of other potential resources to be utilized by the processing sector, especially at the low trophic level, such as lanternfish, squids, krill, etc. (Watari et al., 2017). In addition to human consumption, the aquaculture feeds demand in the Asia-Pacific Area is potentially a big market for these species.

Another, but not less important element of the longer-term strategy is to develop new processing technologies or new recipes that could increase human consumption (and improve the price and profitability) of sardine and anchovy. This would avoid having a long-term strategy dangerously dependent on mackerel for investments. In the 1980s, more than 90% of the sardine catch was used for non-human consumption such as fishmeal or fish oil. This is not a very economically efficient and healthy way of

¹ <https://www.npfc.int/>

utilizing pelagic resources in the future. The creation of new pelagic-fish-food culture and demands, leading to higher prices, is required to better adapt the social system to the natural system fluctuations in a sustainable way.



4. CONCLUSIONS

The social-ecological approach to fisheries can create a new management framework, in a way that cannot be achieved by the conventional single-species approach or the ecosystem approach in its purely ecological version. More than its predecessors, a SES approach to multispecies multi-fisheries management would force us to look more into the interactions between the natural and human components of the ecosystems and their dynamics.

This case-study discussed the interactions between the fluctuation of the ecological system (sequential oscillations of alternating species) and the adaptation of the social system (fisheries infrastructure accumulation, education of consumer preferences, and evolution of food culture) to these oscillations, as well as the appropriate combination of the use of pelagic and demersal species, for the full utilization of the whole species assemblage in a sustainable way. If some of these elements are lacking, the balance between the social and ecological systems may not be ensured and the full utilization and sustainability will not be achieved.

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Rebuilding fisheries: Three multi-sectoral case studies from Western Australia

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Abstract

Western Australia (WA) has a solid history for taking strong management actions to deal effectively with stock and fishery related problems, including those that are targeted by both commercial and recreational sectors. Here we outline three case studies that involved fisheries resource problems generated by different causes and describe the steps taken to develop successful rebuilding strategies. For each case study we describe the causes for the resource declines, the difficulties initiating management interventions which included obtaining sufficient political and stakeholder agreement. We describe the level of success in reducing catches/impacts, any follow up amendments needed, the stock outcomes generated and the current situation.

The first case study examined the recovery of three separate stocks of a demersal scalefish (snapper) all are located within the inner gulfs of Shark Bay, WA. In the early 1990s it was recognised that the increasing catches taken by recreational fishers targeting spawning aggregations was potentially generating overfishing and stock depletion. While some limited management changes occurred in the mid-1990s, given the local importance of this fishery to the local economy, it took until the early 2000s before the final set of management measures was implemented. This was based on setting relatively small Total Allowable Catches for each of the three stocks which were achieved using a combination of tight bag and boat limits, closed seasons, plus, for one stock, the requirement for fishers to use one of a limited number of single-use harvest (quota) tags¹ to legally retain each snapper. Collectively, these actions have initiated stock recoveries and after more than a decade all three stocks have returned to target levels.

The second case involved overfishing of a multi-species demersal scalefish resource targeted by several commercial and recreational fisheries. The level of overfishing was identified in 2007 which resulted in a series of innovative management actions being developed during the 2008-2010 period including sectoral catch allocations, recreational closed seasons and commercial area closures. These arrangements, among others, successfully reduced the catches of the suite of demersal species by both the commercial and recreational sectors to less than 50% of their respective 2005/06 levels to facilitate recovery. By 2014, the level of fishing mortality had started to decline but it is likely that it will be another decade before the recovery of this resource is completed.

¹ The harvest tag must be inserted through the mouth of the fish and secured using a tamper-proof barrel-style locking mechanism prior to landing.

The final case study outlines the recovery of a scallop resource in Shark Bay severely affected in 2010 by a marine heat wave event. A 2011 survey identified a significant decline in adult survival and recruit success resulting in the immediate ban on retention of scallops by the two commercial trawl fleets that operate in Shark Bay. With continued low adult survival and poor recruitment, the few small areas of Shark Bay with known concentrations of scallops were also temporarily closed to all trawling activity (e.g. for prawns) in 2013 and 2014 to protect residual spawning capacity. Following shifts in environmental conditions, there were improvements in both adult survival and recruitment in 2015 and 2016 which led to a sufficient recovery in stock to enable fishing in all areas recommence in 2017.

These successful recoveries were only possible because of the strong and effective management and governance systems that are implemented within WA. Importantly, as each of these situations generated considerable levels of public interest and concern, obtaining the necessary political support was vital to take action. Gaining this support required developing an appropriate combination of management strategies that had been subject to extensive consultation with stakeholders and from having explicit access allocations determined for each sector. These arrangements were also supported by effective education, compliance and monitoring programs.

Given the long (5-20 year) duration for the recovery of these fish stocks, stakeholder engagement programs had to be maintained to avoid premature relaxation of the rules based on unrealistic stakeholder expectations or localised perceptions. Similarly, as each of these recoveries extended over multiple governments (and numerous Fisheries Ministers), support from all sides of politics for the strategies were essential for their longer-term success.

1. INTRODUCTION

Fisheries resources may require rebuilding due to the impacts of overfishing, environmental shifts or a combination of these and other factors. Depending upon the cause of the depletion, different types of management actions may be more appropriate, and different lengths of time required to effect rebuilding. The level of difficulty to implement the rebuilding process will also be influenced by the types and complexity of stakeholder groups who have an interest in the resource, either from a direct catching perspective or where flow on impacts to the catching sector affect them indirectly. One of the most common reasons why rebuilding stocks is difficult is because the management of fish stocks requires altering the activities, behaviours and expectations of fishers.

Successfully managing fisher behaviour and activities requires having effective governance systems and management arrangements. This, in turn, requires a suitable level of political support to enable appropriate rebuilding arrangements to be developed, adopted and enforced for the time required. It has been recognised that the level of effective governance of fisheries is the key element of that determines whether there is successful management of fisheries resources, not only the amount of data that are available (Fletcher, 2008).

Gaining support for changes designed to reduce the catches or activity levels of fishers becomes even harder when there is more than one fishing sector involved. The different sectors often have differing objectives, differing levels of understanding of resource issues and frequently differing levels of political influence. This is especially the case in

Australia where a relatively high proportion of the population are recreational fishers (30% each year in Western Australia; Fletcher et al., 2017). The recreational sector often directly competes for access to resources with the commercial fishing sector which, by contrast with most other countries, are relatively small both in terms of numbers and tonnages landed (Flood et al., 2016).

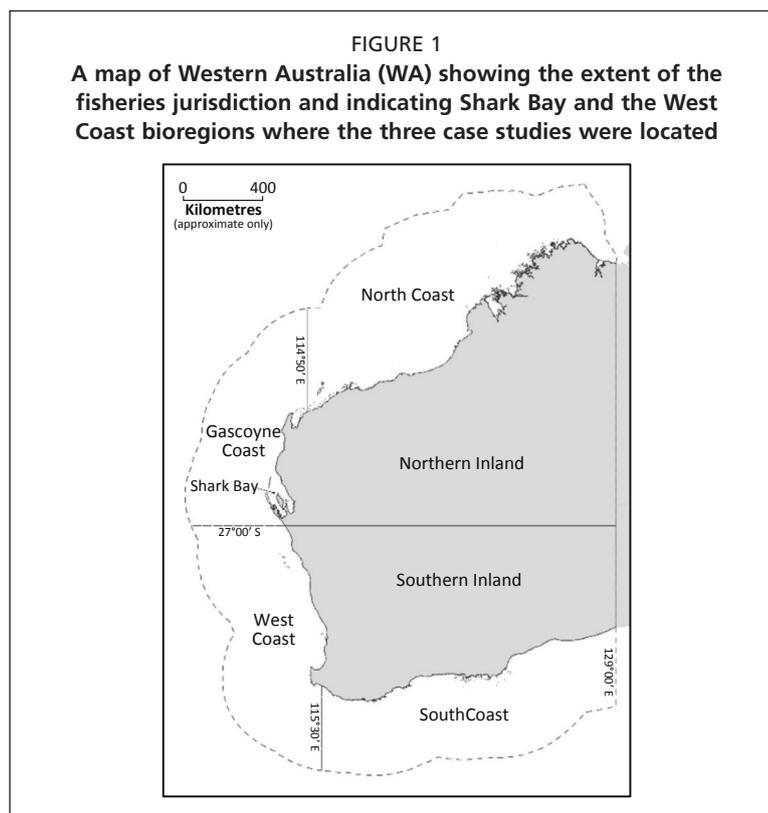
Here we provide three case studies from Western Australia (WA) involving fisheries resources which were depleted by different sets of causes. The case studies all involve more than one fishing sector accessing the resource, including two where the recreational fishing sector played an equal or dominant role in the depletion. There are now documented examples of where recreational fishing is the dominant source of mortality and recreational catches exceed those taken by commercial operations (Love et al., 1998; Coleman et al., 2004). This is particularly the case in coastal waters near large urban population centres or at major tourist destinations in developed nations (e.g. Jackson and Moran, 2016).

In this paper, we provide, first, a short background on Western Australian fisheries resources and management, before analysing three case studies. The first case study examines the depletion and recovery of multiple small, but separate, stocks of snapper (*Chrysophrys auratus*) that inhabit the gulfs of Shark Bay that are nowadays essentially recreational-only fisheries. The second case study examines the recovery of the West Coast Demersal Scalefish resource. This is a multi-species assemblage of more than 100 species (e.g. West Australian dhufish *Glaucosoma hebraicum* and Snapper *C. auratus*) that is fished by multiple gear types (rod and reel, hand lines, drop lines and demersal gillnets) and accessed by different commercial and recreational fisheries operating close to the largest urban population centres in WA. The third case study examines the recovery of the scallop (*Ylistrum balloti*) resource in Shark Bay. While this is only accessed by commercial fishers, it is taken by two separate commercial fleets using different mesh-sized nets and headrope length of trawl gear with different primary target species. In the final section, we identify the key themes that were learned from these examples and how they may apply in other situations.

For each case study we describe: (i) the causes for the resource declines; (ii) what difficulties were encountered in getting additional management arrangement developed and implemented including what stakeholder and political agreement was needed to take action; (iii) what actions were taken for each sector; (iv) the level of success for these actions in reducing catches/impacts; (v) what follow up management amendments were needed; (vi) what stock outcomes have been generated; and (vii) what is the current situation.

2. BACKGROUND – FISHERIES RESOURCE MANAGEMENT IN WESTERN AUSTRALIA

In the waters off Western Australia (**Figure 1**), the State Government has sole jurisdiction for nearly all commercial, recreational and customary fishing out to the 200 nautical miles zone through an Offshore Constitutional Settlement with the Commonwealth (OCS) in 1989. Fisheries management in WA is undertaken through a single Government agency that includes all the management, policy, assessment, science, legal and compliance activities under the one CEO who is directly responsible to the Minister for Fisheries.



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The specific management arrangements for all fishing activities in WA are currently based on the 1994 Fisheries Resource Management Act (FRMA, 1994). These arrangements are, however, in the process of shifting to the new Aquatic Resource Management Act (ARMA, 2016). The drafting of the ARMA was the culmination of a series of policy initiatives undertaken in WA over the past 20 years that were designed to implement the principles of sustainable development, (Fletcher, 2002, 2006), or the term more commonly applied to fisheries, the ‘ecosystem approach’ (Fletcher and Bianchi, 2014). The ARMA adopts the risk based, bioregional Ecosystem Based Fisheries Management system (Fletcher et al., 2010; 2012; 2016) which rather than taking an individual fishing activity-based approach, takes a whole of resource-based approach (Fletcher et al., 2012; Fletcher, 2015) that requires setting of explicit resource level objectives and sectoral allocations (ARMA, 2016).

A critical requirement for the Department is to report to Parliament each year on the proportion of resources where stock levels are considered adequate and the number of commercial and recreational fisheries where catch levels for the year are considered acceptable (see DoF, 2017). This requires the completion of comprehensive status reports for each resource on an annual basis that are largely based on commercial and recreational catch and effort and biological monitoring programs undertaken by the Department (see Fletcher et al., 2017). The commercial catch data have been collected since the 1960s through compulsory catch and effort recording by fishers and data for charter fishing

operators have kept compulsory daily catch records since 2001. Recreational catch surveys spanning one bioregion at a time were carried out sporadically since 1996 (e.g. Sumner et al., 2002) but, with the adoption of a boat-based recreational fishing licence in 2010, this program was expanded in 2012 to recreational surveys that cover all four marine bioregions every two years (Wise & Fletcher, 2013; Ryan et al., 2015).

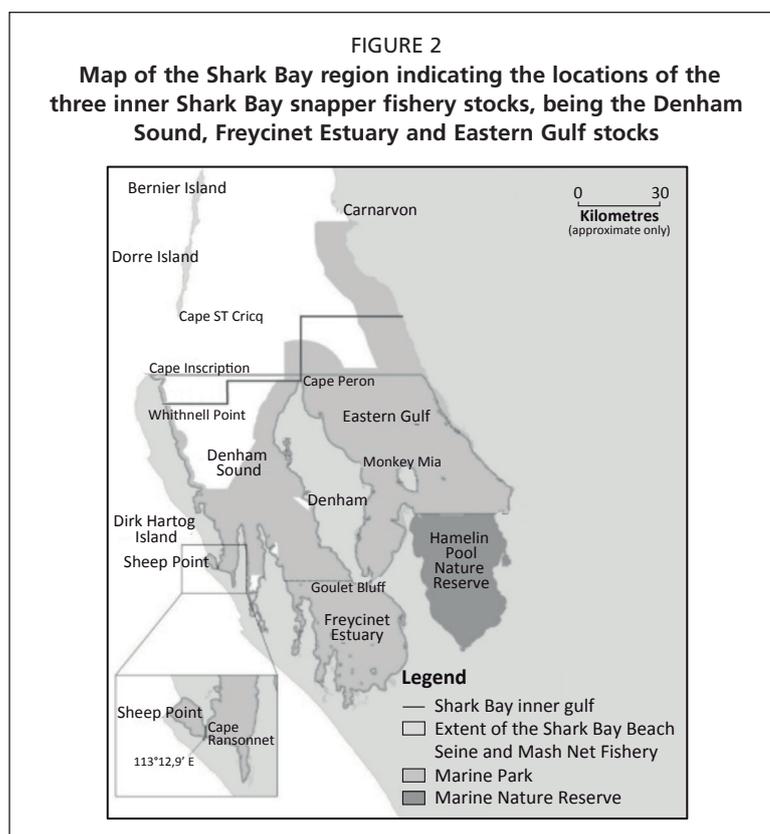
Another important part of the governance systems in WA is the involvement of the two “Peak” stakeholder groups formally recognised by government which are Recfishwest and the Western Australian Fishing Industry Council (WAFIC), representing the recreational and commercial sectors, respectively. These two groups have formal funding and consultation agreements with the Government and the Department which specifies their levels of involvement to facilitate consultation processes with their constituents during the development and review of all proposed management arrangements and the completion of resource assessments.

In addition to the use of these two peak bodies, the Minister may also establish formal Ministerial Working Groups to assist deal with issues that are considered particularly problematic or controversial (e.g. intra or inter sectoral allocation decisions). These groups often undertake their own consultation processes including, where relevant, public submissions or meetings and they generally provide their advice and/or recommendations direct to the Minister.

3. RECREATIONAL SNAPPER FISHERIES IN THE INNER GULFS OF SHARK BAY

3.1 Resources and fisheries

The Shark Bay region in Western Australia has a high conservation value for its diverse marine environments and was listed as a World Heritage Property in 1991 (Figure 2).



This region is most popular for visiting fishers in austral winter when there are calmer sea conditions and milder temperatures, plus this is the time when the principal fishing attraction, snapper, aggregate to spawn. This makes these snapper stocks particularly vulnerable to fishing.

The population structure of snapper in the Shark Bay region is unusually complex with minimal mixing between oceanic waters and the inner gulfs, plus minimal mixing even between gulfs (e.g. Edmonds et al., 1989, 1999; Moran et al., 2003; Jackson et al., 2010; Gardner et al., 2017). Consequently, management has formally recognised that there is an oceanic snapper stock (in oceanic waters outside the bay) and three separate snapper stocks in the inner gulfs.

There is a long history of commercial snapper fishing in the Shark Bay region (Cooper, 1997; Edwards, 2000) but, since the 1960s, commercial effort has largely been on the oceanic stock (Jackson et al., 2010). This also corresponded with the development of the recreational fishery in the inner gulf regions (Wise et al., 2012). Recreational fishing activity inside Shark Bay steadily increased from the 1970s to the mid-80s before escalating sharply in the early 1990s (Department of Fisheries unpublished data). This support for that increase was generated during the 1980s through: (i) improved access to Shark Bay, by the construction of sealed roads and improvements to the airstrip, (ii) increased hotel and caravan park capacity; and greater affordability of recreational boats and related equipment.

The first survey of recreational fishing in Shark Bay (in 1983) estimated the overall recreational catch of snapper for the entire Shark Bay region at approximately 45 t, mostly from the inner gulfs (Jackson et al., 2005). The management of recreational fishing in Shark Bay at this time was largely based on fishing regulations that were limited to size limits and bag limits designed to meet 'social' objectives (i.e. a 'reasonable' retained catch for a day's recreational fishing) rather than control overall harvest levels (Jackson et al., 2005). Consequently, by the early 1990s, with the effectiveness of recreational boat-based fishing increasing with improvements in fish finding technology (e.g. global positioning systems and colour sounders) and increased use of portable generators and freezers, the catch levels increased rapidly. Information gathered by Fisheries Officers estimated that 60 t of spawning snapper were taken over an 85-day period from just one of the important spawning aggregation areas in one of the gulfs suggesting the total catch would have easily exceeded 100 t. This led to the local Shark Bay community becoming concerned that recreational snapper catches had reached unsustainable levels (Marshall & Moore, 2000), and a series of actions have occurred since this time including changes to minimum lengths, bag and boat limits, spatial and seasonal closures (see **Annex 1**).

3.2 Evolution of policy and management

Initial assessment and reactions

Following concerns raised by the local (Denham) Recreational Fishing Advisory Committee, a range of management measures to limit recreational snapper catches were proposed. These included an overall possession limit (i.e. how many kg. of fish an individual could have at any point in time) and species-specific daily bag limit for snapper during the spawning season in 1996. These proposals were unpopular with large numbers of recreational fishers and some of the local businesses that relied on the seasonal tourism. Consequently, they were not supported by the Minister of the

day who requested further research be undertaken to more establish the status of these snapper stocks with more certainty (Marshall and Moore, 2000).

A major issue in generating more precise stock assessments for the three stocks of snapper was the lack of quantitative information available as there were no regular catch and effort data from the recreational sector. The initial assessments relied on research trawl surveys that showed there was poor recruitment of juvenile snapper in the Eastern Gulf at that time. In addition, a survey of recreational fishing in Shark Bay confirmed that snapper were the main recreational target species. The study also showed that the minimum length (41 cm) offered inadequate protection for the breeding stock during periods of high fishing mortality (Sumner and Steckis, 1999). Following this study, a daily bag limit of four snapper per person was introduced and the minimum size increased to 45 cm (TL) in the Eastern Gulf.

In May 1997, a moratorium on snapper fishing in the Eastern Gulf was implemented. Given the expected shift in recreational effort to the other stocks, management measures were also introduced to protect snapper in Denham Sound and the Freycinet Estuary including introduction of daily bag limit, minimum size increased from 41 to 45 cm TL, introduction of limit of two fish greater than 70 cm TL per day. In July 1997, in response to considerable public outcry, the Eastern Gulf moratorium was overturned (Marshall and Moore, 2000). The Eastern Gulf snapper fishery was reopened but further restrictions were imposed (slot limit of 50-70 cm TL, daily bag limit of two fish and the main spawning ground, the 'Patch', closed to all fishing). The Minister called for comprehensive research to obtain better estimates of snapper stock size and recreational catch and effort.

The challenge was there to identify a fishery-independent technique that could provide a rapid assessment of stock sizes for this data-limited, principally recreational snapper fishery. The Daily Egg Production Method (DEPM) had been successfully used to assess snapper stocks elsewhere including the Hauraki Gulf, New Zealand (Zeldis and Francis, 1998). A series of pilot DEPM surveys were undertaken between May and September 1997 (Jackson and Cheng 2001; Jackson et al., 2012) from which it was estimated that the stocks of snapper had declined to very low levels with relatively few mature snappers remaining in the Eastern Gulf. DEPM surveys continued each year in all three areas between 1998 and 2013, to provide annual assessments to fisheries managers which confirmed that these snapper stocks were small (tens to hundreds of tonnes, Jackson et al., 2012) in comparison with snapper stocks elsewhere in South Australia (thousands of tonnes, McGlennon, 2003) and New Zealand (tens of thousands of tonnes, Zeldis and Francis, 1998). They also confirmed that these stocks had been significantly depleted.

A recreational fishing survey of the region was undertaken in 1998-1999 which included interviews at the three main boat ramps in Shark Bay. This study provided the first formal estimates of boat-based recreational catch and effort since 1983 with surveys subsequently carried out at the three main boat-ramps each year between 2000 and 2010 (Wise et al., 2012).

Commercial fisheries management changes

While the main commercial focus had shifted to oceanic waters in the 1960s, some limited commercial fishing for snapper in the inner gulfs persisted through to the mid-1990s. Prior to the stock decline in 1995-1996, the total commercial catch of snapper

taken by the beach seine fishery, prawn trawlers and a limited number of line vessels combined, was around 16 tonnes. After 1996 the commercial catch of snapper was limited to bycatch taken by the beach seine fishery.

Recreational fisheries management changes

The initial set of management restrictions reduced the snapper catch in some areas but not to the degree that was needed. The DEPM surveys in the early 2000s tracked the continuing decline of the spawning biomass in the Freycinet Estuary between 2000 and 2002 (Jackson et al., 2012). The recreational fishing surveys indicating that higher than recommended catches were still occurring in that area because visiting fishers changed their seasonal fishing patterns to avoid the 6-week spawning closure period (Jackson, 2007).

In 2000, when the separation between snapper populations in Denham Sound and Freycinet Estuary was first formally recognized, the recreational fishing regulations were further tightened to reduce recreational snapper catches in Freycinet. This included a reduced daily bag limit (from two to one snapper), an increase in the minimum legal length (from 45 to 50 cm TL), introduction of a slot limit (only one snapper greater than 70 cm TL) and, importantly, the introduction of a 6-week spawning closure in the Freycinet Estuary (cf. **Annex 1**).

After nearly 5 years of the moratorium on fishing for snapper, and given its importance for local tourism operators, by mid-2002, there was pressure from the recreational fishing community to re-open the Eastern Gulf snapper fishery (Jackson et al., 2005). In August 2002, a Ministerial Working Group (MWG) was established to consider future management arrangements for the inner gulf snapper fishery. The MWG was presented with results from the updated assessment which was now able to use integrated age-structured models to assess the status of each stock and to evaluate the effect of different catch levels on stock size (Stephenson and Jackson 2005). Inputs to the models were catch, DEPM estimates and age compositions (biological samples collected with assistance of volunteer recreational fishers). The MWG supported a recommendation that the management objective should be 'to rebuild and maintain spawning biomass of each snapper stock to at least 40% of the unexploited level of spawning biomass' (B_{40}). This was the first time that such an explicit objective had been accepted for a recreational marine fishery in Australia.

To achieve this objective an indicative 'Total Allowable Catch' (TAC) was set for each stock for a 3-year period, i.e. 2003–2005 (Jackson et al., 2005; Stephenson & Jackson, 2005; Jackson & Moran, 2012). Different combinations of management measures were implemented in each area including a novel harvest tag system in the Freycinet Estuary that operated like an ITQ for recreational fishers (Mitchell et al., 2008; Jackson et al., 2016). Here a limited number of harvest tags (<1500) were allocated to recreational fishers via a lottery each year (before the season starts) with fishers restricted to only two tags per person. Within Freycinet recreational fishers were only permitted to retain a snapper when in possession of a harvest tag. During fishing, once a snapper is landed and is to be retained, a harvest tag must be inserted through the mouth and secured using a tamper-proof barrel-style locking mechanism prior to landing.

3.3 Outcomes

Impacts on commercial catch levels

Since the restriction on the commercial line fishing of snapper in the inner gulfs in 1996, the commercial catch has been very small (less than 2 tonnes per year) and limited to bycatch taken by a small-scale beach seine fishery (mostly targets whiting and sea mullet) that has operated since the 1940s (Cooper, 1997).

Impacts on recreational catch and the stock status

The management arrangements introduced in 2003 that resulted from the MWG outcomes were intended to substantially reduce recreational catches to below historic levels. The boat ramp surveys at that time indicated recreational snapper catch in each area was greatly reduced post-2003 with average catches of two and half tonne for the Eastern Gulf, six tonnes for Denham Sound and two tonnes for Freycinet estuary (Jackson et al., 2016), an order of magnitude lower than the catches in the mid-1990s.

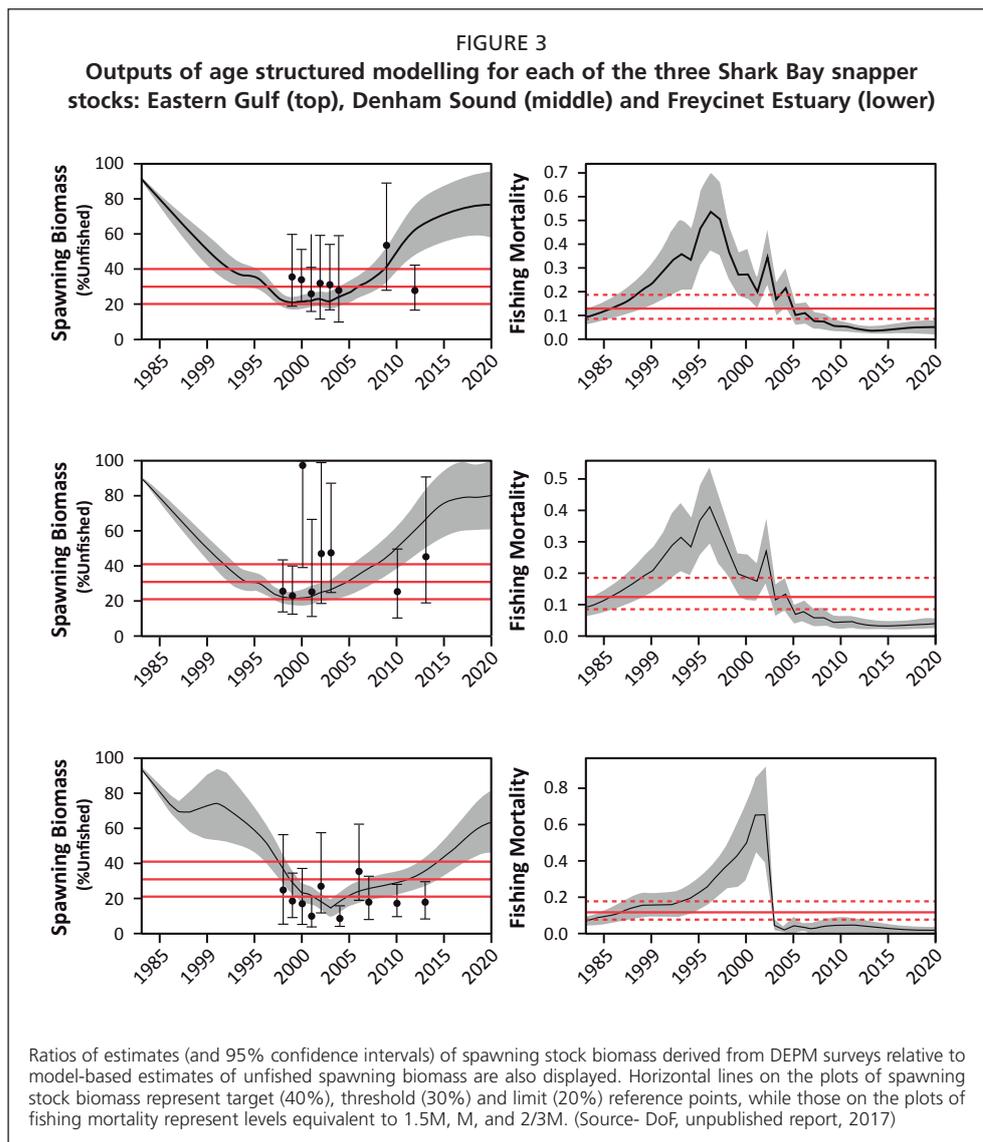
Following the inaugural MWG meeting in 2002, the MWG subsequently met every 3 years (2005, 2008, 2011 and 2014) to review data, assessment updates and effectiveness of the management arrangements. Furthermore, to assist maintain support for these major reductions in catch levels, the monitoring program continued to involve the use of volunteer recreational fishers in the collection of spawning snapper during stock assessment surveys, as had been the case since 1998, from 2003 to 2013.

The major reductions in catch levels for the three snapper stocks generated slow but steady recoveries in each location (**Figure 3**). The most recent assessment of B at the biological stock level, using age composition data collected between 1998 and 2013 indicated that each stock of snapper was above their respective target levels (B_{40}). The biological stocks were therefore classified as sustainable.

Current situation

In their review of use of harvest tags (Jackson et al. 2016) it was clearly demonstrated that these tags were effective in constraining the catch of snapper in Freycinet within the agreed TAC, which contributed to the spawning stock recovery within a 10-12 years period. While management of marine recreational fishing rarely involves the application of hard catch limits, there are some instances where sustainability concerns require total catches to be constrained (Johnston et al., 2007). Harvest tags offered a simple, unambiguous management tool that Compliance Officers can readily check in the field (i.e. no tag equals illegal catch). Moreover, a decade after implementation, 87 percent of harvest tag recipients agreed that the tags were effective in the management of snapper in Freycinet Estuary.

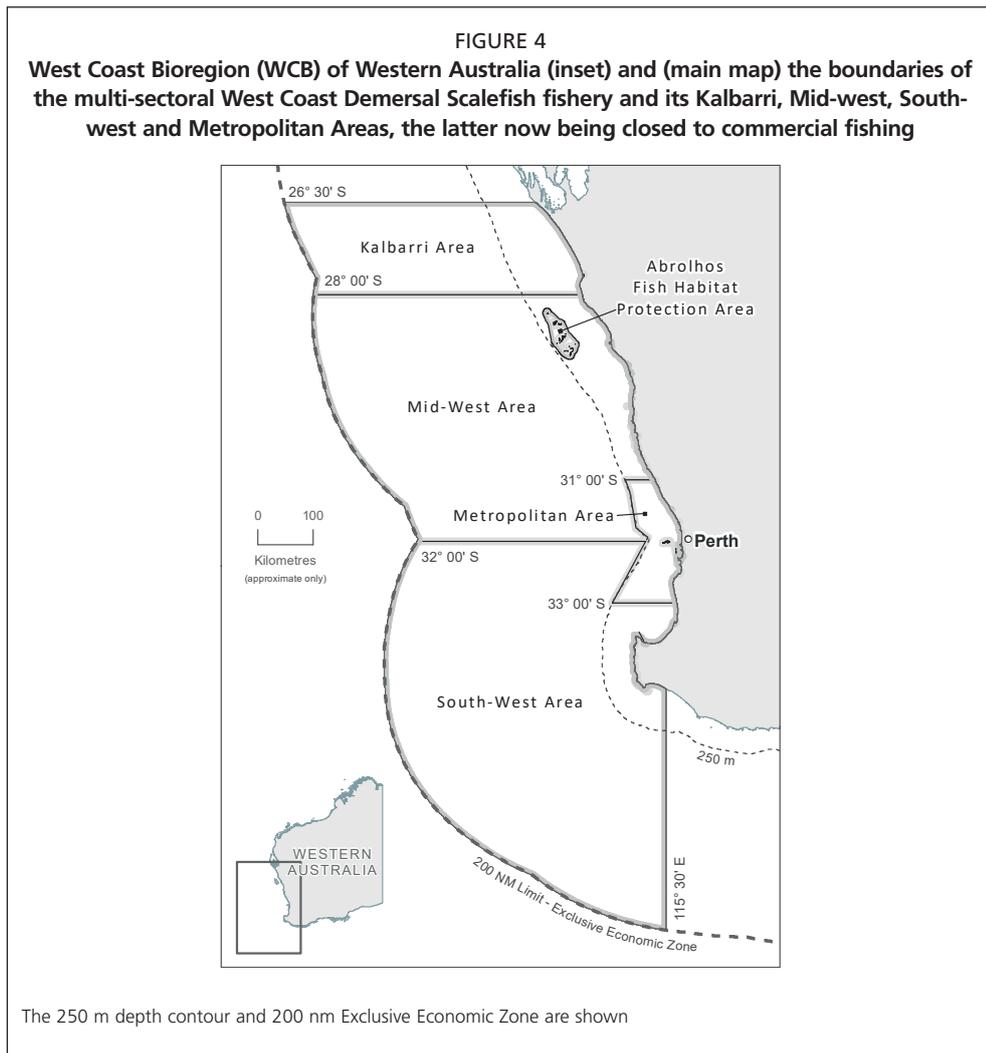
Given the recovery of the snapper stocks in Shark Bay there has been some relaxation of the management arrangements and a reduction in the level of catch and biological monitoring that is undertaken. This included the removal of the requirement for individual harvest tags for snapper caught in Freycinet in 2016. Instead this was replaced with fivekg per person possession limit for this area. Catch monitoring will now have to be increased to determine if this will be adequate to maintain catch levels of the Freycinet stock at sustainable levels.



4. WEST COAST DEMERSAL SCALEFISH RESOURCE

4.1 Resources and fisheries

The West Coast Demersal Scalefish Resource (WCDSR) is a multi-species resource with over 100 scalefish species landed annually. The most important species in terms of catches and targeting are the West Australian dhufish (*Glaucosoma hebraicum*) and Snapper (*Chrysophrys auratus*) and to a lesser extent Redthroat emperor (*Lethrinus miniatus*), Bight redfish (*Centroberyx gerrardi*) and Baldchin groper (*Choerodon rubescens*). The WCDSR comprises multiple commercial fisheries, plus recreational fishing from private boats and charter vessels. These fisheries are collectively referred to as the West Coast Demersal Scalefish Fishery (WCDSF) and are located off the main residential areas of the West Coast Bioregion (WCB) among four management areas, the Kalbarri, Mid-west, Metropolitan and South-west areas (Figure 4).

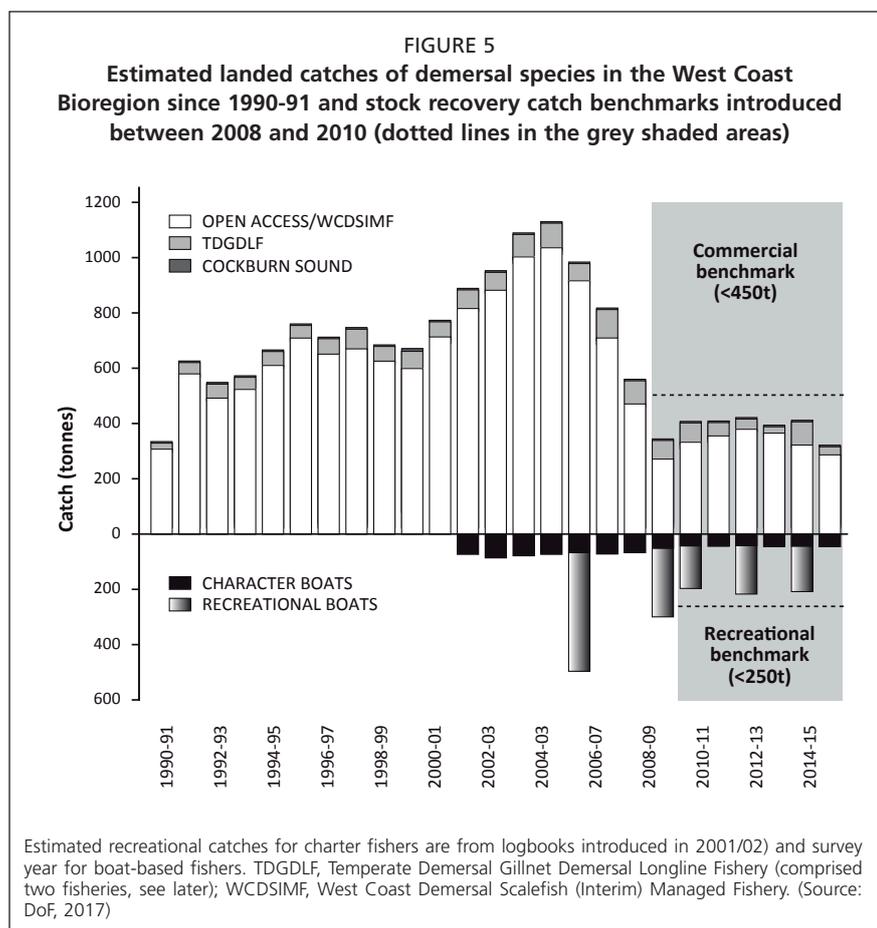


The main commercial fishery for this resource is the line based West Coast Demersal Scalefish (Interim) Managed Fishery (WCDSIMF). The formal management plan for this fishery was implemented in 2008. This is an effort-controlled fishery based on Individual Transferable Effort units (ITEs) with the plan describing the relevant operational requirements (*e.g.* the number of hours that the limited number of permit holders can fish per year; restrictions on the number of lines and hooks they can use *etc.*; see later). Prior to 2008, this was an open access “wetline fishery”, with any WA licensed commercial fishers potentially able to access this resource so long as generic regulations, such as size and gear limits, plus closed seasons for some species were met. Other managed commercial fisheries, including the Temperate Demersal Gillnet and Long-Line Fisheries (TDGDLF) also landed these species in the WCB, but they collectively accounted for 10% of the total commercial catch of these demersal fishes (Figure 5).

Recreational fishing for demersal fishes in the WCB has always been popular, especially in the metropolitan region near Perth (see Figure 4). The main capture method used by recreational fishers is line fishing, primarily from private boats or on charter vessels, although some spear fishing also occurs.

While both sectors had been targeting this resource for many decades, during the 1990s there were substantial increases in catches. The commercial catch increased from

approximately 300 t in 1990 to over 1000 t by 2003. Recreational surveys over this period suggest that recreational catch levels also increased from a few hundred tonnes in the 1990s to approximately 500 t by the mid-2000s (Figure 5). Such escalating catches and anecdotal information that fishers were having to travel further to catch key demersal species raised concern among fishers and scientists, prompting increased focus of management and research on this resource (Pagano & Fuller, 2006).



4.2 Evolution of policy and management

Initial stock assessment and reactions

Given the large number of species in this demersal suite, it is not possible to monitor and assess the status of all the west coast demersal species individually, so the status of the entire resource is inferred by the status of a representative number of ‘indicator-species’ (Wise et al., 2007; DoF, 2011; Newman et al., 2018). The success of this innovative management methodology requires that these indicator-species include the more vulnerable in the suite and are therefore at the highest risk from exploitation. It also requires that the specific management arrangements developed to achieve the sustainability of these indicator-species will also result in a similar relative effect on the exploitation levels of all species within this resource, hence effort controls will often be more effective than output controls. This indicator species approach also assists in preserving the overall “integrity” of the relevant ecosystem (see Garcia et al., 2012).

Indicator species were selected from the dominant species caught by both sectors, by evaluating and scoring their (1) inherent vulnerability as a function of their biology

(e.g. are they long-lived?) (2) risks to sustainability (what is their current stock status?) and (3) management importance, i.e. what is their commercial, social and/or cultural importance and the relative priority for management, monitoring, assessment and compliance among the many fishery resources (see DoF, 2011; Newman et al., 2018 for full details). This information is used to determine an overall score for each species, from which the highest scoring species are adopted as 'indicator' species (e.g. West Australian dhufish and Snapper). The risk status of the indicator species is assessed using consequence \times likelihood matrices, based on AS 4360 and ISO 31000 standards (Fletcher et al., 2011; Fletcher, 2015). The highest current risk to an indicator species is then applied to the entire resource. This approach also recognises that for many multiple species resources you cannot selective catch individual species and therefore management must be based on looking after the weakest link.

With insufficient long term recreational catch data available to use an integrated age-structured stock assessment to provide estimates of breeding stock biomass, another novel approach was adopted to assess the status of indicator species for the stock, this is a 'risk-based weight of evidence approach' (Wise et al., 2007, Fletcher 2015; **Box 1**).

Box 1

Risk Based, Weight of Evidence Assessments in WA

In WA, while there are five different categories of quantitative analysis methodologies applied to assess the status of resources (DoF, 2017), these are all now undertaken using a Weight of Evidence (WoE), Risk-based approach (Fletcher, 2015; DoF, 2017). This requires specifically considering each available line of evidence both individually and collectively to generate the most appropriate overall assessment conclusion. The lines of evidence not only include the outputs that are generated from each available quantitative method but also, where relevant (e.g. model outputs), their individual inputs. It can also include any qualitative lines of evidence such as biological and fishery information that describe the productivity and vulnerability of the species/stock plus anecdotal information from fishers, stakeholders and other sources to ensure that the narrative for the assessment is comprehensive and objective.

The strength of the WoE risk-based approach is that it not only makes use of all available data, but it explicitly shows which of these lines of evidence are consistent or inconsistent with each possible consequence level. This approach clearly shows where there are uncertainties and tensions among data sources which assists in determining the most appropriate overall risk scores, stock status levels and the focus for future research. This approach also provides for the seamless transition from purely qualitative assessments, through semi quantitative and up to a fully quantitative assessment of risk (see also Fletcher, 2015).

In 2007, the first weight of evidence assessment for these indicator species had relatively few older fish (Wise et al., 2007). The fishing mortality rates (F) estimated from age composition data for WA dhufish and Snapper were at least twice as high as standard acceptable performance levels (i.e. $F \geq 2M$ or $2 \times F_{MSY}$), while for Baldchin groper were greater the threshold reference point of F_{MSY} . Consequently, given these results were considered "indicators" of overall fishing pressure on the resource, the assessment concluded there was overfishing of the entire multispecies assemblage.

As WA dhufish and snapper are both relatively vulnerable and the most targeted species in the suite, their fishing mortality rates would also be expected to be among the highest of the suite. Hence the adoption of the risk levels inferred from their status provides a precautionary view of the status of the resource. Similarly, reducing the overall exploitation levels for the suite to reduce the risks to these indicators would therefore also reduce the exploitation on the other species in the resource. The catches of the other species are, however, monitored annually against historical levels to monitor if there are significant changes in their status which would trigger additional investigation. This approach has been successfully applied for a number of multispecies fisheries in WA for about 20 years (see Newman et al., 2018).

Given the high levels of F , the recommended actions based on the control rules (see Wise et al., 2007 and **Annex 3**) required 50% reductions in annual effort and catch for the entire resource by all sectors to generate suitable levels of reduction in fishing mortality. To establish the stock recovery benchmarks, the catch levels from 2005/06 were used as this was the only recent year for which catch data were available from all fisheries in both sectors. It was also identified that, given the life history of these species, the recovery was likely to take in the order of 10-20 years (Fairclough et al., 2007).

Given the major implications of the assessment, and especially because of the politically sensitive nature of these recommended actions, the assessments and their conclusions were subjected to two independent scientific reviews (Haddon, in Wise et al., 2007: 128-130 and O'Neill, 2009). Both reviews supported the conclusion that the catches of demersal scalefish in the WCB were too high and that fishing mortality had to be reduced if the stocks were to be sustainable in the long term.

The primary objective that was finally agreed for managing the WCDSR was to reduce and maintain catches of demersal species at less than 50 per cent of those recorded in the WCB during 2005/06. This led to several changes to the management arrangements of both sectors. The processes for this were however not simple and the timelines for the most significant milestones and responses are presented below and detailed in **Annex 2**.

Commercial fisheries management changes

It was recognised even prior to the assessment of overfishing in 2007, that the commercial line fishery for this suite could not continue to be managed in an open access manner. The commercial sector was therefore put through a process to become a limited entry fishery with a restriction on total effort through an Individual Transferable Effort (ITE) system (Department of Fisheries, 2005a; b; 2006). This process involved two panels, who developed proposals for (1) the specific management arrangements for the fishery and (2) an equitable method of determining who would have access to the fishery and their level of access. The former panel comprised members of both the commercial and recreational sectors and additional observers, e.g. from Conservation bodies, while the latter panel comprised three independent members. In each case, proposals were submitted to the Minister and subsequently made available to the public to also provide comment. This information was considered by the Minister in making final decisions.

This process ultimately resulted in the establishment of the WCDSIMF in 2008 which reduced access from a potential 1 250 licensed fishing boats to 61 permits. This effectively prevented fishers from other fisheries, such as the West Coast Rock Lobster Managed Fishery, which contributed many of those vessels, from also catching demersal species. Such vessels are now only allowed to carry gear (pots) that can be used for catching lobster. Historically many of these vessels only fished for demersal

species opportunistically, being generally of lower market value, and thus their annual catches were low. The determination of whether a fisher received a permit to fish in the WCDSR was dependent on a demonstration that they had a history of catches of demersal species of at least two tonnes per year during benchmark periods, based on compulsory logbook records (Department of Fisheries, 2007b). The intention of this was to create a fishery which contained fishers who were committed to an appropriately managed long term sustainable demersal fishery.

The declaration of this fishery coincided with the release of the assessment report and the closure of the Metropolitan Area (Fig. 4) to all commercial fishing for this resource in recognition of the large recreational sector catch from this area (see later). WCDSIMF permit holders who operated in this area were provided with ‘Act of Grace’ payments to compensate for the loss of fishing access in that Area. Remaining permit holders have a maximum number of hours (entitlement) they can fish each year (monitored by an electronic Vessel Monitoring System), gear and other restrictions also apply (e.g. area closures, maximum numbers of lines and hooks and rules around carrying lines and fish).

In addition to the WCDSIMF, two other commercial fisheries operating in the WCB also catch demersal scalefish. There are 24 licences in the West Coast Demersal Gillnet and Demersal Longline (Interim) Managed Fishery and 20 licences in Zone 1 of the Joint Authority Southern Demersal Gillnet and Demersal Longline Managed Fishery. These had also undergone significant restructuring to address shark sustainability issues which resulted in a 40 percent effort reduction from a 2001/02 benchmark plus a ‘Voluntary Fisheries Adjustment Scheme’ which paid fishers to leave the industry which resulted in a further 35 percent reduction in effort because of the Metropolitan Area closure.

These actions all contributed to the explicit management objective for these fisheries since 2009 which was to reduce the catch of demersal scalefish in the WCB by at least half of 2005/06 levels (see earlier) to allow stocks to recover to at least the threshold reference point.

Recreational fisheries management changes

To achieve the management objective of reducing the recreational sector’s catch by at least 50 percent of that in 2005/06 (see earlier), several steps were undertaken to develop a new set of management arrangements.

One of the initial challenges dealing with the recreational fishery was to effectively convey there was a sustainability problem and that a range of different management tools would be needed to deliver the required catch reductions. A structured communication and education plan was implemented that included a range of strategies including website information, involving recreational fishers in the age structure sampling, brochures, discussion papers and presentations to key target groups (e.g. DoF, 2007a; 2008). This was important in effectively promoting awareness of the research finding and encouraging recreational fishers to adopt a sense of personal responsibility for the stewardship of the fishery.

It took until September 2009 and an additional independent scientific and management review (O’Neil, 2009) and extensive consultation before the Minister for Fisheries announced the first set of new recreational management arrangements. These included reductions to the numbers of demersal fish that could be caught and retained (i.e. personal daily limit for demersal species and boat limit for WA dhufish), an increase in the minimum legal length for retention of snapper, the implementation of an

annual two month closure throughout the fishery (the WCB) prohibiting recreational fishing for demersal species between 15 October and 15 December each year and a requirement to carry a release weight (a weight used to return fish to the bottom, to assist in minimising post-release mortality associated with barotrauma-related injuries). From March 2010, all persons fishing from a powered boat were required to hold a Recreational Fishing-from-Boat Licence. Also, a state-wide cap on the number of charter boat licenses was implemented with operators required to adhere to recreational fishing regulations (DoF, 2012).

Sectoral allocations

A key part of gaining acceptance for the package of reforms from the recreational sector was the setting of explicit sectoral catch allocations. An Integrated Fisheries Allocation Advisory Committee (IFAAC) was established in 2010 to make recommendations to the Minister on how the resource should be allocated (DoF, 2010). This was based on the historical levels of catch by the commercial and recreational sectors of the whole demersal resource and of the key indicator species. After consideration of the IFAAC report, the Minister for Fisheries determined the allocation for the resource (the total suite of species) to be 64% to the commercial fishing sector and 36 percent to the recreational sector (64/36 percent). Catch proportion guidelines for WCB indicator-species were also determined as part of this process, e.g. a 63/37 and 21/79 percent allocations of WA dhufish and Snapper to the recreational and commercial sectors, respectively. These allocations have been used in all reviews of the management settings for these fisheries and they are explicitly included in the draft Harvest Strategy for this resource (Fletcher, et al., 2016).

4.3 Outcomes

Impacts on catch levels

Commercial Catch

As a result of changes to the management of the commercial fisheries, particularly the WCDSIMF and TDGDLF, the annual catch of the demersal resource has been reduced from 949 tonnes to less than 450 tonnes, thus meeting the primary objective of reducing catches by at least 50 percent of 2005/06 levels (to reduce fishing mortality by similar levels) and thus allow recovery of the resource (**Figure 5**). The commercial fisheries have achieved their management objective of a 50% reduction in catches which shows the effectiveness of ITEs and other operational arrangements to manage these geographically large, multi-species fisheries.

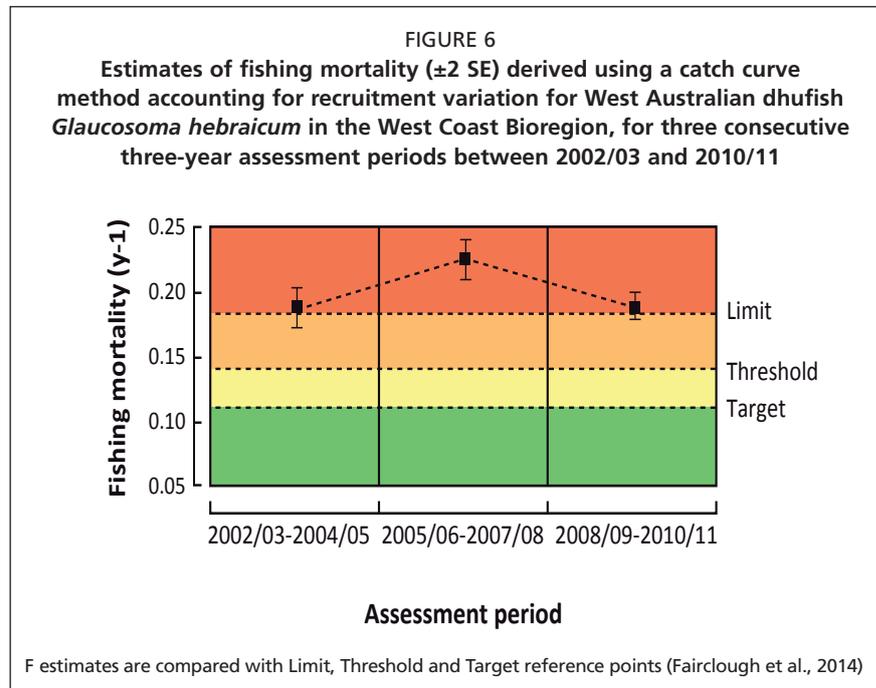
Recreational Catch

The 2009/10 boat-based creel survey results showed that the recreational fishing regulation changes also led to a successful reduction in the catch of the demersal resource in the WCB by more than 50 per cent of the 2005/06 levels (**Figure 5**). That the recreational fishers adopted the new management arrangements is also a testament to the effectiveness of the communication and education strategies, which reinforces the importance educational strategies in encouraging positive behavioural responses from recreational fishers.

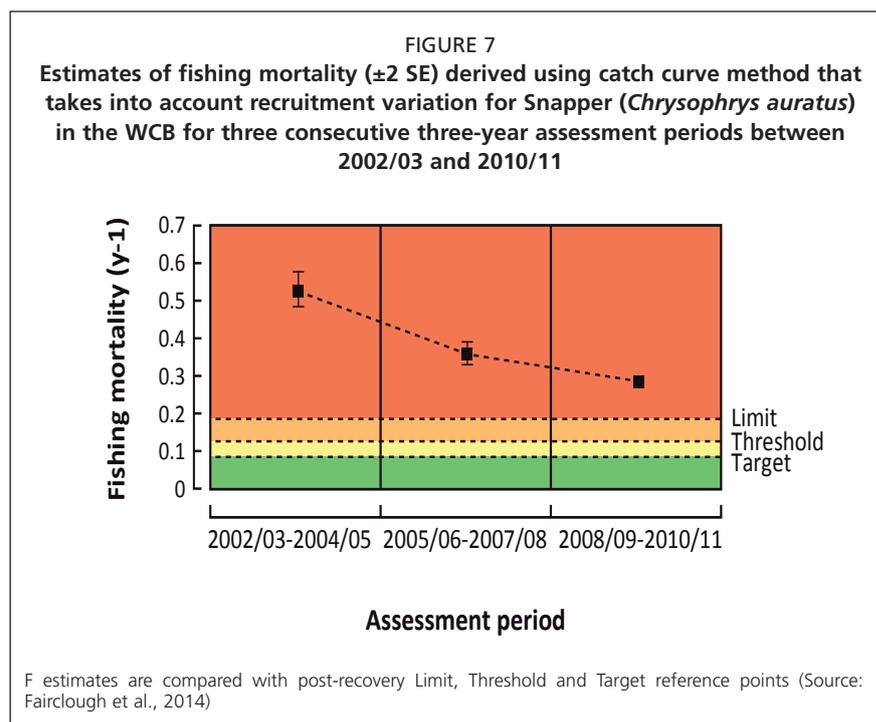
Initial impacts on stock status

The most recent assessment completed for WA dhufish on data collected up to 2011 (Fairclough et al., 2014) found that the fishing mortality (F) had decreased from the previous assessment period 2005/06-2007/08 (**Figure 6**), despite not all the

management actions having occurred at that time. While the F value was still above the limit reference point of $1.5M$, the spawning potential ratio ($SPR = EPR_{F_{current}} / EPR_{F=0}$; where $EPR = \text{eggs per recruit}$) lay between the limit ($0.2SPR_{F=0}$) and threshold ($0.3SPR_{F=0}$) reference point therefore this stock was classified as recovering.



Similarly, the estimates of F for snapper had decreased from the previous period 2005/06-2007/08 (Figure 7; from Fairclough et al., 2014), but were still above the limit reference point of $1.5M$. However, the SPR ($SSB/R_{F=F_{current}} / SSB/R_{F=0}$) was at or below the limit ($0.2SPR_{F=0}$). This indicated that the current level of exploitation, if maintained should allow the stock to recover from overfishing and the stock was also classified as recovering.



Current situation

A formal 'recovery' harvest strategy has now been drafted to assist rebuilding of these stocks by ensuring that all sectors that catch this resource contribute to the recovery by adhering to their formal catch allocations (see **Annex 3**). Given the complex nature of the fishery, species and resource-level stock recovery catch benchmarks, formal limited tolerance levels have been developed to ensure that management intervention is only triggered when tolerance levels are breached (Fletcher et al., 2016). These tolerance levels are based upon catches of a sector exceeding their relevant benchmark level in more than one consecutive year, and by more than 10-20 percent (based on individual species vulnerabilities) and is thus different to a catch quota management arrangement. This would then trigger formal management reviews. Such breaches can occur, for example, because these demersal species exhibit highly variable recruitment, with typically a single strong cohort occurring only once or twice per 10-year period (see e.g. Wakefield et al., 2016). When a relatively much stronger cohort recruits to the fishery, an increase in catch rates is often detected, which can lead to catches breaching the tolerance levels. However, once that cohort declines in abundance, catches may fall back below the stock recovery benchmark. Thus, flexibility is required in the stock recovery catch benchmarks. This approach has already been used to instigate changes to management arrangements for the commercial sector, after their snapper catch benchmarks were exceeded by over 20 percent for three consecutive years. To reduce catches back below stock-recovery catch benchmarks, reductions were made to the total available hours that could be fished per year (applied to each permit) in two areas of the main commercial fishery (the WCDSIMF) and thus the maximum effort that could be expended per year. In contrast, management adjustments for the recreational fishery have not been required because neither the total or indicator-species recreational catches have exceeded their catch benchmarks by more than 20 percent in consecutive years (Fairclough et al., 2015; Ryan et al., 2015).

The Department has continued to undertake ongoing monitoring of stock status of the indicator species for this resource. This includes an innovative method for collecting fish frames of each of the indicator-species (WA dhufish, snapper) from recreational fishers to obtain otoliths for age structure estimates via the "Send us your skeletons" volunteer program (Fairclough et al., 2014; www.fish.wa.gov.au/frames).

The ongoing effectiveness of the rebuilding strategy will continue to be tested using periodic stock assessments of each of the key indicator-species for the resource (WA dhufish and Snapper), with one currently underway using similar methods to the 2014 assessment (Fairclough et al., 2014). Thus, they will examine all available data, to compare current catches against stock recovery benchmarks, examine catch rate trends, analyse age structure data and estimate F and SPR against reference points (see above description of previous assessment). This 'weight of evidence' approach will be used to determine whether there is sufficient evidence that recovery is occurring. It is also expected that when a sufficient time series of robust recreational catch data are acquired, the methods to estimate stock biomass will be evaluated.

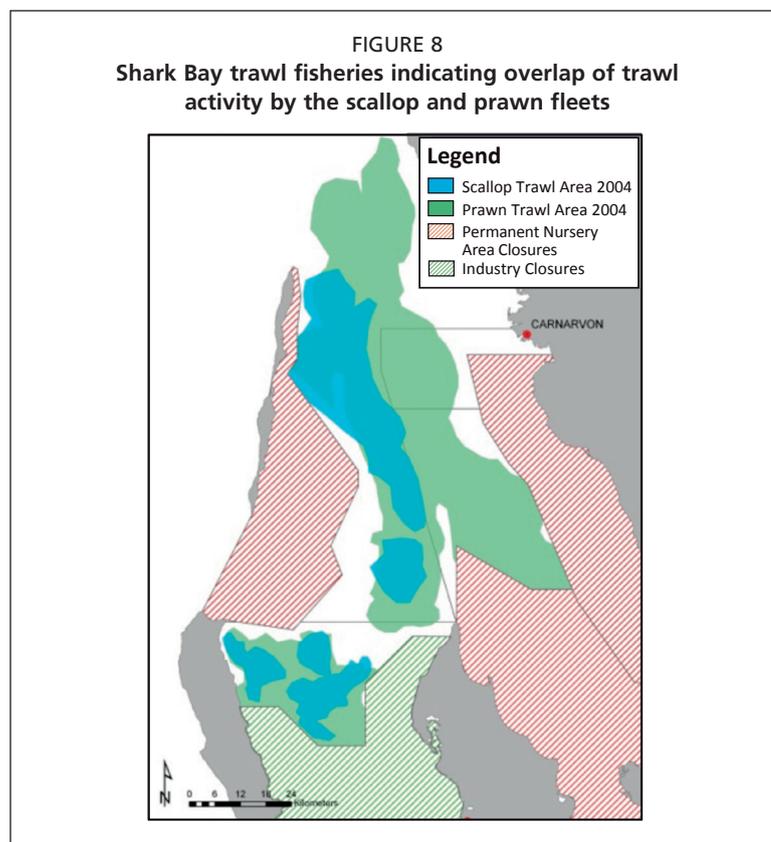
One of the emerging issues for the recovery of the demersal resource is the level of discarding which may be leading to a higher level of fishing mortality than that from retained catches alone. The proportion of fish 'returned' to the sea by recreational fishers in this region is very high (>70% for WA dhufish and Snapper, for example; Ryan et al., 2015). Even assuming reasonable levels of survival, there is probably a much greater level of mortality than is desirable. This has resulted in a review of the overall benefits of using size limits for species that suffer from release mortality (DoF, 2016).

5. SHARK BAY SCALLOPS AND THE IMPACTS OF A MARINE HEAT WAVE

5.1 Resources and fisheries

The saucer scallop *Ylistrum balloti*² (Myrnhardt et al., 2014) is fished commercially in four main regions of Western Australia with the highest production historically from fisheries in Shark Bay (Figure 1). The annual value of the Shark Bay fishery is generally AUD 5-20 million and it generates much needed employment within regional Western Australia (Fletcher and Santoro, 2017). This fishery is accessed by two trawl fleets, a dedicated scallop fleet (presently 11 licenses) that has access to 70% of the available scallops estimated through survey-based catch predictions in any one year, and a prawn fleet (18 licenses) that has access to the remaining 30 percent (DoF, 2017). Between 2007 and 2011 the catch share was managed through “% under and overs” in relation to each fleet from one year to the next. This moved to a trial quota arrangement (ITQ) in 2014. There are differences in the gear each fleet uses and a different start data and length of each fishing season but there are spatial overlaps in areas (Figure 8) where the two fleets operate which have, over the history of this fishery, caused resource sharing challenges (Kangas et al., 2012).

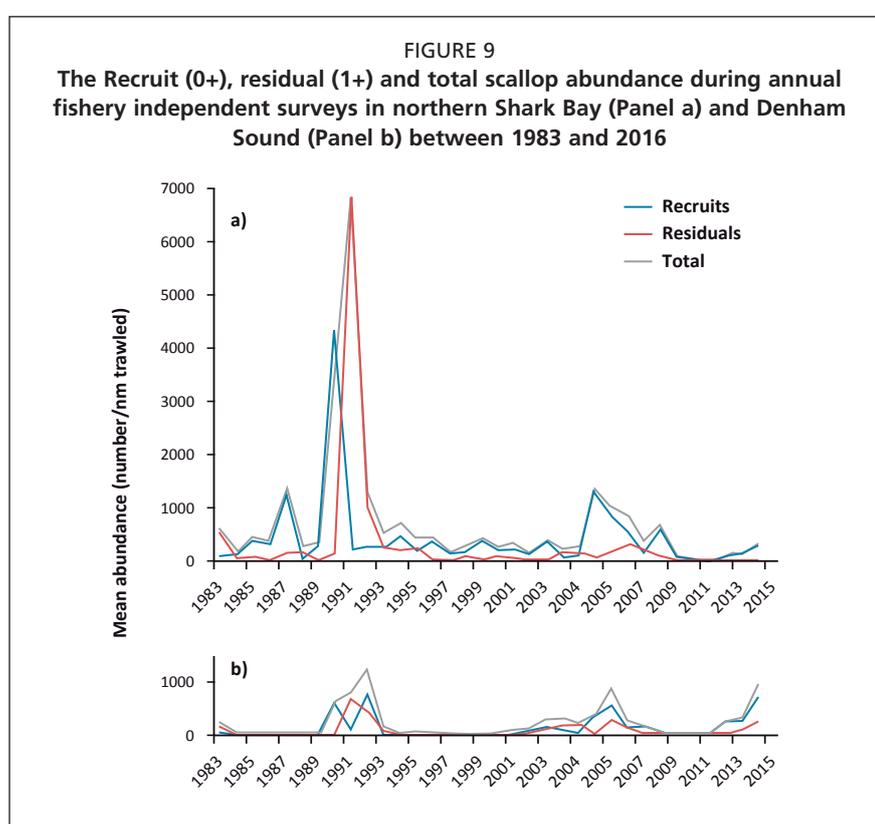
Shark Bay has two distinct stocks of scallops (Denham Sound and northern Shark Bay) which have limited larval mixing between the two regions and no larvae are likely to be sourced from outside the Bay. Also, larval advection modelling indicated a strong likelihood of some larvae being flushed out from the northern entrance to Shark Bay under certain oceanic conditions (Kangas et al., 2012). Like most scallop fisheries, those in Shark Bay exhibit high natural variability in annual landings and some correlation with the strength of the Leeuwin Current which is influenced by ENSO events which may also affect the level of larval flushing (Joll and Caputi, 1995a; Lenanton et al., 2009).



² Formerly *Amusium balloti*

To ensure that the stocks are maintained at adequate levels, annual fishery-independent trawl surveys are conducted in November/December to provide an index of abundance (and size composition) of scallops that is used to provide a catch prediction for the following season and to determine start/end dates for both fleets operations (Kangas et al., 2011). These data allow the annual management arrangements (and industry harvesting strategies) to be tailored to the expected abundance of scallops available because of the significant correlation between the abundance of recruits and residuals (the residual spawning stock at the end of the year) (Figure 9) from surveys and the following year's catch (Kangas et al., 2011; Caputi et al., 2014).

In 2010 Shark Bay experienced cooler than average sea temperatures up to October, but this was followed by extremely high temperatures during the summer, particularly in February 2011, as part of the marine heatwave that affected Shark Bay and the northern parts of the West Coast Bioregion (Pearce et al., 2011). The combination of these events resulted in a significant decline of not only the scallop stock but also the lucrative blue swimmer crab fishery (Fletcher et al., 2017).



5.2 Evolution of policy and management

Initial assessment and reactions

The 2010 annual scallop survey in November had already predicted only a moderate catch of scallops for the 2011 season, but the overall landings were well below those predicted due to small sized scallops and an apparent slower growth rate of scallops. The November 2011 annual survey identified that a major decline in the scallop adult stock had occurred (leaving few residuals) and that there had been low recruitment (Figure 9). As these abundance levels and the predicted catch for 2012 were below the reference levels established to enable the fishery to operate, the immediate management

response was to close the fishery. In combination with the closure, a stock recovery strategy was developed.

Initial management actions

As a full closure of a fishery has a major financial impact on the industry and flow on effects to other service providers and consumers, it was important to understand the cause of recruitment variation and failures to clearly explain these to stakeholders. A workshop involving scallop experts, industry and managers was held to discuss the cause of the collapse; whether these conditions are likely to remain and what could assist recovery.

The workshop identified that the very low breeding stock that remained may inhibit natural stock recovery and consideration was therefore given to investigate assisted recovery measures (such as restocking and reseedling from hatchery production) to re-establish founder populations. Subsequently a Scallop Recovery Plan was drafted for Shark Bay (DoF, unpublished). Additional research funding was sourced to improve the understanding of environmental factors affecting scallop recruitment and investigate additional potential mitigation measures for the 2014 and 2015 seasons.

5.3 Outcomes

The low abundance of surviving residual (spawning) stock in 2011/12 led to a low level of recruitment during 2012 and 2013 in both regions. Despite the absence of any active fishing, the survival of these recruits was low due to poor environmental conditions-, the breeding stock did not increase, and the fishery remained closed for 2013 and 2014. In addition to the full scallop fishery closure (no retention of scallops), further protection was provided, through small closed areas within the two parts of the scallop fishing grounds where concentrations of scallops had been identified through the independent surveys. These closures prevented still active prawn boats from trawling in these areas and catch scallops which would have needed to be discarded. Despite the small size of these closures and their temporary nature, this action was strongly opposed by the prawn fleet but strongly supported by the scallop fleet. Despite extensive consultation between both sectors, this failed to reach a reasonable consensus and therefore, based on the ongoing risks to scallops, the Minister approved the temporary implementation of these closures.

By the November 2014 survey, there was a significant increase in recruitment levels in Denham Sound which was now back to 'pre-heatwave years' survey catch-rates. This recovery was possibly aided in by the spatial closures mentioned above of key scallop aggregations in combination with improved environmental conditions. This enabled limited commercial fishing in Denham Sound in late 2015. In northern Shark Bay however, the 2014 abundance levels had only increased marginally, and this area remained closed.

When the scallop fishery re-opened in 2014, a trial quota management arrangement was established for a total quota of 100 tonnes with the same catch share between the two fleets that applied prior to the closure (of 70% for the directed scallop fleet and 30% for the prawn fleet). In addition, fishing for scallops was delayed until after August to allow most of the spawning for the year to take place (Joll and Caputi 1995b). This resulted, however, in fishing occurring at a time when the scallop adductor muscle (the part of the scallop that is retained and sold) size was small due to loss in muscle mass directly after the spawning events (Joll and Caputi 1995b) so scallop boats ceased

fishing after only 18 days as catch rates for this fleet, with a single target species, became uneconomic. Prawn fishers continued to harvest scallops as part of their multi-species take (prawns, scallop and crabs) within that region until their prawn season finished on 20 November during which time the adductor muscle size would have been increasing well after the key spawning period (Fletcher et al., 2017).

Current situation

Further improved recruitment levels were observed in 2015 and higher residual scallop abundance indicating that not all harvestable scallops were taken during fishing in 2015. In 2016 the recovery had continued such that both parts of the fishery were opened with the trial quota continuing with an increased total take of 160 tonnes (meat weight). At the end of 2016, Denham Sound has completely recovered with scallop abundances at the higher end of the historical range and with northern Shark Bay remaining in the lower end of its' "normal" historical abundance range. With these improved abundance levels, the quota allocation was increased to 330 tonnes (meat weight) across the two fleets for 2017. Industry consultation has commenced to determine if the quota policy would be supported beyond 2017 and a formal Harvest Strategy for the fishery will be developed.

The collapse, the recovery of the scallop stock in Shark Bay and the understanding gained during the last six years (Caputi et al., 2016) puts the management of this resource and its associated fisheries in good stead to address future resource challenges to the stocks related to environmental perturbations. The annual fishery independent sampling of the stock and regular feedback from industry operators permits a quick response to resource fluctuations to prevent overfishing and industry participation in management and development of Harvest Strategies ensures that adaptive management can be implemented.

6. DISCUSSION

The examination of the difficulties encountered, and the strategies applied in each of the three WA case studies, has enabled identification of several consistent components needed to generate successful stock recoveries. In each case, the total or partial recoveries were only possible because of the strong and effective management and governance systems that were implemented but achieving these outcomes requires strong support from all stakeholders, including politicians.

In each situation, the issues surrounding the depletions generated considerable levels of public interest and concern. Therefore, the primary requirement for success was obtaining the necessary political support to take the actions required and, given the political implications, this was more evident when these were to affect the recreational sectors. For the Shark Bay snapper and West Coast Demersal examples, this required getting sufficient appreciation of the actors about the level of risks to the resources. In both cases, pressed by the stakeholders, the Minister of the day delayed action and required additional scientific reviews and/or the collection of additional information before they would consider supporting definitive actions. In such cases the establishment of a Ministerial Working group or similar has been established to facilitate the discussions and consultation among the various stakeholder groups through a more focused group. These working groups have been successful in providing consolidated advice to the Minister that benefits from the ability to have a more considered assessment of the available information, rather than just focusing on emotions that often occurs in more public forums.

A further requirement for successful recovery strategies was to ensure the development of an appropriate combination of management arrangements. The specific set of arrangements that were applied to reduce catch levels were different in each case study including differences in what applied to each of the different sectors accessing these resources. An essential element in getting agreement from stakeholders for new arrangements was that explicit access allocations to each sector were already established. This took away a large amount of the finger pointing among sectors because each group was aware of their allocation and could therefore concentrate on determining their own set of rules to achieve their targets, instead of on what the other sector was allowed to do. A good example for the West Coast Demersal was the establishment of a closed season for the recreational sector but not for the commercial sector. This was only possible because of the setting of explicit proportional allocation of catch for this resource which included the removal of the commercial sector from the metropolitan region.

The successful implementation of the new arrangements required extensive consultation with stakeholders that was supported by effective education, compliance and monitoring programs. This highlighted the often discrepancy between what is reported in newspapers and what the actual level of support or concern is on the ground. Hence when the new recreational boat licence was implemented in 2011, our survey officers at boat ramps reported about 95% support for the initiative compared to the majority of letters to newspapers and websites that were condemning the move.

Having effective peak-body stakeholder representation was also critical to these processes. Both the WAFIC and Recfishwest were essential to the positive outcome for the West Coast Demersal example by holding discussions with their respective stakeholder groups they assisted with the communications process. Importantly, for the case studies, the two organisations accepted the independently reviewed scientific advice, even if some of their members didn't like that advice. They both recognised that failure to take appropriate action to reduce catches by at least 50 per cent of 2005/06 catches could have led to stock collapse. They accepted that action had to be taken across all sectors to ensure the long-term sustainability of the west coast demersal scalefish resource and supported the Department in this regard.

Given the long duration that has been required for the recovery of these resources, stakeholder engagement programs have been maintained to avoid the push for a premature relaxation of the rules before the end of the rebuilding process based on unrealistic stakeholder expectations. Similarly, as each of these recoveries has extended over multiple governments and numerous fisheries ministers, getting agreements from all sides of politics of the need to take action was essential for their long-term success. In the two recreational case studies, briefings of the opposition and other relevant political parties were undertaken. This approach is required because all WA's subsidiary legislation (which includes specific regulations) is open to being disallowed by the WA Parliament.

The governance model that has been adopted by the Department has been able to make decisions that have stakeholder support even when those decisions mean significant reductions in fishing catch and effort. While developing a recovery plan may appear slow, when trying to change the behaviour of a large group of people it is essential to ensure the consultative processes are sufficiently robust to gain (and maintain) political support for (and during) the process. This must, however, be balanced against the risks of a more serious stock collapse being generated if these decisions are excessively delayed. In most all cases, however, where the risks of stock collapse are considered

severe, the Minister now acts quickly to reduce or even shut the relevant fisheries. This is evidenced by 97% of fish resources in WA currently being assessed as not at risk from fishing (DoF, 2017).

It is notable that the time required to take actions for each of these case studies has declined substantially over the 20-year period. This is a result of: (i) the increased level of public expectations for actions to be taken; (ii) the increased level of understanding by Government and stakeholders of the science used to make decisions; (iii) the conclusions of previous assessments indicating high risks have ultimately been proved correct; and (iv) increasingly, the broad adoption of third party certification for WA fisheries (Bellchambers et al., 2016).

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ANNEX 1 – TIMELINE FOR THE MANAGEMENT AND RESEARCH ACTIVITIES UNDERTAKEN TO RECOVER THE INNER SHARK BAY SNAPPER RESOURCES.

Year	Management or Research Action
1950s – early 1990s	<ul style="list-style-type: none"> • Size limit 38 cm (increased to 41 cm in 1986), 10 fish bag limit (first introduced in 1977, reduced to 8 in 1991) • 1983, first survey of recreational fishing in Shark Bay • Genetics and tagging studies indicate separate snapper stocks
1995	<ul style="list-style-type: none"> • Community concern about high catches of spawning pink snapper in Eastern Gulf • Estimates of catch out of Monkey Mia ~60+ t • Denham RRFAC recommends introduction of daily bag limit (6) overall possession limit, and daily bag limit of 4 pink snapper during spawning season only (May-July).
1996	<ul style="list-style-type: none"> • State RFAC recommends minimum size of 45 cm, slot limit of 2 fish > 70 cm, daily bag limit of 4 • Denham RRFAC expressed disappointment, recommends slot limit of 2 pink snapper > 70 cm, 6 other fish < 70 cm • Eastern Gulf, daily bag limit reduced to 4, minimum size limit increased to 45 cm. Denham Sound/Freycinet Estuary, no change to regulations. • Attitudinal survey of recreational fishers at Monkey Mia
1997	<ul style="list-style-type: none"> • Trawl surveys indicate poor snapper recruitment in Eastern Gulf • Eastern Gulf pink snapper fishery closed, re-opened after 2 months, slot size limit 50-70 cm introduced, daily bag limit reduced to 2 • Denham Sound/Freycinet Estuary, minimum size limit increased to 45 cm, slot limit of 2 fish > 70 cm, daily bag limit reduced to 4 • Pilot DEPM surveys conducted in all three areas
1998	<ul style="list-style-type: none"> • Based on 1997 pilot DEPM results, estimated that ~5-20 t of spawning biomass in Eastern Gulf, pink snapper fishery closed (again). DEPM surveys conducted in all three areas. • Gascoyne Recreational Fishing survey commences
1999	<ul style="list-style-type: none"> • First estimates of snapper catch from Gascoyne Recreational Fishing survey - Denham 12 t, Freycinet 26 t, Eastern Gulf closed to snapper fishing. • DEPM surveys conducted in all three areas.
2000	<ul style="list-style-type: none"> • Eastern Gulf fishery remains closed • Based on further research, management recognizes separation between Denham Sound and Freycinet pink snapper stocks. • Denham Sound, daily bag limit reduced to 2, minimum size limit increased to 50 cm, slot limit with only 1 fish > 70 cm. Freycinet, same as Denham plus 6 week spawning season closure (15/8 to 31/10) introduced. • Recreational boat ramp survey (to monitor catches) and DEPM surveys in all three areas
2001	<ul style="list-style-type: none"> • No changes to regulations • Recreational boat ramp survey, DEPM surveys in all three areas.
2002	<ul style="list-style-type: none"> • Ministerial Working Group, review of pink snapper research and management – TACs and management set for each area for period 2003-2006 • First integrated model-based stock assessments • Recreational boat ramp survey and DEPM surveys in all three areas
2003-2005	<ul style="list-style-type: none"> • Eastern Gulf re-opened in March, TAC 15 t (12 t allocated to recreational sector, 3 t to commercial), daily bag limit 1 snapper, slot limit >50<70 cm, spawning closure April-July. • Denham Sound, TAC 10 t (8 t recreational, 2 t commercial), daily bag limit 1 snapper, slot limit >50<70 cm. • Freycinet, TAC of 5 t (3.8 t recreational, 1.2 t commercial), slot limit >50<70 cm, 6 week spawning season closure, plus 900 harvest tags only available to recreational fishers (300 to commercial sector), allocated via lottery system. • Recreational boat ramp survey and DEPM surveys • Ministerial Working Group meets in late 2005 to review stock assessment and set TACs and management for period 2006-2008

2006-2008	<ul style="list-style-type: none"> • Eastern Gulf, TAC 15 t, daily bag limit 1 snapper, slot limit >50<70 cm, spawning closure reduced by one month to May-July. • Denham Sound, TAC increased by 5 t to 15 t, bag limit 1 snapper, slot limit >50<70 cm. • Freycinet, TAC 5 t, slot limit >50<70 cm, 6 week spawning season closure, number of harvest tags available increased to 1,050 for recreational fishers (350 for commercial sector), allocated via lottery system. • Recreational boat ramp survey and DEPM surveys • Ministerial Working Group meets in late 2008 to review stock assessment and set TACs and management for period 2009-2011
2009-2011	<ul style="list-style-type: none"> • Eastern Gulf, TAC 15 t, daily bag limit 1 snapper, slot limit >50<70 cm, spawning closure May-July. • Denham Sound, TAC 15 t, bag limit 1 snapper, slot limit >50<70 cm. • Freycinet, TAC 5 t, slot limit >50<70 cm, 6 week spawning season closure, number of harvest tags available 1,050 for recreational fishers (350 for commercial sector), allocated via lottery system. • Recreational boat ramp survey and DEPM surveys • Ministerial Working Group meets in late 2011 to review stock assessment and set TACs and management for period 2012-2014 • Assessments indicate that both Eastern Gulf and Denham Sound stocks rebuilt to above B_{40}
2012-2014	<ul style="list-style-type: none"> • Eastern Gulf, TAC 15 t, daily bag limit 1 snapper, slot limit >50<70 cm, spawning closure May-July. • Denham Sound, TAC 15 t, bag limit 1 snapper, slot limit >50<70 cm. • Freycinet, TAC 5 t, slot limit >50<70 cm, 6 week spawning season closure, number of harvest tags available 1,050 for recreational fishers (350 for commercial sector), allocated via lottery system. • Recreational boat ramp survey and DEPM surveys • Ministerial Working Group scheduled for late 2014 postponed to 2015
2015	<ul style="list-style-type: none"> • Minister indicates desire for removal of harvest tags • Stock assessment reviewed, including review of DEPM, stock assessments updated, indicates Freycinet stock rebuilt to above B_{40} • Department meets with RFW and to review management in late 2015, discuss alternative to harvest tags to manage snapper catch
2016	<ul style="list-style-type: none"> • Eastern Gulf, TAC 15 t, daily bag limit 1 snapper, size limit >50 cm, spawning closure May-July. • Denham Sound, TAC 15 t, bag limit 1 snapper, size limit >50 cm • Freycinet, TAC 5 t, size limit >50 cm, 6 week spawning season closure, possession limit 5 kg per day • Recreational boat ramp survey (RFIF) commenced

ANNEX 2 - WEST COAST DEMERSAL SCALEFISH RESOURCE REBUILDING AND MANAGEMENT TIMELINE

Year	Management or Research Actions
Late 1990s – early 2000s	<ul style="list-style-type: none"> Recreational and commercial fishers plus Department become concerned with catch of key demersal species. Department announces a new management approach is needed to avoid overfishing and conflict between user groups.
2000	<ul style="list-style-type: none"> The initial Cockburn Sound snapper closure is introduced to protect aggregations of spawning fish.
2001	<ul style="list-style-type: none"> Management for charter operators is introduced.
2002	<ul style="list-style-type: none"> Department releases Policy for implementation of ESD (Fletcher, 2002) A peer-reviewed paper indicates fishing mortality of WA dhufish during the mid-1990s may be too high (Hesp et al., 2002).
2003	<ul style="list-style-type: none"> The Minister for Fisheries commissions a 'wetline' review to bring the State's commercial 'open access' fisheries under more effective management (Department of Fisheries, 2005). A project to establish the first formal stock status assessment of indicator species is initiated (Wise et al., 2007).
2004	<ul style="list-style-type: none"> A workshop is held with key commercial and recreational stakeholders on WA dhufish and reaffirms concerns about the species' sustainability.
2006	<ul style="list-style-type: none"> New management arrangements for the West Coast Bioregion 'open access' (wetline) commercial fishery are proposed Independent panel recommends criteria for allocating access to a commercial demersal scalefish fishery in WCB (DoF, 2006).
2007	<ul style="list-style-type: none"> Minister announced his final Wetline Review decisions for the future management arrangements for the WCDSIMF (DoF, 2007) Results of the stock status assessment of the three indicator species (WA dhufish, snapper and baldchin groper) indicate the need for a reduction in catches of at least 50 per cent of those of 2005/06 across all sectors (Wise et al., 2007). Options to achieve reduction for the recreational sector are presented to the community for consideration (DoF, 2007). Minister introduced the Metropolitan Area commercial fishing closure for demersal scalefish in the Metropolitan area in November 2007 allowing recreational fishing to continue
2008	<ul style="list-style-type: none"> The WCDSIMF commences effectively closing the 'open access' wetline fishery and reducing access on the west coast from a potential 1,250 boats to 61. Second independent review of stock assessment completed. The Minister announces proposed changes aimed at reducing the recreational catch
2009	<ul style="list-style-type: none"> The capacity settings for the WCDSIMF were determined to deliver a reduction of at least 50% in catch based on 2005/06 The Minister announces final package to reduce the recreational catch of west coast demersal scalefish by 50 per cent.
2010	<ul style="list-style-type: none"> Commercial catch reduced to less than 50% of the 2005/06 level. Survey show retained recreational catch of demersal species in the Bioregion reduced to less than 50 per cent of 2005/06 levels. Allocation Committee report released on how to best share the demersal resource among sectors.
2011	<ul style="list-style-type: none"> New state-wide recreational boat fishing survey is launched – the most comprehensive of its kind ever.
2013	<ul style="list-style-type: none"> Minister for Fisheries determined the allocation for the resource to be 64% for commercial and 36% for the recreational sector.
2014	<ul style="list-style-type: none"> An updated stock assessment was conducted on indicator species in the WCB (Fairclough et al., 2014). Estimates of F decreased from the previous assessment, suggesting suite was beginning to recover.
2017	<ul style="list-style-type: none"> A subsequent stock assessment has commenced

Summary of recreational management measures in the West Coast Demersal Scalefishery

Two-month recreational fishing closure (October 15 – December 15);
Mixed daily bag limit of two demersal fish per person;
Daily bag limit of one dhufish;
Daily boat limit of two dhufish (six on charters);
Increase in the pink snapper size limit to 50 centimetres (south of Lancelin);
Compulsory use of a release weight;
Introduction of a Recreational Fishing from Boat Licence; and
Additional \$2 million annually to fund 13 Fisheries and Marine Officers for recreational compliance and education.

ANNEX 3 – SUMMARY OF HARVEST CONTROL RULES FOR THE WEST COAST DEMERSAL SCALEFISH RESOURCE

Adapted from Fletcher et al., 2016

Fishery	Harvesting Strategy	EBFM Component	Management Objectives	Assessment method	Reference Levels	Control Rules	Annual Tolerance Levels (Acceptable Catch/Effort levels)
West Coast Demersal Scalefish Fishery	Proportional exploitation, based on ITEs for commercial sector; closed seasons, bag/boat/size limits and a licence for recreational sector.	Target Species: WA dhufish, snapper and baldchin groper as indicators of the demersal suite	Stock: Maintain spawning stock of the demersal resource at levels where the main factor affecting recruitment is the environment	Level 3: Fishing mortality of indicator species	Target: $F = 2/3M$ Threshold: $F = M$ Limit: $F = 3/2M$	<p>If $F < \text{Target}$, fishing effort/catch may increase</p> <p>If $F > \text{Target}$ but $< \text{Threshold}$, fishing effort/catch can remain at current levels (not increase)</p> <p>If $F > \text{Threshold}$, fishing effort/catches are to be reduced by 0-50% based on vulnerability status of species</p> <p>If $F > \text{Limit}$, fishing effort and/or catches are to be reduced by 50-100% based on vulnerability status</p> <p>Recovery - Trajectory of sequential declining fishing mortality rates (F) over time, from those in the 2007 assessment, required to identify stock is recovering</p>	<p>Under current Recovery Plan, the acceptable catch levels are that the total catch levels and those of indicator species must be: $< 50\%$ of 2005/06 level</p> <p>Total Catch All Sectors: < 700 t</p> <ul style="list-style-type: none"> -WA Dhufish < 200t -Snapper < 160 t -Baldchin groper < 50 t <p>Proposed for acceptable catch range to use 3-year averages with tolerances of 10-20% for each of these categories. If catches are all within these acceptable ranges, no change will be required.</p>
			<p>Social: Ensure sectoral catch levels reflect outcomes of IFM based allocation decisions</p>	Biennial surveys of recreational catch from boats and annual reporting of catch by charter fishers and commercial sector	<p>Target: Sectoral catch levels to remain within tolerance levels of their respective allocated catch benchmarks</p> <p>Threshold: Sectoral catch levels no longer considered within the tolerance levels consistent with allocated catch benchmarks.</p>	<p>Maintain sectoral management arrangements</p> <p>If acceptable range exceeded by commercial sector, then reduce ITEs in relevant management area</p> <p>If acceptable range exceed by recreational sector review arrangements</p>	<p>Total Commercial sector: < 450 t</p> <ul style="list-style-type: none"> -WCDSIMF: < 410t -Total other: < 40t -WA Dhufish < 72t -Snapper < 120 t -Baldchin groper < 17t <p>Total Recreational Sector: < 250 t</p> <ul style="list-style-type: none"> -WA Dhufish < 126 t -Snapper < 37 t -Baldchin groper < 33 t <p>Tolerance levels are likely to be similar to those outlined above</p>

Rebuilding South African fisheries: Three case-studies

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Abstract

South African fisheries, though historically well-managed, have some challenges that make rebuilding of depleted stocks difficult in some cases and more straightforward in others. The study uses three fisheries sectors (the hake deep-sea trawl fishery, the sardine purse-seine fishery and the West Coast rock lobster fishery) as examples to illustrate some of the influences shaping rebuilding efforts and how the biology, management regime and social and economic circumstances in each fishery have interacted, resulting in success or current failures.

1. INTRODUCTION: SOUTH AFRICAN FISHERIES AND THE THREE CASE STUDIES

South African commercial fisheries have a long history of some 120 years and are generally recognised as having had relatively good management systems for many years. They are underpinned by solid legislation, e.g. the Marine Living Resources Act of 1998. (RSA, 1998) with the main pillars of sustainable management, stability and equity among racial groups as important objectives. Institutionally, there have been good developments at government, industry and NGO levels that have interacted to keep these three pillars operating in a relatively balanced and economically beneficial way, although accommodating small-scale fisheries in a meaningful way has been something of a headache for the last decade or so (DAFF, 2014).

Government recognises 22 fisheries sectors (excluding aquaculture), all of which have been subjected to policy reviews from time to time, usually when fishing user rights are to be allocated. The three resources being considered here as case studies are the largest and/or most valuable, with the hake sectors contributing 43 percent of the total (USD 335 million), small pelagic species, 26,4 percent (USD 203 million) and West Coast rock lobster: 8% (USD 61 million) (2014 figures, provided by DAFF).

Policies for each sector are largely based on the Act, particularly in terms of maximum sustainable exploitation of living marine resources. Sector-specific policies are usually set for each iteration of the Fishing Rights Allocation Process and are largely aimed at addressing issues such as transformation (i.e. equitable distribution of rights in terms of race), promoting the efficient use of Rights, avoiding so-called “paper quotas”, and to apply politically motivated social engineering.

Management of the sectors largely revolves around annual TAC regulation (in some other cases besides our three examples, Total Allowable Effort [TAE] regulation), proportions of which are allocated to right-holders according to their long-term rights. Other aspects that are regulated comprise spatial restrictions, gear and vessel restrictions, by-catch limits and effort restrictions (the number of sea-days are limited to be commensurate with allocations).

In terms of compliance, landings are monitored, and vessel monitoring systems (VMS) are compulsory for all vessels larger than 15 m. Legal instruments operate within the context of long term rights (apart from the loss of the right itself, non-compliance raises the risk of losing appreciable capital investments).

All the resources considered here are currently managed in a similar way in terms of institutional structures and procedures, though research, stock assessment approaches and management on the ground are quite different. TACs for all three are set annually after abundance and other research information are considered through a variety of research efforts, and some socio-economic issues are considered at higher levels. In all three cases, Operational Management Procedures (OMPs) have been adopted as the basis for annual TAC adjustment recommendations. The OMPs include stock assessment monitoring and stock projection approaches at various levels of risk, combined with sets of harvest control rules (for a description of OMPs see Kell et al., 2006). The OMPs are revised on a regular basis, usually every four years. In theory, when OMPs have been in place for some years, and the rules have been complied with, stable management and therefore stable fisheries should ensue.

Following this brief background on the South African fishery sector, we consider three rebuilding initiatives, namely the rebuilding of the deep-water hake, sardine and West Coast rock lobster resources. The three resources are at different levels of depletion and have experienced different historical, environmental and socio-political circumstances and management approaches that have promoted or compromised success. We attempt to explain the trends and ultimate fates in each case on historical issues, current management, and varying degrees of success in the application of the OMPs in each fishery. Their inherent biological characteristics have been important in this, as have their management and social, economic and cultural milieus.

For each case study, we describe: (1) the biological background of the resources, the historical development of the fishery and the overfishing process; (2) the evolution of policy and management issues that arose; (3) The outcome of rebuilding efforts, management performance and current status.

In the final section, conclusions and lessons learned as well as outlook emerging from the three case studies are collated and compared. The role of the environment and of social and economic factors on stock rebuilding efforts are also comparatively considered.

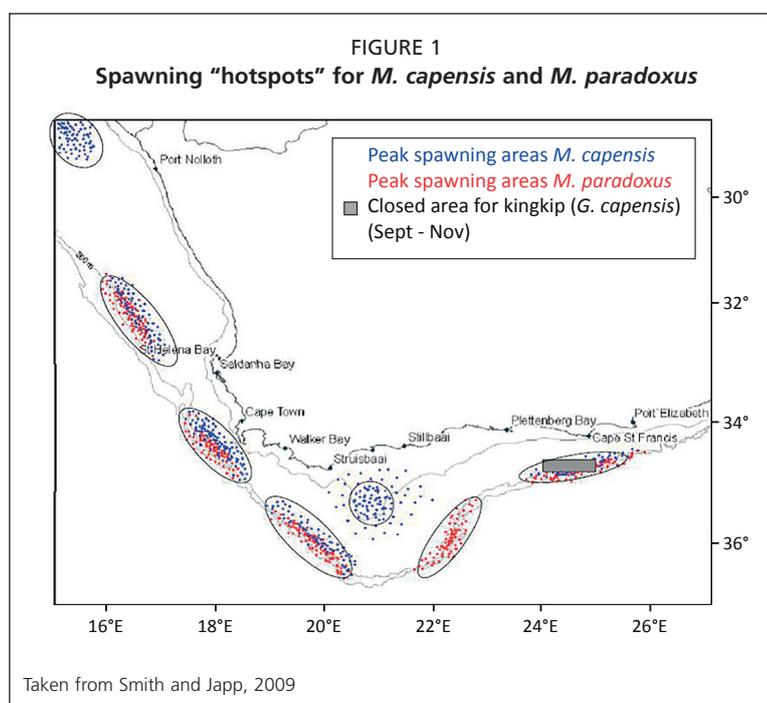
2. HAKE RESOURCES AND FISHERIES

Two species of hake occur in Southern African waters. The shallow-water hake *Merluccius capensis* is distributed from southern Angola to northern KwaZulu-Natal, whereas the distribution of the congeneric deep-water hake *Merluccius paradoxus* extends around the Southern African coast from northern Namibia into the southern parts of Mozambique. The two species are morphologically similar and are not distinguished in commercial catches.

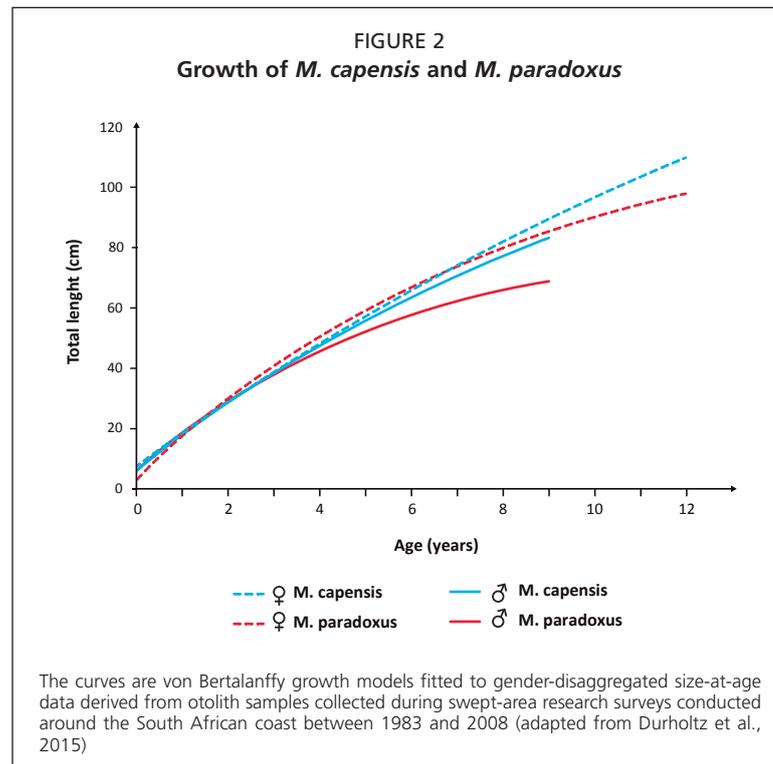
As their names suggest, the two species are located in different depth ranges. In South Africa, *Merluccius capensis* has been recorded between depths of 30 and about 500 m, with most of the population occurring at depths between 100 and 300 m. *Merluccius paradoxus* have been recorded at depths between 110 and 1 000 m, with most of the population distributed between 200 and 800 m. Individuals of both species move further offshore and deeper as they age and grow. Both species display diel vertical migration behaviour, moving upwards into the water column to feed at night, and returning to the seabed at dawn.

Early studies of temporal patterns in hake gonad maturation (Botha, 1985, 1986) suggested that both species spawned from austral spring (September) to early autumn (March/April), with peak spawning in November/December and a second peak in deep-water hake spawning peak in February/March. A more recent study of patterns in hake ichthyoplankton abundance (Grote et al., 2007) suggested an earlier peak in hake spawning (June to October). These differences could reflect a shift in the timing of hake spawning or be a result of methodological differences. Considering that both species are serial spawners, the results of Grote et al. (2007) could reflect periods of enhanced larval survival rather than peak spawning.

Smith and Japp (2009) collated available information mainly on collection of hake roe by the commercial fleet to infer the location of spawning of the two species, and suggested a number of “hotspots” (Figure 1), generally located near or over the shelf edge for both species (*M. capensis* tending to spawn shallower than *M. paradoxus*), although aggregations of ripe *M. capensis* were also encountered in shallow areas on the Agulhas Bank and off the Orange River mouth. The paucity of “ripe-and-running” hake in catches made using demersal trawl gear suggest that hake spawn in the water column rather than close to the sea bed.



Age-at-length estimates derived from analyses of sagittal otoliths indicate that both species of hake typically grow at about $12\text{cm}\cdot\text{yr}^{-1}$ for the first few years of life, with growth rates decreasing with increasing age. *M. capensis* grows slightly faster than *M. paradoxus*, and females grow more rapidly than males in both species (Figure 2).



Both hake species are opportunistic feeders and display an ontogenetic shift in diet. Young fish feed predominantly on crustaceans (mostly euphausiids), but as they grow, their diet shifts increasingly to teleost fish and cephalopods. The diet of *M. capensis* is typically more diverse than that of *M. paradoxus*. As a result of the spatial distribution patterns of the two species, appreciable interspecific predation is a feature of hake diet, primarily predation by large *M. capensis* on small *M. paradoxus*. Some cannibalism of small hake of both species has also been reported (Punt et al., 1992).

While both species of hake have displayed local movements in response to environmental changes, no direct evidence of longshore migrations has been documented. Some evidence of longshore movement of *M. paradoxus* from South African into Namibian waters is apparent in spatio-temporal size distribution patterns. Similarly, the abundance of juvenile *M. capensis* on the West Coast, coupled with a paucity of juveniles on the South Coast suggests that spawning products are transported to nursery areas on the West Coast, and some older fish then migrate back to the South Coast to spawn.

Recent genetic studies (Henriques et al., 2016) indicate a single, panmictic stock of *M. paradoxus* distributed from Namibia throughout South Africa. This conclusion is to some extent supported by the low occurrence of spawning *M. paradoxus* in Namibia, most of which is restricted to the areas south of Lüderitz (Jansen et al., 2015). The genetics analyses indicated at least two largely separate stocks of *M. capensis*, one in Namibia and one in South Africa.

Historical development of fisheries and overfishing

The information presented below is a synthesis of that provided by Durholtz et al. (2015), with some information updated to reflect recent changes.

The fisheries

There are four fishery sectors that target the two species of hake, which are also caught as by-catch in the horse mackerel-directed midwater trawl fishery:

1. Deep-sea trawl sector. The largest sector (and the most valuable South African fishery sector) is the hake deep-sea trawl sector, currently comprising about 50 vessels that land about 84% of the total annual hake catch, about 80 percent of which is *M. paradoxus*.
2. Inshore trawl sector. The appreciably smaller hake inshore trawl sector (currently comprising about 15 active vessels) operates only on the South Coast of South Africa, targeting hake (almost exclusively *M. capensis*) as well as Agulhas sole (*Austroglossus pectoralis*). Hake catches by the sector in recent years make up about 6 percent of the annual total.
3. The longline fishery, established in 1994, comprises about 50 active vessels that collectively land about 6.5 percent of the annual hake catch. Longline catches in recent years comprise about 80% *M. paradoxus*.
4. The handline fishery was established as formal sector in 2000 and operates exclusively in shallow water on the South African South Coast, catching primarily *M. capensis*. About 3% of the TAC is allocated to it and catches of hake by the fishery peaked at just over 7 300 tons in the early 2000s but have subsequently declined to less than 1 percent of the total annual hake catch in recent years, largely due to economic factors. The effort in this sector is controlled through the number of fishing vessels as well as the number of crew per vessel.

The regulations

The primary regulatory mechanism is a species-combined annual Total Allowable Catch (TAC) that is set for all sectors catching hake (and includes a hake by-catch reserve for the horse-mackerel midwater trawl sector). Once the by-catch reserve has been deducted from the TAC, the balance of the TAC is allocated among Right Holders according to their proportional Rights set during the most recent Fishing Rights Allocation Process (FRAP).

The deep-sea trawl fishery operates within the Trawl Ring Fence¹ on both West and South Coasts while the inshore trawl fishery is restricted to the areas of the Trawl Ring Fence east of the 20°E longitude. Both sectors use otter trawls of varying specifications: (i) restrictions on mesh size; (ii) specification of the size of bobbins, weights and “rick-hoppers” gear in permit conditions, and (iii) requirement to deploy bird-scaring lines (tori lines) during all fishing operations.

The hake longline fishery operates on both the West and South Coasts, deploying demersal longline gear.

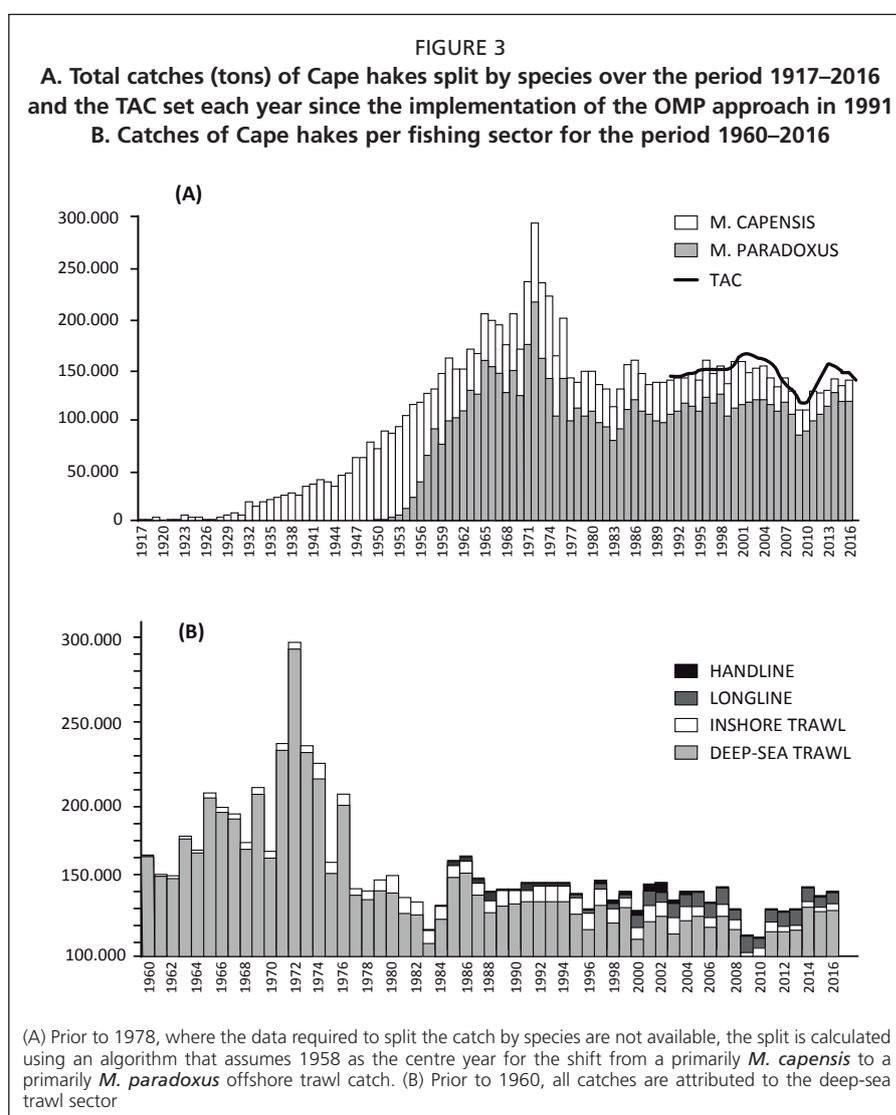
The hake handline fishery is restricted to the South Coast east of the 20°E line of longitude and uses either small deck boats capable of remaining at sea for two to three days, or shore-launched ski boats. Fishing gear is typically either hand-lines or rods and Scarborough reels.

¹ The Trawl Ring Fence is the spatial boundary of the SA hake trawl footprint that was voluntarily “frozen” by the trawl fishery in 2007 to facilitate certification of the fishery by the Marine Stewardship Council, and subsequently formally incorporated into permit conditions in 2015. Demersal trawling outside of the Trawl Ring Fence is prohibited.

Fishery development

The first hake-directed fishery in South Africa was the trawl fishery, which originated with the arrival of the purpose-built research vessel *Pieter Faure* in 1897 that then pioneered the development of inshore trawl grounds around the South African coast.

The first commercial trawler (*Undine*) arrived in South Africa in 1899 and began fishing the inshore areas on the Agulhas bank, targeting Agulhas sole (with hake being caught as by-catch). The trawl fishery gradually began to expand, and by 1920 approximately 12 vessels were active, largely on the South Coast and targeting primarily sole and various linefish species. In 1921, the government marine biologist, John Gilchrist, discovered “good quantities” of hake and kingklip in a deep-sea area near Cape Town (Sink et al., 2012). Commercial vessels were quick to exploit this first offshore trawl ground, and good catches of hake were made in depths of 200 – 350m, averaging about 1 000 tonnes per annum until the early 1930s (Figure 3).



A period of rapid expansion of the trawl fishery then ensued, and in 1935, numerous developments laid the ground for separation of the fleet into distinct inshore and offshore components. Larger, more modern vessels capable of operating further offshore in deeper water were acquired; new fishing grounds were discovered on the South Coast off Port Elizabeth (the so-called “chalk line” grounds), and on-board

freezing facilities began to appear in some vessels. A total of 26 vessels were operating by the start of World War II, and the hake catch in South African waters reached 20 000 tonnes in 1937. The fishery began to escalate rapidly after the Second World War, and by 1948, about 40 trawlers were active in South Africa and hake catches had increased to over 100 000 tonnes by 1954. Knowledge of the abundant hake stocks in South African waters spread, leading to the incursion of foreign vessels (mostly large factory trawlers) into the South East Atlantic in 1962. Over the next decade, fishing effort (and catches of hake) by both the foreign and local fleets increased dramatically and spread from South Africa into Namibian waters. In 1972, catches of hake in South African waters reached almost 300 000 tonnes (**Figure 3**), while more than 1.1 million tonnes of hake were taken from the Southeast Atlantic in that year. These levels of exploitation were clearly not sustainable, and catch rates, which had already been declining throughout the region, dropped to almost economically non-viable levels following the peak catches of the early 1970s.

The impacts of the escalating effort and catches in the SE Atlantic had already been recognized internationally during the late 1960s, primarily by the FAO. This recognition ultimately led to the establishment of the International Commission for the South East Atlantic Fisheries (ICSEAF) in late 1971. ICSEAF subsequently implemented a suite of management measures aimed at rebuilding and preserving the depleted hake stocks, including a minimum mesh size, international inspections and allocations to member countries. Despite these measures, catch rates continued to decline, largely due to lack of compliance with these management measures by the foreign fleets.

The declaration of an Exclusive Fishing Zone (EFZ) in November 1977 resulted in the exclusion from South African waters of almost all foreign vessels and the onset of direct management by the South African government. Catches of hake in South African waters have subsequently stabilized at around 140 000 tonnes per annum.

The third fishery targeting hake has its beginnings in the 1980s, when hake was caught as a by-catch in a kingklip-directed longline fishery, which was closed in 1990 when the kingklip stock collapsed under excessive effort (Japp, 2005). An experimental hake-directed longline fishery was established in 1994 with considerably tighter controls. Formal rights to a permanent longline fishery were first granted in 1997, but it was only the allocation of medium- and long-term rights (in 2002 and 2006 respectively) that introduced stability into this fishery. The number of vessels active in the fishery has decreased from about 65 in 2003 to about 45 in 2016. As with the trawl fishery, exploitation of hake by the longline sector is regulated with a TAC allocated among individuals/companies.

A further small handline fishery targeting hake started in the 1980s. Although line fishers (both “traditional” and commercial) had historically caught hake in small quantities, it was the development of a market for “PQ” hake (whole, fresh fish on ice), predominantly in Spain, that drove an expansion of the fishery through to the mid-2000s. The State officially established the hake handline sector in 2000 and allocated individual fishing rights in 2005. Initially, the sector comprised 130 vessels (small, outboard engine craft of five to six meters length, usually transported to launching sites on a trailer) with about 780 associated fishers. The 2005 allocations resulted in 96 formal rights, encompassing 742 fishers. The 2008 global financial crisis had a profound impact on the sector, effectively destroying the European market (mainly Spain) when hake became unaffordable there and demand fell away. Effort and catches by the sector subsequently declined to negligible levels.

An important development in the hake fishery has been the certification of the two trawl sectors by the Marine Stewardship Council since 2004. This has yielded appreciable economic benefits to the sectors involved (hake deep-sea trawl and hake inshore trawl), as well as driving research and management aimed at minimizing the ecosystem impacts of the fishery (Lallemand et al., 2016). A key management measure arising from the MSC certification of the hake trawl fishery has been the implementation of the “Trawl Ring Fence”, effectively restricting fishing operations to a clearly defined spatial trawl footprint and preventing expansion of the fishing grounds to previously un-trawled areas. This measure was initially a voluntary measure self-imposed by the fishery in 2007 but was formalized into permit conditions in 2015.

2.1 Fishery policy and management history

Prior to 1972, no fishery policy and no effective management existed. The fishery was effectively an open access and unregulated one, dominated by foreign vessels after 1962.

During the ICSEAF period after 1972, there were some broad, vague rebuilding policies with several largely ineffective management measures introduced over the period 1975-1977. Some data collection started too, but the validity of foreign vessel data has not been determined. TACs for the adjacent Namibian (then called South-West Africa) zone were set by ICSEAF.

Following the declaration of an Exclusive Fishing Zone (EFZ) as from 1 November 1977 and the exclusion of almost all foreign vessels from South African waters, direct management of the hake resources by the South African government was first implemented as a “global” (unallocated) TAC (i.e. “Olympic” system), and subsequently as company-specific allocations or quotas. Such TACs were determined and recommended by local scientists and generally accepted without change by administrative and political decision-makers, after due consideration by the Minister’s formally constituted Sea Fisheries Advisory Committee (SFAC). The International Commission for the Southeast Atlantic Fisheries (ICSEAF) was informed annually of the recommendation and the basis on which it was made, but did not question the value, merely noting it and sometimes commenting on the appropriateness of the model underpinning its calculation. Fishery policy at the time clearly aimed at rebuilding the hake stocks, maintaining catches at levels below annual sustainable yields initially using an $f_{0.1}$ -type strategy¹² to limit fishing mortality rates, and subsequently, to further enhance recovery, using a more conservative $f_{0.25}$ -type strategy. TACs were initially set using steady-state surplus production models and later dynamic production models.

Evolution towards the current management regime

Individual rights in the hake trawl fisheries were first allocated in 1979. Additional entrants to the fisheries were introduced in 1992 to broaden access. These changes ultimately led to the implementation of long-term rights in 2006 (of 10 to 15 years depending on the sector).

In the context of the hake-directed fisheries, management policy is implemented as management measures aimed at maintaining the hake resources at the biomass yielding Maximum Sustainable Yield (MSY).

¹² i.e. the fishing mortality rate at which the slope of the relation between yield per recruit and effort is 10% of the slope at the origin.

Following the dissolution of ICSEAF in 1990 (after the Namibian independence), management of South African hake has been in terms of an Operational Management Procedure (OMP). An OMP is essentially a combination of pre-specified methods of data collection and analysis, coupled with a set of simulation-tested decision rules that specify exactly how the regulatory mechanism is to be computed each year. The development of the hake OMP uses a suite of assessment models as a basis for projecting stock dynamics (and other quantities of interest) under various management scenarios (i.e. a Management Strategy Evaluation approach). The hake OMP is reviewed every 4 years to account for updated data sets and possible changes in resource and/or fishery dynamics and management objectives. The next review of the hake OMP is scheduled for 2018.

The hake resource is not managed as separate stocks. Recent assessments have disaggregated the species (see below) but management (TAC) still treats the hake resource as a single stock due to operational difficulties in selectively fishing for one or the other species.

Initially, SA assessments of the hake resource treated the two species of hake as single stock due to the lack of species-disaggregated commercial catch and effort data. The assessments were age- and species-aggregated dynamic Schaefer production models conducted separately for the West and South Coasts. In the early 2000s, however, assessments indicated that stock trends had fallen below the range projected during trials of the OMP in place at the time, indicating that the OMP would yield an unreliable TAC recommendation. This was due to the changed relative contribution by the two species to the annual catch following the introduction of longlining, and to the different selectivity of the longline gear versus trawl. It was apparent that a species disaggregated assessment needed to be conducted to properly understand the changes in resources dynamics. An interim approach was adopted that implemented a phased decrease in the TAC over the next few years while the assessment was being developed. Once completed, the 2006 assessment indicated that the biomass decline was due to several years of poor recruitment for both species. It was also apparent that while *M. capensis* was in a relatively good condition, *M. paradoxus* had declined to well below B_{MSY} (presumably due to the markedly higher exploitation of the latter species during the overfishing of the 1960s and 1970s).

The OMP developed in these circumstances (OMP-2007) aimed to return *M. paradoxus* to B_{MSY} after 20 years, which required an appreciable reduction in catches. Implementation of the OMP-2007 resulted in TAC reductions from 150 000 tonnes in 2007 to just under 120 000 tonnes in 2010. For the development of OMP-2010, the assessments were refined to account for gender-specific differences in growth rates. Assessments conducted during the life-span of OMP-2010 indicated that the recovery plan implicit in the previous OMP had been successful, with *M. paradoxus* reaching 98 percent of B_{MSY} by 2012.

Assessments conducted during the development of OMP-2014 indicated that *M. paradoxus* had in fact reached B_{MSY} in 2012 and could therefore be considered as rebuilt and fluctuating around this target reference point. Examination of indices of recruitment indicated, however, that the resource had undergone another period of below-average recruitment during the preceding few years (2009 – 2013), and that a short-term reduction in spawning biomass was likely.

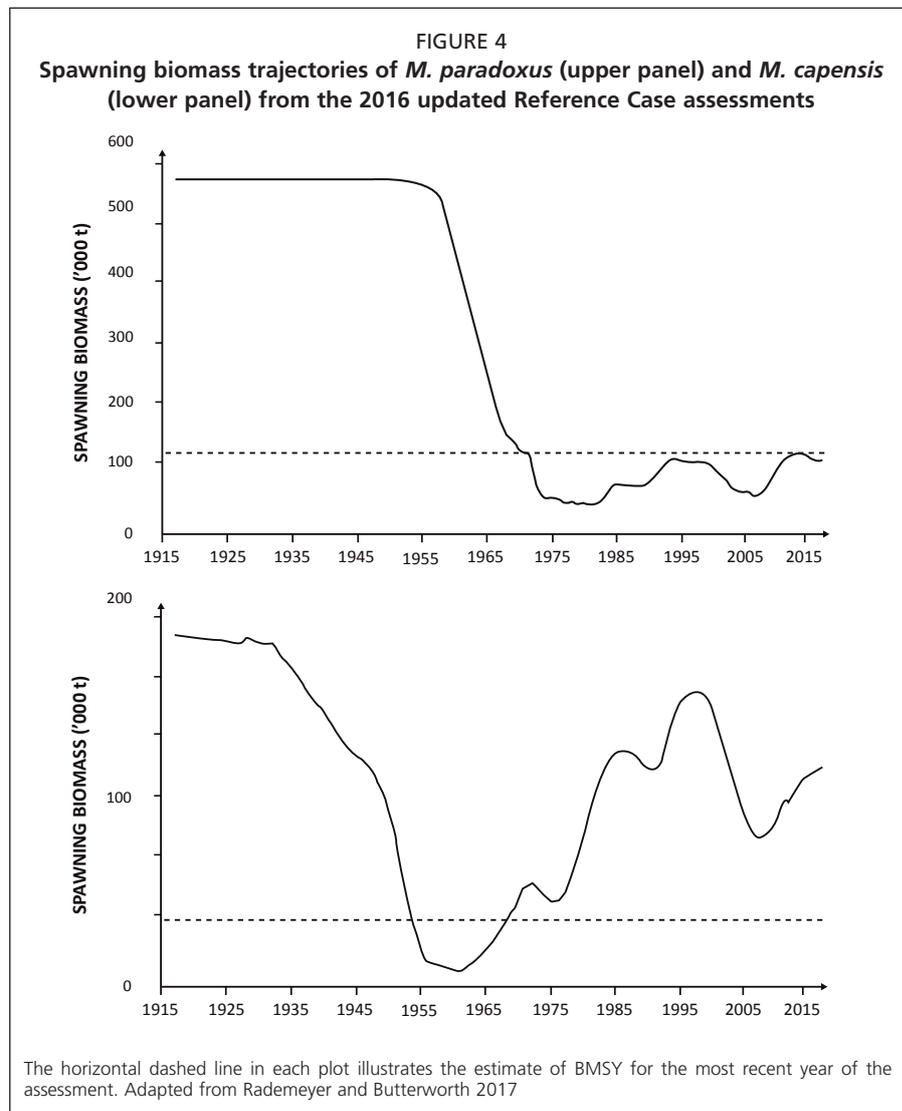
Evaluation of various management strategy options had to consider trade-offs between returning *M. paradoxus* to B_{MSY} as soon as possible and alleviating the socio-economic

impacts of likely TAC reductions on an industry that had “geared-up” to catch recent TACs over 150 000 tonnes per annum. OMP-2014 consequently fixed the TAC at 147 500 t per annum for 2015 and 2016, but at the cost of larger TAC reductions in 2017 and 2018 than would otherwise have been the case to facilitate returning *M. paradoxus* to B_{MSY} by 2023. It also introduced a rule that prevents the TAC from exceeding 150 000 tonnes. The TAC for 2017 was set at 140 125 tonnes.

2.2 Outcomes, issues and performance

Current status and rebuilding efforts

Currently, *M. capensis* is well above B_{MSY} while *M. paradoxus*, although slightly below B_{MSY} , is considered to be in a state of fluctuation about B_{MSY} (Figure 4). The most recent (2017) assessment of the hake resource indicates that implementation of OMP-2014 has yielded positive results with the decline in *M. paradoxus* spawning biomass (predicted during the development of the OMP as mentioned above) appearing to have reversed (Figure 4).



One could tentatively conclude therefore that the performance of the fishery in recent years has been good and can probably be attributed to the rational management system and approach using an OMP as described above.

The last assessment by DAFF of the wholesale value of trawled hake production estimated this to be about ZAR 3 909 billion, or about USD 301 million, of which inshore trawl contributed only USD 7.2 million. Longline-caught hake, on the other hand, contributed another USD 30.5 million. The total value of the hake fishery sectors is therefore around USD 335 million. This does not include value addition and the additional revenue generated in export markets resulting from MSC certification.

Sustainability issues

Climate change/variability is presumed to have an appreciable impact on hake recruitment and hence abundance. Two periods of below-average recruitment (late 1990s and again in 2009 – 2013) is assumed to have resulted from some yet unknown environmental factors, requiring substantial decreases in the TAC to promote recovery.

By-catch (incidental catches of non-target species during sustainable fishing for hake could be unsustainable) are being addressed through several by-catch mitigation and regulation measures that are in the process of being developed.

Current perceptions that *M. paradoxus* is a transboundary resource (i.e. a single stock) shared between Namibia and South Africa has been the basis for several calls for joint management of this resource. It has been argued, however, that immediate joint management is premature in the absence of reliable transboundary assessments and proper evaluation of the benefits of joint management.

3. THE SARDINE RESOURCE IN THE PURSE-SEINE FISHERY

3.1 The resources and the fishery

Biological features

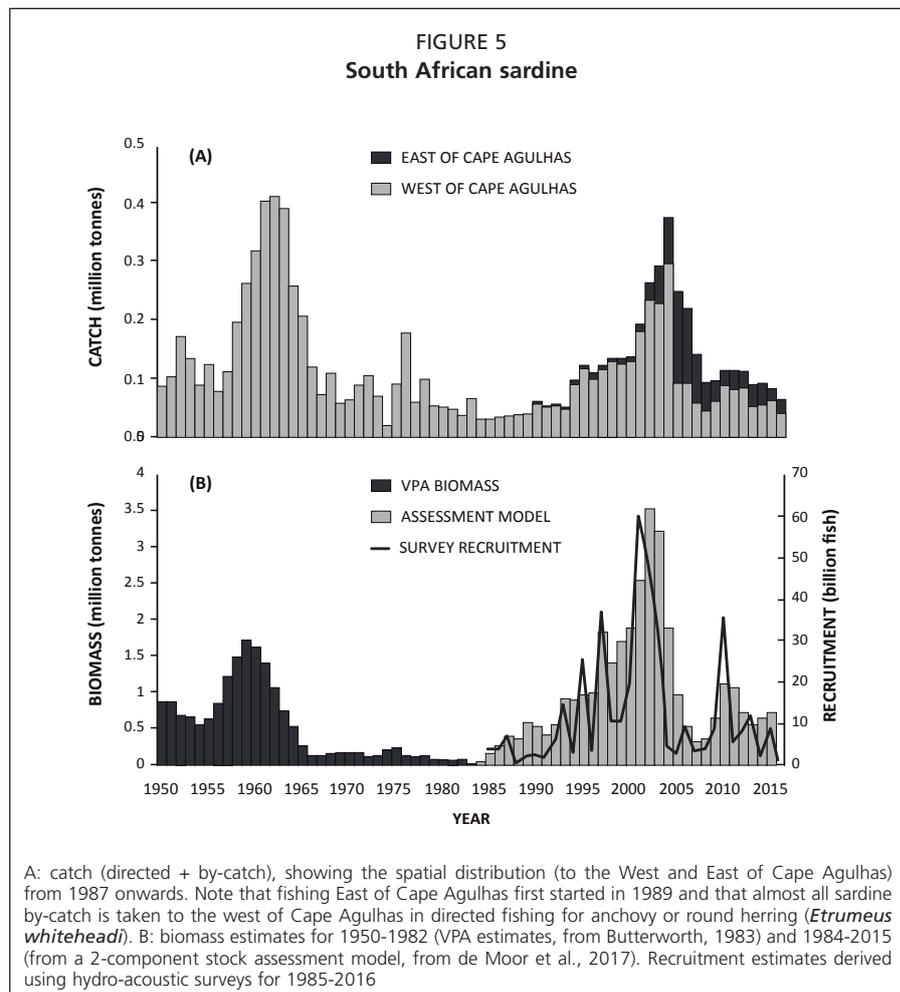
Sardine *Sardinops sagax* is an epi-pelagic fish that occurs in schools in continental shelf waters between Hondeklip Bay on the South African West Coast and Durban on the East Coast (Beckley and van der Lingen, 1999). This species feeds primarily on zooplankton, is highly fecund, and has a rapid growth rate, a small maximum body size, and a short life span. These characteristics make sardine highly responsive to environmental variability, and sardine populations world-wide show marked fluctuations in recruitment strength which results in large natural fluctuations in population abundance over space and time (Checkley et al., 2009).

Historical development of fisheries and overfishing

Sardine are the main target of South Africa's purse-seine fishery, the country's largest fishery in terms of landed mass and its second-most valuable (DAFF, 2014/6). Commercial purse-seine operations started in the early 1940s in St Helena Bay in response to increased demand for canned products during the Second World War. Vessels initially caught sardine and Cape horse mackerel (*Trachurus capensis*). Annual sardine catches increased rapidly from less than 200 000 t in the 1950s to more than 400 000 tonnes in the early 1960s, declining rapidly thereafter (Figure 5a). Catches of horse-mackerel were also much reduced in the 1960s, and the fishery responded by using smaller-meshed purse-

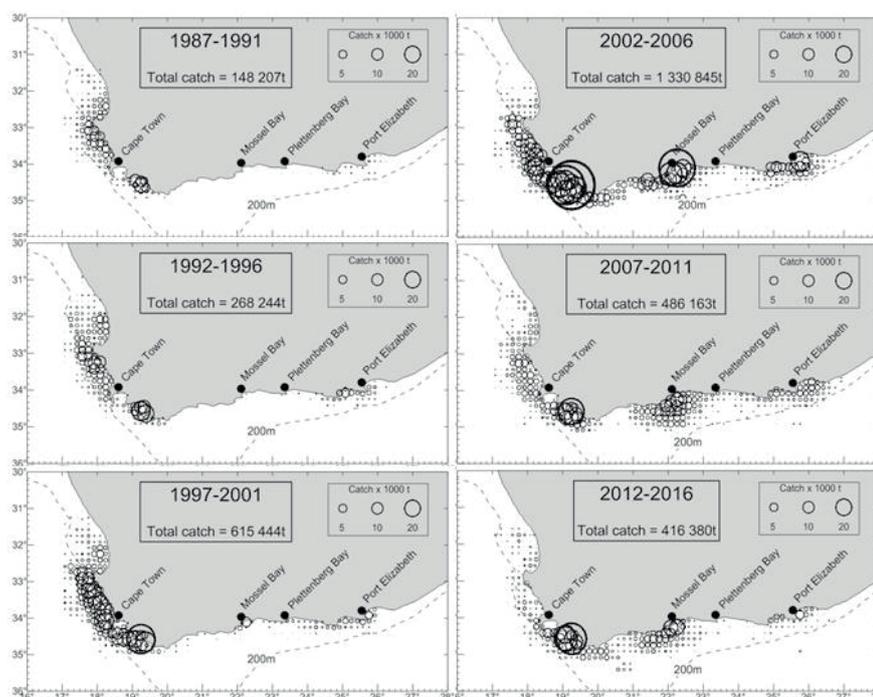
seine nets to target juvenile anchovy (*Engraulis encrasicolus*) off the West Coast in place of sardine and horse-mackerel. Anchovy dominated catches and largely sustained the South African purse-seine fishery for the following 30 years, with annual catches ranging from 41 000 to 600 000 tonnes. Sardine catches increased throughout the 1990s because of increased biomass following several years of good recruitment and under a conservative management strategy that aimed at rebuilding the sardine population (Cochrane et al., 1998). Annual sardine catches over 200 000 tonnes were taken during the early-2000s and peaked at 374 000 tonnes in 2004 (Figure 5a). However, catches again declined rapidly, the second such collapse in this 70-year old fishery, have been below 100 000 tonnes in several recent years, and continue to decline. Sustained low recruitment over the past decade has resulted in a presently low population (Figure 5b).

During the early-1950s fishing for sardine occurred within 25 nm of the coast inside St Helena Bay and catches comprised large (22-24cm standard length (SL)), old (4-6 years) fish (Hutchings et al., 2012). Unsophisticated vessels without echo-sounders and with hand-hauled nets were initially used, but the introduction of echo-sounders and power blocks increased efficiency (Crawford et al, 1987). The number of vessels permitted to fish for sardine was restricted but vessels increased in size which, together with increased efficacy, resulted in increasing fishing capacity and catches (Stander and le Roux, 1968). As catches increased, effort expanded to the south of St Helena Bay towards Cape Agulhas but catches of sardine continued to be restricted to the West Coast (*i.e.* to the west of Cape Agulhas) only following the first collapse.



Spatially-explicit catch data, with catches recorded per pelagic fishing block (PFB; a rectangle of 10 minutes longitude by 10 minutes latitude), have been collected from 1987 onwards. Until 1990 sardine catches to the west of Cape Point were much higher than those on the western Agulhas Bank (WAB; Roel *et al.*, 1994), but catches on the WAB, concentrated in inshore waters around Gans Bay, increased during the early 1990s and became comparable to those taken to the west of Cape Point (**Figure 6**). Fishing for sardine off the South Coast (*i.e.* east of Cape Agulhas) was initiated in the late-1980s, with catches taken off Port Elizabeth and Mossel Bay in increasing quantities during the late-1990s and early-2000s. The centre of gravity (CoG; essentially a spatial average catch location) of directed sardine catches shifted further east each year over the period 1997-2004 and moved to the east of Cape Agulhas for the first time in 2005 (Fairweather *et al.*, 2006). More than 154,000 t (almost two-thirds) of the total directed sardine catch in 2005 was taken to the east of Cape Agulhas, and over half in the subsequent two years (van der Lingen and van der Westhuizen, 2013a). Given the distance between catch location and the West Coast processing factories that could only be made by larger refrigerated seawater vessels, much of this catch was landed by smaller vessels fishing from Mossel Bay and trucked to the processing factories on the West Coast, which increased cost. Annual sardine catches east of Cape Agulhas have declined in both absolute and relative terms since 2008, with very low catches off Port Elizabeth over the past five years (**Figure 6**). That decline has been linked to the development of anomalous, and spatially and temporally extensive, harmful algal blooms (HABs) off the South Coast in recent years (van der Lingen *et al.*, 2016).

FIGURE 6
Cumulative directed-sardine catch per PFB for successive 5-year periods,
1987-2016



Symbol size is proportional to catch amount and the total directed-sardine catch for each period is shown

In addition to spatial changes in catch locations there have also been changes in the seasonal pattern of catches by the sardine fishery throughout its history. During the 1950s catches of sardine taken in St Helena Bay peaked between March and July (autumn/winter), and a closed season was imposed during spring or early summer (Davies, 1956). During the 1960s and 1970s sardine catches to the north of Cape Columbine were primarily taken from mid-autumn to late-winter, whereas those on the WAB were caught from summer to early autumn (Crawford, 1980). Analysis of catches taken between 2004 and 2013 (*i.e.* during the second period of peak catches and following the second collapse) show that catches taken to the west of Cape Agulhas (primarily on the WAB) were highest from mid-February to late-April (*i.e.* late-summer/autumn) and lowest from July to September (van der Lingen and van der Westhuizen, 2013b), as documented by Crawford (1980) for that region. However, a second peak in recent catches off the West Coast in November (spring) is evident. A reverse pattern is seen off the South Coast overall, where sardine catches peak from late-April to late-September (*i.e.* autumn and winter) and are negligible over summer (van der Lingen and van der Westhuizen, 2013b). When examined at a finer spatial resolution, however, it is apparent that this autumn/winter peak is due to the larger catches taken off Mossel Bay; fishing off Port Elizabeth starts early in the year and the bulk of catches is taken by April, with almost no sardine being caught there during winter (van der Lingen and van der Westhuizen, 2014).

3.2 Fishery policy and management history

Early management of the small pelagic fishery was via separate TACs for horse-mackerel and sardine that were instituted in 1953. By the early 1970s a global TAC for all species combined was introduced, which fluctuated between 360 000 and 450 000 tonnes annually for the next decade (Cochrane et al., 1998). Estimates of sardine population size for 1950-1982 derived via Virtual Population Analysis (VPA) were provided by Butterworth (1983). That VPA was based on catch data and samples from commercial catches, which would have come from the west coast only, hence did not include information on sardine off the south coast. In addition, because the VPA biomass estimates were derived from estimates of natural mortality that are now considered too low, and because age length keys derived during the early 1970s were used to age fish sampled at the beginning of the time series, the VPA probably underestimated sardine biomass (D. Butterworth, UCT, pers. comm.).

Species-specific TACs were introduced for sardine and anchovy in 1983 (Butterworth, 1983), and the allocation of individual quotas in the mid-1970s meant that quota-holders no longer competed for TAC and could take a longer-term interest in the resource (Cochrane et al., 1997). More formal mechanisms for making TAC recommendations for the small pelagic fishery were explored throughout the 1980s and early 1990s, with the overall rationale for the sardine fishery at that time being to follow a conservative approach to facilitate stock rebuilding (Cochrane et al., 1998). A maximum-likelihood virtual population analysis (VPA) developed for sardine in 1989 (Punt, 1989) was used to estimate a status quo fishing mortality ($F_{\text{status quo}}$) harvest strategy. This approach aimed to maintain fishing mortality at the same average level as during 1987-1989, a period when the sardine population appeared to undergo considerable growth (Cochrane et al., 1998), and was implemented from 1990-1993.

The fisheries for sardine and anchovy had historically been managed separately. Because sardine and anchovy school together as juveniles, and because around 70% of the anchovy catch is made of juveniles, fishing for anchovy results in a by-catch of

juvenile sardine. This means that catches of the two species cannot be simultaneously maximized because: (i) high anchovy catches will impair sardine recruitment and population growth; and (ii) high sardine catches could only be sustained by limiting the catch of juvenile sardine as bycatch and hence anchovy catches. Since 1991, the South African anchovy fishery has been regulated using an OMP, an adaptive management approach able to respond rapidly, without increasing risk, to major changes in resource abundance. The first joint anchovy-sardine OMP was implemented in 1994, with subsequent revisions. The joint OMP for anchovy and sardine provides a framework for quantifying the required trade-off between anchovy and sardine TACs, given the by-catch issue referred to above (de Oliviera and Butterworth, 2004). The OMP formulas are selected with the objectives of maximising average directed sardine and anchovy catches in the medium term, subject to constraints on the extent to which TACs can vary from year to year to enhance industrial stability. These formulas are also conditioned on low probabilities that the abundances of these resources drop below agreed threshold levels below which successful future recruitment might be compromised.

The rapid increase in sardine biomass, owing to several years of above average recruitment in the late 1990s and early 2000s, coincided with an expansion of the sardine biomass on to the south coast, thereby placing a large portion of the sardine biomass out of the reach of the mainly west coast-based purse seine fleet. This resulted in a mismatch between fish availability and fishing effort described above. Given that the sardine resource was, at that time, considered to comprise a single panmictic population and managed through a “global” TAC for the entire region (de Moor et al., 2011), exploitation levels on the West Coast, close to processing facilities, were much higher than those on the South Coast. In addition to increased pressure on the West Coast ecosystem and threats of higher exploitation levels on dependent predators (most notably central place foragers such as the endangered African penguin, *Spheniscus demersus*), concerns about the impact of disproportionately higher fishing pressure on future West Coast sardine recruitment gradually led to suggestions that the sardine resource may need to be spatially managed (Coetzee et al., 2008a).

Current assessment and management

Recent stock assessments have used both fishery-independent and fishery-dependent data, the former comprising annual estimates of total biomass and recruitment strength made during hydro-acoustic surveys conducted during spring and autumn, respectively, as well as data on the length structure of the sardine population collected during those surveys (de Moor et al., 2008). These surveys have been carried out since the mid-1980s (Barange et al., 1999, Coetzee *et al.*, 2008b). Fisheries dependent data include catches of both directed and by-catch sardine and measurements of the size frequency composition of catches.

Recent research has provided plausible evidence that the population comprises multiple components or stocks, with western, southern and eastern components hypothesized (van der Lingen et al., 2015). The western and southern stocks are targeted by the purse-seine fishery whereas the eastern stock is targeted by a seasonal beach-seine fishery, and annual catches of the latter have never exceeded 1 000 tonnes (van der Lingen et al., 2010). A two-component assessment model that assumed western and southern components which were separated at Cape Agulhas but mixed via an annually-varying proportion of recruits that moved permanently from the western to the southern stock was developed (de Moor and Butterworth, 2015), and found to

be consistent with fishery-dependent and independent data. It also indicated that the western stock was substantially more productive than the southern stock (de Moor and Butterworth, 2015; de Moor et al., 2017), and that immigration by western recruits to the southern stock was appreciable and made a greater contribution to southern stock biomass than local (*i.e.* southern origin) recruitment.

Despite these advances, the sardine fishery is currently still managed based on a single stock assessment model (OMP-14), with an interim agreement that encourages fishers to manage their fishing effort such that the catches on the West and South coasts are proportional to the biomasses observed in each area. The two-component assessment model has subsequently been refined, and now assumes movement of both recruits and older (2+) fish from the western to the southern stock and uses parasite bio-tag data to estimate annual movement (de Moor et al., 2017). In addition, a variable contribution of South Coast sardine spawning to West Coast recruitment is also considered in the simulation testing of alternative candidate management procedures. This will enable a comprehensive evaluation and quantification of the relative benefit of spatial management for the resource and the ecosystem, which is likely to lead to a more acceptable spatial management agreement that balances operational flexibility with average catches (Cox et al., 2017).

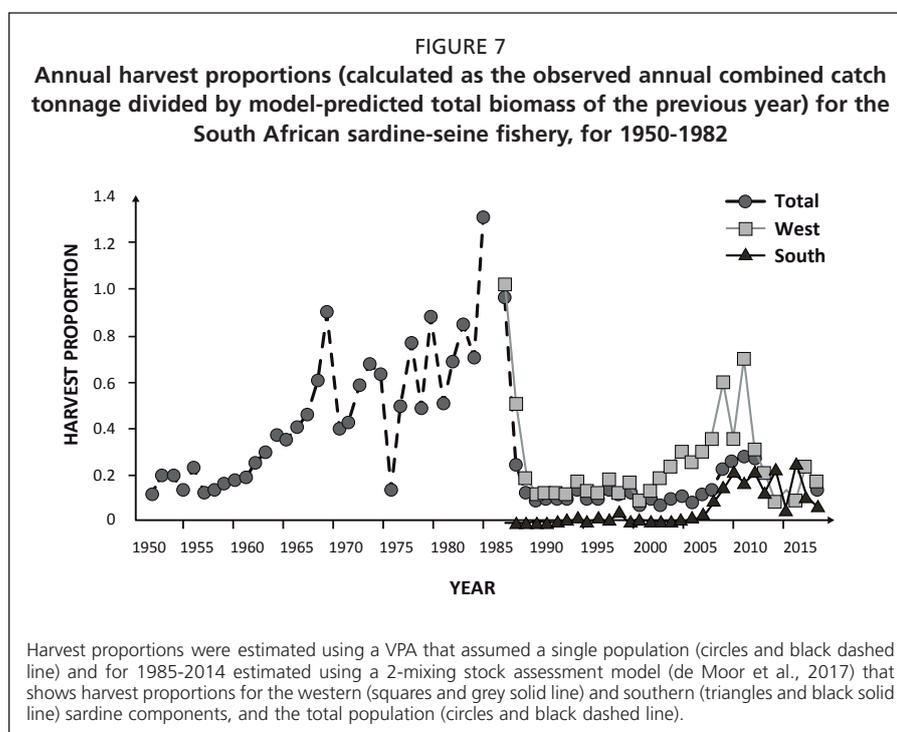
3.3 Outcomes, issues and performance

Outcomes: Collapses, rebuilding efforts, and current status

The first collapse of the South African sardine has been attributed to poorly controlled increase in effort and catches, expansion to fishing grounds in the south, and variable recruitment (Newman et al., 1979; Crawford, 1981; Armstrong and Thomas, 1989). High catches of sardine juveniles may have been another reason; Hutchings *et al.* (2012) report that the annual proportion of juvenile sardine in commercial catches over the period 1950-57 was below 10% but that this increased to 50% or more in six of the eight following years. The second collapse also followed an expansion of the fishing grounds, this time to the South Coast, but effort and catches were well controlled, and landings of juveniles taken as by-catch in the anchovy-directed fishery were also well monitored. The annual proportion of juvenile sardine taken in the sardine-directed fishery was below 5% during the first decade of the 21st century (de Moor, 2017). However, examination of a time-series of annual harvest proportion (a fishing mortality rate simply estimated as the ratio between catch in year (n) and model-estimated biomass in the year (n-1) of the sardine-directed fishery throughout the history of the South African sardine fishery indicates that both collapses followed periods of increasing fishing mortality (**Figure 7**). Whereas the harvest proportion estimates for the early (1952-1982) and late (1984-2015) parts of this time-series are not directly comparable because different assessment models were used, namely a single stock VPA for the former from Butterworth (1983) and a 2-stock, length-based assessment model for the latter from de Moor et al. (2017), they both show a similar pattern.

Harvest proportions of sardines for the early period were between 0.1 and 0.2 for the first decade of the fishery but then increased rapidly to around 0.4 by 1965 (**Figure 7**) and remained above this level subsequently except for a single year (1974). Given that the VPA biomass is considered an underestimate (see below), the harvest proportion will be over-estimated, and the absolute values should be treated with caution, but the trend of low values rapidly increasing to a higher level is clear. Annual harvest proportions at the start (1985 and 1986) of the later period were initially high, likely due to model mis-specification (*i.e.* underestimated initial biomass). They then

remained low (between 0.08 and 0.2) and steady for the total population until 2005, after which they increased to close to 0.3 in 2008 before declining again. This was not considered to be too high a harvest proportion at that time. When examined for the western and southern components separately, however, it is clear (i) that the harvest proportion of the western stock was substantially higher than that for the southern stock for all but the most recent years; and (ii) that the harvest proportion increased fairly rapidly for the western stock from less than 0.2 prior to 2000 to 0.7 in 2008, whereas that for the southern stock that proportion remained low for most of the period and exceeded 0.1 for the first time in 2006, after which it has varied between 0.06 and 0.25 (Figure 7). This clearly indicates that the second collapse of the South African sardine population followed an increasing trend in the harvest proportion (and hence fishing mortality) of the western stock, but this was “masked” by the calculation of relatively low harvest proportions and fishing mortality rates when considering a single sardine population given the then-prevailing perception that the sardine resource was panmictic.



Socio-economics, compliance, sustainability and ecosystem issues

Adult sardines are presently mostly (85%) canned for human and pet consumption, with some packed whole for bait or as cutlets for human consumption. Fish meal and fish oil are also extracted during processing of the offal whereas juvenile sardine caught as by-catch in the anchovy fishery are completely reduced to fish meal and fish oil. The average landed value in 2013 of sardine landed by the directed sardine fishery was ZAR 3,856 per ton, and the combined wholesale value of processed sardine, including canned fish, fishmeal and fish oil in that year was ZAR 1.4 billion (Hutchings *et al.*, 2014). Brick and Hasson (2016) report that the whole small pelagic fishery employed 5 200 staff in 2008, whilst Hutchings *et al.* (2014) report that around 700 full-time sea-going staff, 850 full-time processing staff, and 3 500 seasonal workers were employed in the sardine fishery in 2013.

Compliance in the sardine fishery is generally good and the large catch sizes mean that off-loading can happen at the larger harbours only where they are monitored by fisheries inspectors and scale monitors, but some illegal, unregulated and un-reported (IUU) fishing for sardine has occurred. For example, a portion of a sardine catch may be dumped if the catch is in excess of what the processing factory it is destined for can process. In addition, the dumping of fish that are not of a size suitable for canning (a process also known as “high-grading”) has been reported (Hara, 2013). Some corroboration of this comes from analyses of catch rates of sardine vessels with and without observers, where significant differences between observed and un-observed catch rates, possibly indicative of dumping, have been reported in some instances (Somhlaba and van der Westhuizen, 2011). In addition, a recent court case (known as the “Manny’s Fisheries” case; Attwood, 2017) found 14 accused (two fish processing establishments and 12 individuals) to be guilty of under-reporting of catches, illegal landing of catches at night or when a fisheries inspector or monitor was not present, illegal fish processing and fraud, and fines and/or prison terms were imposed.

Apart from their nutritional, economic and social importance to the country, sardine and other small pelagic species (such as anchovy and West Coast round herring *Etrumeus whiteheadi*) also occupy a key position in the marine food web where they are the link that transfers energy produced by plankton to predatory fish, seabirds, and marine mammals. Given this dependence of many predator species on these forage fish it is important to manage the fishery that targets them in a manner that accounts for their high degree of variability and importance to the Benguela Current ecosystem. This is because of the potentially severe risks of local depletion of forage fish for dependent species such as seabirds, particularly in years of low fish abundance and in certain areas.

The probability that sardine abundance will drop below a specified threshold during the short to medium term (5 to 20 year) is evaluated through simulation during the development of OMPs for this fishery. In addition, performance statistics related to both core decision objectives and secondary trade-off objectives for the resource, socio-economics of the fishery and the ecosystem, are evaluated to quantify the impact that a harvest strategy may have on each of these objectives (de Moor and Coetzee, 2012). The African penguin *Spheniscus demersus* has been chosen as a key predator species for the evaluation of fishing impact on dependent predators because they feed predominantly on anchovy and sardine and because of their conservation status which is of concern due to appreciable reductions in numbers at the major breeding colonies. As part of the implementation of an ecosystem approach to fisheries (EAF) in South Africa’s fishery for small pelagic fish, a model of penguin dynamics was developed for use in conjunction with the small pelagic fish OMP so that the impact on penguins of predicted future pelagic fish biomass trajectories under alternative harvest strategies could be evaluated. These studies have so far indicated that even with large reductions in pelagic catches under an alternative management procedure, there would be little benefit for penguins (Robinson et al., 2015) but further evaluation under a sardine 2-spawning component operating model will be attempted during the development of the next OMP.

Additionally, localised depletion of forage fish may occur when fishing effort is not evenly distributed across the range of fish biomass or concentrated in areas where land-based breeding predators with limited foraging ranges may need to compete with the fishery. For this reason, an experiment which aims to quantify the impact of the fishery on the breeding success of African penguins was initiated in 2008. This entails periods

in which certain areas around breeding colony islands are closed to fishing alternated with periods when fishing is encouraged around these islands. Although conflicting with respect to some impacts of fishing at different breeding localities, these results have to date suggested some benefit to penguins from fishery closures and as a result the experiment is continuing, despite an appreciable economic cost associated with this experiment (Bergh et al., 2014).

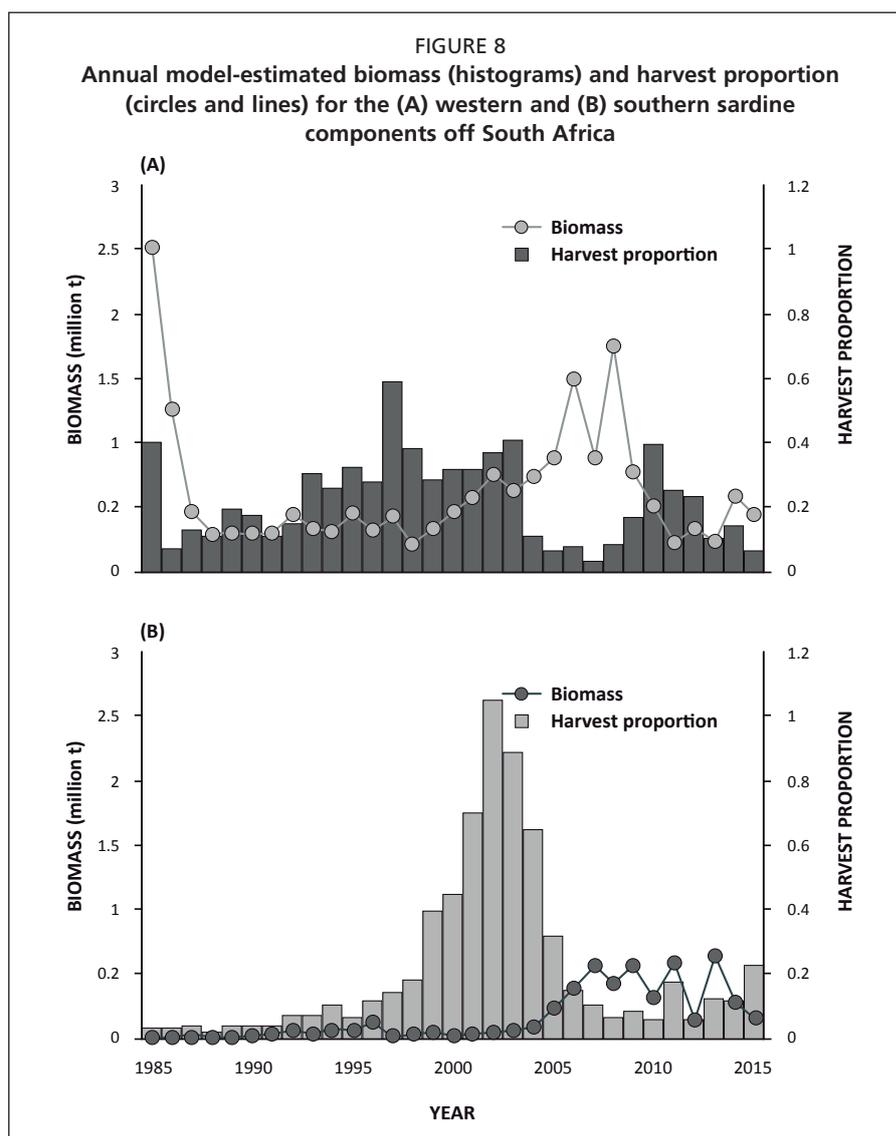
Performance

Management of the sardine fishery was explicitly conservative during the late-1980s and early-1990s in an attempt to rebuild the sardine population, which increased indeed under that strategy and subsequently, before collapsing again. As estimated by the 2-component assessment model, that increase was initially in the western stock, which showed a steadily increasing biomass between 1985 and 2003 at harvest proportions that were below 0.2 until 2000 (**Figure 8a**). In contrast the southern stock was at a low biomass initially, increased slightly in the early-1990s and then increased very rapidly during the late-1990s and early-2000s with that increase thought to be primarily due to substantial immigration from the western component in those years. The harvest proportion was below 0.05 until 2004 and fluctuated around 0.15 thereafter before declining (**Figure 8b**). Population (or stock) rebuilding resulting from low harvest proportions therefore seems plausible for South African sardine. However, whilst the western stock collapsed following higher (>0.25) harvest proportions indicative of localized overexploitation, the southern stock collapsed when harvest proportions were low (<0.1), showing that this could not be attributed to fishing mortality.

A relatively high natural mortality rate for adult sardine of 0.8 was confirmed during the recent updates to the two-component sardine assessment model. Estimates of loss to predation for the entire population are on average about 10 times higher than total sardine catches during the period 1984 to 2015 (de Moor and Butterworth 2016), highlighting the often-overlooked impacts of top-down control by predators on the dynamics of small pelagic fish populations. Whereas, disentangling the impacts of fishing and natural processes remains difficult, recent analyses do suggest that even in the absence of fishing the recent collapse of the sardine population cannot to any large extent be attributed to fishing (Bergh, 2017).

This emphasizes the fact that, despite the best recovery plan intentions, small pelagic fish populations can and do show substantial variability in population size in the absence of fishing and arising from environmental drivers that predominantly act on recruitment. Given the recent understanding that stock collapses occur more frequently and are exacerbated by excessive levels of fishing, particularly when population sizes and productivity levels are low (Essington et al., 2015), management measures should aim to prevent fishing mortality from rising as biomass declines and actively attempt to minimize the risk that the population size decreases to low levels at which recruitment is impaired, or predators are adversely affected.

Presently the South African sardine population is in a poor state, with the spawner biomass observed during the most recent survey (in November 2016) at 259 000 tonnes, below the exceptional circumstances threshold of 300 000 tonnes at which level the TAC is markedly reduced.



4. THE WEST COAST ROCK LOBSTER FISHERY

4.1 The resources and the fishery

Biological features

West Coast rock lobster *Jasus lalandii* is a cold temperate spiny lobster species distributed generally close to shore from about 23°S, just north of Walvis Bay in Namibia, to about 28°S, near East London in South Africa. Commercial densities are, however, only encountered along the west coast from about 25° S in Namibia to slightly east of the Cape of Good Hope in South Africa (Pollock, 1986; Pollock et al., 2000; Cockcroft et al., 2008). At the current minimum size limit of 75 mm of carapace length, the commercial fishery is dominated by male lobsters with females constituting less than 20% of the catch. Adult male and female lobsters moult annually with adult males moulting in late spring early summer (September to November) and females between April and June. The moult and reproductive cycles are tightly coupled with males in a hard-shell state mating with recently moulted females (soft shell state) (Heydorn, 1965; Newman and Pollock, 1971). Most mature females are in berry from July to late October and concentrate close inshore to release their eggs. The timing of the moult and berry cycles varies with latitude,

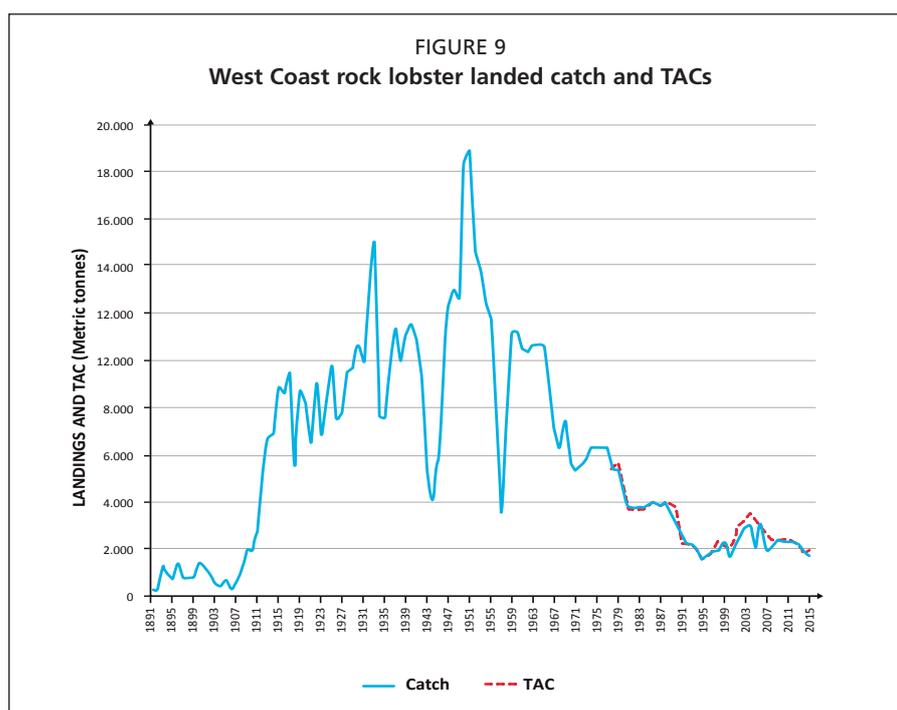
moulting and berry periods taking place progressively later towards the south (Pollock, 1986). The larval cycle (hatching to settlement) is considered to be from about 14 to 18 months (Pollock, 1986) with settlement generally taking place in depths shallower than 10 m. Juvenile lobsters moult several times per year, reaching a carapace length of about 60 mm around 4 years after settlement. Lobster growth rates and size at sexual maturity vary regionally, with moult increment in males and size at maturity in females generally increasing from the northern to southern fishing zones. As adult females redirect energy into egg production, their moult increments and therefore growth rate are generally much lower than that of adult males.

While the adult lobster does not undertake distinct longshore migrations (Atkinson and Branch, 2003), they are known to undergo seasonal migration towards and away from shore in some areas, usually associated with moulting and breeding cycles (Pollock, 1982). Seasonal movement of lobster into shallow water in response to low oxygen water is also not uncommon in certain more northern fishing areas (Newman and Pollock, 1971). Low-oxygen induced mass strandings of lobsters are a common occurrence in certain fishing zones (Cockcroft, 2001).

Historical development of fisheries and overfishing

The earliest records of human exploitation of the species as a food source date back to some 10 000 years before present (Grindley, 1967; Parkington, 1976). In the 19th and early 20th centuries, the abundance and ease of capture of these lobsters in shallow water led to their being an important source of food and bait for the poorer people resident along the coast (Melville-Smith and van Sittert 2005).

Commercial exploitation commenced in the late nineteenth century with the opening of a processing plant to can lobsters for export to Europe (Wardlaw Thompson, 1913). Landings increased steadily from the 1920s until a decrease around the period of the Second World War. A spike in landings followed the war years, eventually levelling off at a catch of around 10 000 tonnes, a level maintained from about 1950 to 1965 (Figure 9).



A minimum size limit of 89 mm CL was introduced in 1933 and a tail-mass production quota in 1946. Despite these measures, catches declined during the late 1960s, probably because of overfishing. The decline was particularly severe in the northern areas, where virtually uncontrolled exploitation took place at a reduced minimum size of 76 mm CL after 1959. In response to the decline, the production quota was cut to the tail-mass equivalent of about 5 513 tons in 1970 and the 89-mm size limit was applied everywhere. In 1978 the tail-mass production quota was replaced by a whole lobster (landed mass) quota. The limitation of annual catches by means of TACs was introduced in 1997/98 and the fishing grounds were divided into specific management zones and areas in the early 1980s. Other management measures enforced early on include prohibition on the possession of berried females or soft-shelled lobsters, a closed winter season and a daily bag limit for recreational fishermen (Cockcroft and Payne 1999).

By the mid-1980s, utilization of the resource had stabilized at annual catch levels of 3 500 - 4 000 tons. At those levels of fishing, catch rates seemed to be increasing and the resource was clearly not under undue pressure. The management measures in place at the time were therefore quite obviously adequate and the approach to management seemingly successful.

The stability in the fishery ended after 1989, presumably as the direct result of reduced somatic growth rates and resulting decreased recruitment to the component of the resource above the minimum size (Cockcroft, 1997). The decline in growth rate had a profound effect on the resource and its management. Continued slow growth and resultant poor catches early in the 1991/92 season resulted in the temporary reduction of the minimum size from 89 to 75 mm CL. The minimum size for the 1992/93 season was initially set at 80 mm, but it was then reduced to 75 mm, largely for economic reasons, in 1993/94 (Cockcroft and Payne, 1999) and has remained unchanged since then. TACs decreased from 3 790 tonnes in 1990/91 to 1 500 tonnes in 1995/96 and gradually increasing to 3 091 tonnes in 2006/07. TACs have remained at levels around 2,000 tons since then.

The fishery was initially based on the use of hand-hauled baited hoop-nets deployed from small boats. Baited traps deployed from larger motorised vessels were introduced to the fishery in the 1960s and came into increasingly greater use since the early 1970s. The use of the larger trap vessels allowed access to previously unfished deeper waters and considerably extended the fishing grounds.

The value of the current commercial fishery for this species (ca USD 61 million per annum) and its importance in providing employment for over 4 200 people from communities along the West coast make it the most important lobster fishery in Southern Africa. It is the third most valuable SA fishery in terms of landed value.

4.2 Fishery policy and management history

Since the attainment of democracy in 1994, the equitable redistribution of fishing rights in South Africa have been achieved via the medium-term (2001/2002) and long-term rights (2006) allocation processes. The long-term rights allocation process for West Coast rock lobster in 2006 resulted in the commercial fishery being formally divided into distinct nearshore and offshore components. The offshore component (245 rights-holders) consists of individuals or companies (juristic persons) who use traps deployed from large vessels in deep water. The nearshore component (812 rights-holders) consists of individual rights-holders (natural persons) who are restricted to the use of ring-nets from small vessels within their fishing zone or area of residence. Following

the rights allocation in 2006 an Interim Relief sector was instituted as a precursor to the establishment of a Small-Scale sector. The number of participants in the Interim Relief Sector increased from 952 in 2006 to 1 809 (from 42 distinct communities) in 2016.

The rights allocation process, due in 2017, and the implementation of a Small-Scale Fisheries Policy whereby coastal community co-operatives will be allocated a basket of species (including West Coast rock lobsters if the community was located within a lobster area) for commercial exploitation will most likely result in considerable changes in the numbers of participants in these sectors.

Management objectives for this fishery prior to 1997 did not incorporate a specific rebuilding strategy and were rather focused on providing TAC levels that would prevent further decline of the resource. The concern for the status of the resource prompted the development and introduction of an operational management procedure (OMP) as the basis for setting the TAC. The OMP introduced in 2007, included an agreed rebuilding strategy for the resource of a 35 percent recovery in the 2006 male biomass by 2021 in median terms (Johnston and Butterworth, 2005). This rebuilding target was incorporated in the OMP revisions in 2000, 2003, 2007, 2011 and 2015.

4.3 Outcomes, issues and performance

Current Status

The projections carried out in the development of the revised OMP in 2015 indicated that the agreed recovery target was likely to be achieved. However, in 2016 updated assessments together with a re-appraisal of estimates of the extent of and trends in poaching were conducted as part of the standard process of monitoring the performance and continued appropriateness of the OMP. The assessments showed results for resource status that were appreciably worse than anticipated (Johnston and Butterworth 2016a). The revised estimates of poaching (**Figure 10**) led to even greater concern, with best estimates suggesting a doubling over the past three years (DAFF, 2006).

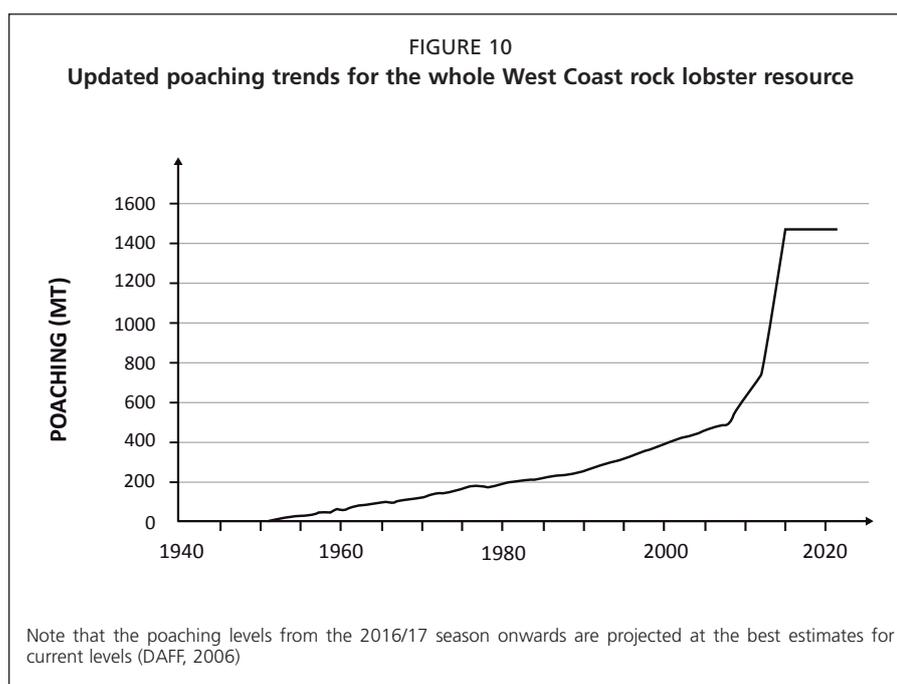
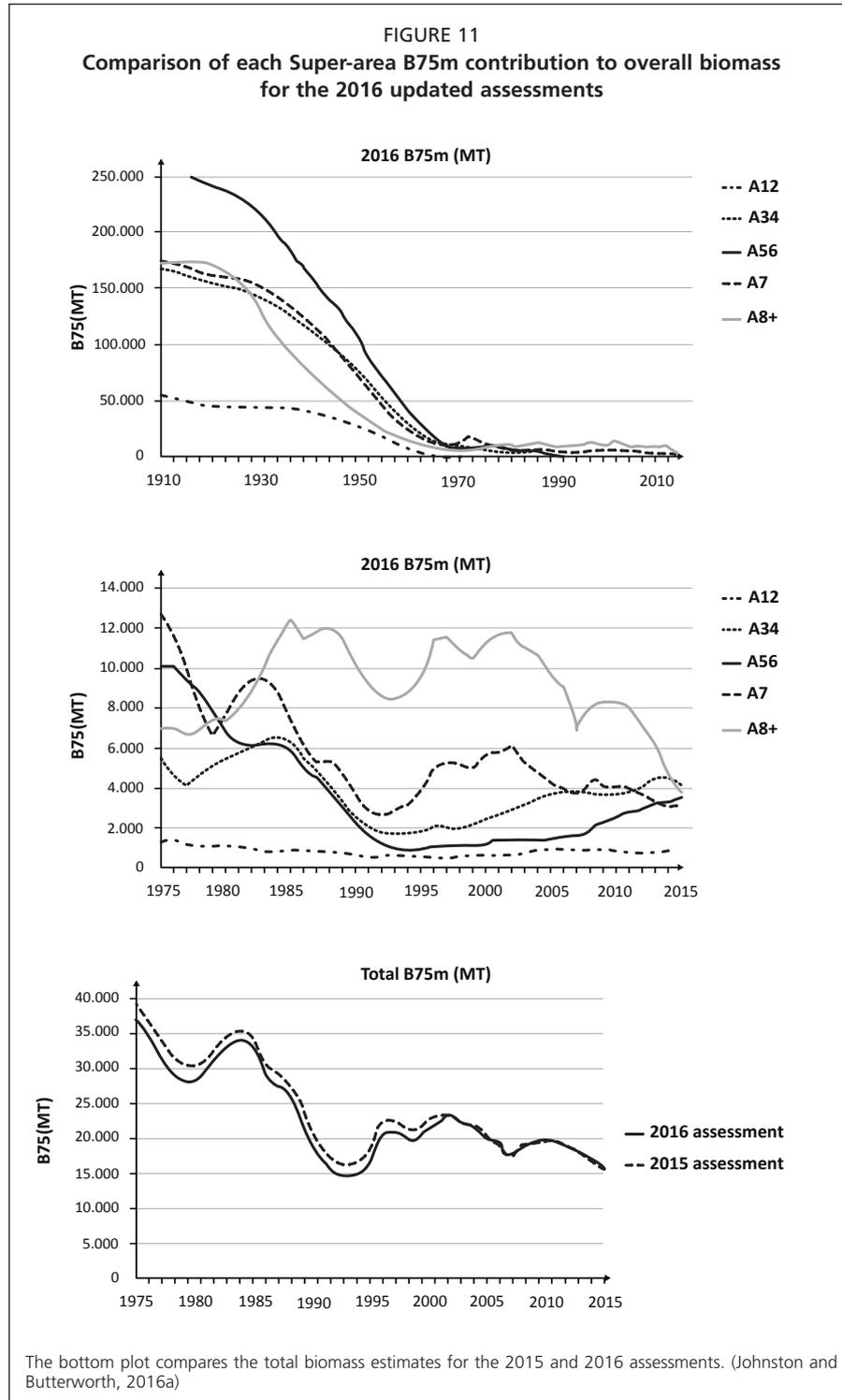
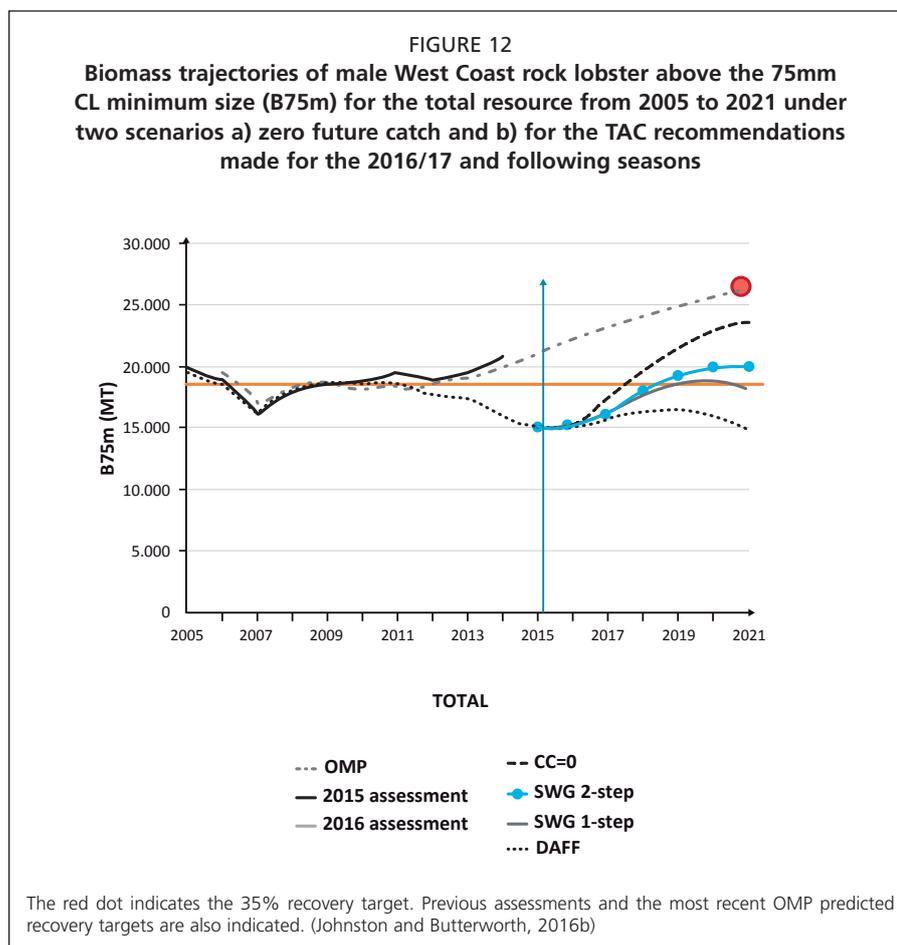


Figure 11 shows abundance trends (male lobster greater than the 75 mm CL minimum size or B75m) for each of the Super-areas. Compared to one year previously, where the resource appeared to be broadly stable as a whole, with a slight recent increase, the updated analysis (given new data) indicated instead a 20% reduction over the last 5 years (Johnston and Butterworth, 2016a). The resource overall was at less than 2% of its pristine level in 2016.



The updated assessments and projections (Figure 12) indicated that if poaching levels remained at current best estimates, the 35% recovery target is unattainable even were the legal fishery to be closed until the 2021 target year (Johnston and Butterworth, 2016b).



Factors affecting rebuilding

Environmental changes

The period between the late 1980s/early 1990s through to the end of the century was marked by three major events that impacted the West Coast rock lobster fishery. These were a sharp decline in lobster somatic growth rates (Pollock et al., 1997), a major increase in the number and severity of lobster “walkouts” in the Elands Bay region (Cockcroft, 2001) and a large-scale change in the spatial distribution of lobsters including an influx of lobsters into areas not previously associated with high lobster abundance (Tarr et al., 1992; Cockcroft et al., 2008; Blamey et al., 2010). These events have had a profound effect on the lobster resource during the past two decades. The temporal coincidence of these three events led Cockcroft et al. (2008) to suggest a linkage in the underlying environmental causes or forcing factors. In contrast to the 1990s, the period since the turn of the century appears to be one of relative stability for the rock lobster fishery (and by implication for the inshore marine environment). Growth rates have recovered slightly (although not to the pre-1990s level), the number of lobster walkouts and the amount lost to these mass strandings has returned to levels consistent with the decades of the 1980s and the range extension of lobsters into the area EPOCH has stabilized with no further eastward movement. As the rebuilding target was set in 2007, these environmental impacts are not considered the major causative factor in the most recent resource decline.

Increased poaching

Poor economic conditions throughout the country, lack of employment opportunities in coastal communities and relatively easy access to a high value commodity (lobster) has meant that illegal harvesting has been a reality in this fishery for many years. An estimated illegal harvest of 500 tons per annum was built into all the OMPs used since 2007 to accommodate this reality. It is, however the increased illegal harvesting over past few years that is considered the major driver of failure to meet rebuilding targets.

The increase in poaching cannot be attributed to a single sector of the fishery but is rather considered to be a problem within in all sectors. The following factors (individually and/or as a combination) are likely to have contributed to this recent increase:

Uncertainty regarding implementation of small-scale fisheries policy, increased numbers of participants (especially in the so-called “Interim Relief” sector where number of participants virtually doubled from 2006 to 2016) and unrealistic (in some instances) expectations of the rights allocation process provide fertile ground for illegal lobster harvesting activity. These, coupled with limited enforcement capacity and budget constraints within the compliance arm of the management authority further exacerbate the issue. In addition, as the abundance of abalone has declined, the organized crime syndicates targeting abalone are now considered to be turning their attention to West Coast rock lobster as an alternative.

Management decisions (Adherence to scientific recommended TACs)

Since the introduction of OMPs in 2007 the management authority has followed the scientific advice arising from the agreed OMP in setting appropriate TACs to ensure the attainment of the recovery target. However, the recommendation for a substantial reduction in TAC, coupled to an effort reduction strategy recommended in 2016 was not implemented by the decision-makers who chose to retain the previous year’s TAC and effort levels. The implications of this decision on the resource rebuilding strategy and specifically the recovery target will only be manifest in future. The likely changes in the composition of the various fishing sectors accessing this resource arising from the rights allocation process in 2017 is likely to further complicate the setting and attainment of an agreed rebuilding target.

Performance

Without substantial reduction in illegal harvesting and strict adherence to a rebuilding strategy by setting appropriate TACs to achieve this rebuilding, the resource will not recover to more productive levels for the benefit of all resource users.

5. SUMMARY OUTCOMES, CONCLUSIONS AND LESSONS LEARNED

5.1 Summary of rebuilding outcomes and outlook

Hake

Merluccius capensis is well above BMSY while *M. paradoxus*, although currently slightly below B_{MSY} , is considered to be in a state of fluctuation about B_{MSY} . Management of the SA hake resource (and *M. paradoxus* in particular) at present is directed at balancing the trade-offs between continued sustainable exploitation of the resource (and minimising negative economic impacts to the fishery) and ensuring the resource returns to levels

yielding MSY following several years of below-average recruitment (2009 – 2013). This is likely to be successful.

Sardine

The resource has experienced two collapses since the 1960s, after several years of exceptionally high biomass (in the early to mid-1960s and again in the mid-1990s to mid-2000s). In the 1960s the collapse followed increasing harvest proportions (fishing pressure) on the whole stock and the second collapse may have resulted from an increasing harvest proportion of the western stock. Rebuilding efforts after the first collapse by cutting the TAC to low levels have been credited for the resurgence in the 1995-2005 period, but favourable environmental conditions may also have played a major role.

West Coast rock lobster

The male biomass has declined to alarming levels recently despite the development and introduction of an operational management procedure (OMP) as the basis for setting the TAC, which included a rebuilding strategy for the resource aiming at a 35 percent recovery in the 2006 male biomass by 2021. Although TACs had been reduced accordingly and the resource (in terms of male biomass) was showing signs of a recovery in the early 2000s, uncontrolled poaching in recent years has clearly been responsible for the decline. This is likely to be exacerbated by poor decision-making by the authorities, who have neither implemented a recommended TAC reduction to counteract the effects of poaching, nor implemented effective management measures to curb poaching.

5.2 Conclusions and lessons learned

Different definitions and measure of success among the fisheries?

As explained above in the background to this Chapter, the use of OMPs are considered appropriate for the rational and sustainable management of the fisheries described in these three case studies. They are attractive for the purpose of maintaining industrial stability and transparency in decision-making. In South Africa they are generally kept in place for 3-5 years before being re-assessed and revised using the most up-to-date data and to accommodate possible changes in management philosophy.

In the case of hake, the stocks status varied over the years. *Merluccius capensis* is currently fluctuating above its B_{MSY} target reference point for spawning stock biomass and *M. paradoxus* is fluctuating about B_{MSY} . The management strategy aims at attaining a future spawning biomass not decreasing below the level estimated for 2007 (a limit reference point). *Merluccius capensis* stocks, therefore, appears to be in good shape and fishing effort well below the level at which stocks could be threatened. Effort levels on *M. paradoxus* have been managed and can be managed again relatively easily in future with the existing management system, where the number of sea days applied are linked to the allocation given to each fishing right holder, and the OMP adjusts the TAC based on annual trends and projections.

Although an OMP has also been used for sardine (albeit with the objective of maintaining a minimum spawning biomass rather than having a MSY objective), the population experienced a second collapse under a generally conservative management procedure that attempted to control harvest. This indicates that low fishing mortality

cannot be guaranteed to result in sustained large populations for small pelagic fish like sardine. This is particularly evident for the southern sardine stock for which research clearly indicates the strong link between environmental drivers and the abundance of small pelagic species, which results in substantial variability in their recruitment success. When examined more closely, however, it is likely that the fishing mortality exerted on the western sardine stock was too high during the early-2000s which resulted in localized overexploitation of that stock. Because of the substantially lower productivity of the southern stock compared to the western stock this has had serious negative implications for the entire sardine population and highlights the need for research to determine the population structure of exploited small pelagic species.

An OMP for rock lobster had a different objective. Rebuilding a male biomass which had declined to 2 percent of its unfished value to, say, even 20 percent of its unfished level, would have taken unacceptably long – in the order of decades - and would have required a virtual closure of the fishery for much of that period to speed recovery. The socio-economic consequences of this would also clearly have been unacceptable. Rebuilding the male biomass to 35 percent above its 2006 level by 2021 was considered a modest but attainable objective, provided poaching could be curtailed. This did not happen and indeed, poaching has surged, being estimated to have doubled during just the past two years. The rebuilding target has consequently become an unattainable one and the future of this stock is of high concern.

Governance: interactions between research, management and compliance

In implementing a rebuilding strategy, it is clearly important that all the components of a fisheries management authority should collaborate effectively and that there should be trust between them. For the most part, this has worked well in South Africa within DAFF, with well-established institutional arrangements and practices, such as Scientific Working Groups, Management Working Groups in each sector, use of OMPs, and an inspectorate that collaborates with the other units on occasion when information is required via formal and informal management meetings at senior levels.

Infrastructure, such as research and patrol vessels and adequate operational funding ensured continuity in most functions. Until about 2012, the demersal and pelagic sectors operated smoothly and communicated relatively well in an atmosphere of trust. However, several political developments and government corruption began to take their toll. Funding began to shrink, research had to be curtailed and scientists began to be mistrusted by politicians and senior managers and accused of having their own agendas. This even led to managers being instructed not to attend scientific working groups (SWGs), leading to a silo mentality and lack of communication. Scientific recommendations on abalone and West Coast rock lobster were not supported by the Minister.

An academic study (Sundstrom, 2014) showed that corruption was widespread in the inspectorate. There was a corruption scandal related to the management of research and patrol vessels which led to them being dysfunctional for several years which affected survey assessments in some sectors. Scientific managers were accused of blocking racial transformation.

All these developments eroded the quality of outcomes and trust between the units and ultimately decision-making began to be affected. These effects were relatively benign on hake and sardine, but with WC rock lobster the effects were disastrous, especially

in terms of curbing poaching, because the perception was at times created that the scientists were deliberately misleading the managers about the status of the resource and the effects of poaching.

In two occasions since 2012, the Minister has not approved the scientifically recommended TAC cuts for political reasons, most recently even when it was beyond doubt that the resource is being severely damaged and even though rebuilding plans had been agreed on by the scientists and major stakeholders and had been incorporated into the Department's own published strategic plans. At the same time, uncertainty was created around the whole WCRL fisheries sector, because of politically raised expectations and a lack of decision-making related to the percentage that would be allocated to the small-scale fisheries component. Eventually 90 percent of the inshore component was allocated to small-scale fisheries without consulting the other sectors. In such a situation of distrust and uncertainty about future access, fishers from all sectors as well as opportunistic poachers tend to throw caution to the winds and ignore limitations, resulting in the stocks being decimated. At the same time, the land-based inspectors stationed in towns along the coast are exposed to intimidation and abuse and cannot effectively prevent poaching, especially in accessible, inshore fisheries such as rock lobster.

The role of stakeholders

In the two larger fisheries, the research process and the role of stakeholders have been crucial in keeping the resources from being overexploited and allowing rebuilding to happen when it has been necessary. The system of scientific and management working groups (SWGs and MWGs) includes a wide range of stakeholders from industry and NGOs. This has promoted buy-in to the development of OMPs, the setting of TACs and general management measures, and discouraged the political interference that has been present in the rock lobster sector. In the two large sectors, there have also been several developments that have been beneficial to the intent of rebuilding initiatives. First, an Ecosystem Approach to Fisheries (EAF) management philosophy has been applied, which identified key ecosystem issues, including those related to the human component, and plans were developed to address them. The hake fishery was also certified by the Marine Stewardship Council, which focused efforts both on stock rebuilding, ecosystem issues such as by-catch, endangered, threatened and protected (ETP) species and benthic impacts, and on governance of research, management and compliance. In 2008, a new initiative called the Responsible Fisheries Alliance (RFA) and comprising several of the largest fishing companies and several NGOs was set up, which provided a platform to address sustainability issues and encourage responsible behaviour. These initiatives included support for rebuilding programmes. In the WCRL fishery, stakeholders have challenged the management authority on decisions which were clearly to the detriment of sustainable resources management and their own wealth in the near future. After an incident in 2012, when the Minister ignored the scientific recommendation, a decision which would have led to the rebuilding plans being violated, the Minister was persuaded by scientists and NGOs to compensate for its impacts by adjusting the rebuilding schedule to meet the original rebuilding objective which had been set by the stakeholders themselves and which had been endorsed by DAFF and included in their strategic plans. In 2017, however, scientific and NGO objections to the lack of implementation of a recommended 35% cut required to keep the rebuilding strategy on track were ignored again. The impacts on the rock lobster stock are consequently likely to be dire.

Role of the environment (including climate change) on rebuilding

Even when plans are developed and implemented to rebuild fish stocks that may have been effective, they can be severely disrupted by environmental perturbations and consequently when those are exacerbated by climate change, they can be devastating. There have so far been no demonstrable effects of climate change in the Southern African region on hake stocks per se, but there is some evidence to suggest that hake catches can be affected by oxygen levels and wind strength affecting upwelling. Augustyn et al (forthcoming) recently reported that climate change effects predicted for the region included increased intensity and prevalence of southeasterly winds, which could have a detrimental effect on average sardine recruitment (whereas anchovy is most likely to respond positively). These increased SE winds may already have resulted in changes in oceanography off the South African coast, such as increased intensity and variability of coastal upwelling in the last two decades. It is considered that a possible increase in frequency and duration of West Coast rock lobster mass strandings may occur. These authors reported that improving prediction capacity was crucial for adaptation to climate change and the quality of responses, e.g. improving foresight) and understanding of the impacts on fisheries and coastal communities and responding with timely changes in terms of adaptive policy and action. Diversification and value-addition in terms of products, consolidation of certain sectors and responsiveness by the industry could also reduce the impacts of climate change.

Role of social and economic factors

Rebuilding efforts in all three of the fisheries discussed have been influenced or can potentially be influenced by social and economic factors.

In the hake fishery, the economics of the fishery have favoured the consolidation of the original 52 right-holders into only nine clusters, because of economies of scale. The most profitable entities are the two largest companies that benefit the most from MSC certification, because they can take advantage of greater volumes that lead to large-scale value-addition and overseas market penetration. These companies are able to access lucrative markets in Europe, North America and Australia, because they are able to sign export contracts that will absorb large volumes and variety of product. A recent study by Lallemand et al. (2015) showed that under several different scenarios, loss of MSC certification would lead to losses of revenue of between 28 and 47 percent to the fishery overall, depending on the scenarios simulated. The relative stability in the fishery engendered by certification and its requirements are conducive to rebuilding efforts, because it is entirely beneficial to and in the interests of right-holders to contribute to optimizing the performance of the fishery.

Although the sardine fishery is not MSC-certified (there is not as much demand for certified products in the target markets for canned fish), similar principles still apply. There are established, relatively stable fisheries and markets and the companies involved are profitable and can be even more profitable if average TACs are higher. It is therefore also in their interest to support rebuilding efforts when stocks have declined, whatever the cause. Although there is robust debate about the social and economic impacts of imminent TAC cuts, and occasionally rumours of dumping (especially of small fish or mixed species catches) there is ultimately a tendency towards responsible behaviour, because of these economic incentives. When sardine catches are down, some companies can focus more on catching other species such as anchovy or round herring, albeit with lower profitability.

In the WCRL fishery, both social and economic issues impact on rebuilding initiatives. As a target of small-scale fisheries and organized poaching gangs resulting from coastal poverty, its accessibility and modest requirements for capital investment, inshore stocks particularly are under enormous pressure. At the same time, as unsustainable fishing increases and accessible stocks become scarcer, the value of the product increases to the local fishery, (but not necessarily for export products, which depends on exchange rates), and a vicious cycle can result. These factors are not favourable for rebuilding WCRL stocks.

A powerful social issue in South Africa which has a bearing on rebuilding initiatives is the need for racial transformation in fisheries. This is a Constitutional imperative, supported by the Marine Living Resources Act (MLRA), and has resulted in great political pressure to bring new entrants, especially black new entrants, into all fisheries sectors. The fishing industry is consequently one of the most highly transformed sectors of the South African economy, with black ownership over 60 percent across all sectors. The proportion is around 62 percent, in the hake sector, 60 percent in the small pelagic species sector and about 70 percent in the West Coast rock lobster (WCRL) sector. However, because of the pressure to bring in as many as possible new entrants in terms of numbers, average allocations for new entrants in these sectors have been relatively small and not always economically viable. This has two perverse effects: it discourages real participation and consequently results in so-called “paper quotas” where the rights are simply sold to larger players as usage rights, or it provides an incentive to poach. In the hake trawl and small pelagic species sectors, due to inability to raise capital because the allocation is not valuable enough to provide security for loans, selling is often an outcome: In the WCRL sector the result is often poaching.

Long-term versus short-term benefits

Rebuilding initiatives in the South African context would logically provide long-term benefits to the sectors where they are implemented over time, but short-term benefits and costs vary according to sector, with the speed of rebuilding being a crucial factor. In large, industrial fisheries, the right-holders can typically absorb a few years of lower catches while they position themselves to take advantage of a recovery. This is true in hake trawling, where there are relatively long cycles of higher and lower abundance and it is possible to regain some losses by focusing more on by-catches of other species for a while. It is also true with small pelagic species where switches can relatively easily be made to other species when one species is under pressure, in this case, from sardine to anchovy and/or round herring. The economic realities in the WCRL sector are harsher, however. The stocks react extremely slowly to reductions in fishing pressure, and widespread poverty among small-scale fishers simply does not allow for long breaks or interim switches to other species. Other species available to small-scale fishers (like linefish) are much less valuable than rock-lobster, while more valuable species like abalone have already been decimated by poaching.

In economic terms that means that the opportunity costs are much higher and must be faced by very vulnerable communities, creating a real challenge for the people and the Minister.

Commonalities and broader lessons learned

We have described three sectors that are managed by the same authority and a similar management system (OMPs with sophisticated stock assessment models), but are subject to very different environmental, social and economic pressures, resulting in

one resource (deep-water hake) that is relatively stable and can be easily adjusted to when stocks are negatively affected, one (sardine) that is inherently unstable because of its biology and susceptibility to environmental variability and probably also fishing pressure, and one (West Coast rock lobster) that is under threat as a result of environmental, political, economic and social pressures and which is very difficult to alleviate in a developing country like South Africa.

Accordingly, unless a better understanding of the economics and social interactions of these fisheries are developed, political will is applied and very strong steps are taken to address the issues discussed above (including addressing poverty and crime in coastal high-value fisheries), it is highly likely that only hake and small pelagic species (not necessarily sardine, possibly resulting from climate change impacts) have a chance as sectors to continue to provide significant economic benefits. Failing such, West Coast rock lobster will surely be doomed to a similar fate as that of abalone – a likely commercial extinction as a viable fishing sector with enormous losses to the nation and some of its poorest communities.

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Northern (Newfoundland) cod collapse and rebuilding

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Abstract

The collapse of the cod (and several other groundfish) stocks in Atlantic Canada during the late 1980s and early 1990s is one of the most publicized “fishery failures” of modern fisheries. Moreover, the long period of negligible or very slow recovery through the 1990s and 2000s continued to keep those stocks in the science and public spotlights. This case-study focuses on the “Northern” cod stock, located in NAFO Division 2J3KL, considering its trajectory from the 1980s to the present, the measures in place to manage harvest, promote stock recovery, and address needs of fishers and communities traditionally dependent on that stock.

From the start of the collapse, experts debated the *major* causes of the collapse. Different scientists presented evidence arguing that the major initial factor was solely overfishing, a change in physical environment causing changes in distribution and natural mortality, a change in bottom-up ecological processes changing physiology and recruitment, and a change in top-down predation. All experts acknowledged that additional factors – particularly excessive harvests – would come into play at some point, as the stock declined to levels so low that it would be vulnerable to many pressures. However, the debate about primary causality of the collapse and subsequent slow recovery persisted well into the 2010s. This debate among experts was scientifically rich but contributed to diffuse responses by government to address any of the issues individually. The extensive community dependency on cod fisheries also posed challenges to management actions to limit harvests during the collapse and recovery. Social assistance costs were very large and conspicuous budget items, and debates among social science experts, and between social and “natural” science experts about necessary measures further complicated efforts at implementing programs for stock recovery.

This chapter presents five “stanzas” of approximately five years each. During each stanza a different suite of both ecological measures and harvest controls, and of social assistance and incentives to permanently leave the fishery were in place. However, until the mid-2000s, there was extremely little recovery of the cod stock, and when some noticeable stock growth did commence, it was in the context of several major changes in both physical and biological oceanographic conditions.

For each stanza the chapter presents information on the major policy instrument implemented and the key measures in place for both harvest restriction, and community support and access to fishing opportunities. It also reports the key changes in stock status and in the biological and physical environment during the stanza.

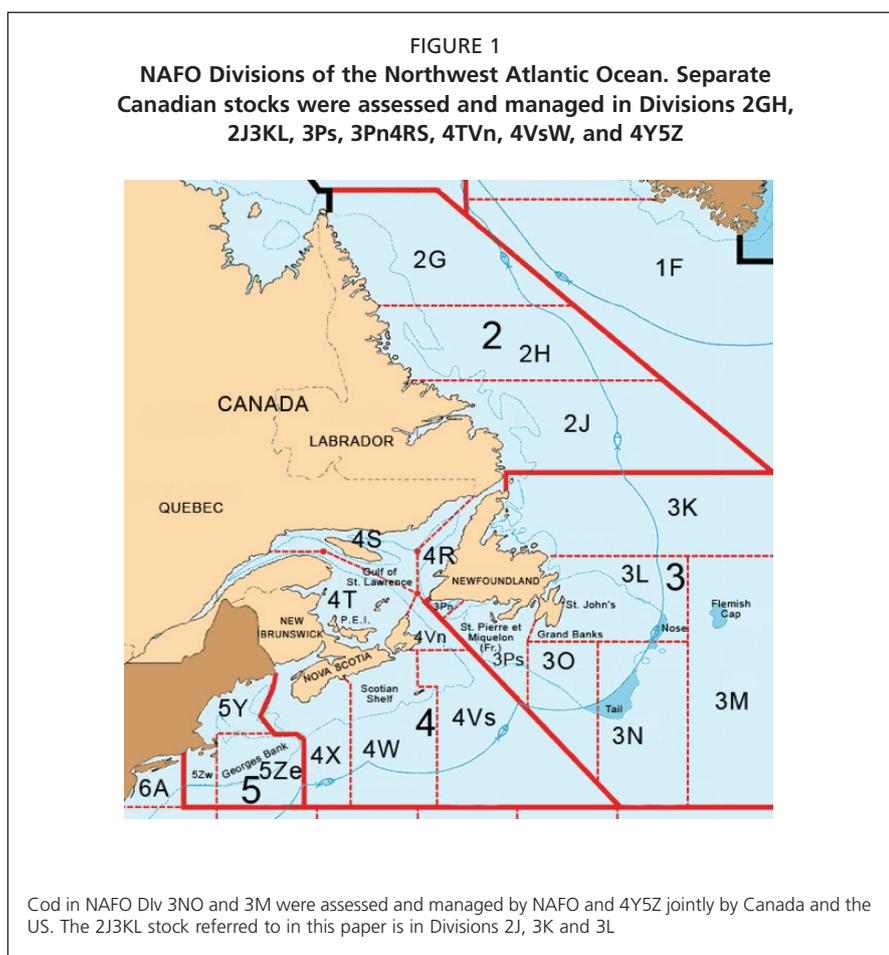
It examines evidence for possible linkages between fisheries management measures and stock trajectory, and between social and economic policy measures and changes to the fisheries.

As a generalization, there was only marginal improvement in stock status until the mid to late 2000s, when the stock began to increase rapidly. The change occurred at a time of large changes in the physical oceanography of the region, but other changes (to the biological components of the ecosystem, the behaviour of cod, and in other fishing opportunities) corresponded in time to the changes in physical oceanography, so the root causes of the collapse, long period of depletion and onset of possible recovery are still not effectively disentangled. With the possible recovery apparently stalled well below the historical levels of the stock, perhaps there will be more opportunity to learn what factors are important to recovery of the stock.

1. BACKGROUND

1.1 Early fisheries and management history

For assessment and management purposes, eight stocks of Atlantic cod (*Gadus morhua*) have been recognized on the Canadian East Coast since the early days of the International Commission for North Atlantic Fisheries (ICNAF), and a ninth on the more isolated offshore Flemish Cap (Figure 1).



Population structure is more complex than the stock delineations, with sub-stock structure, breeding populations semi-resident in some of the deep coastal bays, and even a relict population in a Labrador semi-landlocked bay (Carr et al., 1995; Ruzzante et al., 1996, 2000; Bentzen et al., 1996; Taggart et al., 1998; Beacham et al., 1999). The southernmost stock (in Division 4Y5Z) is shared with the United States and the range of several of the stocks extends to some extent beyond the 200 nm limit of Canadian jurisdiction. However, only the Southern Grand Banks (3NO) and Flemish Cap (3M) are assessed and managed or co-managed by the Northwest Atlantic Fisheries Organization (NAFO), the regional fishery management organization (RFMO). Until 1986, the Northern Cod (in NAFO Division 2J3KL) was also assessed and managed by NAFO, but in that year the Minister of Fisheries and Oceans, Canada declared the stock to be wholly under Canadian jurisdiction. The small extensions beyond national jurisdiction on the Nose and Tail of the Grand Bank were only available to foreign fisheries if arrangements were made between NAFO and the Government of Canada (Bishop and Shelton, 1997), and NAFO continued to review 2J3KL assessments in many of the subsequent years (Bishop et al., 1993, 1994, 1995a, b).

All these stocks underwent major declines in the later 1980s and early 1990s and were subsequently subjected to rebuilding efforts. Although general patterns and timing of population trends are somewhat similar, there are many differences in details of stock performance and management measures implemented (Sinclair and Murawski 1997; Rice and Rivard, 2003; Halliday and Pinhorn, 2009; Bundy et al., 2009; FRCC, 2011). Consequently, this chapter will focus on just one stock – the Northern Cod, in NAFO Div. 2J3KL, by far the largest of the stocks and the stock most closely associated with the Newfoundland and Labrador society, economy and culture. When developments in other stocks help shed light on the decline and recovery efforts of this stock, the specific other stocks will be identified in association with the information taken from their case histories.

From the Basque fisheries underway by the 16th Century until the extension of national jurisdiction in 1978 all these stocks were subjected to fisheries by fleets from many countries¹. Over this long history the international fleets fished nearly exclusively on the offshore banks of Canada, taking cod spawning on the outer slopes of the banks from March to early June and continuing into the summer and fall as long as cod remained in numbers in the offshore banks (Hutchings et al., 1993). Simultaneously, community-based fisheries operated in the spring and summer all along the coastline from the Bay of Fundy to Labrador, where many of the “communities” were summer congregations of fishers from further south in Atlantic Canada, who moved north after their local spring fisheries concluded. The inshore fisheries used small, shore-based vessels to harvest the same cod stocks as the offshore fleets while the cod were inshore, feeding primarily on capelin. These fisheries formed the basis for settlement of much of Atlantic Canada and were the economic cornerstone of these communities from the 1600s until late in the 20th Century.

In 1949 ICNAF was established as one of the first regional international fisheries Conventions. Although it was mandated to address science and management of several northwest Atlantic fisheries, cod was central to the international fisheries and the focus of ICNAF. With fisheries assessment and management in its early stages of development, and very limited authority to regulate fishing operations, even of member States, ICNAF played an important role as a forum for dialogue, for exchanging views

¹ The history of the Canadian Atlantic cod stock and fisheries prior to the 1980s is a compilation of the information in Forsey and Lear (1987). Parsons (1993), Lear and Parsons (1993), Lear (1998) and Rose (2006)

on access and harvest levels as well as sharing information on research finding and fishery performance. ICNAF did recommend quotas, adjustments to effort levels, and gears measures, but, for implementation, could at most coordinate national actions to manage fishing practices, catch and effort of their individual fleets. It also did set fisheries quotas, and adopted measures for effort management and gear regulation, although adherence to the quotas and regulations was at best “inconsistent” among the member States (Templeman and Gulland, 1965).

Immediately following negotiation of the LOSC, Canada declared extended jurisdiction in 1978, and ICNAF was replaced by NAFO. NAFO was a full RFMO, with authority to set and enforce quotas and gear regulations such as minimum mesh sizes, conduct surveillance activities, restrict access to the fishing zone, require catch reporting, and it supported a new generation of analytical stock assessments for the major NAFO stocks.

When it was established, NAFO adopted $F_{0.1}$ as the target exploitation rate for groundfish stocks in the northwest Atlantic, based on scientific investigations of these stocks conducted in the later years of ICNAF. By 1978 the weaknesses of ICNAF had been widely acknowledged and most groundfish stocks in Atlantic Canada were considered depleted to varying and usually poorly known extents. The $F_{0.1}$ harvest strategy was expected to reduce fishing mortality sufficiently that stock recovery would follow while allowing domestic fleets to be developed to replace the international fleets that had been excluded. In some cases, including northern Cod, agreement was reached to accelerate the expected stock recovery by setting quotas at $0.8F_{0.1}$. (Munro, 1980). However, concepts like “responsible fisheries”, the Precautionary Approach and the Ecosystem Approach (FAO 1995, 1996a,b, 2003), were not part of fisheries dialogue at the time. Rather, to the extent that management decisions were based on scientific advice, the advice was based on point estimates from deterministic single-species models not well suited to the low productivity of the depleted stocks, tending to underestimate F and overestimate B . The Canadian management approach will be discussed in **Section 2.1**.

1.2 Stock biology and ecology

Cod in Canada have an archetypical gadoid life history, generally maturing at ages 3-5 and with individual spawning potential per kg continuing to increase at least until ages 9 or greater (Lilly, 1998). Although post collapse many of the Canadian Atlantic cod stocks are estimated to have shown elevated rates of natural mortality (Dutil and Lambert, 2000; Chouinard et al., 2005), for many decades the approximation of $M = 0.2$ seems to be reasonable for all the stocks. Correspondingly, cod up to ages 12-15 were generally present in populations and catches in numbers were large enough to be included in age-disaggregated single species stock assessments.

All the Atlantic cod stocks are seasonally migratory (May et al., 1981; Lear and Parsons, 1993). Northern Cod traditionally spent its juvenile years in nearshore waters along the East and North coasts of Newfoundland and the coast of Labrador. As cod reached the age of maturity they joined offshore spawning migrations that commenced in late summer or fall, moving with greatest concentrations in the deep channels between the offshore Banks of Newfoundland, but with cod moving across the tops of the Banks as well. By late winter, mature cod were aggregated on the outer slopes of the Banks, where spawning occurred from mid-March to early May. Eggs were released into the strong outer branch of the southerly-flowing Labrador current, to be transported during their larval period back to nearshore waters for their juvenile years. The spent cod would migrate back across the Banks and through the channels

towards the nearshore deep waters between the banks, in the inner branch of the Labrador Current and the Newfoundland Labrador coast and the deep coastal fiords, where they would feed for the summer (Hutchings et al., 1993; de Young and Rose, 1993; Rose et al., 2000).

Cod are predatory feeders, primarily feeding on large zooplankton at young ages, and becoming increasing piscivorous until maturity, when diets consist almost completely on other “fish”, particularly capelin and macro-invertebrates, such as shrimp (*Pandalus*). Many predators feed on larval and juvenile cod, but as cod increase in size, most predation is by marine mammals and primarily pinnipeds (Rice, 1988; Link et al., 2009).

2. DESCRIPTION OF SPECIFIC FISHERIES

In 1979, a major meeting on Canadian Atlantic fisheries was held in Corner Brook, Newfoundland, to plan how to share the benefits expected from taking the Atlantic fisheries under national jurisdiction. Representatives from federal and provincial governments, processing plant owners, exporters and union and community leaders were all represented, each with strongly held objectives (DFO, 1979). The outcome of the meeting set the framework for fisheries operations, management, and policy for the promising future. In the immediately following years, strengthened union representation of fishworkers on vessels and in plants, and economic consolidation of the processing and the offshore harvesting sectors built on the Corner Brook framework, combined to shape the Newfoundland cod fishery for the years until the stock collapse. Key outcomes for Newfoundland and Labrador, and often all Atlantic Canada included:

- Establishing a clear differentiation of an offshore fishery and inshore fishery, the latter prosecuted by vessels under 65 feet (approximately 20 m), with specific sharing arrangements to be established on a stock by stock basis, to ensure that the inshore fishery would not be displaced by an expanding Canadian offshore fishery;
- In 1983, almost all major processing companies, including their processing infrastructure and marketing sectors, were restructured into two large companies: (i) National Sea Products (NatSea), with its base in Nova Scotia and an emphasis on flatfish with a significant presence in the cod fisheries as well; and (ii) Fishery Products International (FPI), based in Newfoundland and primarily focused on cod;
- An assurance from the two major companies that community-based processing plants would remain open and operating to contribute to the viability of inshore harvesting;
- Financial assistance for the two major companies to allow each to build a Canadian offshore trawler and longliner fleet to replace the foreign fleets that had been removed with extension of jurisdiction;
- Adoption of $F_{0.1}$ as the default management strategy for groundfish stocks, to promote rebuilding these stocks to provide much large catches of cod and other species, and a special provision for Northern cod to be harvested at 0.8 $F_{0.1}$ until a rebuilding target of 1.2 million tonnes of spawning biomass was reached.

In addition, the federal government committed significant new resources for fisheries science and assessment and for monitoring, control and surveillance, including an observer program for the offshore fleet, dockside monitoring, and vessel inspections (DFO, 1981).

For Newfoundland and its “flagship” Northern cod stock, the sharing arrangement of the cod quota was structured around several carefully negotiated compromises. The key features included:

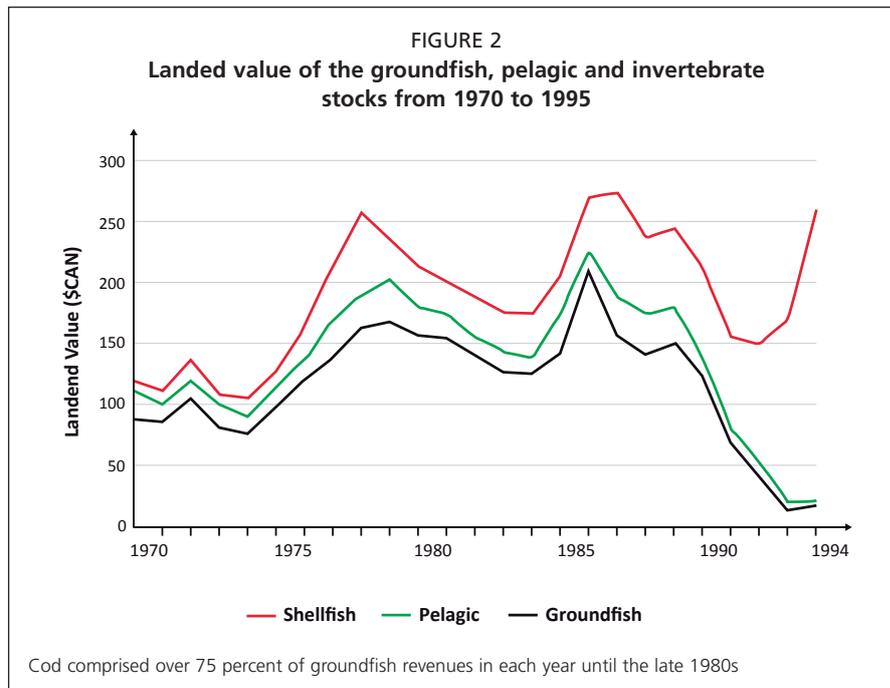
- Whatever the quota for 2J3KL cod, 120 000 tonnes would be taken off the top as an allowance for the inshore fishery. This was not an “allocation” in that it was not limiting on catches by the inshore fishery. If the fishing was good the inshore could continue to fish until either the entire quota for the stock was taken or the fall migration of cod to the offshore resulted in catch rates too low to justify continued effort as weather conditions deteriorated in the fall;
- The offshore share of the annual quota (quota less 120 000 tonnes) would then be available to the offshore trawler fleet. A share of this offshore allocation (starting at 47 000 tonnes) could be taken up to April of each year in a cod-directed fishery on the spawning banks, with the remainder reserved for covering cod taken in a mixed fall fishery, when the trawlers were targeting American plaice, yellowtail and other minor flatfish primarily on the Grand Bank;
- In years when the inshore fishery did not take their allowance in the summer inshore fishery, the difference went back to the stock and was not available to the offshore fleet. In years when the inshore fishery was particularly successful, the surplus would be taken off what was left for the offshore in that fishing year at the end of the summer fishery;
- To reduce the race for fish, after the restructuring of the offshore fishery in 1983 the offshore share of the quota was divided as an “enterprise allocation” between NatSea and FPI. With its focus on cod and basis in Newfoundland the FPI fleet always got the largest share of the offshore cod allocation, most of which they took in the spring cod-directed fishery. NatSea reserved most of their share of the cod quota to cover cod taken as bycatch in the fall flatfish-directed fishery.

This resulted in two very different fisheries being supported by the Northern cod stock. Working out an effective partitioning between them was never simple (Kirby, 1982; Alverson, 1987; Parsons, 1993). By the end of the 1980s the inshore fleet was estimated to support at least 35 000 livelihoods, although employment statistics are not precise. Licenses were mandatory for inshore fishers but were almost an entitlement of any male with a family history in Newfoundland communities, and the number increased by more than 250% from 1980 to 1990. Moreover, licenses were a weak indicator of actual fishery participation, since relatives and neighbours fished together in fluid combinations, and vessels commonly moved up and down the coast, fishing different fiords and nearby deep troughs as the cod moved around the coast seeking prey aggregations (May et al., 1981; Munro and MacCorquedale, 1981; DFO, 1989).

Although crews of the inshore fleet were nearly exclusively male, the community-based fish plants employed many women in the fish processes steps. This made the inshore cod fishery nearly the sole source of employment in many rural communities. Although per capita earnings in the inshore fishery by harvesters and fish plant workers were rarely more than a few tens of thousands of dollars annually, unemployment insurance coverage in the off-seasons of this fishery could multiple that income by as much as a factor of three. This made the fishery often the full source of income for between 35 000 and 45 000 families in Newfoundland and Labrador (Parsons, 1993; Roy et al., 1994).

The offshore fleet taking cod in eventually comprised over 100 large trawler vessels, employing at the peak over 1 000 workers on the trawlers and several hundred seasonal workers in the fish plants. Many of these jobs included time allocated to harvesting and

processing species other than cod, but cod was the backbone of operations for FPI and sufficiently important to NatSea that lack of cod would seriously reduce scale of operations (Carew, 1987, DFO Newfoundland Region, 1993; Kingsley, 1993). The total landed values of major fisheries in Newfoundland from 1970 until the closures are presented in **Figure 2**. At least 75 percent of groundfish revenues came cod, with never more than 20 percent from 3Ps cod, on the south coast of Newfoundland, but mixtures varied each year. The uptake of invertebrate fisheries as groundfish collapsed is illustrated clearly.



3. INITIAL RECOVERY AND COLLAPSE

3.1 Fisheries management measures

At the time extension of jurisdiction in 1977/8, NAFO conducted the assessments of Northern Cod and set the overall quota (NAFO, 1980 to 1986). Although the interactions in the NAFO Fisheries were complex and often difficult Council were complex, *de facto* Canada strove to acquire all quota needed for Canadian fisheries and then allocated “surplus” quota primarily to the EEU, Spain and Portugal. This “surplus” allocation started at 25 000 in 1978 and decreased to under 10 000 t by 1987. NAFO Convention included the principle of consistency between management measures adopted by NAFO and measures implemented by adjacent States. This increased the coherence between management regimes for the Canadian fisheries and for the limited harvests on the Nose and Tail of the Grand Bank, although in several years in the 1980s foreign offshore harvests exceeded the “surplus” allocations by significant amounts (Pinhorn and Halliday, 1990).

The management regime in the 1980s included annual stock assessments by either the NAFO Scientific Council until 1986 and subsequently by the Canadian Atlantic Fisheries Scientific Advisory Council (CAFSAC), a part of the Science sector of the Department of Fisheries’ and Oceans (DFO). The assessments used as primary input data: (i) an annual fall scientific survey and catch at age data from observer records; (ii) vessel logbooks (offshore); (iii) landing slips issued to inshore harvesters; and (iv) dockside monitoring records. These time series were augmented by extensive research

results from tagging studies to measure mortality rates and migration patterns, diet studies, and other life history attributes. Increasingly though the 1980s, physical oceanographic information was also considered in the assessment meetings, although analytical methods to include them in the assessment computations reconstructing or projecting stock dynamics were not available (CAFSAC, 1986 to 1993).

The information from these sources was integrated using analytical methods –that were state-of-the-art for the time– to produce deterministic estimates of numbers at age for the historical period of the data sets, current year, and one year forward projections, assuming status quo population parameters and preliminary estimates of incoming recruitment from classes of 2- and 3-year olds in the research surveys. Initially the harvest strategy used to produce an advised quota for the stock was $0.8F_{0.1}$ (increased to $F_{0.1}$ in 1986). However, as this harvest strategy produced advice for reductions in recommended quotas in the second half of the 1980s, a “50% rule” was introduced, whereby if the catch consistent with fishing at $F_{0.1}$ was less than the quota in the previous year, only 50% of the reduction of quota would be implemented in the coming year (CAFSAC, 1989, 1990). This rule was expected to buffer the inter-annual sensitivity of the stock assessment results to imprecision in the survey and catch data, to make the social and economic performance of the fishery more stable. It was only applied for two years, before the Minister of Fisheries and Oceans took over quota setting based on both the scientific advice from CAFSAC and extensive consultation with diverse interests. The status of scientific advice on $F_{0.1}$ harvest levels and quota decisions from 1986 to closure is presented in **Tables 1** and **2**, taken from the Annex to Rice (2006), where more details on annual decisions is presented.

TABLE 1
Core assessment advice provided, and key actions taken in the Newfoundland cod stock management

Year	Core Science Advice	Key Management Actions
1986	TAC consistent with $F = 80\%$ of $F_{0.1}$ (246 000 tonnes) Indistinguishable statistically from TAC recommended by NAFO (266 000 t).	1987 TAC at 256 000 t consistent with the scientific advice - 10,000 t reduction from the 1986 TAC
1987	Assuming a 1987 catch of 178 000t (with a TAC of 265 000 t), the $F_{0.1}$ catch for 1988 would be 288 000 t.	TAC for 1988 was returned to 266,000 t, the same value as in 1986.
1988	Not released due to Alverson Report recommendations. Special assessment meeting set for January 1989.	First quarter 1989 catch Enterprise Allocation rolled over from 1988 to allow winter fishery to commence. Otherwise wait for new science advice later in year.
1989	status quo catches would yield a high fishing mortality, and the $F_{0.1}$ catch would be 125 000 t.	Reduction in TAC from 265 000t to 235, 00t. and reduction in allocation for foreign catches outside the 200 miles limit from around 25 000t to 0
1990	Confirmed F nearly 0.5, declining SSB, and strong retrospective pattern in assessments. Main advice was to bringing F down rapidly to below 0.35, and to $F_{0.1}$ as quickly as possible.	1990 TAC was set at 190 000 t;
1991	<ul style="list-style-type: none"> • Need to protect 1986 & 1987 year-classes from high F until they had grown more; • Strong recruitment helping the stock grow faster than had been expected in 1990; • Following the multi-year management plan, F would approach the $F_{0.1}$ value by 1993; • The assessment was sufficiently imprecise that it was possible that the stock had not improved at all in the past year 	<ul style="list-style-type: none"> • During 1990 a three-year management plan was adopted, without additional science advice. • Provided for catches of 190 000 t in 1991, decreasing by 5 000 t in each of the succeeding years • Plan stayed in place until moratorium in July 1992

TABLE 2

Status of Canadian cod stocks as reported in the assessment done *closest in time to the decision to close directed fishing on each stock, relative to peak abundance (four-year average) in 1980s*

1	2	3	4	5	6	7
Stock	Value at closure (C)			Value at reopening (R)		
	year	Indicator (C)	%	Year	Indicator (R)	C/R (%)
2GH	NA	No assessment				
2J3KL	1992	SSB (t)	24.3	1998	Offshore Survey biomass**	41.8
3NO	1995	5+ Numbers	8.8	Not reopened		
3Ps	1993	SSB (t)	68.5	1997	Biomass of age 3+	116
3Pn4RS	1993	5+ Biomass	13.1	1997	SSB	96.0
4TVn	1993	5+ Biomass	20.5	1998	SSB	109
4Vn(m-o)	1993	RV # per tow	34.0	1993		
4VsW	1993	3+Biomass	16.1	Not reopened	3+ Biomass	106
4X/5Y*	Not Closed	3+ Biomass	49.1	Never closed	3+ Biomass	141
5Zj-m***	1995	4+ Biomass	39.8	1996	SSB	109

*Stock 4X/5Y is included for illustrative purposes only, to show magnitude of change that did not prompt a closure. Values are for 1993 (column 5) and 1997 (column 7)

** Reopening based on status of inshore component of stock, but no quantitative indicator was available at time of reopening.

*** Georges Bank

Data from CAFSAC and CSAS Research Documents). Col. 3: Indicators of stock status used to trigger a closure. They vary among stocks, due to differences in assessment approaches, but when possible correspond to mature biomass or abundance. Col. 4: Degree of depletion at closure, in percentage. Ratio of the indicators at closure (col. 3) with the best historical 4-year average value. Col. 6: Indicator of cod stock status used to decide on reopening of direct fishing. Col. 7: Value of stock status at reopening (as reported in the assessment done closest in time to the decision to reopen) relative to status at closure (col. 3) in the year of closure *as estimated in the year of reopening*. (http://www.dfo-mpo.gc.ca/csas/Csas/English/Publications/Research_Doc_e.htm). Indicators used in columns 3 and 6 are often different because assessments changed substantially when commercial catches were no longer available.

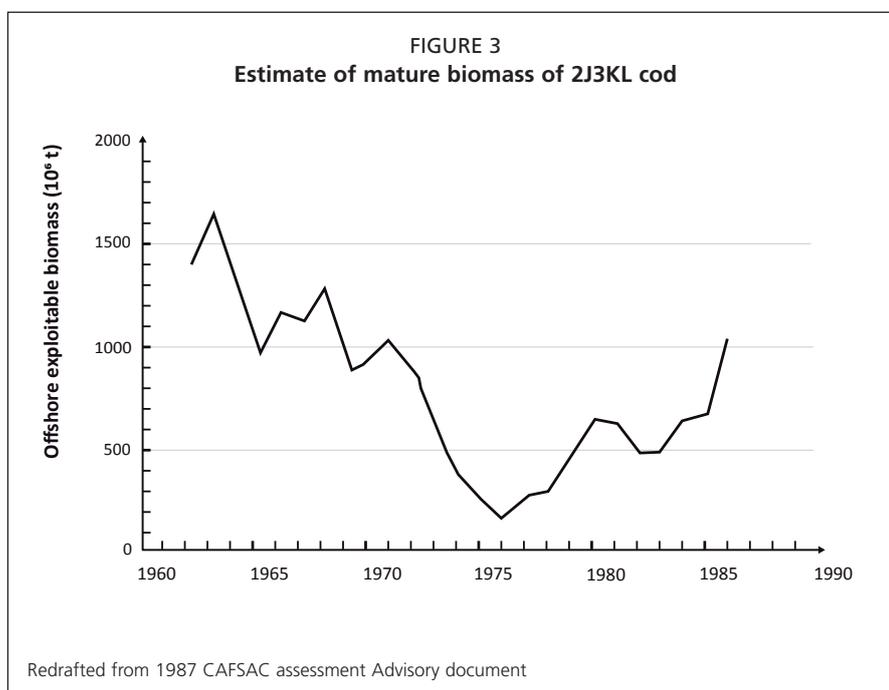
Soon after extension of jurisdiction, the Minister of Fisheries and Oceans began to establish fisheries advisory boards. These included the Atlantic Groundfish Advisory Committee (AGAC), on which the Atlantic provinces, the major fishing companies, the fishermen's unions, and other community interests were all represented. AGAC met several times annually to consider CAFSAC advice, discussed the advice based on their experiences and perspectives, and advised the Minister on a range of harvest measures, including total catches, allocations among fleet sectors, and possible use of various technical measures. These recommendations were not binding on the Ministry of Fisheries and Oceans but were considered seriously in developing annual fisheries management plans².

Taking the advice from CAFSAC and AGAC into account, and respecting decisions by the Minister, the Fisheries Management Sector of DFO developed an annual Fisheries Management Plan for each major stock. The Management Plans for Atlantic groundfish fisheries, including for Northern Cod, specified allocations to all fleet sectors, detail on allowable gears and fishing practices, opening and closing dates and other fishery specific provisions. Implementation of the plan was supported by dockside inspections, mandatory logbooks and inshore purchase slips from landing sites, and observers on offshore vessels. Observers were mandatory on non-Canadian vessels fishing cod in the NAFO Regulatory Area, and coverage of the Canadian fleet increased from under 20 to 100 percent over the 1980s, as debate about stock status and compliance with fisheries regulations increased. When infractions were recorded, DFO was empowered to impose penalties ranging from fines to loss of license, depending on the severity of the infraction (DFO, 1981; Lear and Parsons, 1993; Parsons, 1993; Rose, 2006; Gough, 2007).

² Reports are archived at <http://findingaids.library.dal.ca/atlantic-groundfish-advisory-committee-general-meetings-4>

3.2 Performance under Canadian jurisdiction 1977 – 1992

Following extension of jurisdiction, all depleted cod stocks, including Northern cod, began to increase. A non-binding initial recovery target of 1.2 million tonnes was estimated to be exceeded in 1986 (Figure 3), and that year the target exploitation rate was increased from $0.8F_{0.1}$ to $F_{0.1}$. Catches in all sectors of the fishery increased, although unrest grew as the perception increased that the offshore fleet was gaining a greater share of benefits from stock increases than the inshore fleet. After a particularly poor inshore fishing in 1986 (inshore catch of only 72 000 t) the DFO Minister appointed a Task Group of fisheries and marine science experts to examine the reasons for variation in the inshore fishery performance. This report (Alverson, 1987) concluded that recovery of the Northern cod stock was proceeding, but more slowly than had been estimated. Rather, the Task Group found evidence of a strong retrospective problem in the CAFSAC assessments, such that annual stock sizes had been overestimated by as much as a third or even more in recent years. Regarding the inshore fishery performance, the Report concluded that catches were influenced by a variety of factors other than stock status. Some of the factors were well known, such as age composition of the stock as cohort strength varied between years. However, attention was also given to the impact of physical oceanographic conditions on inshore catches, affecting growth, maturation and migration particularly for cod of ages 3-6. Circumstantial evidence was found that variation of the scale of current concern for the inshore fishery in the 1980s had characterized inshore catches of Newfoundland and Labrador fisheries for at least 250 years, possibly produced by roughly decadal scale environmental variation.



An improved inshore fishery and a very large fall survey estimate for 1986 led to a more optimistic view of stock status, and the improved assessment methods used in the 1987 assessment produced an estimate of spawning biomass well above the 1.2 million tonnes target, and a corresponding quota of 288 000 tonnes (CAFSAC 1987). All seemed well until the 1987 fall survey produced a much smaller biomass estimate that, combined with the rapidly decreasing age composition of the catches, led to a much more pessimistic assessment in 1988 (Baird, 1991, 1992; Bishop and Shelton, 1997).

Inconsistencies among the stock indicators, and the extensive recommendations by the Alverson Task Group for improvements to assessment methods, led to a decision to not release an assessment in 1988. Rather, in January 1989 assessment would be held, using information from both another survey and another year of fishery-dependent data to, to hopefully clarify stock status and trajectory. The 1989 assessment produced a very pessimistic view of a stock already possibly in decline mostly because of weak year-classes in the early 1980s and advised a $F_{0.1}$ TAC of 180 000 tonnes (down from 293, in 1987) (CAFSAC, 1989; Bishop and Shelton, 1997).

The policy responses were a cut in quota to 235 000 tonnes (all from the offshore enterprise allocations), termination of the small international allocation for the Nose and Tail of the Bank (Rice, 2006), and appointment of a second Panel to investigate the entire Northern Cod situation (Harris 1990). In 1990, following another spring assessment that was consistent with the 1989 one, a three-year management plan was adopted (DFO 1991) with a 1991 quota of 190 000 tonnes dropping by 5 000 tonnes in each of the subsequent two years. Inshore and offshore fishing in 1991 was poor, with inshore landings of only 61 000 tonnes and total landings of 127 000 t. Both the 1991 and 1992 CAFSAC assessments found that the fishing mortality F continued to be more than twice the target of 0.20, and the decline in F in the late 1980s had been replaced by rapid increases (CAFSAC 1990, 1991). The initially very promising 1986 and 1987 year-classes were declining very rapidly as they reached commercial size, consistent with verbal reports of extensive high-grading of inshore catches prior to landing catches. However, with no observer coverage of the inshore fleet, this could not be verified. Spawning stock biomass declined at an increasing rate from assessment to assessment until in July 1992, the Minister of Fisheries and Oceans declared a 5-year moratorium on all fishing on Northern cod (DFO 1992). In the following 24 months similar closures or dramatic quota reductions were introduced in all the other Canadian Atlantic cod stocks.

Both CAFSAC and AGAC were disbanded by the Minister when the moratorium was announced, arguing that they had performed ineffectively in their advisory roles. The perception that the industry advisory committee had failed was based on extensive squabbling among inshore and offshore sectors, among provinces, and among various other special interest groups. The perception that the science advisory committee had failed was based on the retrospective problem that had been discovered in the late 1980s, differences from year in estimates of stock status and fishing mortality, and the inability of the science community to provide a consensus explanation of the causes of the decline. There was consensus that overfishing had been occurring for several years and increasing in severity, and that the methods and data sources used in the assessments in the mid-1980s had underestimated fishing mortality and overestimated stock growth. However, lack of consensus on causes of the decline hampered the effectiveness of science advice both in the years just before the moratorium and for several years afterwards, as any consensus advice from the formal advisory processes was extensively qualified, and different science specialist perspectives took many opportunities to criticize arguments of other perspectives and promote the ones they favoured (Hutchings, 1996; Myers et al., 1996, 1997; Rice 2002).

Some experts argued that overfishing and assessment errors alone were sufficient to explain the collapse, and other factors had a best a minor role (Hutchings and Myers, 1994, 1995; Myers and Cadigan, 1995; Myers et al., 1995). During the assessments from 1986 onward, the physical oceanographic data considered at each meeting showed that the Cold Intermediate Layer in the Labrador Current was intensifying, getting colder (below 0.0 °C), deeper and spreading to be in contact with the seabed on the plateaus of

the offshore Banks. Some experts argued that the change in oceanographic conditions could have made large areas of the offshore unfavourable for cod, and directly influence the populations through changes in distribution and/or direct effects on physiological processes (Rose et al., 1994, 2000; Gomes et al., 1995; Wroblewski et al., 1995; Stein and Lloret, 1996; Atkinson et al., 1997; Colbourne et al., 1997; Lilly, 1998; Hutchings, 1999; Rose and Kulka, 1999; Swain et al., 2000; Brander and Mohn, 2004; Rose, 2004). These changes could have decreased stock productivity, making the stock more vulnerable to fishing pressure, leading to overfishing. Several biological oceanographers and experts on lower trophic level processes argued that the oceanographic effects were indirect, and the drop observed in cod productivity was caused by trophodynamic processes arising from changes to the zooplankton community and subsequently in small pelagic stocks (Lilly, 1994; Carscadden and Nakashima, 1997; Dutil and Lambert, 2000; Koen-Alonzo et al., 2007; Sherwood et al., 2007; Buren et al., 2014a, b). Still others noted the substantial growth in pinniped stocks following the near-elimination of the spring seal fishery had greatly increased predation on cod as the cod were concentrated in the decreasing amount of waters with favourable oceanographic conditions. Consequently, the increase in natural mortality, not accounted for in the assessments, had contributed to the assessment inaccuracies and increased vulnerability of the stock to fishing pressure (Lawson et al., 1995; Stenson et al., 1997; Chouinard et al., 2005; Bundy et al., 2009)³.

In the years following the moratorium even more contributing factors began to emerge. For example, although the increasing fishing power of the offshore trawlers was addressed analytically (although not necessarily fully effectively) in the analytical assessments, the inshore catches were merely viewed as produced by static gears: gillnets, traps and pots, longlines, or handlines. There were changes in many of these gears, all improving their efficiency (better twines, improved trap configurations etc) that were never considered in the assessments (DFO Newfoundland Region, 1993). In addition, in the late 1980s, low-cost GPS and fish-finding technologies became available but were never recorded in reporting schemes, despite, as one experienced inshore fisher expressed at an assessment meeting, “*making every 16-year old kid in every community as good [at finding cod] as the best fish-killers on the island*” (pers. comm.). These technological advances may well have played a significant role in how deeply the cod stocks were depleted, but only anecdotal information is available to evaluate their possible effects which have never been seriously investigated.

These debates about the causes of the decline in stock productivity had strengthened the ability of decision-makers to defer action on the science advice to lower fishing mortality substantially. They argued that some of the causes might reverse quickly without government intervention, and the social and economic impacts of dramatically reducing the fisheries would not be unnecessary. The debates provided similarly large impediments to developing a comprehensive plan for reversing the decline in stock status. Even though in 1992 there was no dispute the stock was at a small fraction of its historical size and unproductive, the many possible causes of the low productivity, in addition to simply a depleted spawning biomass left the science advisors unable to agree on a way forward. Similar debate among experts about the causes of decreased productivity occurred with every stock, with a tendency in the early 1990s to assume generally common causes for the declines were shared among all the stocks. This was the stage for the protracted efforts to rebuild the severely depleted cod stocks of Atlantic Canada.

³ Many of the references in this paragraph are dated later than the key years of debate in the early/mid 1990s. At the time relevant research often was not targeted specifically on explaining cod population dynamics, but experts reasonably wanted to link their ongoing research on many topics to the priority fisheries issues of the day. In addition, many of the authors of the ultimate publications were not advocates of any causal explanation of the cod collapses in the early period of the moratorium but trying to present the evidence to inform the debate that began in the early 1990s.

4. THE MORATORIUM 1992-1997

4.1 Management measures and social assistance

The five-year moratorium on fishing Northern cod was extended to most of the other stocks by 1993, and the last Canadian cod stocks in 1994 (FRCC, 1997). The fishing measures were straightforward. No commercial fishing whatsoever was allowed, although loopholes for a small inshore “food fishery” could be conducted by coastal residents (Inkpen and Kulka, 1999). All offshore fisheries for cod were terminated, very strong cod bycatch provisions were imposed on offshore fisheries for other species, and as populations of flatfish also decreased many of these fisheries were also closed. Under pressure from Canada and its claims for greater jurisdiction over all the Grand Banks fisheries (Dunlop, 1994), NAFO adopted a moratorium on Southern Grand Bank cod in 1994 (NAFO 1994), and by 1995 had adopted what Canadian Fisheries Minister Brian Tobin called “the toughest set of control and enforcement measures of any fisheries management organization in the world.» to maintain the closure of all cod fishing on the Grand Banks (Parsons and Beckett, 1997). In general, these measures were effective (Kulka et al., 1995; Kulka, 1997, 1998), as estimates of catches during the moratorium were initially below 11 000 tonnes and, by 1995, below 2 000 tonnes. However, bycatch allowances for cod in other NAFO fisheries did create some opportunity for fishing mortality from fisheries such as for Greenland Halibut, and these poorly quantified fishing mortalities may not have been sustainable on the severely depleted stocks.

In 1995, a sentinel fishery was instituted to monitor the status of inshore cod which by the 1990s were considered to possibly be composed primarily of relict pockets of resident “bay stocks”, not sampled by the fall offshore survey⁴. The sentinel fishery was conducted by a few hundred selected inshore fishermen, who were paid by the government to use standardized gear and effort, fish only in fixed sites, keep detailed logbooks, but could retain the catch for person use or local sale. The sentinel fishery in Division 2J3KL was expected to take no more than 500 tonnes per year, and reported catches never exceeded this value (DFO, 2002).

The Fisheries Resource Conservation Council (FRCC) was created in 1992, to advise the Minister of Fisheries and Oceans on Canadian Atlantic fisheries management. Members were appointed by the Minister, with a careful balance of members from all Atlantic Provinces, inshore and offshore fishing interests, union and business leaders, and academics with expertise in marine ecological, social and economic sciences. It was encouraged to be a deliberative and consensus advisory body and to avoid the regional and sectoral squabbling that was thought to have diminished the effectiveness of AGAC. In addition to annual advisory reports on various fisheries, the FRCC produced several advisory reports on fishery conservation, economic and social issues (FRCC 1996a,b and supporting reports therein). With CAFSAC also disbanded, stock assessments were prepared and reviewed in the individual regions and collected in an annual report on the status of Atlantic groundfish stocks issued by DFO (Sinclair, 1993; DFO, 1993, 1995, 1996a, b).

The potential impacts of the moratorium were subject of an in-depth review, and presented a bleak picture (Moore et al., 1993). The Northern cod moratorium displaced at least 35 000 workers in the fish harvesting and processing sectors. It also undermined the economic basis for the two large offshore harvesting companies,

⁴ <http://ffaw.nf.ca/en/sentinel-program#.Wb7AAGdILF8>

and the additional closures of most other cod stocks increased those numbers by tens of thousands more. This was devastating for the economy of Atlantic Canada, particularly in the outport communities where alternative employment was essentially unavailable. At the time of the initial announcement in July 1992, a five-year social assistance was announced for the affected fishing families and communities. The assistance package started with a CAD 300 weekly payment (reduced to CAD 275 in 1993) to qualifying license holders and plant-workers, and support for retraining for other professions. Over the moratorium, there was substantial evolution of details for additional forms and amounts of compensation, standards for qualifying for assistance, and exiting provisions if those receiving benefits left their home province in search of work, obtained jobs in other professions, or acquired licenses in other fisheries, particularly the crab, shrimp and lobster fisheries that all boomed as the cod collapsed. By 1995 The Atlantic Groundfish Strategy (TAGS), with provisions for permanent license buybacks and vessel replacements was adopted, with payments totalling CAD 31 million in the first round of bidding under the Groundfish Licence Retirement Program (Government of Canada, 1993; Roy et al., 1994; Shrank et al., 1995; Roy, 1997). A voluntary early retirement program for fishermen 56 years and older enabled nearly 1 200 additional fishers to permanently leave the fishery and begin receiving a joint federal-provincial pension (DFO 1996c).

Details were complex and some varied among provinces or even regions or communities within provinces. Many community processing plants were decommissioned, whereas others received financial assistance to retool to process crab, shrimp and lobster. The two major companies both restructured yet again into smaller companies with smaller fleets, targeting shrimp, crab and other non-groundfish species, again with significant financial assistance provided by the federal government. Accounting of how government support was allocated is complex, varied over the moratorium years, and some aspect of “government support” are still disputed. Nevertheless, by the end of the 5-year moratorium, the Auditor General of Canada concluded that the assistance package for displaced participants in the Canadian Atlantic fisheries had amounted to 4.1 Billion Canadian dollars (Government of Canada, 1998; Gough 2007).

During the moratorium years there were great (more than ten-fold) increases in fisheries for macro-invertebrates, particularly shrimp and crab (DFO, 1996a). These stocks were much higher market-value than cod, but in these cases, licenses were tightly limited, so only a small fraction of the fishers displaced from the cod fisheries were able to enter these very lucrative alternative fisheries. Nevertheless, at over CAD 200 million annually, total value of landings from all fisheries in Newfoundland were higher during and after the moratorium than when the cod fisheries were operating (**Figure 2**). This left Newfoundland in an unprecedented social and economic situation. After centuries of outport communities being home to multiple generations of the same families, and almost all residents of the communities having generally equitable, if modest, livelihoods based on the cod fishery, communities saw many residents, particularly the younger workers, emigrate to other provinces, and those that remained facing substantial social and economic inequality, as most families depended on the federal assistance packages, but a few in each community benefiting from a crab, shrimp or lobster license, and enjoying higher income than ever taken from the cod fishery.

4.2 Stock performance

In 1993, the first full year of the moratorium, the assessment was unable to provide a biomass estimate for the stocks (Sinclair, 1993). An area expansion of the fall survey

catches provided an SSB estimate of under 40 000 tonnes for the entire 2J3KL stock, and a total mortality rate (Z) of possibly in excess of 1.0 (DFO, 1993). The 1986 and 1987 cohorts, considered strong in the early 1990s, were now estimated to be below average in strength. With no standard assessment approaches considered to be appropriate under the current stock conditions, a variety of ad hoc and opportunistic methods were investigated, with no clear preferred approach emerging (Atkinson and Bennett, 1994).

A subsequent review in 1995 found the survey-based offshore biomass had declined even further, cod age 7 or older were essentially absent in the offshore, and biological parameters including weight at age and age of maturity had declined by 25% or more since the 1980s but showed slight improvement in 1993 and 1994 (DFO, 1995; Lilly, 1995). A spring hydroacoustic survey also had located a concentration of primarily adult cod in pre-spawning condition in a coastal fiord of Newfoundland (Smith Sound). Estimated at between 10 000-20 000 tonnes, this was the first large aggregation of potential spawners located since 1991 (Anderson et al., 1998, 1999). In addition, the 1994 summer scientific surveys found the first moderate presence of juvenile cod in inshore areas since 1990. The three latter factors, combined with water temperatures increasing to only slightly below long-term averages gave some optimism that the collapse had started to reverse (DFO, 1997; Bratley, 1997; Porter et al., 1998).

The year 1998 marked the end of the five-year moratorium announced in 1992, and a thorough assessment of all the Canadian Atlantic Cod stocks was held in winter. The assessment concluded that none of the stocks showed signs of significant improvement over the years of closure, although a few showed modest improvement. For Northern cod, major conclusions included (DFO, 1998a):

- The offshore fall survey showed a continuing decline since 1994, and a total biomass estimate of 21 000 tonnes, a value between one and two percent of survey-based biomass estimates in the 1980s;
- Cod older than age 5 were rare in both the fall survey and a special offshore sentinel survey using commercial trawl and gill net gears. Age 3+ mortality estimates (Z) from these surveys was 0.77;
- Inshore sentinel survey catch-rates showed variable trends on local scales, and a higher presence of cod ages 5-7 than the offshore surveys, but none showed evidence of strong and consistent recovery of inshore cod, despite the 5-year moratorium. Efforts to develop a biomass estimate from these surveys requires many untested assumptions, and the upper bound on total inshore biomass was 120 000 tonnes;
- Several inshore acoustic surveys produced estimates of between 17 000 and 23 000 tonnes in aggregate for the selected inshore bays that were surveyed;
- Recruitment had persisted at levels far below values before the 1990s;
- Growth and condition factor both had improved slightly since the early 1990s, but weight at age and age of maturity were both less than 75 percent of values in the 1970s and 1980s.

Overall the conclusion was that “*current stock size remains very low in relative to historic levels*” and “*the spawning stock could decline further even in the absence of a fishery in 1998*”. Clearly the five-year quite effective moratorium had not resulted in stock rebuilding, and some further decline in spawning biomass had, occurred.

5. POST-MORATORIUM 1998-2005

5.1 Fisheries Management Measures

In 1998, the DFO stock assessments in winter (DFO, 1998b) and the subsequent FRCC Report⁵ advised the DFO Minister that cod had not recovered and could not support a directed commercial fishery. The Minister announced a post-TAGS restructuring package for the Canadian Atlantic fisheries. This program placed an emphasis on early retirement and license buyouts, supported by an allocation of CAN 730 million (Government of Canada 1998).

Long-term management objectives were announced for the Atlantic Groundfish stocks, including:

- To ensure the conservation and protection of the stocks through the application of sound management practices; and
- In consultation with resource users, to develop Conservation Harvesting Plans (CHPs) and implement management approaches that will enable the stocks to either rebuild to their former TAC levels or maintain existing healthy levels, depending on the stock.

The program included several more operational and management objectives to deal with issues of equity among provinces, priority of the inshore fishery, and addressing bycatch and other sustainability issues. Total licenses had been reduced to fewer than 3 900, with only ten for vessels larger than 65 feet. However, some key social provisions, such as direct payments to licenced fishers unable to fish and plant-workers made idle by the continued catch restrictions, were not continued. Moreover, although the long-term objectives were framed around improving stock status and conservation of the resource, there were no explicit rebuilding targets identified, nor was there even an explicit commitment to ‘rebuilding’⁶.

In terms of actual management measures a new index fishery was implemented, with the rationale of “*improving industry confidence in the stock size estimates and provide a better understanding of migration patterns, seasonal changes and biomass distribution of these cod stocks.*” A cap of 4 000 tonnes was placed on all removals by the index fisheries, the sentinel fishery projects, and bycatches in other groundfish fisheries. In the ensuing years there were numerous minor annual adjustments to these management provisions, adjusting the cap on the index fishery between 3 000 and 5 000 tonnes, altering the regional allocations of the limited fishing opportunities, and other similar minor adjustments. However, the nature of the annual management plans did not change fundamentally. Commercial fishing remained restricted almost exclusively to inshore vessels with total catches of at most a few thousand tonnes, with continued efforts to reduce participation in the fishery. In parallel catches value and participation in the very lucrative invertebrate fisheries continued to expand, becoming almost the sole focus of offshore harvesting with vessels over 65 feet in Newfoundland and Labrador.

5.2 Stock performance

The 1999 assessment of Northern cod generally confirmed the recent past picture of stock status. Given the widespread interest in stock status at the end of the

⁵ <http://publications.gc.ca/collections/Collection/Fs1-61-4-1997E.pdf>

⁶ <http://waves-vagues.dfo-mpo.gc.ca/Library/244152.pdf>

moratorium, the assessments for all Atlantic cod stocks were reviewed together (DFO, 1999a, b) and Northern cod was also reviewed by NAFO (Lilly et al., 1999). There was increasing evidence of substantially more cod in nearshore bays and coastal areas than offshore, and much of the inshore cod did not migrate seasonally to the offshore as traditionally was the case for the stock. Total inshore spawning biomass of the stock was unlikely to be substantially more than 70 000 tonnes. The vessel conducting the offshore component of the new index fishery did not find any concentrations of cod. The inshore component experienced locally moderate to good catch rates in some areas, relative to earlier in the 1990s, but not comparable to earlier decades. The 4 000 tonnes allocation for the index and other fisheries were overrun, with reported catches of around 5 000 tonnes. This level of catch was estimated to have exerted an exploitation rate of between 6-10 percent on the stock, which was above the estimated level likely to have exceeded the rate of possible increase under the conditions of poor somatic growth and recruitment. The assessment concluded that under current conditions prospects for recovery of Northern cod were “*dismal in both the short and medium term*” (DFO, 1999a). Similar or even more pessimistic conclusions were drawn for many of the other cod stocks assessed at the same meeting (DFO, 1999b).

In subsequent years assessments reported comparable findings. Provisions for small index fisheries by commercial fishers continued, with catches overrunning the catch allocation, which was not a binding quota, in most years. Debate continued about causes of the continued low productivity, with explanations of seal predation, small-population recruitment depression, failure of bottom-up tropho-dynamic processes and direct oceanographic impacts on recruitment, growth and mortality, each gaining some support and often also receiving criticism, in 2J3KL or other adjacent cod stocks (Shelton and Healey, 1999; Frank and Brickman, 2000; Swain and Sinclair, 2000; Bundy, 2001, 2005; Rose and O’Driscoll, 2002; Heymans, 2003; Rowe et al., 2004; Bundy and Fanning, 2005; Choi et al., 2004; Chouinard et al., 2005; Frank et al., 2005, 2006; Hammill and Stenson, 2005; Mello and Rose, 2005; Rideout and Rose, 2006; Zwanenburg et al., 2006). No consensus emerged on the relative importance of each of the possible factors, with some scientists arguing that the index fishery alone was of sufficient size to prevent significant rebuilding (Shelton et al., 2006).

The lack of any rebuilding targets remained a concern to those involved in the stock rebuilding. During this period the Precautionary Approach became a more explicit part of fisheries management (FAO, 1996a; DFO, 2004, 2006b, c). In 2003, when Lower Stock Reference Points were being identified for Canadian stocks (Rivard and Rice, 2002), the assessment scientists specified 150 000 tonnes as a spawning biomass that, when reached, could provide sufficient information to conduct analyses to provide an estimate of a biologically based Limit Reference Point, the first explicit reference to a Precautionary Approach for this stock. However, the same assessment concluded that the stock was experiencing an exploitation rate of possibly 20 percent from the existing sentinel and index fisheries and that there was evidence of only slight increase in offshore biomass and declines in inshore biomass since commencement of the limited fisheries in 1998 (DFO, 2003a, b). The slight amelioration in oceanographic conditions towards temperatures closer to normal (DFO, 2003c) and slight increase in year class strengths at the end of the 1990s and early 2000s were not sufficient to justify an expectation of significant stock recovery in the near or medium term. Based on this assessment, the DFO Minister again closed NAFO Areas 2J3KL to all directed fishing both inshore and offshore, unless part of the sentinel fishery or specific scientific research.

By 2005, the assessments still found no evidence of substantial improvement in stock status, with total fishery removals of 5 000 t or more projected to prevent any increase in stock status under the productivity conditions that had persisted since the early 1990s. More lines of evidence were coming available from research projects in tagging, hydroacoustic surveys, seal diets etc. However, the results generally reinforced the pessimism about prospects of Northern (and other) cod stocks. For Northern cod, the research suggested that traditional migration patterns had been disrupted, and that regional differences in cod population parameters and stock status were increasing the difficulty in determining the underlying causes of the whole stock remaining between two and five percent of historical levels for a period of over a decade under very limited fishing. The Stock Status Report did include a reference to a possible neighbourhood of a Limit Report Point for the stock based on historic data, suggesting that such a biological limit would not be lower than 300 000 tonnes (DFO, 2005), nearly an order of magnitude larger than the stock present at that time.

Management advice from the FRCC was generally consistent with the annual scientific advice. There was support for continuation of a small-scale index fishery prosecuted by past commercial fishers, to maintain industry support for the assessment results. Otherwise, however, the calls were consistently for caution in any expansion of the cod fisheries throughout Atlantic Canada, as increasing attention was given to other fisheries, particularly for shellfish and pelagic species, to provide alternative livelihoods as any expectation of large scale return of fishers to cod fisheries waned.

6. COD REBUILDING 2005-2011

6.1 Fisheries Management Measures

In 2005, any expectation of a recovery of Newfoundland cod (and many of the other cod stocks) had essentially disappeared. The Federal and Newfoundland Provincial Governments agreed to establish an independent advisory group, the Canada-Newfoundland and Labrador Action Team for Cod Recovery. It was given a mandate to prepare a strategy that would contribute to the rebuilding and management of the Northern cod stock and the three domestic cod stocks that are adjacent to south and south-western Newfoundland and northern Labrador. Although it had a broad mandate to consider many sources of information, including scientific studies, local and indigenous knowledge, views of ENGOs and the full spectrum of factors possibly involved in the collapse and lack of recovery of the stock, it was explicitly *not* mandated to make recommendations to the DFO Minister on specific management measures. Nor was it mandated to discuss issues related to the allocation of fishing opportunities among provinces, the inshore-offshore splits of opportunities for even limited fishing, or other policy considerations. For the first time it was acknowledged in the mandate that the recovery strategy was to focus on long term recovery and that short-term prospects for any of the stocks were not expected to improve significantly.

After extensive consultation and consideration of many of the possible causes of failure to recover over the past decade, the Action Team tabled its final report. They generally confirmed the conclusions of the annual assessments regarding stock status, although they acknowledged a growing gap between the perception of many inshore fishers that the inshore components were improving, and the scientific assessments concluding inshore biomass had been slightly declining since the mid-1990s. It also considered a much wider range of possible causes of the high mortality rates and poor recruitment, including possible impacts of seismic surveys, oil and gas exploration, and pollution,

but found no strong evidence linking any of those factors to the cod decline and poor recovery (Canada-Newfoundland Action Team, 2005).

The final report also included a recovery strategy for the cod stocks overall, with specific considerations in each stock. The strategy continued to endorse “conservation and sustainable use” as a basic principle, while giving increased attention to “shared stewardship” between industry and government, a stable and transparent process for allocating access to fisheries, and “self-reliance”. The latter term was an indication that further government pay-outs to displaced fisheries were going to be unlikely. Specifically, regarding recovery goals, this report included the views of most industry stakeholders on this issue [rebuilding targets] are as follows:

- The historical high levels for stock parameters such as total biomass, SSB, annual recruitment, etc. do not represent realistic rebuilding targets for these stocks under current circumstances;
- Historical highs should, at best, be used as reference point for what might be possible over the longer term;
- More modest recovery targets should be adopted for a range of parameters such as abundance, stock distribution and age structure - with “stock growth” as the primary objective; and
- The recovery strategy should attempt to achieve an improvement or modest level of growth in these targets over a short-term rebuilding time frame (i.e. 5-10 years).

This discarding of historical stock status as the goal for recovering the Northern cod stocks was justified by the rationale that “*Industry participants fear that long-term and unrealistically high targets imply that fisheries might never resume.* Recovery strategies must address the question ‘recovery for whom’ and must consider the people who depend on the fish” (Canada Newfoundland Action Team 2005: 23).

The Recovery Task Group used these concerns, and reference to a general distrust of the DFO stock assessments by the inshore fishers as their justification not to include any quantitative biological targets nor timeframes in their recovery strategy. Rather they outlined a strategy “*intended to contribute to an improvement or modest growth*” in the stock over the short and medium term. They also acknowledged that DFO had begun to implement Integrated Fisheries Management Plans (IFMPs) for most fisheries, including Atlantic groundfish. These IFMPs included long-term objectives for the fishery, management objectives for conservation and sustainability, and evaluation criteria for management measures and enforcement programs. With provisions for industry participation in many parts of the IFMP process, a more collaborative approach to management was expected. The IFMPs also called for development of an explicit risk-management approach for the stocks, although they explicitly failed to endorse the Precautionary Approach Framework being developed in DFO based on the FAO guidance (FAO, 1996a). They also did call for explicit harvest decision rules, although not delineating the preferred nature or role for such rules.

Specifically, regarding the harvesting of Northern cod, the Recovery team recommended that the moratorium on commercial fishing which has been in place on both the offshore and inshore components since 1992 and 2003 respectively be maintained. However, for the inshore component, they recommended that the moratorium be continued subject to developing on a priority basis a formal process by which government and industry can evaluate the issues, considerations and risks associated with the re-opening of a small-scale fishery on this stock. Regarding specific fishery management measures to

improve the ability to manage fishing mortality, many considerations were discussed, noting that many harvesters felt that no additional measures were needed, as existing measures were already too intrusive and costly to enforce. In the end the report simply *“recommended that the current multi-faceted approach to the management of by-catch, discarding of small fish, etc. be continued and that additional measures be implemented, when necessary, to effectively manage fishing mortality issues related to cod stocks.”*, without specifying the types of factors that would make additional measures necessary. Regarding other measures to promote rebuilding, the Report concluded that no practical measures were known that could be expected to directly enhance recruitment, and none were recommended. Although January to May closures in areas on the south and west coasts of Newfoundland for protection of inshore spawning aggregations were maintained, for Northern cod the only closures recommended were: (i) the existing closure in Hawke Channel off Labrador, originally closed to protect juvenile crab but expanded slightly in area to also protect spawning cod; and (ii) the proposed closure on the offshore Bonavista Corridor where the Grand Bank extends beyond the 200 mile limit. No additional area-based recovery measures were recommended.

The Recovery Action Team did endorse further consideration of an ecosystem approach for all fisheries management, although delineating few features of such an approach other than protection of critical habitat. Measures in place for prey species such as capelin and shrimp were considered sufficient, whereas concerns that seal predation was contributing the elevated cod mortality were passed off to another group developing a multi-year management plan for seals.

This report, the first explicitly named a plan for “recovery” was welcomed by the DFO Minister, and in general formed the basis for management of the Northern cod stock for several years. IFMPs were developed with the types of provisions called for in the report, and generally across Atlantic Canada industry embraced widespread involvement in developing “Conservation Harvesting Plans” (CHP) for fisheries they prosecuted. No commercial offshore fishery for cod was authorized, and bycatches in other offshore fisheries were carefully controlled and fully documented by high rates of observer coverage.

In the inshore, however, fishing opportunities slowly but consistent increased. Although at no time were full commercial mobile or fixed gear fisheries reopened, first the “food fishery” was renamed the “recreational fishery” in 2006, acknowledging its broader reality and given increasing opportunities by more frequent Ministerial announcements of openings for a few days each. The sentinel fishery also received increasing allocations of catch, and as catches increased, it was restructured to remove the financial component of payment for participation and renamed a “stewardship fishery” open twice in a year to over 3 000 inshore fishermen with individual quotas of 2 500 lb (or 1 300 kg) (DFO, 2006a). Many other details were tweaked from year to year, but the main features persisted for the rest of the decade: increasing fishing opportunities inshore, but still with total catches of under 10,000 tons, no directed offshore harvests, and increasing participation of the industry in most aspects of management.

6.2 Stock Performance

Responding to increasing dissatisfaction of inshore fishers with past stock assessments, starting in 2006 the inshore and offshore components of the stock were assessed separately. Conclusions for the offshore were similar those of assessments in the past decade: there was very little evidence of any stock growth, with continued very low

recruitment and non-fishery mortality sufficiently high that cod older than 5 years were very rarely taken in the surveys. For the inshore components, patterns were more variable. The more northerly inshore (2J) indications were for little stock growth and possibly further decline. For the 3KL components however, most indicators of stock size showed evidence of a stable or slowly growing stock. Catches as high as 2 500 t would have only a 0.3 probability of causing further stock decline, and total 4+ biomass had returned to about 23 000 tonnes after a decline during the years of limited commercial fishing in the early 2000s (DFO 2006b).

Subsequent annual assessments continued to show the same general stock status, with total catches between 2 000 and 3 000 tonnes, and little or no growth in either inshore or offshore stock components. This finally began to change in the 2008 assessment (DFO, 2008), when some small drop in natural mortality was estimated (to below 0.5) along with a small growth in age 5+ cod from under 30 000 tonnes in 2005 to nearly 100 000 tonnes in 2007 and the presence of small aggregations of cod in the Hawke Channel migratory corridor and on the spawning banks of 2J. For the inshore, increased catch rates were seen over the period in both the sentinel and stewardship fisheries, but the harvests of over 2 000 tonnes annually were enough to keep stock size relatively static. The same assessments reported substantial warming of bottom temperatures in the offshore, with 2006 well above the long-term average for the area and subsequent years near or slightly above that value. These patterns continued for the rest of the decade. Offshore 4+ biomass reached approximately 150 000 tonnes by the 2010 assessment, with slightly improving year class strengths and decreasing natural mortality. For the inshore, most indicators showed little change, as inshore catches in the stewardship and sentinel fisheries remained around 3 000-3 500 tonnes (DFO, 2010).

Research efforts to explain the slow response of the cod stocks all through Atlantic Canada continued to be inconclusive. Directed studies found evidence supporting the hypothesis that several environmental factors were having some partial role in the stock dynamics. However, the small population sizes made it very difficult to untangle the many factors, both environmental pressures and harvesting (Benoit and Swain, 2008), and additional factors such as evolutionary changes during the period of collapse were added to the mix of possible contributing factors (Olsen et al., 2004).

7. COD – AN ENDANGERED SPECIES? 2011-PRESENT

7.1 Fisheries management measures.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is identified by the Canadian Species At Risk Act (SARA) as the body authorized to assess and recommend a species or population (referred to as ‘designatable unit’ or DU) for listing under SARA. If a species is listed, several very stringent protection measures are mandatory under SARA, to protect individuals and their habitats from harm. However, if COSEWIC recommends a DU for listing, the jurisdiction that must implement the protection measures must assess the potential for recovery of the population were it to receive protection and decide whether to list the species or not. In 2010, COSEWIC recommended the listing of four DUs of Atlantic cod, including Northern cod (COSEWIC, 2010), triggering such a recovery potential assessment. The review concluded that listing was not appropriate (see **Section 7.2**). However, DFO nevertheless reviewed all management measures in place, to ensure that the stock was receiving sufficient protection to ensure that recovery would proceed at or near the most feasible rate given the state of the stock and the environmental conditions. In the end, it was concluded that no additional management measures were needed (DFO, 2011a).

In part triggered by the recommendation for listing by COSEWIC, the Fisheries Resource Conservation Council (FRCC) undertook a major review of the patterns of recovery in many of the groundfish stocks that had declined in the 1990s. The report entitled: *Towards Recovered and Sustainable Groundfish Fisheries in Eastern Canada* was released in 2011 (FRCC, 2011). It provided recommendations for promoting the rebuilding of both the groundfish stocks in Atlantic Canada and more sustainable fisheries on those stocks, when they had recovered. Much of the focus of the recommendations was to endorse measures already in place to “do no harm”, but also stated clearly that measures to actively promote rebuilding were also necessary. Features in such activities was a call for targeted reductions of grey seal populations. For cod stocks in the Gulf of St Lawrence and off northern Nova Scotia there was widespread belief by inshore fishers, and some scientific evidence (although far from consensus), that seal predation was a major contributing factor to the elevated rates of natural mortality in the cod populations. The range of grey seals barely overlaps with the Northern Cod range, however, so grey seal predation was never considered a major factor in Northern cod mortality. The FRCC report summarizes the arguments from the early years of the moratorium that harp seals might be a factor in the elevated natural mortality of Northern cod and explicitly endorses the conclusions of subsequent assessments that evidence did not support that hypothesis. Rather for Northern cod the primary proactive recommendation for promote rebuilding was to have existing fisheries on forage species, particularly capelin, covered by the provisions of the recently adopted DFO Policy for New Fisheries on Forage Species (DFO, 2009) to deter any expansion of this small fishery in future, Otherwise the relevant recommendations for Northern Cod were the endorsement of the Precautionary Approach, use of Harvest Control Rules, and application of the Limit Reference Points that had recently been estimated for all the Atlantic cod stocks (DFO, 2011b).

The FRCC report was accepted by the Minister of Fisheries and Oceans. However, in October of that year, funding for the FRCC was discontinued. The Minister argued that the direct involvement of the fishing industry in development of IPMP and CHP had reached a stage where the FRCC was no longer necessary. Consequently, the guidance in the FRCC document which, for example, made explicit use of Limit Reference Points estimated by DFO Science in the mid-2000s but not adopted in management, was not directly translated into management actions. Many of the management recommendations for short term actions were in fact not substantially different from the measures currently in place. The longer-term recommendations for stock recovery were tied to recommendations for restructurings of the fisheries and processing sectors that were deferred until the Fisheries Act was revised and may be considered in the future.

For actual management measures of the inshore fishery, the set of measures in the Recovery Plan period were generally continued. As the stock continued to increase the stewardship fishery allocation per license continued to increase, from 1 135 kg to 1 475 kg during 2006-08, 1 700 kg during 2009-12, and 2 270 kg during 2013-16. The recreational fishery for personal use had catches per day increased from three to five cods, and the number of days the recreational fishery was open each year increased slightly over the years as well (DFO, 2012). Bycatches in inshore fisheries for other species reached nearly 600 tonnes by the later 2000s and bycatches the NAFO areas outside the 200 nm limit also increased from approximately zero in the early 2000s to 80 tonnes by late 2000s and nearly 300 tonnes in 2011. Although no additional measures were implemented to deter bycatches in inshore or offshore fisheries, all harvesters were encouraged to avoid cod bycatches as much as possible and these bycatches dropped to under 200 tonnes after 2011.

7.2 Stock Performance

Several developments in the science advisory framework for Canadian Atlantic fisheries in 2011 affected context in which evaluation of stock status and recovery for commercial stocks in general, and particularly for Newfoundland cod. First of these was an effort to develop Limit Reference Points for all major Newfoundland groundfish stocks (DFO, 2011b). Expanding on a framework developed several years ago (DFO, 2006c) many options were considered. Several approaches to provide values for SSB for the stock were considered and rejected, but in the discussions a few key points emerged that are germane to defining what was considered a healthy and productive stock. One was that the evidence was very strong that Northern cod showed multi-year, and possibly multi-decadal regimes of higher and lower productivity and although spawning biomass may play some role in the stock productivity within regimes, ecosystem changes are the major factor between them. However, as in the early 1990s, when efforts were being taken to account for the cause of the cod collapses, there was still no consensus on whether the regime changes are driven primarily by physical oceanographic changes (that directly affect many species in the system, directly changing their productivities and causing predator-prey relationships to adjust), or by changes in food web relationships, with the physical oceanographic effects acting more like a trigger for the trophodynamic changes. Without consensus on this point, determining regime-specific biomass reference points was not possible. There was agreement that earlier “preliminary estimates” of 300 000 tonnes –from when the PA framework was developed– remained a reasonable guide for stock status where productivity might be expected to improve, but that a LRP that would help to avoid the stock entering an unproductive state would be higher by at least 100 000 tonnes and possibly more.

A second key conclusion was that whatever improvements might be noted in the inshore, Northern Cod could not be considered to have recovered its potential for high productivity until the offshore components of the stock had increased substantially. On this basis, the meeting also accepted an average catch rate of 55 kg of cod per tow in the standard fall survey as a possible index-based Limit Reference Point for the stock. This was justified by this value being the average value for the survey index during the mid-1980s, the last period when the stock produced average or above average year-classes. An area-based expansion of this catch rate would provide an SSB of 660 000 tonnes, so that a “recovered” state would be at least well above 300 000 tonnes and possibly twice that level. Application of this standard has proved difficult and controversial, because of a major gear change in the surveys in 1995, requiring analytical adjustments based on a single season of comparative fishing when post-1995 and pre-1995 survey catches are compared.

Also, in 2011, the Recovery Potential Assessment required for stocks recommended by COSEWIC for listing, was conducted (DFO, 2011a). Again, it reviewed sources of information on the collapse and subsequent dynamics of the stock. In addition to the patterns discussed in most annual assessments, it noted particularly three features:

- The contraction of the spatial distribution of the stock to less than 25% of its historical offshore range at its lowest point in the collapse process, in the mid-1980s and expansion to around 75 percent of its range by the end of the 2000s;
- The elevated total mortality rate on all ages, but particularly on ages 2-4, during and after the collapse, but returning to values near 0.2 for the younger ages by the mid-2000s;
- The collapse in annual year-class strengths from 1990 until some modest increase (to levels still not 10 percent of an historical typical year-classes) in the second half of the 2000s;
- A decline in age of 50 percent maturity of over half a year in the 1980s, for which no improvement was observed.

Projections of short term stock status indicated continued improvement until 2016, using the productivity parameters considered to apply at the start of the 2010s. Beyond the mid-2010s further stock performance would depend on what assumptions were made on natural mortality rate, the continued expansion of the stock in its historical offshore range, and on whether recruitment continued to improve. Expansions of fisheries would increase Z and decrease the rate of stock rebuilding in all time-frames, but with current levels of harvest there was a high probability of continued stock increase.

These reports marked a change in approach to evaluating stock status in the region. Subsequent assessments considered a wider set of species and environmental indicators in a somewhat more integrated manner. The 2013 science evaluation of prospects (DFO, 2013, 2014) looked at both the shrimp and crab stocks that had supported the commercial fisheries for the past 15 years, and the cod and capelin stocks that had both been severely depleted over the same period, as well as at more information about the physical oceanographic conditions. It confirmed the warming trend in bottom and water column temperatures that started in the mid-2000s, as well as the return of total mortality rates of cod to historical levels and improvements in growth rates and recruitment. Offshore and total biomass estimates remained uncertain but definitely improved over the previous two decades, although still well below the LRPs now being used for reporting on stock status.

The 2013 report also reported a more than 5-fold increase in the index of capelin abundance offshore in the past 2-4 years, consistent with a value over 1 000 000 tonnes, after having indicated a capelin stock below 200 000 tonnes since 1990, although this “high” index value was still less than a third of its typical values in the 1980s. On the other hand, all indicators of both shrimp and snow crab continued to show that declines in stock biomass that had started between 2005 and 2007 and were initially precipitous for shrimp. Clearly the status of the Northern Cod was continuing to improve but was viewed as part of a change in the entire ecosystem and not solely as the recovery of a single depleted stock.

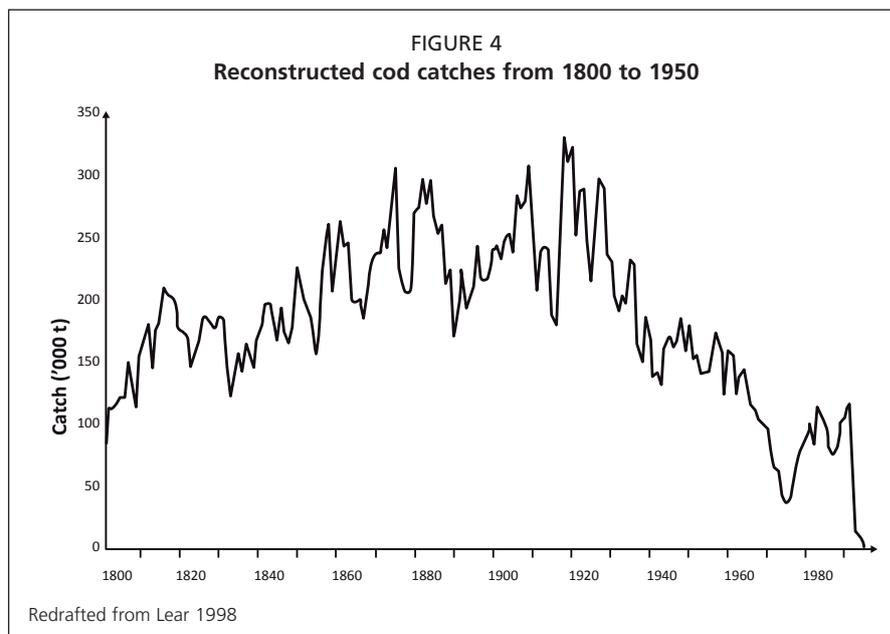
The targeted analytical assessment of Northern cod in the same year (2014) provided more detail on the cod status, including SSB estimates for only a portion of the stock that exceeded 130 000 tonnes, and provided a warning that the recreational fishery had been growing rapidly in recent years to possibly equal the harvest being taken in the regulated and monitored inshore commercial stewardship fishery. Together these removals might be large enough to impact future growth of the inshore stock components. In addition, continued low capelin abundance remained a concern, although experts continued to debate many details of the role of trophodynamics in the weak stock recovery (Buren et al., 2014a, b; Mullowney and Rose, 2014).

Notwithstanding claims that the corner had been turned for Newfoundland cod (Rose and Rowe, 2015) a cautious attitude had continued to the 2016 evaluation of stock status (DFO, 2016). That assessment estimated an SSB of over 300 000 tonnes and increasing, with fishing mortality overall around 0.014 and stable or decreasing. Natural mortality was substantially below 0.3 and possibly declining, whereas somatic growth was the highest observed in nearly 30 years. The oceanographic warming had slightly reversed in the most recent years, but was still within the range when, historically, the stock had been productive. The stock was projected to continue to increase in the near future, even with small increases in harvesting, and would be likely to exceed the various values being considered as an LRP in the near future. Hence, although full recovery of the stock to historical levels was still far in the future, it was likely that before the end of the decade, stock would have returned to condition where productivity was not impaired.

8. CONCLUSIONS AND LESSONS LEARNED

The collapse of the Canadian Atlantic cod stocks has become one of the most widely known failures in the modern era of natural resource management, and no part with wider attention than the Northern Cod of Newfoundland and Labrador. Thirty years after the declines began, there is still no consensus among experts on the extent to which bottom up, top-down, and solely physical oceanographic changes contributed to overfishing, resulted in the magnitude of collapse, or even which of the factors initially triggered the decline and created the context in which the other factors were brought into the dynamics, each amplifying the pressures from the others. There is no disagreement that delays in detecting the problems and in gaining industry buy-in to available options created a policy-making environment amenable to delaying decisive management actions until the stocks declines had become collapses. There is also nearly universal agreement among experts that major changes at the ecosystem scale occurred in the late 1980s and early 1990s along the entire Northwest Atlantic, even if the exact causal linkages of the changes in ecosystem regime to cod stock dynamics continues to be debated. Whether faster and more decisive policy and management actions could have at least mitigated the magnitude of collapse, even if some level of decline had been unavoidable, will remain a matter for speculation and modelling scenarios far into the future.

These dynamics of the marine ecosystem and the decision-making processes created a far from ideal environment for planning and implementing plans to recover the cod stocks. This was particularly true for the Northern cod stock, where recovery was to be undertaken in very cold oceanographic conditions, with a greatly depressed stock of capelin, traditionally the major forage species for the stock. Analyses of more than two centuries of cod productivity (Figure 4) indicate that regimes of different productivity have characterized to stock for the entire period and the effects of the very poor productivity conditions in the early 1990s had increased greatly when combined with the unprecedented extent of overfishing.

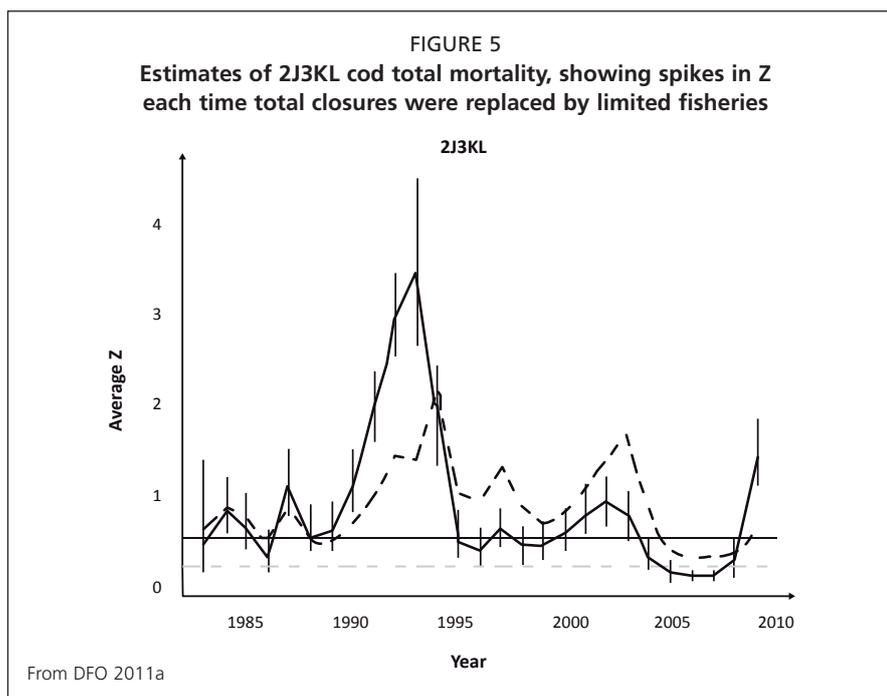


In addition to the very unfavourable state of the natural environment, the socio-political environment was also unfavourable for swift and effective recovery. There was distrust between all combinations of science and management experts, fishing industry participants, and decision-makers. Moreover, each group had substantial

internal discord, with disagreements among experts from different specializations, between inshore and offshore fishers, and between federal and provincial politicians. Even if all perspectives agreed rebuilding was the top priority, there was ample opportunity to spend time and effort on allocation of blame for the collapse and on burden-sharing for the costs of recovery, and these opportunities were taken in many planning settings. Despite this unfavourable policy environment, some decisions were made that, in retrospect, were wise.

The first important decision was the total moratorium itself. With the cod stock depleted to less than one percent of its historical size, evidence soon emerged that much of the residual population was concentrated in small areas. Had even small scale directed fishing been allowed, these also could have been depleted as they were found, with possibly loss of what residual spawning potential remained in the stock (noting that it has not been established if the improvements in stock status in the 2010s were the consequences of spawning by these small residual inshore aggregations).

A second important decision was to provide a very large social assistance package to the harvesters and plant workers displaced by the moratorium. Although some harvesters and plant-workers were able to get work in the highly lucrative invertebrate fisheries that expanded greatly during the period when cod was depleted, this represented far less than a third of the employment that had been available in the cod fishery prior to the collapse. Had the TAGS program of social assistance not been available certainly the impacts of the moratorium on the coastal communities and fishing families would have been far worse (Government of Canada, 1998; DFO, 2001; Gough, 2007). In addition, but more inferentially, without the TAGS program the moratorium is unlikely to have been able to keep fishers off the water for the initial five years of the moratorium. This inference is supported by the evidence that for the 5 years following the moratorium, and again in the late 2000's when even small scale commercial fisheries in the inshore were opened, catch limits were usually overrun, there was suspicion of widespread unreported catches being disguised with legal catch, and pressure on the remnant stock immediately increased (Figure 5).



The widespread social assistance did not continue after the initial 5-year moratorium. Rather, funding to decrease the impact of the collapse on fishery participants became strongly redirected towards license buy-back and early retirement programs. These programs were undoubtedly valuable in reducing demands to reopen the cod fisheries further or provide fishing opportunities by increasing effort in other fisheries. With licensed inshore fishers decreased by nearly an order of magnitude by the early 2000s the need to reduce potential fishing effort as the stock recovered was addressed effectively, although it is difficult to isolate how large a role the financial incentives played, relative to fishers either simply giving up expectations of ever returning to fishing as a livelihood or finding alternative careers outside the fisheries. Whatever the combination of causes, the reduction in the number of fishers pressing to return to the cod fishery was valuable in allowing the stringent catch restrictions to be maintained for over two decades, although without the social assistance available through the moratorium years, the number of fishers leaving may have been even greater and the effects experienced even earlier.

The change in governance of the fisheries also made a valuable contribution to keeping the buy-in from fishers and coastal communities to support the moratorium and then maintain low fishing effort on the stock. The FRCC was structurally more inclusive than its predecessor AGAC, with its membership not as closely slotted as representatives present to argue for specific interests. In addition, some of the members were always experts in the natural and social sciences so there was technical capacity internal to the FRCC, as well as the ability to call on external experts in government and academia as needed. Perhaps more importantly, the FRCC held extensive public consultations on the issues it was considering, providing key and reciprocal communications channels. The consultations were fora where communities and interests could bring their concerns and be heard by a group composed of individuals they knew shared many of their concerns and experiences. They also gave the FRCC members a much broader range of inputs to consider in their deliberations and recommendations than just briefings by “experts” and a few leaders from the various interest groups. As an advisory body, the FRCC did not have actual authority to make decisions, and it can be argued that, in some cases, the federal Ministers may have used the FRCC recommendations as a rationale for decisions that the Ministry was going to make in any case, but expected to be unpopular, in hopes that any dissatisfaction with the decision would fall on the FRCC and not directly on the Minister. Nevertheless, the FRCC recommendations did help to structure a more constructive and participatory discussion prior to decisions being made, and such discussion was very likely to have facilitated both the quality of the decisions when taken, and the ability to implement them afterwards.

Two other developments in Canadian fisheries management more generally also contributed to keeping fishing on a small scale while the stock was most severely depleted. The first was an endorsement of the Application of Precaution in Science-Based Decision-Making by the federal government generally in 2003. This new policy prompted the initial efforts with DFO to identify Limit Reference Points for all stocks (DFO, 2004, 2006b) and even though, as described above, their inclusion in science advice and decision-making only progressed gradually in the years thereafter, by the 2010's the status of the stock relative to its tentative precautionary LRPs was a central factor in management advice and discussion.

The second was the growing adoption of a more ecosystem-based approach to management and advice through the 2000s. This, again, was a gradual process, foreshadowed even in the late 1980s by discussions about how the physical

oceanographic environment was changing, and what those changes might mean for the productivity of Northern cod. Through the 1990s and 2000s, the stock assessments, the FRCC discussions and the advice from each source, gave steadily increasing attention to the status of cod prey populations, the possible impacts of seal predation, and the overall oceanographic environment. By the end of the 1990s, these discussions were building an understanding in both the political settings and communities that recovery of the cod stocks was not going to be swift and easy, helping to manage expectations about how quickly the constraints on harvesting should be lifted. By the time: (i) COSEWIC made its recommendations on listing the Northern Cod stock as endangered; and (ii) Major ecosystem considerations were such an intrinsic part of the analyses of the recovery potential for the stock that it was concluded that major revisions to management approaches to accommodate more ecosystem considerations, would not add significantly to the likelihood or speed of cod recovery. Tools such as MPAs were unlikely to offer significant incremental value to the spatial measures adopted in the previous decade to protect spawning and migrating cod aggregations when they were particularly vulnerable to targeted fishing.

It took 25 years, but with recovery of Northern cod to at least above its LRP, we can conclude by asking what did cause the recovery that finally began between approximately 2005 and 2007. No new management measures were implemented that could have suddenly changed the trajectory of the stock. Rather survivorship of all ages, but particularly juveniles, improved, followed quickly by increases in somatic growth rates, year-class strengths, and spatial occupancy by the stock of its traditional range. Just as debate persists about the roles of the various ecological pressures on cod during the collapse, debate is ongoing about whether the change in cod is due to improvements in prey populations or if the changes in the larger fish community – shrimp and crab declining, cod, flatfish and capelin increasing – are all driven initially by the changing physical oceanographic conditions, with the trophodynamic changes reflecting subsequent adjustments of predators and prey to their altered respective productivities. The precipitous drop in shrimp productivity well before the Northern Cod stock had grown to a size that would exert greatly increased predation pressure on the shrimp, argues for a major role of physical oceanography in at least triggering the respective increases or decreases in the stocks. The relationships are still being examined at the end of the 2010s, and the jury is out on the ultimate outcomes.

The ultimate outcomes for the coastal communities and fisheries are also uncertain. The numbers of inshore small-scale fishers have been reduced from over 40 000 to under 4 000, and the large-scale fisheries have greatly reduced and redirected their effort to invertebrates and other groundfish. The fishing communities have lost many residents, particularly from the younger generation, as people left for better career opportunities (Government of Canada, 2004; FRCC 2011). With federal government policies now promoting “professionalism” and “self-sufficiency” in fisheries, the policy environment does not favour a return to the fisheries of the 1970s and 1980s, either inshore or offshore. Nevertheless, if the ecosystem regime changes continue, currently lucrative invertebrate fisheries will have to scale back, and the greatest opportunities may exist in expanded groundfish fisheries, including for cod. It was much more changes in the environment than changes in fisheries policies (beyond consistently restricting all catches as much as possible) that eventually has prompted the strong but incomplete recovery of Northern cod. However, it will be policies and the economies of other sectors and regions that will have great influence on whether the fisheries on that stock recover and how.

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MPAs, fishery closures and stock rebuilding

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Abstract

Few regions on earth remain untouched by fishing activity. As such, effective long-term no-take marine reserves (NTMRs) and other area-based management systems that restrict fishing serve as vital reference areas for assessing the magnitude and recovery potential of marine ecosystems from human influence over both space and time. Much of the peer-reviewed literature and meta-analyses demonstrate variable but overall positive responses to such protection for fish and some other taxa. These include significant increase of stock species abundance and biomass within boundaries, cross-boundary spill-over of adults and larvae, and increased egg production. A reserve may meet its biodiversity objectives and contribute to fished stocks, however, determining the extent of that contribution depends on several factors. These factors include: understanding and monitoring the species biology, and the effectiveness of and compliance with management, and changes in fishing pressure external to the NTMR or other type of spatially-managed area from which some fishing activities are excluded. This presents significant data and cost challenges of scope, scale and monitoring method for assessment of NTMRs and fishery management throughout the, often extensive, range of the stock. The situation is one in which proof is hard to establish and absence of proof of effect is not proof of absence of effect (the issue of Type I and Type II errors in experimental design).

The response of marine biota to the implementation of a fishery closure typically take 3 to 5 years to appear. In contrast, the loss of access to fishing opportunities is immediate and is particularly challenging for fishers with high dependence on it. This raises the need to engage with stakeholders to address issues such as displacement of effort to other areas already subject to fishing and may require compensation or support for development of alternative economic activities to achieve effective temporary or permanent removal of fishing effort. In situations where the benefits from closures are uncertain, scientists, planners and managers need to express due caution in forecasting their contribution to stock rebuilding. Unrealistic expectations and unrealised benefits harm relationships with stakeholders and undermine future management relationships that depend on trust.

Performance evaluation of NTMRs or other area-based management measures in relation to the different primary objectives of conservation of fish stocks and holistic conservation of marine biodiversity presents data challenges. These challenges are exacerbated in the broader multi-sectoral context of blue economy uses and land-sourced and atmospheric impacts that affect marine biodiversity. The scope, scale and precision of data required for the management and evaluation of fish and shellfish

stocks throughout their range differ from the data-reporting required to evaluate and achieve holistic biodiversity conservation within protected areas and networks of protected areas. This mismatch limits the capacity to discriminate the effect of a protected area on stocks that function at large spatial scales. A convergence of the conservation and fisheries science communities is required to scale data collection appropriately to understand more fully the contribution of protected areas to the conservation of commercially exploited species.

1. BACKGROUND

For most of history prior to the 19th century, fisheries have been locally based, seasonal and often varied considerably according to longer-term natural variations in species availability. Consequently, there was a prevailing understanding that the scale of human activities was unlikely to have significant impacts at an oceanic scale. Historical access (e.g. exploitation of cod on the Grand Banks in the 15th century) of distant fish stocks was constrained by vessel capability, the high risks of seafaring and challenges of product preservation (Jennings et al., 2001). Late 19th century concern at the decline of fish stocks in the North Sea led in the 20th century to the development of marine science, and concepts of management for conservation of fish stocks and more recently biological diversity.

The vulnerability of marine ecosystems to the application unsustainable human pressures is increasingly evident. Wild caught fisheries peaked in terms of landings by the 1990s followed by a decline to c 80 Mt at present (FAO, 2016). Natural refuges have reduced because of the increases in the range and scale of fishing capacity, precision of navigation and fish finding technologies, and degradation of habitat as a secondary effect of fishing. There is also an increasing range of economic uses of marine space and coastal lands that impact (but do not depend on) on the productivity or well-being of marine ecosystems (e.g. land-based pollution, coastal developments, shipping, renewable energy installations, mining). The links between biodiversity and ecosystem services such as primary and secondary production (including fisheries production) are supported by a variety of lines of evidence (see Worm et al., 2006). For these reasons, there has been a steady convergence of fisheries and biodiversity conservation management objectives over the last 20 years. Hence it is no surprise that some of the tools used by managers to achieve these management objectives have considerable overlap, e.g. the use of area closures or fishing gear restrictions.

The concept of using closed areas to limit human activities is not new. Customary management of local fisheries includes examples of the use of permanent, seasonal and temporary closures (e.g. Johannes, 1981). Nevertheless, the more recent concept of closures for the protection of biodiversity has often generated conflict between fishing and conservation interests. This is arguably a distraction from the shared interest in sustaining biodiversity and food production in the context of increasing human activities and impacts affecting marine space.

In this chapter we present a summary of the state of knowledge and challenges of assessing the effects that areas closed to fishing may have in terms of fish stock rebuilding irrespective of whether the primary objective of the closures was biodiversity conservation. We provide brief overviews (but not a comprehensive survey) of reported outcomes of the utilisation of different categories of marine protected areas that exclude fishing through no-take marine reserves (NTMRs) or other management systems that include area closures or preclude some form of fishing from a specified area of the sea. NTMRs are also referred to as No-Take Zones, or MPAs categories I and II, as defined by the International Union for the Conservation of Nature (IUCN) classification (Day et al., 2012) and they exclude all extractive forms of activity (e.g. fishing).

2. POLICY DRIVERS AND INEVITABLE TENSIONS

The primary objectives of fish stock and biological diversity conservation differ but both depend on the wellbeing of the marine environment in the face of the increasing range and extent of human uses and their associated impacts on marine ecosystems. The extent to which a spatial closure may contribute to fish or shellfish stock maintenance or rebuilding depends on the biology of the target species; the management of the fishery throughout its range and the ability to achieve user or stakeholder engagement and compliance with fishery and MPA measures.

The international framework for conservation of marine fish stocks and biodiversity is provided through the United Nations Convention on Law of the Sea (LOSC) and the United Nations Convention on Biological Diversity (CBD).

- Article 61 of LOSC refers to conservation of “living resources through measures designed to maintain populations of harvested species at levels that can maintain the maximum sustainable yield”. The primary objective of fisheries management is to achieve maximum sustainable yield of living natural resource stocks;
- Article 8 of CBD identifies protected areas as a primary means of addressing conservation of biological diversity. The primary objective is conservation of biodiversity which is defined as: “diversity within species, between species and of ecosystem” at levels from populations, species and communities to ecosystems.

The IUCN definition of a marine protected area is: *A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.* The IUCN has six broad categories of protected area (Dudley, 2008).

Day et al. (2012) have provided guidance on how IUCN categories should be applied and interpreted in the marine context of sustainable use, cross-boundary and multi-directional linkages of the seabed and water column. For all practical purposes, Marine Protected Areas (MPAs) are spatially defined areas in which human activities are more explicitly controlled than outside them. Impact assessment and specific conditions are typically required for a new or altered form or level of activity. For any activity the control may be defined within a spectrum ranging from total prohibition of any use, to specific uses allowed with permit, subject to environmental impact assessment and consequent conditions, and to uses that are allowed subject to any general constraints or operational conditions defined in regulation.

The most restrictive conditions exclude fishing in IUCN MPA categories I and II or NTMRs (also referred to as No-Take Zones). Category I excludes all access and activities other than for approved research and management actions while category II provides for access and enjoyment of areas free from extractive activities. Fishing activities with significant habitat impact such as trawling and dredging are excluded from reserves aimed at habitat protection (IUCN category IV). Multiple-use areas (Category VI) are consistent with the overall conservation objective that provides for verifiably sustainable human use and impacts. Such management systems often include buffers zones with higher levels of protection than other parts of the same system. The term MPA is often used as a generic name for NTMRs, creating regrettable confusion.

The different concepts of conservation implicit in international targets for restoration of fish stocks and marine biodiversity conservation create further regrettable confusion. Targets have been set and extended since the 2002 WSSD Plan of Implementation (§31

and 32). The most recent reiteration was contained in United Nations Sustainable Development Goal 14 (United Nations, 2016):

- 14.2 *By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans;*
- 14.4 *By 2020, effectively regulate harvesting, and end overfishing, illegal, unreported and unregulated (IUU) fishing and destructive fishing practices and implement science-based management plans, to restore fish stocks in the shortest time feasible at least to levels that can produce maximum sustainable yield as determined by their biological characteristics;*
- 14.5 *By 2020, conserve at least 10 percent of coastal and marine areas, consistent with national and international law and based on best available scientific information.*

The target of conserving 10% of coastal and marine areas reiterates the CBD Aichi Target 11 of the UN Convention on Biological Diversity (CBD, 2011)¹. This target is not strictly about MPAs, as it calls for the consideration of “*other effective area-based conservation measures*” This definition opens the possibility to assess the contribution to the conservation of biodiversity that could be made by implementing spatial area closures as fishery management tools. The use of closures in fish stock conservation mostly addresses protection of fish stocks at vulnerable life cycle stages and is designed to minimize and mitigate the collateral impact of fisheries on biodiversity.

The use of NTMRs in biodiversity conservation provides for holistic protection of marine biodiversity in precautionary networks of healthy representative marine ecosystems to provide resilience in the face of increasing human impacts and environmental change. Typically, there is competitive tension between the social, economic and political drivers of fish stock and biodiversity management systems. Depending on context, a closure intended to achieve one objective may have positive, neutral or negative effects for the other. The different shades of meaning of “conservation” reflect constructive ambiguity in developing text to address different and potentially conflicting sectoral priorities.

For the purposes of this chapter, we focus primarily on the performance of NTMR areas that are closed for long periods of time (years) and their apparent roles in fish stock rebuilding irrespective of whether or not the primary objective of the closures was biodiversity conservation or fishery management. Whilst our main focus has been on the usefulness of NTMRs, we have also examined the use of habitat protection zones within MPAs that eliminate bottom gears but enable continuation of other fisheries. We explored this literature to understand to what extent these areas can have significant benefits for conservation of benthic biodiversity (Sciberras et al., 2015)

3. DATA CHALLENGES FOR PERFORMANCE ASSESSMENT OF NTMRs IN FISH STOCK AND BIODIVERSITY CONSERVATION

The performance criteria, management arrangements and monitoring of MPAs are elaborated to address the primary objective and scale of holistic biodiversity protection of a site or network. They differ markedly from those of fisheries surveys that are designed to assess population status across much larger geographic areas and across

¹ Target 11: By 2020... 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures...

time. Thus, the different sampling approaches create inevitable difficulties when trying to determine changes in population status that might be attributable to the use of MPAs or other spatial restrictions.

Effective assessment of the performance of MPAs worldwide is constrained by the high proportion of poorly resourced and inadequately enforced “paper parks”. Edgar et al. (2014) used an extensive database to investigate the ecological response of fish communities within MPAs and concluded that when there was an absence of evidence of recovery of fish biomass, in the case of many MPAs this could be attributed to ineffective MPA compliance and high spatial variability in fish densities. It is also noteworthy that much of the literature has tended to focus on the responses of “fish” because these are most often the focus of exploitation and hence the group expected to respond most strongly to protection from exploitation. This focus on fish means that we have far fewer insights into the responses of a wider range of taxa at lower trophic levels that might benefit indirectly from protection (Stewart et al., 2009).

Despite these limitations, much of the peer-reviewed primary literature and meta-analyses demonstrate overall positive responses of the studied taxa to reserve protection on the biomass, numerical density, species richness, and size of fished target species (most often fish species) within the boundaries of NTMRs. These responses were recorded over periods from several years to decades (e.g. Abesamis et al., 2006; Lester et al., 2009; Stewart et al., 2009; Russ et al., 2015; Sciberras et al., 2015). There is substantial evidence that, with high compliance, NTMR closures of both reef and coastal fish and shellfish fisheries can lead to a demonstrably significant increase in population and biomass of fishery target species within the NTMR, in some cases after a period of several or more years (e.g. Stewart et al., 2009). This increase in abundance and biomass continues thereafter until carrying capacity is reached which depends on the species and the environmental context (Kaiser et al., 2018). There is evidence of increased larval and juvenile settlement and adult recruitment outside reserves (otherwise known as spillover) of fish providing an increase in CPUE or body-size near NTMRs (McClanahan & Mangi, 2000; Cudney-Bueno et al., 2009) and of increased egg production per unit area of reserve (Beukers-Stewart et al., 2006; Kaiser et al., 2007).

The assessment of the effect of NTMRs and fishery closures on a fish stock requires consideration of the biology and history of management of the target fish species in the protected area and throughout its range. There are two ways in which NTMRs may contribute to fished stocks: (i) post-settlement and adult spillover; and (ii) net export of eggs and larvae from accumulated biomass of reproductively mature adults within the reserve. In contrast to this rather ‘area-specific’ approach, fish stock management demands a more complex ‘whole stock’ approach with comprehensive sampling across wide geographic areas of population status (age, size-distribution, abundance) coupled with estimates or quantification of natural and fishing mortality. This mismatch in the scaling of the science to address these two different questions means that it is difficult to understand how one management objective impacts upon the other (either positively or negatively).

The monitoring conducted to inform effective fisheries management focuses primarily on total harvest, catch per unit effort (CPUE) and, as required, on by-catch of non-target species. Long standing fisheries have typically existed and grown with new demands and technical capacity and have thus been managed with no pre-fishery baseline or control data. New fisheries may start with exploratory fishing and expand ahead of substantial scientific evaluation of stock or environmental sustainability.

Science-based assessment for fishery management is thus constrained by the absence of unfished control sites (Papworth et al., 2009) and the phenomenon of shifting baseline due to discontinuous records (Pauly, 1995).

Determining the effect of a NTMR or a network of NTMRs on a fishery resource should be informed by (but in many cases is typically constrained by limitations of) detailed area-based data on the management of the fisheries and its performance on the target stocks and other species richness, abundance and distribution throughout the resources range.

A further data constraint may emerge on legal grounds of commercial confidentiality of high-density fishing data that could otherwise inform on the relative significance of areas of the stock range in terms of CPUE and cost per unit effort. Aggregating data at coarse spatial scales to preserve confidentiality makes it difficult to identify the broader effects of a positive fish stock signal from NTMR monitoring in the noise of fishing data throughout the population range (Hinz et al., 2013).

The limitation of fisheries data may be partly compensated by modelling based on approximations and assumptions from backward-projection of stock size under zero-fishing conditions and from similar fisheries in similar situations. These approximate comparators are imperfect for the target stocks or well documented non-target stocks and are constrained by the underlying assumption of ecosystem stability with respect to past and projected climatic conditions, population traits, and on the level of compliance with management measures. When considering the extent to which we could determine the effects of a reserve on wider population status, it is important to acknowledge that that model predictions often have such large measures of uncertainty that the effects of any single reserve or network on population status would likely be 'lost' within the boundaries of error within the estimated projections. It is sufficient to acknowledge that it remains difficult to achieve precise assessment of the large-scale comprehensive impacts of fisheries and their interactions with other human uses and impacts) affecting marine ecosystems, including of climatic oscillations and change.

The criteria for monitoring the performance of measures designed to achieve holistic conservation of marine biodiversity usually focus on community metrics such as species abundance, extent, biomass and diversity. Adequate assessment of the performance of these metrics is complicated by the lack of reference areas against which to assess them. Often the primary focus on establishing representative areas of habitats and communities that are protected from impact is to enable them to act as control or reference sites against which the effects of direct human uses may be discerned against the combined effects of system dynamics and indirect human impacts from coastal run-off and atmospheric change.

Russ (2002) identified five measurable indicators of the status of fish community status within the boundaries of a reserve:

1. Increased density of target species;
2. Increased biomass of target species;
3. Larger mean size/ increased age of target species;
4. Greater production of propagules (eggs/larvae) of target species per unit area; and
5. Lower or no fishing mortality (F) within reserve sites.

The first three of these indicators can be assessed through biological monitoring. The fourth indicator is usually inferred from the relationship between abundance, body size and propagule production which is sometimes coupled with oceanographic modelling of propagule dispersal (e.g. Kaiser et al., 2007; Carter et al., 2017). The issue of quantifying fishing mortality (F) is more complex due to the challenges of acceptance of closure and robust monitoring to assess levels of compliance. Poaching, illegal fishing and inadequate reporting of catch are frequently mentioned as constraints to assessing the effects of closure. In addition, while F may be reduced or eliminated within the boundaries of a reserve, the net effect on F at a population level may be neutral or even negative if fishing pressure outside the reserve increases (including through effort displacement) or if other human impacts or environmental change affect recruitment. Often, existing fisheries surveys (where they exist) will have their own objectives (e.g. measuring recruitment or overall biomass distribution and structure) and hence be spatially mismatched –in terms of data location and scale of sampling - with the objective of measuring increases of F specifically within areas external to a particular reserve.

Limitations of data on species richness, abundance and distribution may be partly compensated by modelling that is based on inferences derived from seabed mapping and limited sampling of fish and larger invertebrates and surrogacy based on assumptions and extrapolations from knowledge of habitat dependencies in similar situations. Multibeam sonar seabed mapping can be used to describe the physical properties of the seabed which is then related to ground-truthing samples. The downside of such an approach is that the collection and processing of samples of the seabed and associated species is time consuming and resources are typically limited for subsequent analysis, particularly of small sized and soft bodied species that can be important food for fished species (Kenchington and Hutchings, 2012).

In well-resourced NTMR, the effects of management and science programs may be monitored or inferred within the boundary. However, a robust understanding of the broader performance of an NTMR in relation to fish stock rebuilding or overall maintenance of biodiversity depends on many other factors. These include the biology and life-history of the target species, inter-annual environmental variation, adequacy of and compliance with fishery management, and other human impacts throughout the species adult and recruitment range.

4. PERFORMANCE

Adequate management and monitoring programmes may be able to demonstrate performance of increased biomass of species within a well-managed NTMR. Outside the NTMR, this may be accompanied by a reduction, increase or no change in biomass of target and non-target species outside the protected area (e.g. Dinmore et al., 2003). Attributing cause and effect of the contributions of NTMR, fishery management, and factors beyond either management system is challenging. **Table 1** summarises possible causal mechanisms for observed stock biomass performance.

Against this background we present a collection of meta-analyses of reserve performance such as: (i) closures in small scale fisheries; (ii) the experience of Great Barrier Reef Marine Park; (iii) closures in demersal trawl fisheries; (iv) fisheries closures for Highly Migratory Species; and (v) examples of the contribution of fishery restricted areas to biodiversity conservation.

TABLE 1

Summary of the response of the status of the population of fished species coincidental with the effective implementation of a no-take marine reserve (NTMR) with an explanation of possible causal mechanisms

Indicator	Possible causal mechanisms
Increased stock biomass	<ul style="list-style-type: none"> • Spillover of adults and juveniles from NTMR; • Larval export from NTMR; • Better management of fishing effort; or • Strong overall recruitment, unrelated to NTMR.
Stable stock biomass	<ul style="list-style-type: none"> • Spillover of adults and juveniles from NTMR • Larval export from NTMR • No detectable impact of NTMR, or • External factors offsetting NTMR spillover, or larval export such as impacts of land sourced pollution, other uses of marine space or climate change, compensatory increase in fishing effort
Reduced stock biomass	<ul style="list-style-type: none"> • No or inadequate spillover of adults and juveniles from NTMR • No or inadequate or larval export from NTMR • Poor overall recruitment unrelated to NTMR • Unsustainable fishing effort outside the NTMR, or • External factors such as impacts of land sourced pollution, other uses of marine space, climate change or predator prey trophic interactions leading to natural decline in background stock biomass

4.1 Meta-analyses of reserve performance

Sciberras et al., (2015) and Halpern (2003) noted that the empirical literature on marine reserves uses a wide range of methodologies to quantify the effects of reserves on specific taxa, and moreover that the characteristics of reserves and control sites can differ dramatically, and both can be affected by inter-annual and decadal oscillations or stochastic impacts (e.g. Stephenson et al., 1970). Both issues complicate comparisons of the performance of different MPAs. In particular, the most common shortcoming of comparative studies of the outcomes of MPAs is the habitat confounding effect and lack of adequate comparator sites for MPAs (Stewart et al., 2009). Furthermore, while there are numerous meta-analyses that attempt to synthesise general patterns from this diverse array of studies (Claudet et al., 2008; Lester et al., 2009; Sale et al., 2014; Sciberras et al., 2015), often the conclusions of such meta-analyses are weakened due to lack of rigour in the methodological approaches adopted within the review process which leaves them prone to bias (see Woodcock et al. 2017). Many of the more widely cited meta-analytical papers on the performance of marine reserves achieved only medium scores for rigour which is a concern if policy makers use these analyses to inform policy development. Nevertheless, despite the potential for bias in some meta-analyses published to date, the conclusions are broadly similar across all syntheses.

Sciberras et al. (2015) compared the response of target and non-target species to the use of NTMRs and areas with partial protection from fishing. They concluded that the response to protection was strongest (and positive) for target species and that NTMRs resulted in larger positive responses than partial protection areas. Stewart et al. (2009) examined the response of target species to NTMRs in temperate waters and found significant and positive increases in abundance, biomass and diversity. However, they noted that most studies were confounded by habitat effects (i.e. when the comparator site is not similar to the manipulated site (in this case the NTMR) and that there was potential bias in the reporting of the response in biomass data. Halpern (2003) provided a review of 89 empirical studies of the effect and the influence of size of marine reserves. Whilst the study was challenging because of differences in the environmental

and geographic context, design and methodology of studies and in many cases lack of rigorous standards of broader scientific literature, the overall conclusion suggested that reserves were generally effective. Gruss et al. (2014) reviewed results of empirical studies and reports of the conservation and fishery effects of 28 NTMRs specifically designed to protect the spawning aggregation sites of targeted species for periods ranging from 3 to 38 years. Whilst 12 had positive results for biodiversity conservation effects, 10 had negative results, 5 showed no clear change and one had no data. There was no information for fishery effects in 17 of the studies, 3 results were positive, 3 negative and 5 showed no clear change. The “non-positive direct conservation effects” of Fish Spawning Aggregation (FSA) protected areas were attributed mostly to poor or non-existent internal enforcement; small size of the FSA; exploitation of fish in their migration routes to the FSA; and absent or ineffective measures to control fishing mortality during non-aggregating times.

While the general conclusion from most of the published analyses indicates a consistent positive outcome following the implementation of NTMRs and partial protection areas, the response in individual cases is strongly variable and there is a lack of data on the intensity of resource exploitation and compliance as shown in the analytical outputs in Stewart et al. (2009).

4.2 Small-scale coastal fisheries

4.2.1 Changes in community metrics

Recognition of the need for marine conservation in the late 1970s – 1980s coincided with the publication of studies undertaken on the West Pacific, South East Asia, Japan and northern Australia of surviving traditional practices of coastal fishery management through tenure, cultural rights, closures or taboos (e.g. Johannes, 1981; Ruddle, 1988). Many of these traditional practices had been displaced or weakened by colonial rule or were being overwhelmed by economic development or population growth. In the islands and coastal areas of South East Asia and the Western Pacific growing population combined with falling yields and low income from traditional fishing activities around the coral reefs provided perverse and damaging incentives to use more efficient (but destructive) fishing methods including explosives, poisons, muro-ami push nets, small-mesh nets, and spear fishing using SCUBA (Russ et al., 2004).

A research and community engagement program supported and monitored by Siliman University in the Philippines enabled the establishment of a NTMR at Apo Island in 1974 and Sumilon Island in 1982 with long-term monitoring of the outcomes of these management measures inside and outside the reserves. Importantly, the program drew on traditional practices and developed additional economic opportunities to enable participation and empowerment of community-based comparisons of reserve and non-reserve biomass of coral reef fished species and total catch. The Apo Island observations included a serendipitous replication when the reserve area was re-established after a governance change had re-opened the reserve area to fishing for 3 years.

Alcala and Russ (2006) reported a 3.1-fold increase of all target fish over a 9-year period at Sumilon Island and 4.6-fold increase over an 18-year period at Apo Island. For the larger predatory fish, the increases were respectively almost 12-fold and 17.3-fold over 9 and 18 years respectively. There was a 3 to 17-fold increase in biomass of fished species within the reserves. Outside the reserves there was no overall increase of biomass. A similar outcome was reported by Guidetti et al (2008) from visual surveys undertaken in 15 MPAs in Italy. They found that total fish density in reserves was on

average 1.15 times greater than in fished areas noting that the effects of protection on fish species and trophic groups were not detected in unenforced reserves.

In a well-monitored MPA (the Bamboung bolong, in Senegal) surveyed in 2003, closed by fishermen in 2004, and monitored for 5 years, total biomass, maximal fish length, number of species, percentage of large iconic species increased. The community structure was modified, with more small fish, more big fish (new large species and more large individuals in the original species) and fewer medium sized fish. The trophic structure was modified with an overall increase of the mean trophic level, resulting from an increase of the percentage of generalist or piscivorous predators and a sharp decrease of herbivorous and detritivores and other low trophic level species. The marine predators which numbers and size were reduced by fisheries became again important components of the protected system (Ecoutin et al., 2014).

4.2.2 Changes in measures of catch per unit effort

There are relatively few experimental studies of the effects of MPAs on the CPUE in surrounding fished areas. Alcalá and Russ (2006) quantified changes in CPUE for Sumilon Island and Apo Island. They found that higher numbers of fished species were recorded within 200 m of the reserve boundaries together with a 50% increase in CPUE and a 46% reduction of total fishing effort. These observations suggest that a spillover effect had occurred because of the implementation of the marine reserve. The long-term outcome of the implementation of these reserves demonstrated that closure of 10 to 25% of fishing area of Apo and Sumilon islands improved CPUE and did not reduce the total fish yield at either island (Alcalá and Russ, 2006). Guidetti and Claudet (2010) reported on a 3-year experimental study co-managed with fishers to compare CPUE in one reserve with an MPA buffer zone that was opened after 5 years of enforced protection and then compared with the CPUE in the surrounding fishing ground. The objective was to maintain catch levels through effort control and by using specified fishing methods and effort intensity. The outcome after three years of co-managed exploitation was a level of CPUE that was approximately double that which occurred outside the MPA.

In South Africa (Kerwath et al., 2013) studied a boat-based commercial fishery to compare CPUE and total catch trends in 5 nautical mile grid squares of three south coast fishing regions with those close to the Goukamma marine reserve. This demonstrated increases in population and biomass of target species in the reserve and a doubling of off-reserve CPUE over five years near the NTMR boundaries suggesting adult spillover and larval dispersal for a resident species with occasional home range relocations unrelated to density dependence. In a similar study, Blyth-Skyrme et al. (2004) used records of trophy fish catches by sport fishers to ascertain changes in the mean size of trophy fish of a range of species that varied in life history. They compared catches in large geographic areas adjacent to and immediately surrounding a 350 km² partial protection area. For species with relatively early age at maturity, the mean size of trophy fish of all species recorded in the study remained stable or increased close to the partially protected area but decreased away from it. For species with late age at maturity no impact on trophy size was noted. This may mean that short-lived animals reacted positively while long-lived ones did not, at least in the time-frame of the experiment. However, this remains speculative in the absence of more formal tagging studies to confirm this hypothesis. The latter is a particularly insightful study as it indicates the importance of considering fish life history characteristics when considering the size and configuration of marine reserves and seeking to understand and compare the effects of NTMRs on fish stocks or biodiversity.

4.3 Great Barrier Reef Marine Park – a case study

The Great Barrier Reef Marine Park (GBRMP) was established through sequential declaration of sections between 1977 and 1988 with a total area of approximately 345 000 km². The objective was to provide for conservation of biological diversity and sustainable use of an area of recognised global environmental significance. In 1981, the Great Barrier Reef was included on the World Heritage Register. The concept of creation of significant no-take zones to address an issue of environmental primacy in a marine jurisdiction was novel and controversial. Initial zoning provided 20.6% habitat (no-trawl) protection that included NTMRs that accounted for a total of 4.6% of the entire area. The remaining 79.4% comprised General Use zones within which all forms of fishing were allowed subject to the overall provisions of the Queensland Fisheries legislation and some local MPA conditions.

In 2004, an amalgamation and revision of initial zoning and associated management came into effect addressing experience of implementation of the initial zoning, greatly increased scientific knowledge of the biodiversity and of the outstanding universal values for which the Great Barrier Reef was inscribed on the World Heritage Register. The revised zoning increased habitat protection (no-trawl) to 66% of the entire area including a greatly increased 33% of the area ascribed to implement a connective network of NTMRs. The effect of the revised zoning was that 99.5% of no-take reefs have a no-take reef within 14 km; more than 75% of fished reefs have a no-take reef within 16 km; and more than 90% have one within 22km (McCook et al., 2010).

Referring to impacts of the additional closures on areas outside them, McCook et al. (2010) show that responses differed between areas of the GBR and reflect biological and behavioural differences within and between species that are poorly understood. They note that adult coral trout (*Plectropomus* spp and *Variola* spp - main target species in the GBR) rarely move between coral reefs and that this lack of movement means that increased biomass in no-take zones will have little direct (conservation and fisheries) benefits through export of adult fish to the 2/3 of reef area that is open to fishing. In deep shoals, in southern GBR, abundance in no-take areas was twice that in fished areas and whilst some targeted species showed benefits, others showed none. In deep shoals in Central GBR, however, target fish were found to be either more abundant or less abundant, in protected shoals than in fished ones.

McCook et al. (2010) also considered that reproductive output from no-take reefs may be of enormous significance, due to disproportionately higher output per unit area from the more plentiful, larger fishes in reserves. Life cycle strategies of many targeted coral reef fish involve predictable annual short-term spawning aggregations lasting from days to weeks at specific locations. Depending on the identity of the species, the fish migrate from a few to hundreds of kilometres from their normal residential territories to spawn. Spawning aggregations can enable very high CPUE making targeted species vulnerable to over-exploitation. Spawning aggregations with consistent location and predictable timing may be protected in permanent or seasonal NTMRs under conservation legislation, by seasonal fishery closures under fishery legislation or a combination of both. Many species that exhibit such aggregations have been listed by governments as threatened or vulnerable (Gruss et al., 2014).

Elmslie et al. (2015) provide another example of inter-regional variability. They used long term data sets for 1983-2012 and 2004-2012 to compare mean density, and biomass of coral trout in the GBRMP before and after the additional closures. Density and biomass increased by 50% and 80% respectively within the closed areas. The increased

body-size and abundance of coral trout within NTMRs is an important consideration for egg production and planktonic export of larvae to fished areas. Most of the targeted reef fish species are protogynous hermaphrodites with the largest females changing sex when males are removed. Larger fish have substantially higher reproductive output, larger egg size and hence likely higher larval survival. Carter et al (2017) calculated egg production per unit area (EPUA) from 2004 to 2013 for coral trout on fished and NTMR reefs throughout the GBR. They found that geographic region, NTMR status, fish size and population density all affected EPUA. The regional differences were substantial and illustrate need to understand differences of reproductive contributions of components of fish stocks, and other species, in NTMRs and throughout their range. Within-region comparison of NTMR reefs against fished reefs showed that EPUA was 21% greater in the southern region; 152% greater in the central region but 56% less in the northern region. EPUA was found to vary at both small and large spatial scales thus, despite the southern GBR having 2–4 times greater densities of *Plectropomus leopardus* than the other regions, EPUA in the southern GBR was at least one order of magnitude lower than in the central and northern GBR. This conflicts with a simple assumption that greater densities lead to greater EPUA and points to the need for better understanding and quantification of the spatial variation of EPUA to understand sink/source recruitment linkages in the design of MPA and fishery networks (Carter et al., 2017).

Finally, McCook et al (2010) they indicate that the socio-economic benefits for the main business, tourism, as well as total benefits, were very significant while those for fisheries were “*potential*” and “*concerns remain among fishers.*”

Shortly after the 2004 rezoning, a Great Barrier Reef structural adjustment package for commercial fisheries was introduced with a fishery license buy-back program and revised fishery management plans. An analysis of total commercial fishery performance over the period, 2001–02 to 2013–14, reported that while the area open to forms of fishing dropped from 95.4% to 66%, fishery production dropped by 36% from 15 341 tonnes to 9 858 tonnes. The number of fishing licenses decreased by 48% and fishing effort decreased by 46%. The value of production per person-day of fishing increased by 13% over the period. These observations suggest that by restricting the area over which the fishery occurred, the catch per unit effort increased (ABS, 2015).

The outcomes of the 2004 increase in protected areas coverage have led to controversial analyses. Fletcher et al. (2015), stress that: (i) the forecast of losses was strongly underestimated (10% compared to the 30% observed); (ii) the estimated recovery time (3 years) was underestimated (more than a decade and not yet achieved). They conclude that losses are proportional to closures, allocate all the impact to these closures, and basically question their utility. However, Hughes et al. (2016), argued that (i) the future of many resources was giving serious concern before the closure; (ii) the effect reflects additional fishery management measures planned before and implemented after the; (iii) the Beyond-BACI analysis (comparing the GBR with neighbouring areas) was flawed by significant differences between the areas; and (iv) the fishery statistics used were incomplete. The lack of data on CPUEs trends outside the closed areas, for different species (e.g. predators and preys) is particularly crippling.

Altogether, the analyses by McCook et al., Fletcher et al., and Hughes et al. illustrate differences of outcomes in different areas. In the absence of an indisputable counterfactual situation, it is very difficult to empirically compare situations before and after closing an area (particularly in large and complex systems as the GBR). The positive impact inside the closure is usually confirmed even if it is variable and depends on

closure duration and species. Interpretation of the impact in the fished areas remains controversial and constrained by limitations of the form and scale of data.

These observations concur with those from temperate systems which show that direct management of trawling footprints has potential to support the achievement of environmental outcomes since outside core fishing grounds, the environmental footprint of trawling on the seabed per unit of landed fish declines markedly (Jennings et al., 2012).

4.4 Closures used in demersal trawl fisheries

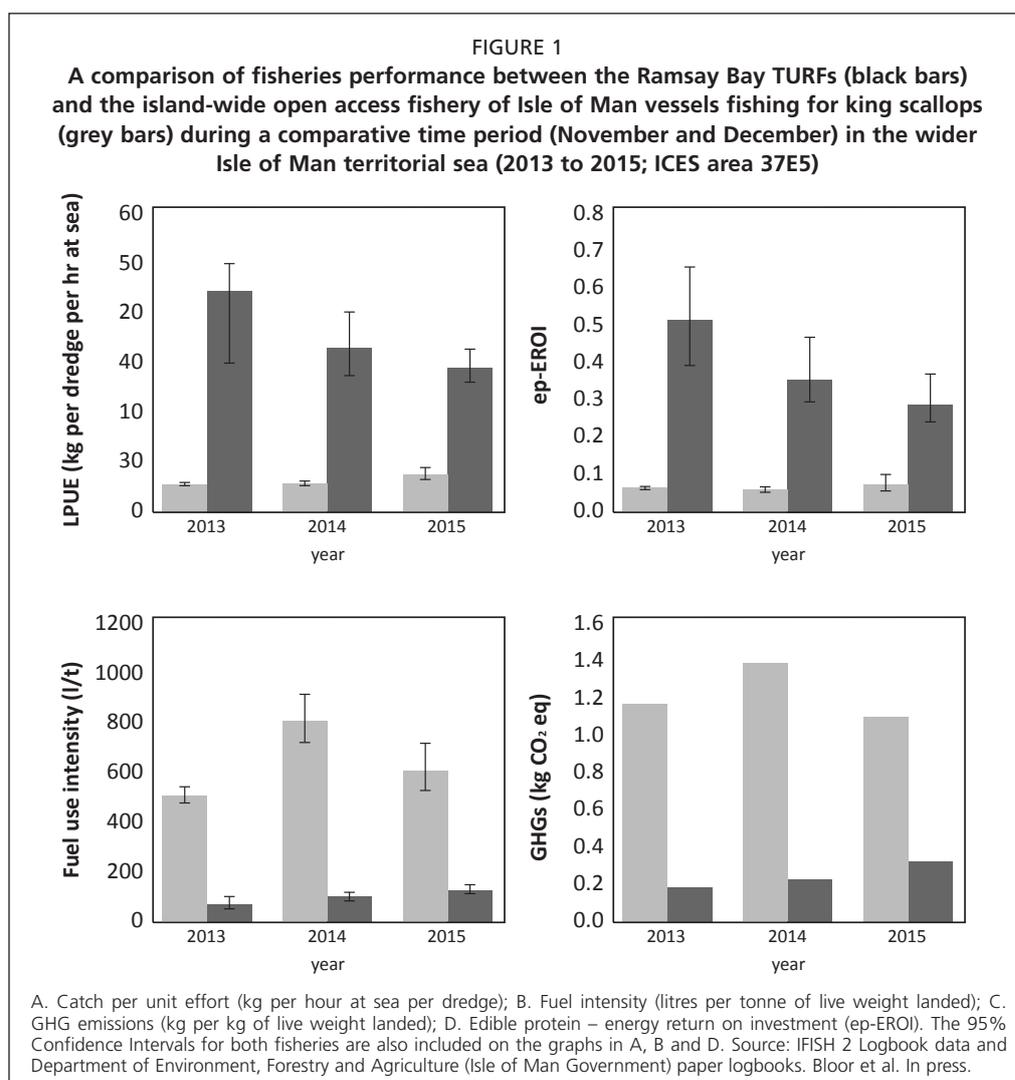
In this section, we use the term ‘trawl’ to include any form of towed fishing gear and include otter and beam trawls, seine nets and dredges. Area closures have been used as management tools in trawl fisheries for many decades. Often, they have been used to protect specific life stages (e.g. spawning areas and nursery grounds) or as effort reduction measures or as a means of reducing conflict with other fishing sectors (e.g. between mobile and static fishing gears).

Murawski et al. (2005) reported changes in the spatial distribution of otter trawl fishing and the associated catches that occurred in response to year-round and seasonal closed areas off the coast of New England (U.S.A). Prior to the closure, 31% of trawl effort was recorded within the 22 000 km² of area that eventually was closed year-round. In the years following the implementation of the closure, 10% of trawl effort for the groundfish fleet was located within a 1 km wide strip adjacent to the marine protected area (MPA), with 25% of effort located within 5 km of the MPA boundary. Based on recorded CPUE data, a wide variety of groundfish (including silver hake, yellowtail flounder haddock and monkfish) showed density gradients that were consistent with (but not a confirmation of) spill-over from MPAs. These higher CPUEs were reflected in higher revenue per unit of effort within 4 km of the MPA boundary. Another unforeseen outcome of these closures was the large increase in scallop biomass within these areas which has resulted in a highly sustainable rotational scallop fishery in subsequent years.

The example above indicated a positive outcome of using large-scale spatial closures to exclude the use of towed mobile fishing gear with reference to both fish and scallops. The large scale of these area closures was probably critical to their success for the groundfish. In contrast, smaller-scale area closures have led to rapid (after 2-5 years) increases in scallop biomass and abundance (e.g. Beukers-Stewart et al., 2005; Kaiser et al., 2007; Sciberras et al., 2013; Kaiser et al., 2018). Scallops appear to be a species that can recover to high densities in a relatively short period of time provided there is an adequate supply of larvae and suitable substrata for settlement. One of the potentially important life-history bottlenecks that occur with poorly managed scallop fisheries is the secondary ecosystem habitat impact of removing settlement substratum as a result of abrasion on the seabed by the dredge gear, an effect that becomes increasingly deleterious as the spatial footprint of a fishery expands (Lambert et al. 2014). Scallops (and presumably other relatively sessile species) are well suited to spatially restricted management systems.

In the Isle of Man, the combination of a conservation zone that intentionally incorporated a designated fishing area has led to successful rebuilding of scallop biomass and has continued to sustain a regular and well-managed fishery (Bloor et al., in press). This system is relatively unusual in the northern hemisphere as it is a territorial user rights fishery (TURF) system. The system is characterised, in addition,

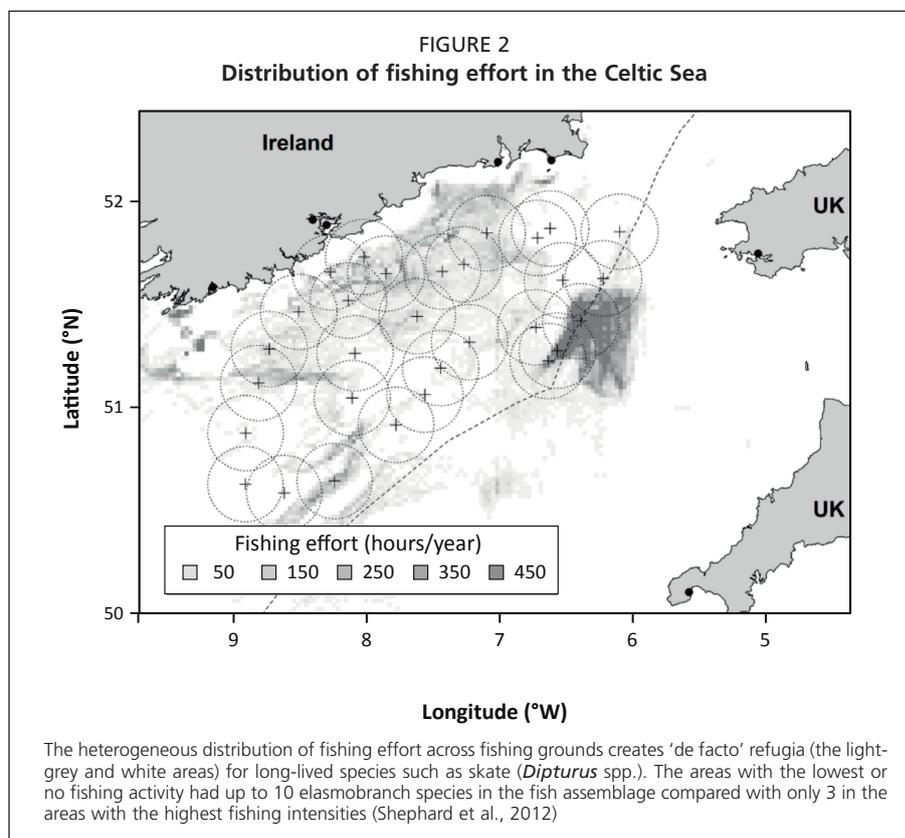
by a high level of scientific support, detailed surveys of stock undertaken by the fishing industry, detailed knowledge of the distribution of conservation features, high compliance and effective enforcement. These factors have resulted in a fishery that is six times more profitable than open access fisheries in the surrounding territorial sea area, has minimised environment footprint to a few percent of the available area for fishing, and reduced greenhouse gas emissions through reduced fuel consumption (Figure 1, Bloor et al. in press).



It is important to note that spatial management measures can lead to negative management outcomes for both fisheries and conservation objectives. A good illustration of this phenomenon was the unforeseen change in fishing behaviour and associated ecosystem effects in the North Sea that resulted after the implementation of the plaice box. This reserve was implemented to lower the by-catch of undersized plaice in the commercial fishery. The trawl fleet responded by ‘fishing the line’ such that vessel monitoring system records of fishing activity clearly demarcated the boundary of the plaice box with high intensities of fishing activity. As a result of the secondary effect of fishing which led to an increase in the secondary production of polychaetes (the main prey of juvenile plaice), a cultivation effect occurred whereby the by-catch of juvenile plaice increased outside the plaice box and thereby undermined its primary management objective (Hiddink et al. 2008). In a similar example, Dinmore et al. (2003) analysed the consequences of the temporary implementation of the North Sea cod box.

This closure was designed as a conservation measure to reduce effort on cod as part of a stock rebuilding programme. In subsequent assessments of the performance of the cod box the ICES advice concluded that it was not possible to determine any positive benefit for the cod stock as effort was not reduced but merely displaced into alternative areas. The displacement of activity extended the footprint of fishing on the seabed which resulted in a predicted reduction in benthic biomass (Dinmore et al. 2003).

Another often over-looked consideration is the fact that fishing activity is usually heterogeneously distributed across fishing grounds such that considerable proportions of the seabed may experience either little or no fishing which could create de facto refugia. Such areas might be considered as contributing to a conservation network. This point is nicely illustrated by an example from the Celtic Sea, in which Shephard et al. (2012) modelled elasmobranch biomass in fisheries-independent survey hauls as a function of environmental variables and fishing effort (h y^{-1}) within areas with a 20 km radius (Figure 2).



Shephard et al. (2012) found that sites that occurred in the lowest 10% of the observed fishing effort range had a high number of elasmobranch species including the skate (*Dipturus* spp.). Sites with the highest fishing frequency had only three elasmobranch species. They noted that management measures that changed fisher's behaviour could displace effort into these areas and thereby eliminate their function as refugia for long-lived elasmobranch species. Interestingly, after the publication of this study, the areas with the highest occurrence of long-lived elasmobranchs were put forward by the fishing industry for formal designation as conservation zones from which fishing activities would be excluded by legislation.

4.5 Closures used in pelagic/high seas migratory fisheries

Pelagic high seas fisheries, by definition, operate in areas beyond national jurisdiction (ABNJ), and largely target stocks of highly migratory, commercially valuable pelagic species. Fisheries in ABNJ are often very remote, spread over vast areas, managed by Regional Fishery Management Organisations (RFMOs) with no central enforcement capacity, and hence often more poorly monitored than developed fisheries in EEZs. In addition, some of the target and bycatch species are poorly studied due to their highly migratory biology. Few studies have focused on the effects of spatial protection on these fish stocks.

RFMOs were introduced to address coordination of management of offshore international fisheries targeting highly migratory or straddling demersal or pelagic fish stocks (Swartz et al., 2010). They focus mainly on the management of regional fisheries on tuna and tuna-like species and are subject to multilateral treaties (e.g. the UN Fish Stocks Agreement, UNFSA) and international conventions created to promote conservation of species threatened by international trade (Convention on International Trade in Endangered Species of Wild Fauna and Flora, CITES) and highly migratory species (HMS) including species of fish, whales, seabirds and sea turtles (Convention on Migratory Species, CMS). However, overall fishing pressure on a pelagic stock is still hard to control due to the multinational nature of the fisheries and often conflicting management regimes involved. It has been estimated that about 67% of stocks managed by RFMOs are overfished or depleted (Cullis-Suzuki and Pauly, 2010).

Protection and management of HMS, biodiversity and ecosystems in ABNJ is gaining more public attention with increasing knowledge becoming available on the biology and migration behaviour of the target species and new technologies to support high seas fisheries management. Satellite-based vessel tracking through Automatic Identification System (AIS) and Vessel Monitoring Systems (VMS) that are capable of monitoring vessel location and operational status (e.g. fishing or cruising) can now aid with fleet monitoring and enforcement (McCauley et al., 2016).

While modelling and simulation studies have explored the efficacy of spatial protection for fish stock rebuilding (Gerber et al., 2003) the majority of these studies either ignores HMS or concludes that they are unlikely to benefit from spatial protection unless the protected areas are very large. Applicability of many models to the context of HMS is limited as they assume either homogenous or random distribution of fish and fishing effort (Roberts and Sargant, 2002), which does not apply to migratory fish and high seas fisheries often associated with physical (e.g. seamounts) and oceanographic features (e.g. upwellings and fronts). To improve modelling and simulation efforts, better understanding of the intrinsic linkages between a species' biology and life history, especially movement patterns, and the dynamics of associated fisheries is vital (Botsford et al., 2009). Data on this can be derived from tagging and genetic studies as well as from fishery-dependent research. RFMOs are ideally suited to collect data on fisheries associated with HMS as their convention areas cover vast regions and often multiple exclusive economic zones. Although many RFMOs collect data on the fisheries in their area, the spatial scale of reporting, aggregation of data in reported outputs and access to these data for researchers and the public can be so limited that the spatial implications for species biology and CPUE used for conventional stock assessment (ignoring most of the finer stock structures) are uninterpretable at a more detailed scale. This is particularly the case when data for individual vessels is aggregated at coarse scale on the grounds of legal or commercial sensitivity for confidentiality (see Hinz et al., 2013). Newly available studies looking at efficacy of an MPA for pelagic fisheries come from the Galápagos

Marine Reserve, Ecuador. Bucaram et al. (2017) and Boerder et al. (2017) examined the influence of the reserve on associated tuna fisheries using a mix of modelling tools, onboard observer data and publicly available satellite vessel tracking, and conclude that the reserve increased fishing productivity as well as fish stock availability. Another example of the efficacy of spatial closures for HMS comes from Baja California, Mexico. Building on previous work, Jensen et al. (2010) reported positive effects of two spatial closures in Mexican waters on the rebuilding of striped marlin (*Kajikia audax*) stocks.

Based on the scientific literature available focussing on benefits of spatial protection for HMS, three key factors appear to influence efficacy of closures for HMS and associated fisheries: (i) target species' biology, especially movement rates as well as aggregation and homing behaviour, (ii) management state of the associated fishery operating above or below maximum sustainable yield, and (iii) fishing fleet dynamics, especially attraction and displacement of fishing effort to or from closures.

Spatial protection can be adapted to species' life history traits to protect e.g. vulnerable life stages such as juveniles, and areas of importance such as feeding and spawning aggregation habitats, and fisheries need to be managed accordingly. If significant fishing effort is displaced from a protected area and not properly managed in the fishing area, it can compromise potential benefits of the closure as illustrated by the redistribution of displaced fishing effort following the closure of the Pacific High Seas Pockets and the negative impacts on bigeye tuna (*Thunnus obesus*) stocks in the Western Central Pacific (Sibert et al., 2012). This highlights the importance of a combination of spatial protection and traditional fisheries management tools such as effort and catch controls.

4.6 Contribution of fishery restricted areas (FRAs) to conservation

FRAs are fishery management areas that restrict some forms of fishing (e.g. trawling) but that permit fishing with low impact fishing techniques and can therefore contribute to conservation and biodiversity targets. A good example of this is the use of territorial user rights for fishery systems in Chile (Gelcich et al., 2005, 2008). In Chile, the Government has developed a policy to create management TURFs known as Management and Exploitation Areas for Benthic Resources (MEABRs). In these systems, cooperatives of fishermen are allocated the rights to exploit and manage specific benthic species resources within designated areas of the seabed. This leads to highly targeted and modest exploitation of a limited number of species such as the gastropod *Concholepas concholepas*, key-hole limpets *Fissurella* spp. and the red sea urchin *Loxechinus albus*. Although there are potential cascade effects that might be associated with the harvesting of these species, Gelcich et al. (2008) undertook comparative studies to understand the extent to which non-harvested (but commercially important) species may have responded within these management zones. They compared both targeted species (the focus of management) and non-targeted species that occurred in kelp forests of similar complexity within the MEABRs and in areas not subjected to this management regime. They found that populations of both the exploited and non-exploited species were enhanced within the MEABRs, compared with those areas outside, and suggested that these fishery management systems had considerable conservation benefits within the MEABR while permitting controlled exploitation. In another study, Gelcich et al. (2012) compared the performance of the MEABRs with NTMRs in the same regions and found that when compliance was good and management rules were well enforced within the MEABRs and the NTMRs their biological characteristics were not different. However, in those MEABRs where compliance and enforcement were weak, the densities of commercially important species were significantly lower than in NTMRs.

5. DISCUSSION

The performance of fishery and biodiversity management systems depends on the wellbeing of marine environment. A human-induced degradation or a natural oscillation of the marine system may impede even draconian attempts to reverse trends in species depletion (e.g. cod in Newfoundland remain under very strict management conditions imposed for several decades). For both management systems, the primary objective of one has potential benefits and/or costs for that of the other. The SDG 14 goals for fisheries and biodiversity make no reference to the form, precedence or precautionary arrangements for inter-sectoral management of risks reflected in the expressed expectations of current and future access to fisheries and maintenance of marine biodiversity and ecosystem processes. Rice et al (2012) reported the outcomes of a workshop of fisheries and conservation specialists considering the role of MPAs in fisheries management. An expert opinion process was used to score objectives of fishery management and biodiversity conservation interests drawing on the experiences of workshop participants. Whilst the workshop was not broadly representative, it indicated that half of all fisheries objectives and 40% of biodiversity objectives were considered likely to receive support from both perspectives. Conversely, only 25% of fishery objectives and 30% of conservation objectives were likely to be the cause of fishery/conservation conflict.

There are tensions between fish stock and biological diversity conservation management systems that should be explicitly addressed. Determining the effect of a well-managed NTMR on a stock or set of stocks is particularly difficult because it depends substantially on the adequacy of information from substantial socio-economic and biological research and knowledge sharing. It requires data on species and community biology, past, current and expected fishing effort, socio-economic dependency and compliance with protected area regulations and with fishing regulations in the fished stock area. Indeed, for many developing nations and particularly for coastal, fisheries we lack robust data on recruitment, natural mortality, food web linkages, fish catch, fishing effort, compliance, local and market dependencies, economics and other human impacts on stocks.

The examples addressed in this chapter demonstrate that effective implementation of removal of fishing activities from defined areas of the sea most often results in an increase in abundance, biomass, diversity and also reproductive output in the areas from which the fishing activities are removed. In addition, areas with partial protection can generate similar responses, but these responses are generally less pronounced than the response seen within NTMRs or areas from which all extractive activities are removed (Sciberras et al., 2015). Depending on the biology and range of target species, a NTMR may have positive effects in stock maintenance or rebuilding for some species but no discernible effect for other species with large ranges or recruitment linkages (Claudet et al., 2010). There is some evidence to support the observation of spillover from some NTMRs with declining CPUE of quasi resident species as fisheries move further away from the boundary of NTMRs (Abesamis et al., 2006; Lester et al., 2009; Murawski et al., 2005; Russ et al., 2015). Most of these studies relate to nearshore areas and target species with limited or intermediate range and represent situations with a reasonably high level of support for and compliance with fishery constraints.

Adequate monitoring programmes may be able to demonstrate increased biomass of species within a well-managed NTMR which may be accompanied by increased stock biomass, stable stock biomass or falling stock biomass for the same species outside of the NTMR. Where beneficial responses that result from NTMRs and partial

protection areas have occurred, typically they take more than 3 – 5 years to occur (e.g. Russ et al., 2004; Sciberras et al., 2013; Murawski et al., 2000). This presents challenges of managing displaced or increasing fishing effort in the fished areas outside the spatially protected area.

The introduction of a NTMR results in an extended burden for the displaced fishers until any benefits from the NTMR become apparent outside the boundaries. This may in turn result in increased effort through displacement into other areas unless a reduction in effort is implemented (as in the GBR). This medium-term shadow of lost fishing opportunities was elegantly demonstrated by Steele and Beet (2003) who compared the performance of conventional fishery management tools (e.g. effort reduction) and the use of NTMRs as stock-rebuilding tools. Fishing effort reductions resulted in instantaneous positive effects on stock status and had a modest impact on loss of fishing opportunities, whereas the use of NTMRs led to an instantaneous substantial reduction in fishery yield which did not recover to a point that compensated for the initial loss in fishing opportunities until 5 years after implementation. The timescale for compensation to occur when using an NTMR as a fishery management tool is similar to the response time-scales for species recovery within NTMRs (e.g. Murawski et al., 2000). While some site-specific conservation features or species might need instantaneous protection by excluding certain fishing activities in some areas, fisheries rebuilding can also be undertaken at a slower pace which avoids a catastrophic loss of livelihoods (Steele and Beet, 2003).

At present, we consider that, for most fisheries, the data are inadequate for anything other than speculation about or modeling the response of a ‘stock’ or population to the use of spatial closures such as NTMRs or partial protection areas. Current monitoring and management of fisheries is undertaken at large spatial scales over 1000s km² although greater management precision is possible where VMS and AIS data are made available so that landings or catch records can be more precisely resolved with respect to catch location. While NTMRs and different fishery stocks may be encompassed within such areas, the design of monitoring programs is focused on measuring overall trends in the change in population status in a consistent manner. These programmes primarily address recruitment and fishing effort/mortality in the system and occasionally take account of limited environmental parameters such as temperature. While fishery data may be collected at finer scales, it may be aggregated and legally protected on grounds of commercial confidentiality. This can constrain provision of data at a spatial or temporal scale that would enable the definitive establishment of a causal spatial relationship between a change in recruitment or mortality and other impacts within the geographic range of a stock. The determination of such links requires a more experimental approach with surveys designed to answer the specific question about whether a NTMR is the causal factor for a change in stock status. This inability to differentiate the effects of an NTMR on stock status is further compounded by the additional management measures that are often applied in conjunction with the use of the NTMR. Only in the absence of change in all other management measures or in climatic conditions would it be possible to infer that any positive change in the status of a stock was directly attributable to the implementation of an NTMR. Nevertheless, it is worth remembering that, in many areas of the world, particularly but not only in small-scale fisheries, even the most basic information on catches and landings is lacking and hence the possibility to precisely determine such effects is extremely limited. To this extent it is probably impossible to break away from the use of expert opinion as the likely consequences of the effect of the implementation of a NTMR, facing nonetheless the possibility of happy or nasty “surprises”.

Considerations of the use of spatial management measures to enhance stock status aside, areas may also be permanently closed to fishing for the purposes of biodiversity conservation, scientific research, or safety and security of military, navigational or industrial facilities (e.g. windfarms). Within such areas it is important to understand and monitor both biodiversity and potential responses in fish and shellfish stocks (e.g. Gelcich et al., 2012). When areas are closed (or planning to be closed), the loss of fishing incomes and the shadow effect identified by Steele & Beet (2003) necessarily becomes an important consideration to achieve buy-in by stakeholders and improve chances of success. In such cases a positive change in biomass, age and size structure will presumably increase resilience of surrounding stocks.

An important factor in the history of the use of NTMRs is the engagement of the local governance arrangements, fisher and other marine user communities as primary stakeholders in the process of development (Gelcich and Donlan 2015). This requires a process of knowledge-sharing and building trust about managing marine resources, understanding of basic marine ecological concepts, community organisation and empowerment. In some cases, fishers come to perceive the benefits of the use of NTMRs after a prolonged period during which the biological benefits of such areas become apparent (Steele and Beet 2003; Blyth-Skyrme et al. 2004; Gelcich et al. 2008). If some fishers are lost from the system due to reduced fishing opportunities, the remaining fishers are likely to achieve greater harvests and profitability which may underpin misleading change towards a positive attitude to effective spatial management systems.

Areas may be closed to fishing in order to address objectives of biodiversity conservation or fishery management. A closed area may contribute to the achievement of either or both objectives but it is important to avoid ungrounded expectation of benefits against one objective from a closure to address the other. Scientists and managers need to ensure that they do not 'promise' stock rebuilding benefits from NTMRs if these are uncertain. Unrealised benefits harm relationships with stakeholders and undermine future relationships that depend on trust (Jones 2012). One of the case-studies that sheds some light on the importance of this issue is the Ramsay Bay fishery in the Isle of Man. In this fishery, both fishermen and Government agencies realised the need to close the area to fishing for a period of time to enable recovery of the scallop stock. This provided the platform to devise a novel management area that integrated partial protection areas with conservation objectives alongside a fishery management area that was leased to the producer organisation. The outcome of introducing this TURF (which ensured future resources ownership) was greater fishing profitability when compared with the surrounding open access fishery. Nevertheless, even this fishery may have unknown spillover effects (benefits) for the wider open access fishery but these benefits (if they occur) are difficult to assess.

To conclude, while NTMRs and partial exclusion zones often are associated with positive changes in community metrics within their boundaries and have been observed to generate near-field spillover effects, the potential benefits of these systems remain difficult to quantify at the level of a 'stock' or population, as indeed at the level of the ecosystem in relation to biodiversity conservation. This difficulty arises from a mismatch in the scale of current monitoring programmes that were not resourced or designed to specifically address the question of the extent to which NTMRs contribute to improve stock status. The situation is one in which proof is hard to establish and absence of proof of effect is not proof of absence of effect. This prognosis may seem pessimistic but could be changed quite simply if there was greater determination to understand more clearly the effect of using NTMRs on wider stock status. This could

be achieved with a proper time-limited experimental approach that examined multiple lines of evidence that include: stock metrics within and beyond NTMRs, reproductive output, recruitment, environmental variation within the timescale of the experiment, and social and economic indicators of performance and well-being. The latter approach would be facilitated by greater integration between the fisheries and conservation science disciplines. Scientists working in these respective fields overlap considerably in expertise, but the policy questions that they are tasked with answering do not facilitate the consideration of questions that span these discipline areas.

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Conclusions: lessons learned from rebuilding programmes in selected fisheries

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IUCM-CEM-FEG

1. PREAMBLE

The complexity and diversity of fisheries rebuilding, and their implications, are comprehensively addressed in Part 1 of this book (Garcia and Ye, 2018), based on an extensive review of the literature available. The purpose of the limited collection of case studies offered in Part 2 is to illustrate this complexity through detailed descriptions of real cases, the nature of the resources, the types of fisheries, their historical evolution, the depletion process, the adaptation of governance and management institutions and processes, the measures taken, their intended effect, and the final outcomes of the rebuilding process in ecological, social and economic terms, drawing lessons that could be used elsewhere in the future.

The intent is not to present the cases described as “typical”, the processes undertaken as “exemplary”, the outcomes as “best cases”, or to invite inferences of universal application. The challenge of making useful inferences from empirical observations, in this domain, is formidable. There are probably not, in the whole world, two fisheries requiring rebuilding, or having gone through a rebuilding process which could be said to be fully comparable. All fisheries – or groups of fisheries simultaneously exploiting an ecosystem – are high-dimensionality social-ecological systems. The four basic dimensions (ecological, economic, social and governance) are themselves complex and further subdivided into components. For every fishery, all these dimensions and components have a history of their own which has shaped their past trajectories, explains their present state, and will condition their future and their responses to rebuilding measures, in ways that are only very weakly predictable and even difficult to analyse *ex-post*. The cases, therefore, do not represent blueprints to be followed elsewhere. They probably do not represent even blueprints to be blindly followed if a new collapse occurred exactly in the same place on the same resources. In any future time, at least the socioeconomic conditions are likely to have changed, as well as many aspects of bio-physical system. Adaptation will be necessary to develop an appropriate new plan for re-rebuilding, and further adaptation would be needed as it is implemented. It is that need for adaptation that motivated inclusion of the case histories. The information they contain can be used to acquire or increase awareness and familiarity with the rebuilding issues, their diversity, dimensions, range of possible responses and outcomes. This knowledge can be used to better prepare to face analogous situations in other places, using this knowledge, a precautionary approach, an ecosystem approach and an inclusive adaptive governance process, to reduce the number of mistakes, manage the risks and, possibly, shorten timing of the rebuilding process.

These case studies should illustrate the fact that (i) rebuilding depleted fisheries is feasible and (ii) that there are a few principles that help in significantly increasing the probability of success.

2. CASE STUDIES

Thirteen case studies were undertaken review of stock rebuilding initiatives in a diversity of situations. A 14th analysis considers specifically the role of closures (MPAs and fishery closures) in rebuilding. The cases were not “cherry-picked” to advocate anything, except perhaps the fact that rebuilding a depleted stock is mandatory and the earlier the task is addressed, the better, for the resources and the people. The main authors were identified based on their known competence and their availability, trying to cover a large diversity of fishery “landscapes”. The cases were proposed by them. Some fell-out on the way, as usual, because of deadlines, underestimate of the workload involved in fully documenting the dimensions of the case, etc. The cases cover the following areas and fisheries (numbers in brackets will be used to identify the cases later in the text):

1. Atlantic and Mediterranean Sea. The Bluefin tuna fishery (1) (Fromentin and Rouyer, this issue);
2. Norway and surrounding waters. Two fisheries on the spring spawning herring (2.1) and North-Atlantic cod (2.2) (Gullestad et al., this issue);
3. Southeast Australia. A multispecies (scalefish and sharks) trawl fishery (3) (Smith et al., this issue);
4. Japan. Three alternating fisheries on sardine (4.1), anchovy (4.2) and chub mackerel (4.3) (Makino, this issue);
5. Western Australia. Three fisheries: a recreational snapper fishery in Inner Shark Bay (5.1), a multispecies demersal scalefish fishery on the West coast (5.2) and a scallop fishery in Shark Bay (5.3) (Fletcher et al., this issue);
6. South Africa. Three fisheries: the shallow and deep-water hakes trawl fishery (6.1), the sardine purse-seine fishery (6.2) and West coast rock lobster fishery (6.3) (Augustyn et al, this issue);
7. Canada. The Northern (Newfoundland) cod fishery (7) (Rice, this issue);
8. MPAs and fisheries rebuilding (Kenchington et al., this issue).

The sample is very small compared to the high diversity of ecological, jurisdictional and socio-economic dimensions of the world fisheries and hence their rebuilding processes. Nonetheless, this sample includes a number of contrasting situations regarding:

1. Resources: (i) Demersal and pelagic species including large highly migratory species; (ii) Vertebrates and invertebrates; (iii) Very high value to very low value resources; (iv) Single species, multispecies and whole-resource examples; (v) Very small stocks (10s to 100s of tonnes) and very large ones (> 10 million tonnes);
2. Governance: (i) National, Federal and international (RFMOs) jurisdictions; (ii) Under top-down management or various forms of community-based management or co-management;
3. Fisheries: (i) Commercial and recreational; (ii) Large-scale, small-scale, often interacting; (iii) Single and multi-fleets considerations;
4. Environment: (i) Temperate and cold; (ii) Coastal areas, shelves and deep-sea grounds; (iii) Strong or weak influence of environmental drivers;
5. Socio-economic contexts: (i) Developed and (advanced) developing countries; (ii) Large scale companies or small fishing communities;
6. Causes of depletion: Overfishing, biological or environmental causes, or all of them;

7. Information content: (i) data-rich and data-poor systems; (ii) With excellent historical and current research capacity or lacking most of it;
8. Types of outcomes: From totally successful to sluggish and totally failed recoveries.

The coverage is certainly not exhaustive, and the fact is that well described rebuilding strategies are still scarce, even with these cases now available (but see Part 1 for more published examples. The set is sufficient, however, to highlight the multiple dimensions of the rebuilding problem. There are not enough examples in each dimension to disentangle interacting factors as a basis to make reliable scientific conclusions about their role and the outcome of the interactions among them. However, each example vividly brings together, in real situations, dimensions which, in Part 1, are examined more exhaustively but separately, in different chapters. A summary of main measures taken and their outcomes are given in **Table 1**.

TABLE 1
Measures taken to rebuild depleted resources, in addition to, or in replacement of, measures already in force under “ordinary management”.

FISHERY/STOCKS	MEASURES TAKEN	
	Pressure reduction	Technical measures and governance
NEA Bluefin tuna	<ul style="list-style-type: none"> • Rebuilding regime • TAC reduction & fleet reduction 	<ul style="list-style-type: none"> • NGO action
NSS Herring	<ul style="list-style-type: none"> • HCR: No “rebuilding plan” 	<ul style="list-style-type: none"> • Min. Landing size; Juveniles protection
NEA Cod	<ul style="list-style-type: none"> • Reducing access & quotas • Upgraded MCS; Landings controls • Zero transshipments 	<ul style="list-style-type: none"> • Larger mesh sizes & Sorting grid • Zero subsidies • Capelin quota (cod food) • Intl. cooperation & Participation • EAF & Precautionary approach
SEA SESSF	<ul style="list-style-type: none"> • Management strategy evaluation • Minimum biomass level • Fleet reduction package 	<ul style="list-style-type: none"> • MPA network • Multisector, multispecies management • Good participation
Japan pelagic species	<ul style="list-style-type: none"> • Recovery plan (Chub Mackerel) • TACs; Effort reduction 	<ul style="list-style-type: none"> • Protect strong year classes) • Participation
WA Snapper	<ul style="list-style-type: none"> • Partial moratorium • Decline of commercial fishing • TACs; Harvest tags 	<ul style="list-style-type: none"> • Bag limit & Size limit • Spawning closure • Minimum biomass target. • Participation
WA scalefish	<ul style="list-style-type: none"> • Effort caps; ITE quotas • HCRs & Catch reduced by 50% • Limited entry (95% reduction) • Compensation for access loss • Sub-sectoral allocation 	<ul style="list-style-type: none"> • Closure of an MPA • Gear restrictions & Bag limits • 2-months closure • Lower release mortality (recreation) • Educational programme
WA Scallops	<ul style="list-style-type: none"> • Introduction of ITQs • Total fishery closure (no landing) 	<ul style="list-style-type: none"> • Protection of localised concentrations • Spawners protection
SA Hakes	<ul style="list-style-type: none"> • Limited entry & TAC reductions • Voluntary Ring Fencing • OMPs 	<ul style="list-style-type: none"> • Gear specifications; Mesh size regulation • “Tori” lines (birds scaring) • MSC certification
SA sardine	<ul style="list-style-type: none"> • TAC management 	<ul style="list-style-type: none"> • Participation
SA Rock Lobster	<ul style="list-style-type: none"> • Management zoning • OMP. TAC reductions not acted 	<ul style="list-style-type: none"> • Min. landing size progressively reduced. • Participation and user rights
Canadian Cod	<ul style="list-style-type: none"> • Reduced TACs and allocation • Moratorium (1992) • Assistance scheme • No rebuilding targets 	<ul style="list-style-type: none"> • On-board observers; Sentinel fisheries • Gear regulations • Seasonal closures; • Measures on forage fish & seals • Strong participation • EAF approach; Prec. approach

They may not be the only measures in place.

TABLE 2
Key outcomes of the rebuilding programmes and problems faced at the end of such programmes.

FISHERY/STOCKS	OUTCOMES		PROBLEMS
	Biological	Socioeconomic	
NEA Bluefin tuna	<ul style="list-style-type: none"> Decreased F Higher B and catch 	<ul style="list-style-type: none"> Improved relation with fishers 	<ul style="list-style-type: none"> Uncertain data & models Science-Policy tensions Updating the man. plan
NSS Herring & Cod	<ul style="list-style-type: none"> NSSH rebuilt NEA cod rebuilt 	<ul style="list-style-type: none"> Reduced fleets & Jobs Higher CPUE & profits 	<ul style="list-style-type: none"> F did not decrease Possible overcapacity
SEA SESSF	<ul style="list-style-type: none"> Stabilized biomass Variable rebuilding Reduced overfishing Rebuilt O. Roughy Lower sharks & Rays bycatch 	<ul style="list-style-type: none"> Decreased fleet size, total catch & value Increased net economic returns 	<ul style="list-style-type: none"> Some stocks still overfished Catches < TACs Higher research costs Recent drop in economics Optimal F on species mix? Maintaining commitment?
Japan pelagic species	<ul style="list-style-type: none"> Rebuilding of sardine & mackerel (?) 	<ul style="list-style-type: none"> Asynchrony between sector and resources 	<ul style="list-style-type: none"> Multispecies management
WA Snapper	<ul style="list-style-type: none"> Slow/steady recovery Increasing bag limit 	<ul style="list-style-type: none"> Reduced catch 	<ul style="list-style-type: none"> None
WA Scalefish	<ul style="list-style-type: none"> Reduced catch (-50%) SSB recovering 	<ul style="list-style-type: none"> Reduced F (still high) 	<ul style="list-style-type: none"> Recovery strategy drafted Monitoring continues Concern on discarding
WA Scallops	<ul style="list-style-type: none"> Improved R Recovery 	<ul style="list-style-type: none"> Recovered 	<ul style="list-style-type: none"> Resource sharing challenge Maintain quota? HCR?
SA Hakes	<ul style="list-style-type: none"> Both species rebuilt 	<ul style="list-style-type: none"> Value has been rebuilt 	<ul style="list-style-type: none"> Mixed stocks Natural variability Bycatch of NT species Transboundary issues
SA Sardine	<ul style="list-style-type: none"> Stock collapsed (natural condition) 	<ul style="list-style-type: none"> Depressed economics 	<ul style="list-style-type: none"> Stock structure Natural variability Pelagic sp. as forage food Discarding, underreporting
SA Rock Lobster	<ul style="list-style-type: none"> Collapsed 	<ul style="list-style-type: none"> Unknown(?) 	<ul style="list-style-type: none"> Poaching; corruption Unlikely rebuilding Natural variability?
Canadian Cod	<ul style="list-style-type: none"> Slowly rebuilding Ecosystemic changes 	<ul style="list-style-type: none"> Collapsed industry Sectoral mutation Uncertain future for coastal communities 	<ul style="list-style-type: none"> Natural variability What rebuilding targets? Predator-prey relations Offshore stocks recovery (?)

Numbers refer to the case studies and are used as references in the text.

In a nutshell, the 13 case studies show that key measures intended to reduce fishing pressure in various ways (TACs, effort and catch quotas, fleet reduction programmes) combined with high participation, and improved management (MSE, OMPs, HCRs) and MCS, often within EAF and precautionary approaches. Complementary technical measures contributed to reduce pressure on specific life-cycle stages. The existence of natural oscillations confused diagnoses and disturbs the science-policy-sector relations. Participation appears to have been an important factor in many if not most of them.

The case studies also illustrate that outcomes may be extremely variable, from total success to total failure, depending on context with a strong role of governance (MCS),

assistance programmes, sector buy-in, and environment. Concerns for the future, in terms of action and expected outcomes, relate to these factors: stock structure; species relationships; sector-wide coordination and plans; good governance; socioeconomic issues; collateral impact (habitat, bycatch); environmental forecasts; and science-policy relations. With such a long and wide-ranging list of considerations, it would be nice to be able to prioritize the measures. This is not possible, however, beyond platitudes like “reduce pressure on the stock” and “consider the socio-economic and environmental context of the stock and fishery” because of the inability noted earlier to fully disentangle causality for either the collapse of most of the case histories or the success or failure of recovery in all the cases. We cannot conclude that all the measures taken in rebuilding processes –which have often been “adaptive”– were necessary, how much each measure added to the success, or that any of them is a guarantee of success. The significant reduction of fishing pressure is a necessary albeit not sufficient condition of success.

Nonetheless, several important lessons have been learned, that we will review in the following section.

3. LESSONS LEARNED

Important “take-home messages” are available in the more global review of literature on stock rebuilding published as Part 1 of this publication (Garcia et al., 2018). In this section, we summarize the key lessons learned from the 14 case studies, referring to them by their number (from 1 to 8) in **Section 2** above. Despite the large variability among fishery and resources situations and their general context, the lessons are likely to be of generic value and should be considered, probably, in any case even though their relative importance as guides for action in any rebuilding challenge will depend on local conditions (resources, fishery, climate and governance). The findings below are generally in accordance with those in emerging from the OECD case studies (Khwaja & Cox, 2010).

The triggering factor is multidimensional

The special concern for rebuilding is usually triggered by both the excessive decline in the state of resources, whether brutal or protracted, and the related degradation of economic and social conditions of the sector.

Rebuilding is possible

Rebuilding is likely if the drastic actions needed to cut down significantly on fishing pressure are taken, and rapidly. It is possible for large pelagic resources (1), demersal resources (2.2; 3; 6.1; 7) and small pelagic resources (4.1; 4.2; 4.3; 6.2). Delaying the action needed and attempting to rebuild resources while maintaining fishing activities, while sometimes dictated by local conditions and economic realities, delays rebuilding, protracting the problems (1; 7). Integrating the rebuilding measures in the “ordinary” management scheme instead of instating first a special “on-off” rebuilding regime and enhancing the ordinary management later on to avoid sliding back might be effective in the long term provided the measures are introduced fast enough to obtain a significant impact (2.1; 2.2).

Reactivity and timeliness are essential

Procrastination about overfishing can be very expensive. The first and perhaps more important lesson is that rebuilding problems often get serious and unavoidable following

a long period of neglect, complacency with non-compliance, and/or inter-sectoral bickering about whom or what to blame for the problems (1; 6.3;) and/or in which early scientific warnings and empirical observations from the sector are undervalued or disregarded (1; 7). Procrastination may be the result of ignorance (when information is unavailable), government reluctance to take politically and economically costly measures, or conflicting scientific assessments with no consensus on which to base a decision. Delayed action to correct excessive fishing pressure leads into very difficult and costly problems when depletion reaches a point where rebuilding strategies become unavoidable either because of its socio-economic consequences (on fleets viability or community livelihoods) or because of public and societal pressures through NGOs, international alliances and the media. Even though comparative economic analyses of action versus inaction scenarios (counterfactuals) are not available, this conclusion transpires in all case studies (more particularly 1, 7).

Rebuilding objectives should be clear

The objectives of rebuilding programmes usually (and necessarily) refer to the stock biomass to be rebuilt as a priority (2). Other related objectives might be a reduction of bycatch and discards to reduce waste or rebuild threatened species. However, Social and economic conditions are key drivers of the whole process, providing the necessary incentives for buy-in and accepting short term costs in the expectations of future gains and improved livelihoods. Social and economic objectives (including those related to fleets profitability, reduction of manpower, number of vessels, sector transformation) must be addressed very early in the process and actively pursued (2; 6). Planning for the social and economic objectives of rebuilding may be necessary to get agreement on solely the stock-based objectives (e.g. in 7). Equity in the allocation of resources is a central concern in case of shared or transboundary resources, (1; 2) as well as in national resource allocation systems (5.2).

Rebuilding requires an unpredictable time

The rebuilding programme took a decade in Japan (4), five to 20 years in Western Australia (5), over 20 years in Norway (6), 30 years or more in Canada and about 15 to 60 years in South-eastern Australia, depending on the species concerned (3). It is not clear that these indications of time refer exactly to the same thing and hence may not be strictly comparable, but they give an indication, perhaps, of the range and variability one might expect. The scarcity of rapid (3-5) year recovery successes should be a warning to planners to manage expectations of all the actors (fishers, NGOs, governments, civil society) in planning recovery of depleted stocks.

Taking some time to adjust the sector in a step-wise process, may be necessary also to keep the sector “afloat”, avoiding a harder collapse, and keeping a capacity to rebound in case of rebuilding. Consequently, initial measures have often been too bland, insufficient to effectively trigger rebuilding (1; 2; 3; 5; 6; 7), protracting the process. Pressures tend to build-up to reopen the fishery the longer a moratorium is in place, despite the risk of sliding back into depletion and further lengthening of the process (4; 7). In addition, the rebuilding process continues well after biomass has recovered, as stock structure and the fishery system continue to evolve, and climate continues to change, maintaining a risk of sliding back if counter-measures are not in stock, ready to be used.

Institutional-building takes time

The governance and management system may need overhauling to respond properly to the rebuilding challenges. The building up of data, scientific capacity, scientific consensus (7), network of MPAs (3; 8) and the institutional change needed to improve participation (3), monitoring, enforcement (6.3), etc. require time, particularly in cross-jurisdictional or international rebuilding programmes (2)

Rebuilding inside of a No-Take Marine Reserve (NTMR), and hence spillover to the whole fished stock, may be expected to take 3-5 years to start becoming apparent. The response will be faster for short-lived species, and transitory as they get eaten by larger predators which rebuild later. The response is also stronger with total removal (moratorium) than partial removal of fishing pressure. The response time is very important for vulnerable populations with little alternative livelihoods and good governance is needed, in the NTMR and the fishery, paying great attention to the fate of the effort eliminated from the NTMR (8) and to the need to provide financial and social safety nets to fishing populations during the transition phase.

Rebuilding may be problematic in some cases

Rebuilding may be difficult in three different scenarios: (i) if the coastal communities are so vulnerable that, without a central plan to help them (a necessary but not sufficient condition) they cannot support the new restrictive regime and massively fail to comply (6.3); (ii) if the decision-making system is corrupted (3; 6.3); or if rebuilding may depend to a very significant extent on environmental conditions being in favour of good recruitments (4; 6.2; 7). Large packages of socio-economic assistance may be fundamental to avoid the collapse of small-scale highly dependent communities (7) and limit civil disobedience (6.3) and unbearable pressure to re-open prematurely the fisheries (7). Rebuilding may be impossible in certain socio-economic conditions (e.g. in 6.3) and the social part of the socio-ecological system may be irreversible when protracted rebuilding times lead to hardly reversible or irreversible evolutions (e.g. emigration away from the fishing sectors and territories). The latter is facilitated in cases where there is a booming national economy offering exit opportunities (e.g. in 2), but in some places fishing still remains an employer of last resort or is deeply embedded in cultural identity.

Rebuilding trajectories are rarely exactly predictable

Because of the above, the rebuilding trajectories, the evolution of key variable and the time needed to reach rebuilding targets, may not be easily predictable, particularly in the case of multispecies, multigear fisheries whether small-scale (4) or commercial (3) and when stocks are strongly affected by environmental conditions (1; 2; 4; 6.2; 7). They also depend on the sector's cooperation and hence both on the set of incentives put in place and the deterrence of enforcement.

Table 1 shows that outcomes have been quite variable among the different cases depending on the species involved, their interactions, the sequence and timing of the action taken, the contextual evolution (climate, markets) and the reactions of the sector. Fishing pressure was decreased in most cases. Biomass declines were at least stopped (except in 6.3). In multispecies systems, the number of stocks suffering from overfishing declined (3; 5). The extent of rebuilding has been variable though, from failure (4; 6.2; 6.3) to limited and variable (5.2,7) or very successful (1; 2; 5.3). Net economic returns for those remaining into the fishery increased (3). Abundance may increase for single species (1) or remain rather stable in multispecies systems (3). Gross value may be

rebuilt (2) or decrease (3). In some cases, good results have also been obtained on non-target species and habitats (3; 7). This is generally to be expected when fishing pressure is significantly reduced but has not been addressed in many of our case studies.

The legal framework may need to be complemented

The “ordinary” legal frame underpinning fishery management is often insufficient to face rebuilding needs, e.g. to facilitate stronger management action, regulate the conditions of exit from the sector, or broaden the scope of management to cover non-target species and habitats. Bridges might be needed between the fishery and conservation legal frameworks to afford more protection to depleted or collapsed species (3). Adjusting the legal framework is more complicated in an international framework than a national one but good research cooperation and formal international (1; 2) or bilateral (2) agreements can be sufficient and are likely to be necessary to ensure compatibility of approaches across the entire stock distribution area (1; 2.1; 2.2; 7). The Norwegian case studies (2) illustrate the fact that the basic legal frame may be identical for multiple stocks, even though the specific regulations are tailored to the resources.

The fishery policy framework must be strengthened

Reform of the conventional policy framework is often unavoidable, given its inadequacies have been demonstrated by the stocks and fisheries’ degradation. Such reforms may have to spread across entire sub-sectors or species assemblages (3; 4; 5.2). The historical underplaying or complacency on overfishing needs to be corrected, fixing more clearly the objectives, the management targets, the mandatory limits, the types of measures that may be put in place (e.g. for capacity reduction), the enforcement system, and mobilizing the funds needed for it. The adoption of the ecosystem and precautionary approaches to fisheries at high policy level is a significant enabling factor for rebuilding regimes, promoting the consideration of oceanographic factors, predator-prey relationships and uncertainty (3; 4; 5.2; 7).

Good governance becomes more essential than ever

Conventional governance must evolve to become: (i) more unified across the entire distribution range, under a single national management authority whether national (2) or international (RFMO); (ii) more inclusive, instating or reinforcing use rights (2; 3); (iii) promoting more active participation of a broad set of stakeholders to decision-making and enforcement (2, 3, 4, 5, 6, 7); (iv) evolving with time in an adaptive and precautionary process (5, 7). A close collaboration of science, management and the sector is essential (2; 3; 5; 6, 7). Conflicting scientific theories are not particularly useful and developing consensus or finding ways to combine conflicting assessments in a minimum-risk decision is important (3; 7). Not taking action despite scientific advice or taking action contrary to that advice is a decision-maker prerogative but the reason for not following the advice should be transparently noted. Working groups are useful to tackle special issues in an effective way. In practically all case studies, this evolution has happened and has been beneficial despite increased interaction costs. Conventional management units may need to be merged at ecosystem level, for better integration of species and fleets interactions into the rebuilding strategy (3). The improvements needed may be seen as part of an “exceptional” rebuilding regime (requiring a special harvesting framework (3) or of a progressive evolution towards more effective “ordinary” management (2), progressively reducing the risk of sliding back into collapse (1; 2). At least some of the key changes in governance brought about

in the rebuilding policy (e.g. for participation, communication, timely response) might be usefully considered for integration into the “ordinary” governance framework.

The management tool box must be strengthened

There is no single silver bullet measure to correct depletion and collapse. In all case studied, a central element remains the decision to significantly reduce fishing pressure, reducing effort and removals (catch and efforts quotas) and/or excess capacity, through mandatory or voluntary vessels scrapping schemes, eliminating perverse subsidies but providing adequate incentives and compensation, including buy-back (1; 2.1; 2.2; 3; 4; 5.2; 6; 7). The use of moratoria is controversial. They have been considered essential factors of success (e.g. in 7) but their short- and long-term costs calls for caution in using them, as compensation costs may be very high (7) and possibly indispensable to ensure compliance with a moratorium that may seriously compromise the sustainability of dependent populations. The fundamental role of a decisive pressure-reduction is confirmed by the fact that rebuilding was sluggish (6.3; 7) or non-existent (6.3) when related decisions were delayed or not applied. Controlling fishing mortality levels is particularly tricky in strongly environmentally-driven stocks as catchability as well as productivity, may vary with time (2; 4; 6.3). In such circumstances, the capacity to foresee and possibly predict the variations (particularly if they are periodical) is important and should be developed (4; 6.2).

Measures to enhance stock-productivity might be useful to improve recruitment as much as possible, e.g. reducing bycatch, discards and wastes; introducing minimum landing sizes; using sorting grids or closures of spawning and recruitment areas (2; 5.1; 5.2). Technological innovation may play a positive role as shown by the use of individual fish “harvest tags” in WA snapper recreational fisheries (5.1) and efficient bycatch reduction grids (2.2). Fishing reserves and other closures (or MPAs) might be valuable to protect/restore important critical habitats or a residual spawning stock (3; 4; 5.2). Technical measures, alone, are usually not sufficient, however, to rebuild severely depleted resources. Strong incentives help and may be of different nature: Legal, e.g. specific rebuilding regulation (all case-studies); Fiscal, e.g. deterrent penalties eliminating free riders; Economic, e.g. improved profits; improved market shares and exports through certification once the stock is rebuilt. Technical measures used for rebuilding (e.g. catch limits, pre-season surveys, temporary closures, and protection of spawners) were not very different whether depletion was related to mostly to fishing, or climatic variations or both (e.g. 6.2; 5.3).

Closed areas may contribute to a variable extent

The use of No-Take Marine Reserves (NTMRs) (a term covering MPAs Type I and II and total fishery closures) in a rebuilding framework is mentioned only in (3) and is the focus of (8) from which most of the content of this section is drawn. NTMRs established for biodiversity conservation or fishery purposes, may usefully complement more direct measures of reduction of fishing pressure, enhancing ecosystem wellbeing, possibly stock reproduction and productivity (8). In other cases, they may be deemed unnecessary (7). Challenges are numerous. In most cases, MPAs contribute to rebuilding the ecosystem and the part of the stock standing inside the closure even though the impact is variable and depends on the relative size of the closure, the species concerned, compliance with the NTMR regulation and other factors, inside and outside the area, such as compliance, environmental degradation and climatic variations. A spillover to the open area can be expected only if the rebuilding is fully effective inside the closed area, the resources are mobile and move outside the

NTMR, and the stock is not yet rebuilt outside the reserve, using more conventional fishery management measures. Assessing the impact of a NTMR faces two challenges: availability of data and discrimination of causal links.

1. The data challenge relates to: (i) inadequacy of conventional stock assessment data location, density and scale to measure the localized impact of a NTMR; (ii) Lack of robust data on recruitment, natural mortality and food web linkages (particularly for non-target species), migrations, people dependencies, other human impacts fish catch, fishing effort, compliance, local and market dependencies, economics and other human impacts on stocks. and habitats. The lack of knowledge is greater in temperate and cold areas, for pelagic resources, particularly highly migratory species (HMS), and in offshore or deep-sea areas;
2. The causal links challenge is caused by the fact that the fishery system is dynamic, changes affect continuously the ecosystem and the fishery system (including the markets and management measures). In these conditions, discriminating the various cause-effect relationships, and measuring the existence and extent of a spillover is most often impossible. The lack of proof of a spillover is, however, not a proof of lack of spillover and modelling may often be the only way to figure out its likely nature and extent. Specifically-designed observation programmes may also be effective if they last long-enough to “see” the maturation of all effects. The large bibliography available on MPAs is very useful to figure out the type of effects that might be expected but not to assess with any precision the effects to be expected in any particular case.

The rebuilding regime might never end

It is common knowledge that because of the continuous changes in the resource system (including in MSY), the fishery system and their climatic and socio-economic contexts, reaching and maintaining “sustainability” is a dynamic continuous process. So is, to a large extent, the rebuilding task. First, the need for rebuilding should be averted by steady efforts to maintain fishing pressure at the correct level. Second, if lessons are learned and management systems enhanced, repetitions should be avoided (2; 4) and in any case corrected as soon as possible. When rebuilding has been “successful”, there may be doubts as to whether it has been achieved to the point that risks of sliding back into deep depletion is really minimized. After “rebuilding” biomass has been achieved, other parameters of the past fishery resource system may need “rebuilding”: the age structure; the genetic stock structure (subpopulations); the species interactions and trophic chain (the ecosystem structure) (2). This takes some time and may never be completely achieved. In addition, the fishing communities and their web of fishery-related livelihoods have been damaged by the collapse and unless alternative jobs can be offered, they need some rebuilding to a level commensurate with resources productivity. What form that takes, needs at least as much care in planning as does the stock and ecosystem rebuilding. If over-capacity or technology change played some role in the initial collapse, the “rebuilt” human part of the fishery system needs to be to some smaller size that can be sustained by the rebuilt stock and ecosystem, and robust to likely trends in technology. To the extent that environmental changes contributed to the initial collapse, the rebuilt harvesting system needs to be in a configuration robust to that degree of natural fluctuation in resource status (2; 4; 7). Thus, the post-collapse evolution of the human system may take many years to reconfigure and, hopefully would remain dynamic in a changing development context.

A post-rebuilding strategy and management plan are needed to avoid sliding back

The past management regimes having showed its limits, the rebuilding regime, or key components of it, need to become part of an enhanced “ordinary” management system and strategy, less prone to inadvertent sliding-back into depletion. This may involve: consolidating fishing rights and MCS; more careful management of fleet size; better accounting for technological changes that increase fishing power of harvesters (including in SSF as well as LSF), institutionalizing the use of MSE (3; suggested in 1.) and pre-agreed strategies such as HCRs (1; 2.1; 4; 5.2) or OMPs (6.1; 6.2; 6.3). This is facilitated when the rebuilding regime has indeed resulted from a progressive evolution of the normal regime and cannot be distinguished from it anymore (2).

A formal management plan with objectives, targets, limits, and deterrent control is close to indispensable and, as mentioned above, the use of OMPs, HCRs tested through Management Strategy Evaluation (MSE) have shown to be important for effective and transparent decision-making and for the stability of the management system in very different resources systems (2; 3; 5; 6;). In the case of highly fluctuating stocks, OMPs may specify a mandatory lower biomass limit (6.2). In addition, there may be important benefits to be drawn by coordinating multiple-years developments and management plans on the set of alternating stocks/species (4), identifying uncertainties and optimizing economic outcomes at sub-sector level across the key stocks/species.

Good management/rebuilding plans should be multiple-year (3) and adaptive, incrementally increasing sophistication and cost, as needed, and as information (on stocks, ecosystem and sector) improves and assessment and management capacity increase (2). Because of interactions between species (predator-prey relations) and fleets (bycatch and choke-species) a rebuilding programme should be considered at the level of an ecosystem, coordinating measures across interacting fleets and species (3).

Enforcement efficiency should be maintained or enhanced even though some constraining measures may be relaxed due to rebuilding (3-1; 3.2). Deterring Illegal Unreported and un regulated (IUU) fishing is a must and a condition to avoid free-riding and discourage those otherwise willing to comply (1; 2). The use of Vessels Monitoring Systems and on-board observing systems and control of landings (verification of declarations and scales) (2); control of transshipments (2). The need is reduced when community buy-in and cooperation is ensured, and the community has, or gets the capacity to detect and react appropriately to violation of the harvesting controls. On the opposite, poaching may surge, making rebuilding unlikely if not impossible, in highly vulnerable small communities, hedging on organized crime (6.3).

Economic and social issues are fundamental

They are frequently mentioned and appear essential in some case studies (e.g. 2, 7) but they are not thoroughly examined in most case studies (e.g. in terms of costs and benefits of rebuilding and distribution of these among actors, sub-sector, etc.). Rebuilding is an investment in future biomass and has immediate costs (including reconfiguration and re-dimensioning costs) which might be shouldered by a large-scale industry if the rebuilding time is short and a return to better harvests in future are likely (6; 7). Such transitional costs, might not be affordable in vulnerable, highly fishery-dependent, small-scale communities (6.3; 7). The social and economic stresses are likely to be more acute during a rebuilding programme (because of the crisis) than in a normal management programme. The problem is particularly significant when dealing with slow growth species requiring longer rebuilding times (6.3) and,

as a consequence, some State-driven assistance to help the sector survive through the long and uncertain transition rebuilding phase. Such assistance should include active support to restructure the sector, cut down on overcapacity, and incentivize alternative income-generating activities to facilitate exit from the fishery sector, and not just unemployment payments, if the stress on vulnerable communities is to be significantly reduced also in the future (3, 5.2, 7).

The science base is particularly important when managing a collapse

A painfully learned lesson is that, because of the continuous changes in the fishery and resources contexts, the respective contributions of management measures and contextual factors to recovery, may not be easier to establish than their contribution to the initial collapse (2; 4; 7). The database and research capacity must be strengthened in most cases to improve understanding, address more complex requirements than usual and provide answers in less time. Modelling capacity must be upgraded to be able to analyse options available and their multidimensional implications, contributing to the implementation of a precautionary approach to fisheries (7), e.g. through systematic management strategy evaluation (MSE) (3), or development of adapted Operational Management Procedures (OMPs) (6.1; 6.2) and Harvest Control Rules (1; 2.1; 2.2; 5.2). Such instruments will be more useful if they integrate the ecological, social and economic dimensions of the fishery system (3; 7) allowing the consideration of a broader range of options and impacts. Assessment capacity is also needed to react rapidly during process in case of unexpected developments (2). Capacity to foresee (and possibly forecast) environmental changes (e.g. oscillations) is essential in highly variable resources (2.1; 4.1; 4.2; 4.3; 6.2; 7) and even for demersal resources at the extreme limit of their geographical distribution (7). Knowledge on species interactions may be important, particularly in terms of the food needed for the species to be rebuilt (2). The research burden increases as the number of stocks being assessed grows, from the main economic ones to most of those impacted directly or indirectly. Budgets are limited, however, so indicator species may be used for monitoring (5). However, what constitutes an appropriate “indicator species” for a community when key species are severely depleted is not a straightforward question.

Scientific consensus greatly facilitates “smooth” decision-making. When fishery and climate effects are compounded, fining the exact contribution of each set of factors is nearly impossible and “ideological” fight among scientists impedes progress towards decisions (7). In the presence of multiple (conflicting) assessments apparently equally valid, but with different implications, the problem is to find a way to combine the most robust ones to produce the less “risky” decision applying a risk-based decision framework (5.2). In such a case, implementing two independent reviews of the assessments assisted in taking the final decisions (5.2)

External pressures may play a decisive role.

There is generally an initial reluctance, in the fishery system, to take costly and risky corrective measures without clear assessment of the impact of action... and inaction. There is also usually a heavy pressure from conservation interests to call for reduction of fisheries without a clear assessment of the costs and benefits of such action and their distribution among actors and in time. However, lobbying and advocacy have been the rule in democratic systems for decades already and, play in both directions. Certainly, in many cases fishery interests can be lobbying strongly for either continued harvesting until there is more convincing evidence that reductions are needed (1; 2.1; 4; 6.2; 6.3), or for other fishing sectors take the harvest reductions (7). Correspondingly

it can be noted that, in many instances, outside pressures from leading States, environmental NGOs and the media have accelerated, if not triggered, more decisive action by authorities in charge of fisheries (e.g. in 1). In other cases, socio-economic pressures from the sector have slowed down and delayed the reform process (6.3; 7). Environmental factors have a strong influence; (i) on the understanding of the cause-effect relations and identification of best rebuilding actions; (ii) on the trajectory and timing of the rebuilding trajectory (6).

The environment has the final word?

Finally, and perhaps more importantly, environmental factors are often determining the outcome. Notwithstanding the difficulty in determining the causal mechanisms of collapse, taking drastic measures to reduce fishing pressure is a necessary but not sufficient condition for rebuilding. A key empirical lesson seems to be that rebuilding tends to follow the occurrence of one or more good recruitments which, if well protected will trigger rebuilding (2, 7) and if not will trigger sliding back into depletion (4.3).

Rebuilding factors and challenges

Enabling factors of general value include: (i) Strong public involvement and policy support; (ii) Good governance (e.g. inclusive, adaptive, science-based) with specifically adapted legal and policy backbone. (iii) Well organized system of representation of stakeholders; (iv) Favourable national economic context, facilitating exist from the fishery and central funding of assistance packages; (v) Formal adoption and effective implementation of EAF (6.1) ; (vi) Certification processes that tend to promote and accelerate progress towards improved stewardship (6.1); (vii) Forecasting and favourable phasing of climate-driven stock variations with rebuilding efforts(2, 4, 6); (viii) Active programmes of fisher's education, monitoring of their activity and promotion of compliance (5); (ix) well-funded programmes of research and enforcement infrastructure (6). Responsiveness of the management system to contextual changes has not been tested in any case study. However, monitoring, analyses of feed-back responses, and the adoption of pre-agreed management decisions (MSE-tested OMPs and HCRs) seem to have facilitated both foresight, flexible decision-making and hence responsiveness, reducing bickering time and institutionalizing flexibility.

Limiting factors are often the lack of the enabling factors identified above (e.g. top-down governance, unfavourable economic (or political) conditions, lack of financial and administrative assistance, lax enforcement (civil disobedience).

Particularly difficult challenges may be: (i) the rebuilding of a species assemblage exploited by a range of diversified fleets (métiers) (3; 4); (ii) Similarly, dealing with the operational constraints of multiple specialized fleets exploiting jointly (or in competition) a multispecies assemblage (3; 4). Many trade-offs between fleets operations are needed that may impede the full optimization of fishing on such assemblage; (iii) dealing with recreational fisheries (and often their lobbying power) in which estimating effort, catch and discards (including in catch-and-release) (5.2) is uneasy; (iv) Interaction between science and “politics” (often reflecting non-transparent social and economic pressures or concerns) may confuse and slow the action required (7); (v) Corruption is particularly discouraging, particularly when MCS agents face physical threats (6.3).

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Part 2 of the global review of “Rebuilding of Marine Fisheries” provides 13 case studies of fisheries on which rebuilding initiatives were undertaken, in various parts of the world and under different circumstances, as well as an analysis of the role of closures (MPAs and fishery closures) in rebuilding. The cases studies relate to: Northeast Atlantic and Mediterranean Bluefin tuna; Norwegian spring spawning herring and Northeast Atlantic cod; Southeast Australia multispecies (scalefish and sharks); Japanese sardine, anchovy and chub mackerel; Western Australia snapper, multispecies demersal resources and scallop fisheries; South African fisheries on hakes, sardine and rock lobster; and Canadian (Newfoundland) cod. The MPA analysis considers many examples of MPAs and fishery closures, including the Great Barrier Reef. The case studies illustrate contrasting situations regarding the nature of the resources, the types of fisheries, the governance structures and processes, the environmental and socioeconomic contexts, the causes of depletion, information richness, and outcomes. They highlight the multiple dimensions of the rebuilding problem. A number of lessons are learned regarding the triggering factors, the likelihood and factors of success in rebuilding, the importance of reactivity, timeliness and clarity of the objectives, the weakly predictable nature of the process, the main problems, the uncertainty inherent in rebuilding trajectories, the needed improvements in the legal, policy, governance and management frameworks, the rebuilding and post-rebuilding regimes, economic and social considerations, science - policy issues, environmental issues, enabling and limiting factors and challenges.

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