CSIRO WEALTH FROM OCEANS NATIONAL RESEARCH FLAGSHIP
www.csiro.au

Technical Reviews of Formal Harvest Strategies

Malcolm Haddon[1], Cathy Dichmont[2], Neil Klaer[1], Sean Pascoe[2], Andrew Penney[3], Tony Smith[1], David Smith[1], Simon Vieira[3], Peter Ward[3]

1. CSIRO Wealth from Oceans Flagship, GPO Box 1538, Hobart, TAS 7001, Australia.
2.CSIRO Wealth from Oceans Flagship,GPO Box 2583, Brisbane, QLD 4001, Australia
3. ABARES, GPO Box 1563 Canberra ACT 2601, Australia

May 2014 FRDC Final Report 2012/225

Australian Government
Department of Agriculture, Fisheries and Forestry
ABARES

FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Citation

Haddon, M., Dichmont, C., Klaer, N., Pascoe, S., Penney, A., Smith, A.D.M., Smith, D.C., Vieira, S. and P. Ward (2014) Technical Reviews of Formal Harvest Strategies. CSIRO and ABARES. FRDC Final Report 2012/225. Hobart. 28 p. plus appendices

National Library of Australia Cataloguing-in-Publication entry

Title: Technical reviews of formal harvest strategies / Malcolm Haddon [and eight others]

ISBN: 9781486301263 (paperback)

Series: FRDC final report; 2012/225.

Subjects: Fish stock assessment--Australia.
Fishery management-Australia.

Other Authors/Contributors: CSIRO and Fisheries Research and Development Corporation (Australia)

Dewey Number: 639.20994

Important disclaimer

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry

Contents

1 Non-Technical Summary

2012/225: Technical Reviews of Formal Harvest Strategies

PRINCIPAL INVESTIGATOR:	Associate Professor Malcolm Haddon
ADDRESS:	CSIRO Marine and Atmospheric Research GPO Box 1538 HOBART TAS 7001 Telephone: (03) 6232 5097

OBJECTIVES:	1.Provide a technical review of recent research on fisheries harvest strategies (both in Australia and overseas) so as to identify information, methods or strategies that may help to address key issues identified by the review of the Commonwealth Fisheries Harvest Strategy Policy.
	2. Identify further research required to update the harvest strategies used for Australian fisheries.
	3. Provide technical advice on how the harvest strategy policy (including the Guide-lines) might be revised in the light of the review conducted in this project and, where relevant, suggest associated technical refinements of the Policy's wording.
	4. Identify alternative indicators of economic performance.

Outcomes achieved to date:

1. The reviews contained in this document have been used by the Commonwealth harvest strategy policy review committee, in both draft and final versions, to provide the basis for recommending potential adjustments to the Commonwealth fisheries harvest strategy policy. The outcome of the review has yet to be made public (October 2013) so any changes recommended are currently unknown but the reviews contained here have already played and met their roles. The individual reviews are publically available at: http://www.daff.gov.au/fisheries/domestic/harvest_strategy_policy/review.
2. In addition, the reviews provided a resource for use by the project 2010/061 Development of a National Harvest Strategy Framework.

Draft versions of the reviews that form the main appendices of this report were presented to the Commonwealth harvest strategy policy review committee on Tuesday 5th February 2013 in Canberra. These presentations involved formal descriptions of the review findings in each case followed by questions to the different authors by the committee members.

Four separate reports relating to material prepared to facilitate the 2013 review of the Commonwealth Harvest Strategy Policy (HSP) and its Guidelines are presented and briefly summarized in this umbrella project report. While each of the four component reports was independently produced there are obvious linkages between them.

The work in this project was all designed to assist the review committee with the review of the HSP. Some aspects considered were directly related to the policy itself, such as the discussion of the use of $0.5B_{MSY}$ as the default limit reference point in the section on reference points appropriate to life-history characteristics. On the other hand, most sections and discussions would have more to do with the guidelines, which determine how the policy is interpreted.

The first review document was: Haddon, M., Klaer, N., Smith, D.C., Dichmont, C.D. and A.D.M. Smith (2012) *Technical reviews for the Commonwealth Harvest Strategy Policy*. FRDC 2012/225. CSIRO. Hobart. 69 p.

This considered six major fields in the field of harvest strategies relating to reference points and harvest controls and each of these sections considered an array of different issues. The sections were 1) Reference Point Appropriate to Life History Characteristics, 2) Buffered Targets or Meta-Rules, 3) Data Poor Fisheries and Tiered Harvest Strategies, 4) TAC Setting and Multi-Year TACs, 5) Rebuilding Strategies and Bycatch only TACs, and 6) Spatial Management. The summary from each of these sections is included in the Results/Discussion Section 7.2 and all details are given in Appendix 3.

The second review was: Vieira, S. and S. Pascoe (2012) *Technical Reviews for the Commonwealth Harvest Strategy Policy: Economic Issues.* FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, and CSIRO Wealth from Oceans, Brisbane. p53.

This considered issues around the use of the Maximum Economic Yield (MEY) as the overall target for the Harvest Strategy Policy. These issues included 1) its definition and how the phrase is understood, 2) Challenges in operationalizing MEY, especially for 2a) Data-poor species, 2b) Mixed species fisheries, 2c) Variable stocks, and 2d) Internationally shared stocks, and finally 3) The influence of the market for product. The summary from each of these sections is included in the Results/Discussion Section 7.3 and all details are given in Appendix 4.

The third review was: Ward, P., Marton, N., Moore, A., Patterson, H., Penney, A., Sahlqvist, P., Skirtun, M., Stephan, M., Vieira, S. and J. Woodhams (2013) A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy, FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

This review detailed issues relating to the difficulties encountered when implementing the Commonwealth Harvest Strategy Policy across the diversity of fisheries within the Commonwealth of Australia. It covers the main problems covered by the policy including the use of target and limit reference points, the attention needed to risk and uncertainty and the relationship between the two, the rebuilding of depleted stocks, the need for testing and evaluation of harvest strategies for particular fisheries, temporal and spatial management issues, and the management of stocks shared between jurisdictions, both national and international. Finally the review included case studies to illustrate some of the issues and their related solutions. The summary from each of these sections is included in the Results/Discussion Section 7.4 and all details are given in Appendix 5.

The final review was: Penney, A., Ward, P. and S. Vieira (2013) *Technical reviews for the Commonwealth Harvest Strategy Policy: Technical Overview*. FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

This review attempted to summarize the findings from the first three reviews and then identified particular issues that the review committee might want to pay particular attention to in their considerations. The subjects covered included 1) Reference points and Proxies, 2) Alternative MEY Targets, 3) Target Ranges and Dynamic Targets, 4) Tiered Harvest Strategies, 5) Data Requirements and the Risk-Catch-Cost trade-off, 6) Multi-year TACs, 7) Rebuilding Strategies, 8) Reduction of Discards, 9) Spatial Management, 10) Ecosystem Based Fisheries Management, 11) and the role of all of these in the Implementation of the Harvest Strategy Policy. The summary from each of these sections is included in the Results/Discussion Section 7.5 and all details are given in Appendix 6.

KEYWORDS; Harvest Strategy; Commonwealth Fisheries Harvest Strategy Policy; Fisheries management.

2 Acknowledgments

Each document has its own list of acknowledgements and these should be referred to for the full details, which differ between documents.

3 Background

The development and implementation of harvest strategies is considered a crucial step to improving fishery management in Australia (Smith et al, 2008) and internationally (Cadrin et al., 2004; Cadrin and Pastoors, 2008).

The Commonwealth Fisheries Harvest Strategy Policy and Guidelines (HSP) are widely acknowledged as a key driver of improvements in the performance of Commonwealth fisheries since its introduction in 2007. It has cultivated a transparent, evidence and risk-based approach to setting target and limit reference points for assessing a wide range of species along with decision rules for generating advice for managing key commercial species in Commonwealth fisheries. It is considered an example of world's best practice for managing fisheries.

A review of the HSP is underway, with the review's report to be considered by Ministers Ludwig and Burke in March 2013. As part of the review, ABARES and DAFF have consulted various Commonwealth agencies, scientists, economists and stakeholders on their views on the HSP and identified areas where it might be improved. The review's advisory committee (representing a wide range of stakeholders) has provided input; and wider opinion is being sought via public consultation. This project will link past and current research with the review, providing technical advice on those areas of potential improvement.

4 Need

Since the HSP was introduced in 2007 there has been a great deal published both nationally and internationally concerning the development and application of harvest strategies. This work needs to be reviewed for new technical content, especially with respect to new and developing methodologies for stock assessments and risk evaluation, and how the new work relates to issues that have been identified in the current HSP. For example, a 10 July 2012 letter from DAFF to FRDC identified issues arising from the review of the harvest strategy policy as a key research priority.

The HSP is generally regarded as successful. However, the review has identified aspects of the policy, the guidelines, and its implementation, that might be improved to better meet the policy's objectives. Areas of improvement include consideration of appropriate limit reference points based on trophic role or the biological characteristics of different groups of species (e.g. teleosts vs. chondrichthyans), incorporation of spatial management, approaches to setting total allowable catches (TACs) in multispecies fisheries, data-poor stocks (including byproduct), rebuilding strategies and indicators of economic performance. This project will review the latest publications relevant to those priority areas along with research work in progress so as to provide the HSP advisory committee with technical advice on potential improvements to these aspects of the existing policy. Evaluation of current research and developing technologies will provide a basis for a revised policy to incorporate greater flexibility in responding to shifts in stocks and ecosystems from environmental drivers, such as climate change. This work will ultimately contribute to continued improvements in the economic performance and sustainability of Commonwealth fisheries and will have relevance to shared fisheries, fisheries in other jurisdictions, and internationally.

5 Objectives

1. Provide a technical review of recent research on fisheries harvest strategies (both in Australia and overseas) so as to identify information, methods or strategies that may help to address key issues identified by the review of the Commonwealth Fisheries Harvest Strategy Policy.
2. Identify further research required to update the harvest strategies used for Australian fisheries.
3. Provide technical advice on how the harvest strategy policy (including the Guidelines) might be revised in the light of the review conducted in this project and, where relevant, suggest associated technical refinements of the Policy’s wording.
4. Identify alternative indicators of economic performance

6 Methods

This project constituted the production of four separate reports CSIRO staff were responsible for the first report listed below and some of the second, while ABARES staff were responsible for the rest of the second report and the last two. Instead of repeating the material in each of the reports in this umbrella report each of the four final report documents is given in its entire and original form (with appropriate permission) in Appendices 3 – 6. Contact details for each set of authors is provided in each appendix.

1. Haddon, M., Klaer, N., Smith, D.C., Dichmont, C.D. and A.D.M. Smith (2012) *Technical reviews for the Commonwealth Harvest Strategy Policy*. FRDC 2012/225. CSIRO. Hobart. 69 p.

2. Vieira, S. and S. Pascoe (2012) *Technical Reviews for the Commonwealth Harvest Strategy Policy: Economic Issues.* FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, and CSIRO Wealth from Oceans, Brisbane. p53.

3. Ward, P., Marton, N., Moore, A., Patterson, H., Penney, A., Sahlqvist, P., Skirtun, M., Stephan, M., Vieira, S. and J. Woodhams (2013) A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy, FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

4. Penney, A., Ward, P. and S. Vieira (2013) *Technical reviews for the Commonwealth Harvest Strategy Policy: Technical Overview*. FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

The methods used in each review involved standard bibliographic methods when reviewing published and otherwise reported technical and policy related advances. The subjects chosen for particular consideration were those deemed most likely to be considered for confirmation, modification, or change. Ideally, the reviews might have been conducted after the period of public consultation so that they might have more easily addressed matters raised in the public submissions; however time constraints prevented such an arrangement.

7 Results and Discussion

7.1.1 Introduction

This document is a combination of the final reports from four major components of a project producing technical and other supporting reviews to be used when conducting the current review of the Commonwealth Harvest Strategy Policy. The primary results and discussion are thus captured by transcribing the executive summaries of each of these reports, which are presented in their entirety in their separate appendices.

7.2 Haddon, et al (2012) Technical Reviews

The following six sections attempt to identify key points raised in each of the sections of this set of reviews. It should be noted that this material is diverse and relatively complex so, unfortunately, brief summaries of each section are not possible. The following are not conclusions but rather constitute important points that require noting.

7.2.1 Reference Points Appropriate to Life-History Characteristics

The range of suggestions for what would constitute an appropriate target biomass and fishing mortality value is very great but the difficulty in estimating the real risks of running relatively high fishing mortality rates at low stock sizes indicates that the suggestion of $B_{40\%}$ rather than something lower is a reasonable compromise. The current default biomass target reference point of $B_{48\%}$ would appear to be highly conservative (biologically) for many species, although it may be quite appropriate for slower growing sharks and rays and may not be sufficiently conservative for some key low trophic level species. For example, the Commonwealth small pelagic fishery, in line with a number of regulations world-wide, has adopted a biomass level of at least 80% B_0 as the B_{LIM} for each species in this fishery (with higher values in the more data poor situations), and for such ecologically important species such apparent high levels seem appropriate. However, such a level would ignore the fact that such species are naturally highly variable and could quite naturally vary in abundance, sometimes down to very low abundance levels. An alternative could be not to accept a limit with reference to a fixed B_0 but rather to only take a standard proportion of available biomass. Such constant escapement strategies are not currently included in the HSP but would be useful for naturally highly variable species such as scallops, small pelagic species, and squid, for which the concept of a stable unfished biomass, B_0, may not be meaningful. Full implementation of this would thus mean that management of such stocks would not be in relation to specific biomass limit and target reference points but rather in relation to estimates of current stock size. In addition, such a strategy might need to include some minimum level of predicted harvest before fishing could occur so as to avoid encouraging unprofitable fishing.

For productive species where $0.5B_{\mathrm{MSY}}$ is less than $B_{20\%}$ the current HSP suggests that levels of biomass < $B_{20\%}$ would be acceptable. Given the uncertainty inherent in estimation of stock productivity, the precautionary approach would firstly require good evidence that $0.5B_{\mathrm{MSY}}$ is indeed below $B_{20\%}$. In the face of these various doubts and uncertainties it would be difficult to argue that there would be no increase in the risk of depletion affecting consequent recruitment levels if the limit biomass reference point was permitted to vary below the current $B_{20\%}$. For small pelagic fisheries, because of ecosystem based fishery management considerations the limit reference point would tend to be either the same as or very close to the target (which has similarities to having a constant escapement strategy.

7.2.2 Buffered Targets or Meta-Rules

The present arrangements where those harvest strategy control rules in which a break point is clearly defined at the proxy target reference point certainly stabilizes catches and another meta-rule that prevents TACs varying by more than 50% between any two years has also been helpful in preventing serious dislocation and disturbance in the fishery for some relatively unstable species. These particular meta-rules have already been simulation tested using MSE.

If it was decided to pursue the issue of buffers and meta-rules around the targets in an attempt to stabilize catches through time then it would be beneficial to use simulation testing (MSE) to consider the effect of such changes to the expected dynamics of different fisheries.

7.2.3 Data Poor Fisheries and Tiered Harvest Strategies

We define fisheries or species as data poor if information is insufficient to produce a defensible quantitative stock assessment.

For data poor fisheries, difficulties can arise in almost every component of the harvest strategy – for example, little or no regular monitoring means time series are rare, the assessment method is undertaken with an unknown degree of uncertainty, reference points are poorly defined and the associated control rules do not necessarily address risk clearly. Yet, a recognized component of the present Harvest Policy is the application of a consistent degree of risk across all fisheries, irrespective of fishery type.

Often the efficacy of a data poor harvest strategy can be very fishery specific. The use of a tiered system of assessment methods and associated control rules allows for the development of detailed, integrated stock assessments (Tier 0 and 1) down to the lowest Tiers where data is limited to catch rates, catches, or even just catches (Tiers 6 and 7). Below these tiers is the Ecological Risk Assessment, which aims to determine whether there are particular species that are exceptionally vulnerable to the effects of fishing.

7.2.4 TAC Setting and Multi-Year TACs

Generally, when TACs are set for individual species, catches of other species are not considered. In multi-species fisheries, there are often technological interactions where fishing effort directed towards one quota species will normally result in a mixed catch of fish that may include other quota species. Fishers can usually ‘target’ to some degree through fishing different areas and depths, seasons, times of day and by modifying gear. But it is the degree to which fishers can target that is the issue. The species mix in catches may not necessarily match the mix in combined TACs or in quota holdings. This difficulty in balancing quotas for multiple species with actual catches may then lead to increased discarding, TAC over-runs, effort restrictions or fishery closures when quota is constrained on some species. It is possible to characterize recent multispecies catch data into primary and companion components. The approach of identifying companion species within a given fishery provides an empirical means to examine the impact of individual species TAC decisions across all of the quota species in a fishery.

In general, multi-year TACs will require a "discount" (reduction) of some level of catch to balance the greater risk associated with less frequent review and adjustment. There are obvious risks of stock depletion if the multi-year TACs are set too high. While there is debate about how best to set multi-year TACs no decisions have yet been made. Currently there has been little testing of the robustness of fisheries to the application of multi-year TACs.

7.2.5 Rebuilding Strategies and Bycatch-only TACs

A primary objective of the Commonwealth Harvest Strategy Policy (HSP) is to maintain key commercial fish stocks at ecologically sustainable levels and within that context, maximize the economic returns to the Australian community. If a fishery falls below the default limit reference point of $B_{20\%}$ the HSP states that: "Typically recovery times are defined as the minimum of 1) the mean generation time plus ten years, or 2) three times the mean generation time." However, attempting to meet these guidelines has been problematic, for example, in at least three conservation dependent species in the SESSF.

The HSP already states that not all species in a multi-species fishery need be maintained at the target reference point (default of $B_{48\%}$ as a proxy for B_{MEY}) as long as all assessed species stay above the limit reference point. So the rebuilding target for each species is not always clear.

The HSP makes the assumption that rebuilding of a depleted species will always occur. However, in a changing marine environment this may not always be true. Potential regime shifts have already been identified in particular species (Jackass Morwong) on Australia's east coast (a world hot spot for sea water temperature rise) and this provides an example of a species whose long term productivity has declined. There is thus a need to recognize that there are circumstances under which rebuilding to previously experienced levels would not be expected to occur.

It is also possible that some species, particularly when they were fished under a basket species category (e.g. gulper sharks) may have been reduced to such a low level that the probability of them recovering would become influenced by random events. In addition, if the projected timeline for recovery is extremely long it becomes possible that long term changes in the marine environment will become influential on the probability of eventual recovery.

Finally, there are some species which are naturally extremely variable (e.g. squid and scallops). Simulation testing can be used, and has been used, to demonstrate that the harvest strategies in place are potentially capable of achieving the intent of the HSP, even though it is very hard to identify adequate proxies for a particular limit or target biomass reference point. However, some unpredictable events, such as the recent almost complete die-off of scallop beds in south-east Australia, unrelated to any fishing, are not amenable to anything other than reactive management.

7.2.6 Spatial Management

Spatial management may be applied in various contexts within a harvest strategy. It can form the main harvest strategy framework (such as in a system of rotational closures), it can be used to augment a harvest strategy framework, or spatial management measures can be invoked as a control rule (a variation of rotational closures). For some species a management scheme that controls fishing mortality with large spatial and temporal fishery closures offers a management strategy more robust to uncertainty than direct control of catch, since only a small component of the stock gets exposed to the fishery. However, this relies on good compliance with fixed closure boundaries (the Commonwealth Vessel Monitoring System ensures this) and is mainly applicable to species that do not move large distances.

7.3 Vieira and Pascoe (2012) Economic Issues

7.3.1 Summary

The key objectives of Australian Commonwealth fisheries management as defined in the Commonwealth Harvest Strategy Policy (DAFF 2007) is that Commonwealth fisheries be managed sustainably and to maximise the net economic returns to the Australian community. This is interpreted in the Guidelines as maximum economic yield (MEY), which is the level of catch and fishing effort that maximises sustainable economic profits in the industry over time. To this end, the biomass associated with maximum economic yield (B_{MEY}) is recommended as the target reference point to be used in all Commonwealth fishery harvest strategies.

Maximum economic yield ensures that all resources used in fishing are used at their optimal level, including the resource itself. A key component of the surplus generated is resource rent, which represents the return generated by the fish stocks – a key input into the production process. How much (if any) resource rent is realised by the community directly is a separate issue: the concept of MEY is concerned with maximising its generation.

A key challenge in achieving MEY is determining the actual harvest target itself. MEY is more than just a catch target – it also relates to a stock size and level of fishing effort that enables the catch to be taken. Estimating MEY requires some form of a bioeconomic model, which in turn requires detailed information on the biology of the species, technical interactions between fishing gears and catches (especially in mixed fisheries), cost structures of the fishing fleet and market conditions. In many cases, information on one or more of the required model components is not available, such that bioeconomic modelling is unable to be undertaken. In Australian fisheries, this is a major issue as the number of operational bioeconomic models available for management advice is limited.

Proxy measures of the target reference point have been proposed for use in cases where bioeconomic models are not available, or sufficiently reliable, to estimate MEY. These range from measures based on biomass estimates, to simpler estimates in cases where data are limited. Alternative indicators of optimal fleet structure include capacity utilisation, which do not provide a measure of MEY directly but provide an indication of the level of excess capacity in a fleet. For international fisheries where target catches are given, such a measure provides useful information on optimal fleet size and structure.

Recently, there has also been confusion over what sectors need to be considered in bioeconomic analyses for the purposes of estimating MEY. In particular, several researchers have proposed that downstream businesses such as wholesalers, processors and retailers should be included in the definition, and that the impacts of upstream businesses supplying the fishing industry should also be considered. The effect of their inclusion is higher catch and effort levels in the fishery, but lower industry profit levels compared to the definition of MEY above. However, the use of greater levels of inputs in fishing beyond what is optimal not only reduces rent generation, but also diverts resources from other sectors of the economy where they could be used to greater benefit. Further, empirical analysis has demonstrated that in most cases, improved profitability in fisheries leads to improved economic activity in regional communities (counter to the previous arguments).

An area where the definition of MEY may need to be modified is the case where fisheries have some degree of market power such that price varies with the quantity landed. In such fisheries, maximising the profit to the industry results in higher prices to consumers, and potentially a net loss in overall benefits through lower consumer surplus. In these fisheries, maximising the net economic returns requires maximising the sum of both producer and consumer surplus. This results in a higher level of catch (and effort) than that which maximises industry profits alone.

7.4 Ward et al (2013) Technical Review of Implementation

7.4.1 Summary

This review focuses on technical aspects of the implementation of the *Commonwealth Fisheries Harvest Strategy Policy and Guidelines 2007 (DAFF 2007). It* includes information on whether fishery management actions and decisions have been consistent with the policy, challenges encountered in implementing the policy and changes in the biological and economic status of fisheries that might be attributed to the policy's implementation.

A harvest strategy is a formal system for managing a fishery. Harvest strategies consist of reference points that reflect management objectives, indicators that measure status against those reference points, a process for assessing stocks and monitoring the fishery and control rules designed to modify fishing activities in response to indicators and thereby meet the fishery's objectives. Harvest strategies are often tested using management strategy evaluation (MSE) to ensure that the decision rules have a high probability of achieving the objectives under a wide range of plausible scenarios.

The policy's overriding objective is to maintain key commercial fish stocks at ecologically sustainable levels and, within this context, maximise economic returns to the Australian community. It requires the implementation of harvest strategies that maintain stocks at a desired state (target reference point) that is equivalent to the stock's size or biomass (B) that will produce the maximum economic yield (MEY). The policy also requires stocks to be above a limit reference point beyond which the biological risk to the stock is considered too high. The proxy for the limit reference point is at least half of the biomass that would produce the theoretical maximum sustainable yield (MSY) in the absence of fishing ('at equilibrium'). If B_{MSY} has not been estimated, then the proxy for B_{MSY} is assumed to be $0.40B_0$, with the proxy limit being $0.20B_0$. The proxy for the target reference point is 20 per cent above the biomass that will produce MSY ($1.20B_{\mathrm{MSY}}$) or 48 per cent of the unfished biomass ($0.48B_0$).

Since the policy's introduction in 2007, AFMA has implemented harvest strategies for 71 fish stocks that are managed in 12 of the 13 active Commonwealth fisheries. Harvest strategies have been developed, but not implemented, for several species in the relatively small Coral Sea Fishery, which harvests numerous species. The policy requires harvest strategies to be implemented for all key commercial species, which are defined as ‘a species that is, or has been, specifically targeted and is, or has been, a significant component of the fishery.’ The fish stocks under harvest strategies include all quota-managed species and several other commercial species, including rebuilding stocks that were previously commercial species, e.g. eastern gemfish. Harvest strategies have been implemented for several byproduct species, e.g. squid in the Northern Prawn Fishery (NPF). There are other species that are sometimes retained for sale but which are not under harvest strategies, e.g. ocean jacket in the Commonwealth Trawl and Scalefish Hook sectors (CTS).

In several fisheries, multiple stocks or are managed together as a single entity. The eastern and western stocks of jackass morwong, for example, are assessed as separate stocks but are managed under a single total allowable catch (TAC). Similarly, there are several fisheries where multiple species are managed together, e.g. scampi consist of at least three species in the North West Slope Trawl Fishery. Multispecies stocks arise through uncertainty over stock structure or species identification or are a legacy of past management arrangements. Grouping of different species under single assessments and harvest strategies inevitably results in increased uncertainty as a result of the different productivity and stock status of each species or stock. Uncertainty in assessments could be reduced by verifying the species composition of catches and encouraging management at the individual stock level.

The economic performance (generated net revenues) of many Commonwealth fisheries and the biological status of fish stocks have improved since the late 2000s. The number of Commonwealth stocks classified as not overfished, for example, increased from 21 in 2007 to 38 in 2011 and the number classified as not subject to overfishing increased from 37 to 55. Many improvements in stock status are likely to be due to the implementation of harvest strategies. However, it is difficult to separate the influence of harvest strategies from the effects of other factors over this period, particularly fishing effort reductions that have resulted from various structural adjustments. Other factors influencing economic performance include fluctuations in the demand for seafood, fluctuating currency exchange rates, changing operating costs and implementation of management measures (e.g. marine parks and closures). In combination with harvest strategies and other management measures, improved data, research and assessment have contributed to the improved biological status of many stocks.

The harvest strategies implemented in most Commonwealth fisheries are consistent with the policy. For the larger, data-rich fisheries with quantitative assessments, harvest strategies have been designed and tested to directly achieve the policies objective of MEY. Harvest strategies of several small, low-value fisheries (for example, the Western Deep Water Trawl Sector) are often rudimentary or are not routinely used, but are nonetheless consistent with the policy’s intent. Many of the impediments to implementing the policy are related to cost (specifically for improved monitoring and assessment), human resources and data availability, and not due to problems with the policy itself. Sophisticated stock assessments requiring the collection of additional data might not be justified for low-value fisheries and cannot be undertaken in the absence of the necessary data or analytical capacity. Priorities for harvest strategy implementation have therefore tended to reflect more the economic value of stocks, and less the level of risk.

There is a need to encourage the further development of generic and cost-effective approaches for small fisheries and data-poor stocks, including the implementation of risk-based approaches and prioritising the development and implementation of harvest strategies for lower information but high risk species. Ecological risk assessments can be used identify low-risk and high species, allowing ecological risk management programs or harvest strategies to be developed for the high risk species, using a combination of monitoring, mitigation and adaptive management.

About two-thirds of the harvest strategies implemented in Commonwealth fisheries have specified target and limit reference points. The harvest strategies of most low-value fisheries or data-poor fisheries have triggers instead of reference points. The triggers are intended to activate a process of data collection and assessment in response to an indicator (e.g. catch) reaching a pre-agreed level. However, the most appropriate levels of triggers for many of these fisheries are unknown and have not been MSE tested. The existing triggers may also not be regularly monitored or the data required for assessments or implementing management measures when a trigger is reached may not be routinely collected and such assessments may not be feasible within a suitable timeframe. Further work is needed to evaluate trigger-based harvest strategies and to undertake MSE testing of their effectiveness in achieving the policy's objectives. Statistical models that combine biological and economic information are necessary for determining MEY and estimating the levels of biomass, fishing effort and catch that correspond to MEY. These bio-economic models have been used to estimate B_{MEY} for six stocks in the NPF and Great Australian Bight Trawl Sector (GABTS). Bio-economic models require reliable data on market prices, operating costs, a quantitative stock assessment model and experts to run those analyses, and they need to forecast prices and economic conditions. These data are difficult to collect for many fisheries. Instead of estimating B_{MEY}, most harvest strategies use the policy's proxies for target reference points, which are based on biological quantities instead of economic quantities, e.g. $1.20B_{\mathrm{MSY}}$. Low-cost alternatives to statistical bio-economic modelling using available economic information and assessments are needed. The policy's $\mathrm{B}_{\mathrm{MEY}}$ proxy for the target reference point also needs to be validated over a wide variety of fishery types and species.

In addition to maintaining stocks at the biomass that will produce MEY, the policy states that MEY should be optimised across the fishery as a whole, across all species. Fishery-wide MEY has been estimated for two fisheries (GABTS and the tiger prawn sub-fishery of the NPF). However, fishery-wide MEY has not been estimated for most Commonwealth fisheries for the same reasons that stock-specific MEYs have not been estimated: inadequate economic data, no quantitative assessment models, insufficient capacity or insufficient funding.

Many harvest strategies rely on the catch-per-unit-effort (CPUE) reported by commercial fishers. These harvest strategies assume that CPUE is a reliable index of stock biomass and that the selected reference period represents MEY or, in some case, the unfished stock. CPUE is often also the main abundance index used in quantitative assessment models. Fishery-independent surveys can be a reliable alternative or adjunct to commercial CPUE. Examples of such surveys in Commonwealth fisheries include acoustic surveys for orange roughy. The Small Pelagic Fishery has run daily egg production surveys to collect data for estimates of current spawning biomass. The Bass Strait Central Zone Scallop Fishery's harvest strategy involves pre-season surveys.

Trawl surveys have been established in several valuable fisheries, including the NPF, CTS and GABTS. However, it takes many years of surveying to compile a time-series that can be used as an index of trends in abundance and those estimates may only be robust for a small suite of frequently encountered species. Fishery-independent surveys are also expensive. For fisheries where such surveys are not possible or are considered unaffordable, there is a need for additional work on developing reliable commercial CPUE indices.

There is higher uncertainty associated with low information and this increased uncertainty results in increased risk. The policy requires that harvest strategies achieve comparable (low) levels of risk across all categories of information availability. This has to be addressed by adopting increasing precaution as the uncertainty in stock status increases. Multi-year TACs have been introduced in several fisheries to reduce annual assessment costs and to provide industry with stability and certainty about short-term catch levels. Multi-year TACs are sometimes based on projections of future stock status under alternative levels of catch and thereby ensure that future catches at those levels do not result in increased risk. Nevertheless, it may be necessary to determine whether discounts should be applied to multi-year TACs and to provide further guidance on setting break-out rules for multi-year TACs.

Harvest strategies have prevented many stocks from falling below their limit references points and becoming overfished. However, several stocks that were depleted to below these limit levels prior to adoption of the policy have not subsequently rebuilt, despite the requirement to not allow targeted fishing and the setting of low incidental catch allowances. The reasons why stocks have not rebuilt are not clear. Reasons may include the possibility that ongoing catches exceed levels that will facilitate rebuilding or changes in stock productivity caused by ecological factors, such as changes in the marine environment or climate that affect spawning success. The reference points of most harvest strategies are fixed at estimated 'equilibrium' levels and do not reflect the dynamic nature of fish stocks.

Fixed reference points cannot reflect environmentally-induced productivity changes. Apparent changes in productivity have resulted in the revision of reference points for eastern jackass morwong to reflect the understanding that the productivity of this stock has decreased. Guidance on identifying productivity shifts and development of non-equilibrium reference points might help in these situations. Regardless, there is need for firmer guidance on setting incidental catch allowances and managing the catches of companion species.

In many cases, reduced abundance or the effects of mandatory and voluntary restrictions on fishing activities may have reduced the availability or quality of fishery-dependent data required for stock assessments and to monitor rebuilding. Rebuilding timeframes have sometimes been too optimistic because stock productivity has been overestimated or a return to average historical levels of recruitment has been assumed, e.g. eastern gemfish. Furthermore, the policy's Guidelines are not entirely clear as to whether the formula for calculating the rebuilding timeframe refers to rebuilding from the current biomass to the limit reference point or whether it refers to another reference point (e.g. B_{MSY} or B_{MEY}) or from the limit reference point to B_{MEY}.

Some stocks will take many years to rebuild. For example, orange roughy has very low growth and productivity with projected recovery times of many years. The *Orange Roughy Conservation Program* (AFMA 2006) aims to maintain biomass on the Cascade Plateau at or above 0.$60B_0$*, which is* more conservative than default proxy reference points specified in the policy. Projections of the eastern, western and southern stocks of orange roughy indicated that those stocks may take many years to recover despite no commercial catches. However, recent acoustic survey results suggest that eastern orange roughy may be recovering more rapidly than initially projected.

The policy recognises that more conservative reference points might be required for species that are important in the maintenance of food webs or communities (‘keystone species’). The Macquarie Island Toothfish Fishery, which adapted its harvest strategy from the international Commission for the Conservation of Antarctic Marine Living Resources, has taken into account the ecological role of harvested species. In recognition of the important role of forage fish in food webs, the harvest strategy for the Small Pelagic Fishery stipulates that the harvest of small pelagic species should not exceed 20 per cent of the most recent estimate of abundance, with this being sequentially scaled down by 0.25 per cent per year since the last assessment, down to 7.5 per cent.

The policy states that harvest strategies should be formally tested to demonstrate that they are highly likely to meet the policy’s core elements. Management strategy evaluation (MSE) involves computer simulations of harvest strategies over a range of uncertainties, including model structures and the assumptions in assessments, parameter values, fishing activities, reporting and management decisions. MSE has demonstrated that the harvest strategies of most Commonwealth fisheries are robust to uncertainty. However, insufficient information has precluded testing of the harvest strategies of some small fisheries and data-poor stocks, alternative targets in multispecies fisheries, discount factors and some multi-year TACs. These aspects of current harvest strategies still require testing. MSE should be used to test both generic and species-specific harvest strategies. MSE testing results can be significantly different among species within the same fishery and so there may be a need for testing at the species level as well as generically.

Harvest strategy control rules generate a recommended biological catch (RBC) and limiting total fishing mortality to the RBC should move the stock’s biomass towards the target reference point. TACs are usually based on these RBCs. However, there have been situations where assessments were not accepted, resulting in TACs being based on other considerations or rolled-over from a previous year. Sometimes the TAC that is rolled over is based on a previous assessment that has similar problems to the assessment that has not been accepted, e.g. redfish. The policy does not provide guidance on setting TACs in the absence of an agreed assessment, other than advocating a risk-management approach where exploitation rates are steadily reduced as time elapses since the last assessment and uncertainty around stock status increases.

Stock assessments and harvest strategies attempt to take into account fishing-induced mortality from all sources. The next fishing season’s TAC for the Commonwealth fishery is then derived by deducting other sources of mortality from the RBC, e.g. estimates of state and recreational catches, catches in other Commonwealth fisheries and Commonwealth discards. For several species, reliable estimates have not been available for significant sources of mortality, e.g. recreational catches of silver trevally. For other species, state catches have been deducted from RBCs and, in the absence of state–Commonwealth catch-sharing arrangements, the TAC available to Commonwealth fishers has been reduced. For example, the annual state catch of school whiting has ranged between 750 and 1400 t in recent years, over half the RBC. State catches are deducted from the RBC, so that the TAC available to Commonwealth fishers is less than half the RBC. However, state catches are sometimes not actively managed, resulting in the possibility that escalating state catches can result in unpredictable reductions in Commonwealth TACs. Improved stability in Commonwealth fisheries could be achieved through negotiation of catch-sharing arrangements with relevant states and territories.

Several fisheries have attempted to deal with the effects of spatial management measures, such as marine reserves and closures for protected species, that have been implemented outside the harvest strategy. However, the treatment of effects of closures has been inconsistent across fisheries. In particular, it has been difficult to determine how RBC estimation and TAC calculations should take closed areas into account and to identify meaningful reference points in open areas for fisheries or species affected by closures. Research is underway on how RBCs might account for these effects. This research will contribute to the development of guidance on how harvest strategies should deal with closures, including possible modifications to reference points and harvest strategies applied to remaining open areas.

The policy recognises that it is difficult to apply the policy to jointly managed stocks or regional fisheries management organizations (RFMOs) and it does not prescribe management arrangements for these stocks. Australia’s domestic policy settings have been advocated where relevant at various regional fisheries management organisations (RFMOs), including the Western and Central Pacific Fishery Commission (WCPFC) and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). International harvest strategies have been implemented by RFMOs for several stocks (e.g. southern bluefin tuna), which are consistent with many aspects of the Commonwealth harvest strategy policy. However, there are often delays to progress within RFMOs in adopting new approaches to fishery management because of diverse aspirations among members. The Australian Government’s approach of using an explicit MEY-based target reference point has not been adopted elsewhere, although some jurisdictions do recognise the benefits of managing above B_{MSY} under certain circumstances.

Where international harvest strategies have not yet been adopted for international straddling stocks, AFMA has developed and implemented harvest strategies for the domestic components of several international fisheries, e.g. the Eastern Tuna and Billfish Fishery (ETBF), which is considered a subcomponent of the international Western and Central Pacific Fishery. However, the implementation of harvest strategies for the domestic component of several ETBF stocks has been delayed by uncertainty over the extent to which fishing activity in the wider western Pacific affects ETBF stocks, and vice versa. The policy states that ‘in the absence of agreement [on RFMO catch level decisions], Australia’s domestic catch allocation decision would be consistent with the agreed whole of government position’. For these stocks, AFMA has applied a TAC that was based on historical catch levels in the fishery.

7.5 Penney et al (2013) Technical Overview

7.5.1 Non-Technical Summary

The main technical conclusions and issues of direct relevance to revision of the Harvest Strategy Policy and Guidelines, as identified in the various technical review reports, group themselves into a number of key categories. The key issues raised under each of these categories are summarised below. Under each category, a statement on the current situation is followed by identification of aspects of the policy or guidelines that might benefit from improvement at the moment (in black), as well as aspects that probably require further work before further options for improvement can be identified (in *blue italics*).

As a direct result of the fact that these issues have been identified in technical reports, most of the potential improvements relate to the technical implementation guidelines, and not the HSP itself. However, some of the options for improvement in the guidelines may require consideration of supporting or enabling text in the Policy.

7.5.2 Reference Points and Proxies

Current HSP target and limit reference points (B_{MEY}, B_{MSY}, B_{LIM}) and proxies (48%B_0, 40%B_0, 20%B_0) meet international best practice. Use of B_{MEY} (48%B_0) as a target exceeds international best practice. The use of F_{MSY} as an effort limit and to define overfishing is also international best practice.

- Account needs to be taken of recent work suggests that best practice targets for different species groups vary, depending on biology and productivity:
  - Targets for important forage fish, such as small pelagic species, should be around 75%B_0 to ensure ecotrophic function (Smith et al. 2011, Pikitch et al. 2012).
  - MSY targets for a range of teleost species groups range from 26%B_0 to 46%B_0 (Thorston 2012). For chondrichthyans, Brooks et al. (2010) obtained similar values for a numbers-based analogue of B_{MSY}/B_0 ranging from 21% to 47%, with most sharks lying towards the upper end of that range.
  - Although estimated B_{MSY} ratios are similar for bony fishes and sharks, Zhou et al. (2012) found that the ratio of F/M differs substantially between teleosts and chondrichthyans, with F_{MSY} = 0.87M for teleosts and F_{MSY} = 0.41M for chondrichthyans.
- Proxy B_{MSY} in the range 35% - 40%B_0 minimizes the potential loss in yield for teleost species compared to that which would arise if B_{MSY} was known exactly (Punt et al. in press). This is consistent with the current HSP proxy of 40%B_0 for B_{MSY}. The proxy B_{MSY} for some shark species may need to be closer to 50%B_0.
- Given the differences in B_{MSY} ratios for different species groups, the principle of setting B_{LIM} = 0.5BMSY should be retained to cater for those species where BMSY > 40%B0, to ensure that limits designed to prevent unacceptable biological risk also take into account factors that dictate a higher B_{MSY} proxies, including the ecotrophic role of forage species.
- *Due to higher uncertainty in cost data, the proxy for B_{MEY} to minimize the potential loss in profit lies in the range 50% - 60%B_0 (Punt et al. in press). This is*

higher than the current proxy of 48%B0 for B_{MEY} as a result of higher uncertainty around cost data.

- *Proxy values for B_{MEY} may more appropriately be 1.3-1.4B_{MSY} as opposed to the currently recommended 1.2B_{MSY}. Optimal effort levels are most likely to fall between 55% and 65% of MSY effort levels (Zhou et al. 2013).*
- *Harvest strategies may need to be revised and MSE re-tested for some species / fisheries if higher B_{MEY} targets are indicated.*

7.5.3 Alternative MEY Targets

MEY targets have been estimated for the Northern Prawn and Great Australia Bight fisheries. For all others, the proxy (1.2B_{MSY} or 48%B_0) is used. One of the main problems has been difficulty in getting the necessary representative cost data to enable bio-economic modelling.

- Where alternative targets (B_{MSY} or lower) are established for secondary species in multi-species fisheries, these should be MSE tested to ensure that risks remain acceptable.
- *Further practical guidance is required on the circumstances under which an MEY target should be estimated, how it should be estimated for different fishery types and key principles of successful implementation.*
- *Better guidance is required on economic objectives (what MEY means) and how it can be best achieved for different fisheries, such as variable fisheries and those with market power.*
- *A more practical approach is required to using existing economic data and incorporating economic parameters into stock assessment outputs.*
- *There should be further exploration of alternative indicators and reference points for MEY, including those based on optimal fishing capacity and catch rates and improved proxies.*
- *Further guidance is required on what constitutes meeting the MEY objective for data-poor stocks and what is an appropriate level of research investment for such stocks.*

7.5.4 Target Ranges and Dynamic Targets

Targets and limits are currently set as single fixed (static) values, either estimated from assessments or using default proxy values, assuming that the stock will achieve some long-term equilibrium. However, even in a perfectly managed fishery, stocks will fluctuate naturally around the target due to inter-annual variability in environmental conditions, spawning success and recruitment.

- Target ranges can cater for this natural variability by defining the target as a range between two plausible values (e.g. New Zealand hoki) or using the uncertainty around estimates of MSY or MEY. Target ranges can be implemented within harvest strategies by adopting decision rules that incorporate a TAC plateau over the target range (Haddon et al. 2013).
- Limits should remain as single specified values (whether static or dynamic), as the required probability of not breaching these constitutes (<10%) already constitutes a range. Where target ranges are set, these should be tested to ensure that there is

still a less than 10% probability of stocks declining below the limit if managed at the lower end of the target range.

- *In addition to natural inter-annual variability, highly variable stocks can show inter-decadal cycles in recruitment and productivity in response to environmental cycles (e.g. El Niño), or long-term climatic trends or regime shifts.*
- *Fixed target levels or ranges are inappropriate for species showing trends in productivity. Targets for such species are more appropriately specified as a ratio of the stock status if no fishing had occurred, referred to as $B_{Unfished}$ (e.g. 40%$B_{Unfished}$), where this can be estimated.*
- *Where variability in species productivity indicates the need for a dynamic target as a result of trends in productivity, a similarly dynamic limit (e.g. set at half the target) would also be indicated.*

7.5.5 Tiered Harvest Strategies

There is a wide range in data availability for different fish stocks, from low information for discarded bycatch species to high information for main commercial target species. Tiered assessment approaches have been developed and applied to stocks in the SESSF. These have recently been expanded to cater for stocks for lower information stocks, such as where only catch data are available (Dichmont et al. 2013).

- Discount factors applied to RBCs derived from various assessment tiers (5% - 15%) are not always consistently applied. These should be MSE tested to ensure that they achieve comparable risk across the tiers.
- Below these analytical approaches, ERAs should be used to determine whether particular species are vulnerable to the effects of fishing.
- These methods should all be integrated into a comprehensive hierarchical guide to assessment methods, data requirements, potential indicators and feasible harvest strategies at each tier, covering the full range from ERA to stock assessment.
- *Additional by-product species brought into a revised HSP would need to be evaluated to determine whether they are at low biological risk from current fishing levels, using existing or updated Level1 or 2 ERAs.*
- *ERAs may need to be reviewed to ensure that determination of 'low risk' under an ERA is analogous to there being low probability of these species declining below B_{LIM} levels under current fishing.*
- *Additional work is required to develop and test harvest strategies that could be effectively applied to the additional lower information assessment tiers (Tiers 5 – 7) developed by Dichmont et al. (2013).*
- *Development and MSE testing of harvest strategies designed to manage stocks towards targets and away from limits at each tier level should mean that additional discount factors are not required. If harvest strategies have not been tested to ensure low risk of breaching limits, and if discount factors are to be applied, then these discount factors should be extended to the new Tiers 5 – 7, and should themselves be MSE tested.*

7.5.6 Data Requirements & Risk-Catch-Cost Trade-Off

Data requirements for the various ERA and analytical assessment tiers are well understood (Dichmont et al. 2013). However, managing data-poor fisheries towards maximum economic yield (BMEY) or proxy (48%B0) is difficult without significant increased data collection.

- There are increasing costs associated with moving to more certain, lower risk assessments. Selection of assessment tiers and data collection requirements should be guided by the Risk-Catch-Cost trade-off.
- *More work is required to develop B_{MEY} proxies for use with such data-poor fisheries.*

7.5.7 Multi-Year TACs

Multi-year TACs have been established for a number of species in the SESSF to reduce the annual assessment burden and cost. Multi-year TACs provide greater certainty regarding the level of future TACs and can provide greater catch stability. In general, multi-year TACs require a discount of some level of catch below optimised annual TACs to balance the greater risk associated with less frequent review and adjustment.

When MYTACs are established, ‘breakout’ rules are usually adopted to detect extraordinary conditions not tested for when the MYTACs were determined (such as an unexpectedly large increase or decrease in CPUE), and which require stock status and the MYTAC to be reviewed. Adequate monitoring of the data required to calculate the breakout rule has to continue to allow these breakout rules to be annually evaluated.

- Additional guidance is required on when and how best to set multi-year TACs.
- For stocks with Tier 1 assessments and for which projections can be generated, projections at various catch levels and over various periods of time should be used to determine the level of MYTAC appropriate over various time periods (i.e. what level of catch is ‘safe’ over 2, 3 or 5 years).
- *For higher tier, lower information stocks for which projections cannot be run, MSE testing should be used to determine the appropriate discount rates to use for setting of MYTACs over different periods.*

7.5.8 Rebuilding Strategies

The HSP requires that active rebuilding strategies be implemented for all stocks that decline below B_{LIM}, to rebuild these towards B_{TARG}. Targeted fishing must cease below B_{LIM}. Stocks managed under rebuilding strategies have not shown the expected rebuilding within the planned timeframe. Some depleted species (e.g. Eastern gemfish) would not recover in the 10 years plus one generation time stipulated in the HSP. Reduction in productivity as a result of some sort of ‘regime shift’ have been proposed (jackass morwong, Wayte 2012) and suggested (eastern gemfish) as the reason why these stocks have not recovered as predicted.

- There is some uncertainty regarding whether recovery timeframes stipulated in the HSP apply to recovery to above B_{LIM}, or recovery to B_{TARG}, and whether targeted fishing can occur on conservation dependent species even if they are above B_{LIM}.
- Recovery timeframes stipulated in the HSP (10 years plus one generation) may not account for differences in productivity, variability in recruitment and the possible relationship between spawning biomass and recruitment. A biologically appropriate definition of recovery time is required that can account for differences in productivity.

- USA and New Zealand require re-building in relation to Tmin, the minimum time to recovery under zero fishing: USA = Tmin plus one generation; NZ = twice Tmin. This sort of approach is able to deal with a wide range in species productivity and recovery rates.
- Persuasive evidence of a change in productivity resulting from some external environmental factor is required before an environmental regime shift can be adopted as the justification for changing the productivity parameters, targets and limits, for a species under a rebuilding plan. Reduced recruitment as a result of spawning depensation in a depleted stock does not necessarily alter the productivity of the stock.
- *McIlgorm (2012) notes that the formally legislated recovery plans used in the USA appear to have one of the best records of stock recovery.*

7.5.9 Reduction of Discards

International best practice aims to achieve zero discards by either legislating for this, or implementing a deemed value system. One of the factors that has reduced the ability to monitor rebuilding of depleted stocks is the poor estimates of discards for stocks subject to rebuilding plans. Reduced information on discard rates can mask recovery that may be occurring.

- Rebuilding plans for depleted stocks should include requirements to ensure adequate monitoring and data collection, to be able to obtain accurate estimates of discards and to track increases abundance or availability.

7.5.10 Spatial Management

The HSP recognises that spatial management may be used in various ways: rotational closures to protect spawning seasons or nursery areas; rotational harvesting; separate TACs by area; or protection of key habitat areas. These are all valid and useful management options that are particularly applicable to protection of non-mobile (shellfish, sea cucumbers) highly resident species or seasonally aggregating species.

- Additional guidance is required on evaluating the extent to which a stock is considered to have been protected, and fishing mortality rates decreased, by closures, or how management of the remaining stock in open areas should be revised to account for the effects of closures.
- *Work is underway (FRDC project 2011/032: The Influence of Closures on the HSP) to evaluate the extent to which fishing mortality on a range of stocks has been decreased by the establishment of an increasing number of MPAs or large-scale, permanent closures for protection of other species.*
- *Assessment approaches and harvest strategies may need to be revised for some species to account for the protective effect of these spatial closures. This will require some understanding of the rate of movement between closed and open areas and agreement on objectives for how the remaining stock in open areas is to be exploited.*

7.5.11 Implementation Review

The report '*A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy*' (Ward *et al*. 2013) summarises experiences, successes and difficulties with development and implementation of harvest strategies for Commonwealth fisheries since adoption of the HSP. This review identifies many of the same technical issues relating to harvest strategies that are identified in the Haddon et al. (2013) technical review of the HSP and guidelines, but identifies some additional issues relating to implementation.

Reference Points and Indicators

Most harvest strategies use the policy's proxies for target reference points and several harvest strategies (particularly for low information byproduct species) do not have target and/or limit reference points. For most species, reference points are fixed and do not reflect the non-equilibrium nature of variable fish populations. It has been difficult to identify meaningful reference points for spatially structured species.

Harvest strategies for several low-value and data-poor fisheries have triggers instead of reference points because it has been difficult to identify meaningful reference points. For many of these, the appropriate levels of triggers are largely unknown and the assessments and management actions that are triggered may not be feasible within an appropriate timeframe.

Targets required to optimise fishery-wide MEY have not been estimated for most Commonwealth fisheries.

- The reliance on target and limit proxies for many stocks emphasises the importance of ensuring that these proxies appropriately reflect the biology and productivity of various species groups.
- Where triggers (such as catch or CPUE) for low information stocks are designed to trigger immediate additional assessment work (e.g. to support in-season adjustment or some other immediate management action), monitoring and data collections programmes need to be in place to ensure that the data required for such additional assessment us available.
- *Problems with implementing MEY targets for many stocks emphasises the need for further work on appropriate MEY proxies for various species groups and fisheries, and for a more practical approach to using existing economic data and incorporating economic parameters into stock assessment outputs.*

Spatial Management

The treatment of marine reserves and other closures has differed across fisheries.

- Harvest strategy implementation could be improved with additional guidance on evaluating the effects of closures on protection of stocks in closed areas, and management of remaining stocks in open areas.
- *Assessment approaches and harvest strategies may need to be revised for some species to account for the effects of spatial closures.*

Management Strategy Evaluation and Testing

Most harvest strategies have been tested using Management Strategy Evaluation to ensure that there is low risk (<10%) of breaching limits. For low information species, some of this MSE testing has been generic, rather than species-specific, evaluating the performance of a particular harvest strategy approach across a group of species in a fishery.

Insufficient information has precluded testing of the harvest strategies of some small fisheries and data-poor fisheries. MSE testing has also not been conducted: to evaluate the effectiveness of proposed discount factors applied to when moving from Tier 1 to higher tier (Tier 3 and 4) assessments; to evaluate the increase in risk that might be associated with moving to alternative targets below B_{MEY} for secondary species; or to evaluate MYTACs, where these have not been developed using projections from a Tier 1 assessment.

- *Additional MSE testing should be used to evaluate the effectiveness of discount factors and MYTAC catch levels for low information stocks.*

Application of Harvest Strategies

Harvest strategies for small fisheries and data poor fisheries are often rudimentary or are not routinely run. Several stocks or species are assessed and managed as stock 'baskets' and harvest strategies have not been implemented for other significant commercial species, e.g. ocean jacket.

For several species, reliable estimates have not been available for significant sources of mortality, e.g. recreational catches, discards. Delays in data acquisition, processing and assessment have contributed to uncertainty in stock status.

It is unclear whether harvest strategies are required for the domestic component of three ETBF stocks because of uncertainty over stock connectivity between the EEZ and high-seas, and therefore over the effects of high-seas fishing on stock abundance in the Australian zone.

- Inclusion of additional low-information species under a revised HSP will require a tiered approach to determining whether a harvest strategy is required, and what form this should take, depending on information availability and the risk-catch-cost trade-off. Harvest strategies could be unnecessary and unfeasible for low information, low risk (as determined using ERA) minor by-product species.
- Where harvest strategies are agreed and adopted, monitoring and data collection programmes need to be implemented to ensure that the data required to apply those harvest strategies is available.
- *Additional harvest strategies may be required for important secondary species not currently under harvest strategies (e.g. ocean jacket), or species evaluated by ERA to be at medium or high risk from current fishing activities.*

Rebuilding Strategies

A number of stocks depleted to below limits prior to the introduction of the HSP, and placed under rebuilding plans have so far failed to rebuild to above limits reference levels. There are likely to be a number of factors that have contributed to the failure of these stocks to rebuild, including: rebuilding timeframes may have been too optimistic; some level of targeted fishing may have continued and fishing mortality may have been high enough to prevent rebuilding; or changes in the stock's productivity or ecosystem changes may have inhibited rebuilding.

- *Alternative approaches should be explored and consideration given to how to best define biologically appropriate rebuilding timeframes, able to deal with the wide range in species productivity and recovery rates.*

- *Evidence of a change in productivity is required before an environmental regime shift can be adopted as the justification for changing the productivity parameters, targets and limits, for a species under a rebuilding plan.*

7.5.12 Ecosystem-Based Fisheries Management

There are several international ecosystem and environmental monitoring and management trends that have surpassed the Australian HSP (McIlgorm 2012).

- The HSP was not intended to meet Australia's international undertakings to implement an ecosystem approach to fisheries under the Convention for Biodiversity or the FAO guidelines for responsible fisheries.
- Australia has a multi-agency approach to environmental management, probably requiring some additional broader or over-arching policy to address requirements for ecosystem-based fisheries management.

8 Benefits and Adoption

These reviews have already been distributed to the HSP review committee and will be formally transferred to the Minister's office at the end of March. Their use in the review of the form and operation of the Commonwealth Harvest Strategy Policy and its Guidelines has already begun.

The benefits of this work relate to the improvements that will follow from the HSP review. The current HSP has been very successful in providing a framework with which to significantly reduce over-fishing and begin to allow over-fished stocks to recover (ABARES, 2012). Correcting over-fishing is much more rapid that allow for rebuilding as over-fishing can be prevented by simply reducing catches. Rebuilding towards targets will always be slower as depleted populations need to successfully reproduce and grow.

9 Further Development

Draft versions of the reviews that form the main appendices of this report were presented to the Commonwealth harvest strategy policy review committee on Tuesday 5th February 2013 in Canberra. These presentations involved formal descriptions of the review findings in each case followed by questions to the different authors by the committee members.

The Final versions of each review were distributed to the review committee in March 2013 by the ABARES team. These were the versions used as the final advice to the review committee.

The next step with this work is the pursuit and implementation of the recommendations from the proposed Commonwealth Harvest Strategy Policy review. It is currently expected that the review committee will report back to the Minister for Fisheries by July 2013.

The advent of the countrywide parliamentary election led to a care-taker period in government, which meant that no decisions could then be taken until after the election result on September 7th 2013. The outcome was the election of a new government, which led to a change in the Minister responsible for Fisheries and the future developments of the HSP review are now with this new Minister. The intention is, however, that the current Commonwealth Harvest Strategy Policy will still undergo revision but the details of this process may now be altered from previous plans. The reviews encapsulated in this report provide a sound foundation of advice and alternatives choices with their relative pros and cons that relate directly to any potential revisions of the Harvest Strategy Policy and its guidelines.

10 Planned Outcomes

The project will provide a sound basis for potential adjustments to the harvest strategy policy. This will benefit the long-term economic performance and sustainability of Commonwealth fisheries. Through linkages with the National Harvest Strategy Framework project regional fisheries management organisations, this project will also contribute to improved management of fisheries in other Australian jurisdictions.

The main beneficiaries of this work will be DAFF, Commonwealth fisheries managers, and eventually, Commonwealth fishers. In particular, the immediate beneficiaries will be the DAFF Advisory Committee charged with developing recommendations for the Minister in relation to the Commonwealth Harvest Strategy Policy review.

Trying to estimate the economic impact of improving the Harvest Strategy Policy is not possible, however, by identifying ways to make the harvest strategy policy more inclusive and general with the aim of making it simpler and easier for the industry to conduct sustainable fishing operations in a profitable way, there will be advantages to the industry in terms of ease of operation, profitability, and sustainability. By clarifying the dangers (or otherwise) of perceived risk there should also be improvements in the public licence to fish.

In addition, as there is an intention to publish aspects of the technical reviews and as examples of good management practice this work will be valuable to fisheries managers everywhere.

The Review Committee met in Canberra on Tuesday February 5th and formal presentations were made in which the contents of the reviews were surveyed and it was attempted to explain the review's main points. A primary objective of the meeting was to allow the committee members the opportunity of discussing the material with the authors and asking questions about the content and any aspects they wanted more information on.

The final versions of the reviews themselves are either on the following website or can be found from there:

http://www.daff.gov.au/fisheries/domestic/harvest_strategy_policy/review

11 Conclusions

1. Provide a technical review of recent research on fisheries harvest strategies (both in Australia and overseas) so as to identify information, methods or strategies that may help to address key issues identified by the review of the Commonwealth Fisheries Harvest Strategy Policy.
2. Identify further research required to update the harvest strategies used for Australian fisheries.
3. Provide technical advice on how the harvest strategy policy (including the Guidelines) might be revised in the light of the review conducted in this project and, where relevant, suggest associated technical refinements of the Policy's wording.

These three objectives were met with the in the first review (Haddon et al., 2012).

4. Identify alternative indicators of economic performance

The objective was met with in the second review (Vieira and Pascoe (2012).

The other reviews related to extensions to this original project that included the review of the implementation of the harvest strategy policy (Ward et al., 2013) and an overview of all the separate reviews (Penney et al., 2013).

12 References

ABARES (2012) *Fishery Status Reports 2011.* Woodhams, J., Vieira, S. and I. Stobutzki (*eds.*) Australian Bureau of Agricultural and Resource Economics and Sciences. Canberra. 440p.

Cadrin, S.X., Boutillier, J.A., and Idoine, J.S. 2004. A hierarchical approach to determining reference points for Pandalid shrimp. Canadian Journal of Fisheries and Aquatic Sciences 61(8): 1373-1391.

Cadrin, S.X., and Pastoors, M.A. 2008. Precautionary harvest policies and the uncertainty paradox. Fisheries Research 94(3): 367-372.

Haddon, M., Klaer, N., Smith, D.C., Dichmont, C.D. and A.D.M. Smith (2012) *Technical reviews for the Commonwealth Harvest Strategy Policy*. FRDC 2012/225. CSIRO. Hobart. 69 p.

Smith, A.D.M., Smith, D.C., Tuck, G.N., Klaer, N., Punt, A.E., Knuckey, I., Prince, J., Morison, A., Kloser, R., Haddon, M., Wayte, S., Day, J., Fay, G., Pribac, F., Fuller, M., Taylor, B., and Little, L.R. 2008. Experience in implementing harvest strategies in Australia's south-eastern fisheries. Fisheries Research 94(3): 373-379.

Vieira, S. and S. Pascoe (2012) *Technical Reviews for the Commonwealth Harvest Strategy Policy: Economic Issues.* FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, and CSIRO Wealth from Oceans, Brisbane. p53.

Ward, P., Marton, N., Moore, A., Patterson, H., Penney, A., Sahlqvist, P., Skirtun, M., Stephan, M., Vieira, S. and J. Woodhams (2013) A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy, FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

Penney, A., Ward, P. and S. Vieira (2013) *Technical reviews for the Commonwealth Harvest Strategy Policy: Technical Overview.* FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

13 Appendix 1: Intellectual Property

There are no issues concerning intellectual property relating to this research project. Parts of the reviews are expected to be published, widely disseminated and promoted; all outputs will become available in the public domain.

14 Appendix 2: Staff

CSIRO Staff:

Cathy Dichmont
Malcolm Haddon
Neil Klaer
Sean Pascoe
Tony Smith
David Smith

ABARES Staff

Nic Marton
Andy Moore
Heather Patterson
Andrew Penney
Phil Sahlquist
Simon Vieira
Peter Ward
James Woodhams

15 Appendix 3: Technical Reviews

Haddon, M., Klaer, N., Smith, D.C., Dichmont, C.D. and A.D.M. Smith (2012) *Technical reviews for the Commonwealth Harvest Strategy Policy*. FRDC 2012/225. CSIRO. Hobart. 69 p.

Technical Reviews for the Commonwealth Harvest Strategy Policy

Malcolm Haddon, Neil Klaer, David Smith, Cathy Dichmont, and Tony Smith.

CSIRO Wealth from Oceans National Research Flagship,
CSIRO Marine and Atmospheric Research,
GPO Box 1538,
Hobart, TAS 7001,
Australia.

January 2013

FRDC 2012/225

Australian Government
Fisheries Research and Development Corporation

National Library of Australia Cataloguing-in-Publication entry

Author: Haddon, Malcolm, author.
Title: Technical reviews for the Commonwealth Harvest Strategy policy / Malcolm Haddon, Neil Klaer, David Smith, Cathy Dichmont, and Tony Smith.

ISBN: 9781486301256 (paperback)

Series: FRDC final report ; 2012/225
Subjects: Fisheries--Environmental aspects--Australia.
Fishery management--Australia.
Fish stock assessment--Australia.

Other Authors/Contributors:
Klaer, Neil, author.
Smith, David Charles, 1951- author.
Dichmont, C. M., author.
Smith, A. D. M. (Anthony David Miln), 1953- author.
CSIRO. Wealth from Oceans National Research Flagship,

Dewey Number: 338.3727

CITATION

Haddon, M., Klaer, N., Smith, D.C., Dichmont, C.D. and A.D.M. Smith (2012) Technical reviews for the Commonwealth Harvest Strategy Policy. FRDC 2012/225. CSIRO. Hobart. 69 p.

COPYRIGHT AND DISCLAIMER

IMPORTANT DISCLAIMER

ACKNOWLEDGMENTS

Thanks go to CSIRO’s administrative staff and the staff at FRDC for speeding this project through the necessary processes.

Contents

I

1 Executive summary

The following sections attempt to identify key points raised in each of the sections of this set of reviews. It should be noted that this material is diverse and relatively complex so, unfortunately, brief summaries of each section are not possible. The following are not conclusions but rather constitute important points that require noting.

1.1 Reference Points Appropriate to Life-History Characteristics

The range of suggestions for what would constitute an appropriate target biomass and fishing mortality value is very great but the difficulty in estimating the real risks of running relatively high fishing mortality rates at low stock sizes indicates that the suggestion of $B_{40\%}$ rather than something lower is a reasonable compromise. The current default biomass target reference point of $B_{48\%}$ would appear to be highly conservative (biologically) for many species, although it may be quite appropriate for slower growing sharks and rays and may not be sufficiently conservative for some key low trophic level species. For example, the Commonwealth small pelagic fishery, in line with a number of regulations world-wide, has adopted a biomass level of at least 80% B_0 as the B_{LIM} for each species in this fishery (with higher values in the more data poor situations), and for such ecologically important species such apparent high levels seem appropriate. However, such a level would ignore the fact that such species are naturally highly variable and could quite naturally vary in abundance, sometimes down to very low abundance levels. An alternative could be not to accept a limit with reference to a fixed B_0 but rather to only take a standard proportion of available biomass. Such constant escapement strategies are not currently included in the HSP but would be useful for naturally highly variable species such as scallops, small pelagic species, and squid, for which the concept of a stable unfished biomass, B_0, may not be meaningful. Full implementation of this would thus mean that management of such stocks would not be in relation to specific biomass limit and target reference points but rather in relation to estimates of current stock size. In addition, such a strategy might need to include some minimum level of predicted harvest before fishing could occur so as to avoid encouraging unprofitable fishing.

For productive species where $0.5B_{\mathrm{MSY}}$ is less than $B_{20\%}$ the current HSP suggests that levels of biomass < $B_{20\%}$ would be acceptable. Given the uncertainty inherent in estimation of stock productivity, the precautionary approach would firstly require good evidence that $0.5B_{\mathrm{MSY}}$ is indeed below $B_{20\%}$. In the face of these various doubts and uncertainties it would be difficult to argue that there would be no increase in the risk of depletion affecting consequent recruitment levels if the limit biomass reference point was permitted to vary below the current $B_{20\%}$. For small pelagic fisheries, because of ecosystem based fishery management considerations the limit reference point would tend to be either the same as or very close to the target (which has similarities to having a constant escapement strategy.

1.2 Buffered Targets or Meta-Rules

The present arrangements where those harvest strategy control rules in which a break point is clearly defined at the proxy target reference point certainly stabilizes catches and another meta-rule that prevents TACs varying by more than 50% between any two years has also been helpful in preventing serious dislocation and disturbance in the fishery for some relatively unstable species. These particular meta-rules have already been simulation tested using MSE.

If it was decided to pursue the issue of buffers and meta-rules around the targets in an attempt to stabilize catches through time then it would be beneficial to use simulation testing (MSE) to consider the effect of such changes to the expected dynamics of different fisheries.

1.3 Data Poor Fisheries and Tiered Harvest Strategies

We define fisheries or species as data poor if information is insufficient to produce a defensible quantitative stock assessment.

For data poor fisheries, difficulties can arise in almost every component of the harvest strategy – for example, little or no regular monitoring means time series are rare, the assessment method is undertaken with an unknown degree of uncertainty, reference points are poorly defined and the associated control rules do not necessarily address risk clearly. Yet, a recognized component of the present Harvest Policy is the application of a consistent degree of risk across all fisheries, irrespective of fishery type.

Often the efficacy of a data poor harvest strategy can be very fishery specific. The use of a tiered system of assessment methods and associated control rules allows for the development of detailed, integrated stock assessments (Tier 0 and 1) down to the lowest Tiers where data is limited to catch rates, catches, or even just catches (Tiers 6 and 7). Below these tiers is the Ecological Risk Assessment, which aims to determine whether there are particular species that are exceptionally vulnerable to the effects of fishing.

1.4 TAC Setting and Multi-Year TACs

Generally, when TACs are set for individual species, catches of other species are not considered. In multi-species fisheries, there are often technological interactions where fishing effort directed towards one quota species will normally result in a mixed catch of fish that may include other quota species. Fishers can usually ‘target’ to some degree through fishing different areas and depths, seasons, times of day and by modifying gear. But it is the degree to which fishers can target that is the issue. The species mix in catches may not necessarily match the mix in combined TACs or in quota holdings. This difficulty in balancing quotas for multiple species with actual catches may then lead to increased discarding, TAC over-runs, effort restrictions or fishery closures when quota is constrained on some species. It is possible to characterize recent multispecies catch data into primary and companion components. The approach of identifying companion species within a given fishery provides an empirical means to examine the impact of individual species TAC decisions across all of the quota species in a fishery.

In general, multi-year TACs will require a “discount” (reduction) of some level of catch to balance the greater risk associated with less frequent review and adjustment. There are obvious risks of stock depletion if the multi-year TACs are set too high. While there is debate about how best to set multi-year TACs no decisions have yet been made. Currently there has been little testing of the robustness of fisheries to the application of multi-year TACs.

1.5 Rebuilding Strategies and Bycatch-only TACs

A primary objective of the Commonwealth Harvest Strategy Policy (HSP) is to maintain key commercial fish stocks at ecologically sustainable levels and within that context, maximize the economic returns to the Australian community. If a fishery falls below the default limit reference point of $B_{20\%}$ the HSP states that: "Typically recovery times are defined as the minimum of 1) the mean generation time plus ten years, or 2) three times the mean generation time." However, attempting to meet these guidelines has been problematic, for example, in at least three conservation dependent species in the SESSF.

The HSP already states that not all species in a multi-species fishery need be maintained at the target reference point (default of $B_{48\%}$ as a proxy for B_{MEY}) as long as all assessed species stay above the limit reference point. So the rebuilding target for each species is not always clear.

The HSP makes the assumption that rebuilding of a depleted species will always occur. However, in a changing marine environment this may not always be true. Potential regime shifts have already been identified in particular species (Jackass Morwong) on Australia's east coast (a world hot spot for sea water temperature rise) and this provides an example of a species whose long term productivity has declined. There is thus a need to recognize that there are circumstances under which rebuilding to previously experienced levels would not be expected to occur.

It is also possible that some species, particularly when they were fished under a basket species category (e.g. gulper sharks) may have been reduced to such a low level that the probability of them recovering would become influenced by random events. In addition, if the projected timeline for recovery is extremely long it becomes possible that long term changes in the marine environment will become influential on the probability of eventual recovery.

Finally, there are some species which are naturally extremely variable (e.g. squid and scallops). Simulation testing can be used, and has been used, to demonstrate that the harvest strategies in place are potentially capable of achieving the intent of the HSP, even though it is very hard to identify adequate proxies for a particular limit or target biomass reference point. However, some unpredictable events, such as the recent almost complete die-off of scallop beds in south-east Australia, unrelated to any fishing, are not amenable to anything other than reactive management.

1.6 Spatial Management

Spatial management may be applied in various contexts within a harvest strategy. It can form the main harvest strategy framework (such as in a system of rotational closures), it can be used to augment a harvest strategy framework, or spatial management measures can be invoked as a control rule (a variation of rotational closures). For some species a management scheme that controls fishing mortality with large spatial and temporal fishery closures offers a management strategy more robust to uncertainty than direct control of catch, since only a small component of the stock gets exposed to the fishery. However, this relies on good compliance with fixed closure boundaries (the Commonwealth Vessel Monitoring System ensures this) and is mainly applicable to species that do not move large distances.

2 Introduction

2.1 Document Structure

The Commonwealth Harvest Strategy Policy (HSP), and the guidelines for its application, provides a management framework that uses evidence based methods when assessing individual fish stocks and then applying a risk-based, precautionary approach to the setting of harvest levels controlled by effort or catch for each stock. One of the reasons for its implementation was to provide "… the fishing industry and other stakeholders with a more certain operating environment where management decisions for key species are more consistent, predictable and transparent." (DAFF, 2007, Minister's Foreword, p iii).

The HSP and Guidelines is a complex document with many facets and these technical reviews reflect this in their scope and in their details. There are a number of reviews with separate headings and mostly separate subject matter but there is an unavoidable element of overlap between some subjects because of the inter-relationships between the sections. This technical review document is composed of eight sections each providing the details for each of the subject matters covered. However, the main conclusions are extracted from the text and placed under sections in the executive summary. A ninth section relating to Alternative Economic Targets and Reference Points will be presented as a separate report.

The eight sections relate to: 1) this introduction, including an introduction to fisheries and harvest strategies, 2) reference points appropriate to life-history characteristics, 3) buffered targets, 4) data-poor fisheries and tiered harvest strategies, 5) TAC setting and multi-year TACs, 6) rebuilding strategies and bycatch-only TACs, 7) assessing byproduct species, and 8) spatial management and metarules.

Two other sections in this document deal with "Other Issues" and with research projects potentially valuable to the HSP and its further development.

2.2 Objectives for Fisheries

For a range of reasons the management of natural fisheries resources is a difficult problem everywhere fishing occurs. The fundamental problem of fisheries management is that instead of being able to measure the status of different harvested stocks directly it is only possible to infer their status from samples, which usually only provide an uncertain view of a stock. While the development of time-series of fishery observations (such as catches, catch rates, age-structure data, and many others) can improve our understanding of events (if the quality and representativeness of such data is good enough) there always remains a degree of uncertainty in any assessment. In addition, there are also many data-poor or data-limited fisheries and species globally (Vasconcellus and Cochrane 2005; Pikitch 2012). Nevertheless, fishery managers are required to make decisions in the face of that uncertainty. Unfortunately, this uncertainty and its implications have not always been recognized though now, around the world, the countries with the most effective fisheries management attempt to account for uncertainty in an explicit fashion.

The history of fisheries management documents the movement away from not realizing that management of these natural resources was required through to the current environment of a wide array of management approaches in use in different fisheries around the World (Smith, 1988; Hilborn, 2012). A major change through time relates to the objectives which systems of fisheries management attempt to achieve. When declines in large fisheries were first identified at the end of the 19th century the concerns that arose involved a combination of wanting to maintain catch rates (to fish economically) and to maximize the yields from different fisheries (Garstang, 1900). At that time the primary objective was to maximize yield but it took some years before it was recognized that for many species applying more fishing effort did not necessarily lead to increased catches (the yield-per-recruit problem; Russell, 1931, Beverton & Holt, 1957). It may be difficult now to grasp the simplistic view of how to manage fisheries that existed in the 1910s right up to the 1970s but serious attention, acted on at national levels, was only paid to fisheries dynamics and management from the late 1950s onwards. Prior to the late 1950s most thought was given to increasing catches and the efficiency of fishing gear and it still seemed contrary to intuition to recommend limiting catches. At the second FAO conference in 1946 the FAO, for example, was strongly urging the development of fisheries as a source of protein and food: “The fishing grounds of the world are teeming with fish of all kinds. Fisheries are an international resource. In underdeveloped areas especially, the harvest awaits the reaper.” (FAO, 1985).

Early stock assessment approaches effectively ignored uncertainty and tended to produce deterministic management advice based on the assumption that natural populations are in equilibrium with each other and with any fishing effort imposed on them (Schaefer, 1954, 1957; Gulland, 1965; Megrey, 1989). These assumptions of stability were clearly invalid in many cases but nevertheless this approach led to concepts such as the Maximum Sustainable Yield (MSY), which related to catch levels, and F_{MAX}, the fishing mortality which related to the effort expected to lead to the maximum yield; which would often be larger than the MSY. Both these concepts were early fisheries targets or objectives with fisheries legislation in many countries including the achievement of MSY as the aim of management; though generally, that same legislation neglected to define the concept of MSY. How to achieve such objectives was rarely made explicit. In the 1970s it became apparent, following the collapse of a number of fish stocks, that MSY, as it was then interpreted, was not necessarily the safest objective to adopt (Larkin, 1977) and more serious efforts were made to find alternatives although the concept of MSY is still used but has evolved into use as an upper limit to fishing mortality or has been redefined to account for risks of alternative catch levels (Smith and Punt, 2001). In the 1970s and early 1980s, input controls relating to effort, gear, vessel numbers, and closed seasons were the management tools in most fisheries and some of the more successful management objectives focussed on defining an optimum fishing mortality rate. This work led to the concept of $F_{0.1}$, which was an effectively *ad hoc* advance over F_{MAX} in terms of sustainability as well as profitability as it usually led to a large reduction in fishing effort (reduction in fishing mortality) but only led to a minor loss in yield (Hilborn & Walters, 1992). Even though this was an improvement over F_{MAX} or F_{MSY} it was still based on the notion that fish stocks were able to achieve equilibrium with the fishing mortality imposed on them. While this was well known to be an approximation there was still a great deal of development needed to produce the methodologies required for taking uncertainty into account.

The importance of acting to provide management advice in the face of uncertainty was a growing theme in fisheries resource management through the late 1980s and early 1990s; the need to act before scientific consensus could be achieved rather than calling for more research was identified as a key problem for management (Ludwig *et al*., 1993); this notion of not using a lack of scientific certainty about the risk of serious environmental damage as an excuse for not acting to prevent that damage is the basis of the precautionary approach in fisheries (FAO 1995, 1996).

2.3 Explicit Recognition of Harvest Strategies

As stock assessments were becoming more sophisticated so were the management options that were developed. In the late 1980s and early 1990s the effects of variability, uncertainty, and associated risks began to be addressed in stock assessments (Francis, 1992) and the notion of presenting a table of management options with their associated risks was also developed. Hilborn & Walters (1992, p453) defined a harvest strategy as "…a plan stating how the catch taken from a stock will be adjusted from year-to-year depending upon the size of the stock, the economic or social conditions of the fishery, conditions of other stocks, and perhaps the state of uncertainty regarding biological knowledge of the stock." The harvest strategies discussed at that time revolved mainly around the classical three: constant catch (e.g. TACs; output controls), constant fishing mortality (e.g. $F_{0.1}$; input controls), and constant escapement (e.g. always leaving at least 75% of estimated Mackerel Icefish biomass in the Heard and McDonald Island fishery; mixed input and output controls). There are at least three modifications or alternatives to the classical three harvest strategies. The first would involve periodic or pulse fishing, which, as the name implies, entails only fishing a stock or region at intervals (e.g. rotational harvesting is effectively pulse fishing, such as used recently in scallops; Harrington *et al.*, 2007; Haddon, 2011). The second modification to a classical harvest strategy would entail taking into account the economics of the fishery and perhaps trying to optimize profitability rather than yield. Finally, the third alternative harvest strategy would entail adding details that account for aspects of the species' biology to other harvest strategies (this is only considered an alternative because such actions can often dominate the control of fishing). Examples include sex selective fishing (e.g. only male mud crabs can be taken in Queensland) and size limits that exclude a significant proportion of mature females (e.g. size limits in scallops in Bass Strait and minimum size of Bugs in the northern prawn fishery).

Harvest strategies in the early 1990s focused mainly on setting out fishery objectives (defining biological reference points; Smith *et al.*, 1993) and what constraints should be used. In more recent parlance, this was about determining how to assess each stock's status and what limit reference points to put in place. This may have been driven, at least in part, by new legislation in the USA that required definitions of overfishing that would explicitly guard against recruitment overfishing (Mace & Sissenwine, 1993)

A number of very influential documents were published by the FAO in the mid-1990s, including: the *Code of Conduct for Responsible Fisheries* (FAO, 1995), the *Precautionary Approach to Capture Fisheries* (FAO, 1996), and *Fisheries Management* (FAO, 1997); these latter two documents being parts of the *Technical Guidelines for Responsible Fisheries* series. The authors stated: "Long term management objectives should be translated into management actions, formulated as a fishery management plan or other management framework" (FAO, 1995, p 11). Giving more details, the *Guidelines* appear to be one of the first documents to describe the components of what are now termed Harvest Strategies. Thus it identified the needs for *targets*, described as the desired outcomes for a fishery, *operational constraints or limits*, described as the undesirable outcomes that are to be avoided, and *control rules* which specify in advance what action should be taken when specified deviations from the operational targets and constraints are observed (FAO, 1996). Early work on simulation testing of management arrangements (now known as management strategy or procedure evaluation) appears to have contributed to this approach to describing harvest or management strategies. Thus, in the *FAO Guidelines* it defines a *management procedure* as a description of the data to collect, how to analyze it, and how the analysis translates into actions. This is a standard way to describe a modern harvest strategy: define the data needed, the analysis of status, and the control rules used to generate management advice; however, in the *guidelines* the emphasis that was given to *management procedures* was placed on the investigation of how uncertainties influenced the management process (which stemmed from how these management procedures were implemented in South Africa; Butterworth & Bergh, 1993).

The main difference brought about by the adoption of formal harvest strategies was the inclusion of explicit decision (control) rules. Prior to the introduction of harvest strategies the data required for stock assessments was certainly collected and the primary thrust of research was the development and articulation of improved stock assessment methodology. With the addition of formal control rules, management responses become predetermined based on the outcome of the assessment. The control rules in the Australian HSP represented a major change to the management of Commonwealth fisheries and constitute the primary basis for improving the consistency, predictability, and transparency of management that the Minister spoke of in 2007 (DAFF, 2007).

2.4 Ecosystem Based Fisheries Management

In addition to pointing the way to what was required for the responsible management of fisheries the importance of taking into account the ecosystem effects of fishing, such as bycatch and habitat modification was identified in both the *FAO Code* and the *FAO Guidelines*. This was generally expressed in terms of using the precautionary approach to avoid unrecoverable damage to stocks and related ecosystems (Garcia, 1994; FAO, 1995, 1996, 1997).

Formal fisheries management policies have been proposed, and in some cases adopted, by a range of countries such as Australia, the USA, New Zealand, South Africa, and Europe. Each has included the major aspects of ecosystem based fisheries management as an important component within the proposed systems (DAFF, 2007; Ministry of Fisheries, 2008; US Department of Commerce, 2007). Most of these pieces of legislation were preceded by earlier fishery acts that included EBFM as directly relevant. Thus, the US Magnuson-Stevens Act was preceded by the Sustainable Fisheries Act in 1996, at the time when many of these changes recognizing the broader context in which fisheries operate were being formally adopted. Nevertheless, it was only more recently that more emphasis has been placed on EBFM.

Ecosystem Based Fishery Management is, however, very difficult to put into detailed practice. In practice, in many instances, EBFM is being implemented as an evolutionary extension of conventional fisheries management and entails single species stock assessments combined with sometimes detailed considerations of any bycatch, which may include a full ecological risk assessment (especially of threatened and endangered species), and the potential interactions of the fishing gear used with physical habitats (Pikitch et al, 2004; Haddon, 2007). This, however, remains a great improvement over simply ignoring the issue and neglecting these potentially important contributors to the retention of the ecosystems supporting the fisheries. A more recent manifestation of EBFM within Australian fisheries involves setting more conservative reference points for species of ecological importance, such as low trophic level species (Smith *et al*., 2011; Pikitch *et al*., 2012).

2.5 Australia's Limit and Target Reference Points

Each country with a formal fisheries management system of harvest strategies has implemented them in ways that suit their own particular collection of circumstances. Australia, for example, is characterized by numerous different fisheries but none are particularly large by world standards. This is a reflection of Australia's geographical location and great age. Australia has fisheries ranging from the tropics, such as indigenous hunting for dugongs in the Torres Straits, about 10° south, to industrial fishing for sub-Antarctic Patagonian toothfish around Macquarie Island at about 54° 30" south. The generally low productivity of Australian fisheries reflects the low run-off of nutrients from the generally dry and previously eroded continent, the fact that most major coastal current systems flow south from nutrient-poor tropical waters, and finally the small number of permanent areas of upwelling from deeper nutrient rich waters (Haddon, 2007). This diverse range of fisheries constitutes a serious challenge to the specification of a Harvest Strategy Policy that can apply to all.

The selection of the particular limit and target reference points for the Australian Commonwealth's fisheries, that form the foundation of the HSP, differs in some respects from practice elsewhere. The selection of $B_{20\%}$ as the limit reference point reflects earlier literature. The earliest reference to this Limit Reference Point depletion level of $20\%B_0$ appears to be Beddington & Cooke (1983). Their analyses, looking at potential yields from different stocks, were given a constraint such that:

> *"… an escapement level of 20% of the expected unexploited spawning stock biomass is used. This is not a conservative figure, but it represents a lower limit where recruitment declines might be expected to be observable. … We have chosen a twenty year period in which to investigate the probability that the escapement will fall below the 20% level. … In presenting the results of this analysis, we have calculated the appropriate level of catch, that will ensure that the probability that the SSB falls below 20% of its unexploited level is less than 0.1" (Beddington & Cooke, 1983, p9-10; this approximates the statements on* B_{LIM} *in the HSP, p4)*

Myers *et al* (1994) examined the stock recruitment relationships of 72 different fish stocks in an effort to determine a workable depletion level limit or threshold that would prevent recruitment overfishing in most cases. They concluded that in relation to methods that used estimates of $B_{20\%}$: "… based on both empirical and theoretical considerations we do not recommend them for general use." (Myers *et al*., 1994, p 204). Instead of using $B_{20\%}$ as a threshold beyond which the risk of recruitment overfishing was unacceptably high they suggested using 50% R_{MAX} (the maximum average recruitment), however, they were using very poor methods to estimate the unfished biomass, which in turn gave poor estimates of $B_{20\%}$.

The most influential document giving rise to the notion that $B_{20\%}$ is a reasonable depletion level to use as an indicator of potential recruitment overfishing was a document prepared for the NMFS in the USA (Restrepo *et al.*, 1998). In fact, they recommend ½ B_{MSY} but consider $B_{20\%}$ to be an acceptable replacement for that figure. However, it is important to note that this is only a 'rule of thumb' and there is no empirical basis that links the proxy B_{LIM} of $B_{20\%}$ and $0.5B_{MSY}$. Indeed, selecting $0.5B_{MSY}$ for some species could result in B_{LIM} much lower than 20%. Nevertheless, this relationship and proxy has been adopted in Australia.

It is in the selection of the maximum economic yield as the explicit target reference point where the Australian commonwealth is unusual; this is discussed in policy documents from other places, usually pointing out that MEY requires a lower fishing mortality rate, less yield, but higher profitability. Despite this recognition and often setting targets that are more conservative than using MSY, explicitly setting MEY as the target is uncommon. Elsewhere there has been discussion and attention paid to setting the targets by considering the risk of falling below the limit reference point. In Australia the strategy is to "...ensure that the stock stays above the limit biomass level at least 90% of the time." (DAFF, 2007, p 4) This suggests a probabilistic approach to setting targets. Caddy and Mahon, 1995 and Caddy and McGarvey (1996) described methods, improved on by Prager *et al*. (2003), for estimating a suitable target reference point that should prevent the particular stock involved from breaching the selected limit reference point with a probability equal to that chosen.

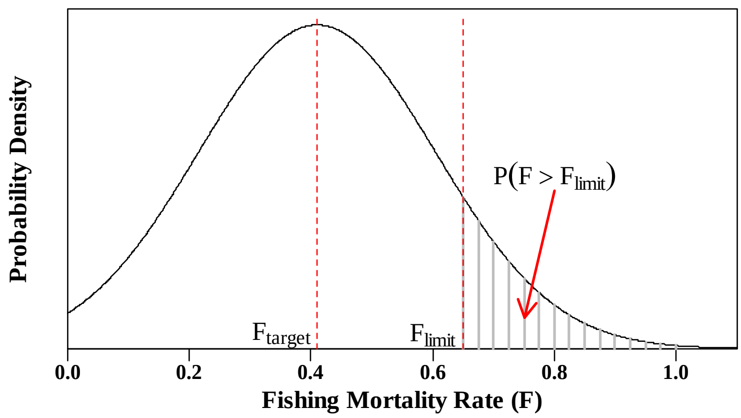


Figure 1. The probability density function describing the expected variation in annual fishing mortality for a given fishery and the relationship between the target and limit reference points. After selecting a given set of limit reference points (possibly $F_{0.1}$ or F_{MSY}), a search is made for the target fishing mortality that produces the pre-specified probability of falling below the limit reference point (after Caddy and Mahon, 1995). Prager *et al.* (2003) improved this by including uncertainty in the estimation of the limit reference point but the basic idea of having a probability density function around the target reference point which is defined by selecting the long-run probability of staying above the selected limit reference point is common to these approaches.

2.5.1 GENERAL APPLICABILITY OF REFERENCE POINTS

The Commonwealth HSP simply states that the limit reference point will not be breached with a probability > 0.1. Despite this requirement it also selects $B_{40\%}$ as a default proxy for MSY and a target of $B_{48\%}$ as a proxy for the target reference point of MEY, with no reference to whether or not this will achieve the stated risk level of falling below B_{LIM} or even be far more conservative. Currently there is no operational way to estimate the rates expected for the management imposed to breach the limit except to develop a mathematical projection model of the stock dynamics. This is done, for example, in the sub-Antarctic Patagonian toothfish fisheries (*Dissostichus eleginoides*) where the CCMALR control rule is specified in terms of the expected outcomes following 35 years of projecting the proposed management regime forward (the spawning biomass must be at or above $B_{50\%}$ (50% escapement) after 35 years with a < 10% chance of falling below $B_{20\%}$). While this has been translated in the Australian context into a manner consistent with the Australian Commonwealth Harvest Strategy it is intrinsically difficult to translate a control rule based on a projected future status into one based on the most recent status relative to reference limits and targets. This means that currently the requirement of not falling below the limit reference point more than 10% of the time is useful only when testing harvest strategies using Management Strategy Evaluation, or if projections are added to the assessments (which are not part of the current harvest strategies endorsed by the harvest strategy policy that only consider the next year's catch or fishing mortality.

The CCAMLR rule applied to Patagonian toothfish aims to achieve a target of 50% of spawning biomass rather than 48%; in other ways too (the scale of MPAs in both the Macquarie Island and Heard and McDonald Islands fisheries, and the level of observer coverage) it exceeds the expectations of the HSP. Despite these advantages before such a harvest strategy can be accepted in the current HSP framework it is necessary to conduct a management strategy evaluation to demonstrate that this alternative management strategy is at least as capable of achieving the intent of the HSP for the fisheries concerned. Even after this further analysis has been done, in practice such strategies need to be translated, sometimes artificially, into terms consistent with the explicit structure of the HSP. The explicit requirements of the HSP are not sufficiently broad to allow direct acceptance of alternative criteria for successful management. The HSP currently requires Commonwealth fisheries to be managed based on reference points that relate the present estimates of fishing mortality or spawning biomass (or their proxies) to the unfished state (in particular it involves the concept of B_0 the equilibrium unfished spawning biomass). Concepts such as a constant escapement, either now or at some projected future date, if correctly applied, are perfectly capable of managing a fishery to achieve the intent of the current HSP but are not currently part of the HSP.

The lack of this recognition is a problem for Australian fisheries on internationally distributed species (e.g. Patagonian toothfish and various tuna species) as well as a few difficult to manage highly variable Australian species. For example, with extremely variable species such as Bass Strait scallops and squid the concept of unfished biomass (B_0) does not appear to have any meaningful interpretation. Haddon (2011), in an evaluation of scallop management strategies, interpreted the regulation of having at least 40% of viable areas closed to fishing at all times (with at least 500t of biomass) as being a spatially explicit proxy for the B_{LIM} limit reference point. This aims to achieve the intent of the sustainability objective. While this spatial proxy does not relate to any notion of B_0 or of $0.5B_{MSY}$, it is a pragmatic way forward within the HSP. There are control rules for when to allow fishing in a scallop bed (there must be < 20% under the legal size), but defining a suitable target for scallops remains difficult:

> *The target for the fishery might be characterized as aiming to have a fishery each year and to achieve a catch level that matches the processor and market capacity. The first rule* [minimum size requirement] *acts to maintain profitability by avoiding waste and*

focusing on the larger scallops that generate a higher yield of scallop meat for a given number of scallops processed; in this manner the objective of achieving the most profitable fishery is approached, but this is difficult to interpret as a specific target. (Haddon, 2011, p 20)

The fundamental idea of Limit and Target reference points assumes that there is such a thing as a long term average or that fishing mortality can be considered as continuous through time. Fishing a scallop bed usually means completely depleting it to low levels, while other beds are left alone. Fishing mortality is thus relatively episodic in such species as the stock size tends to step down in jumps rather than smoothly declining (it also increases in jumps as new beds establish). While in principle such reference points might be thought reasonable if a long enough time period was considered it also seems reasonable that the time period over which stock dynamics should be averaged should be related to how rapidly management needs to react to stock changes. Even with such idiosyncratic management arrangements as those used in the Bass Strait scallops, which still attempt to meet the intent of the HSP, it is not possible to predict events such as virtually the whole Bass Strait stock (probably > 20,000 tonnes) dying off in only a few months, as happened in 2011. Such difficulties might be alleviated if some means was developed, other than time consuming and expensive approaches such as MSE, which could lead to the certification of alternatives to a strict interpretation of the HSP. Alternatively, a wider range of acceptable harvest strategy objectives and control rules, such as the inclusion of a constant escapement strategy into the HSP, might achieve the same aim.

3 Reference Points and Life-History Characteristics

3.1 MEY and MSY Proxies

Key Questions from the Discussion Document

- *…whether the Guidelines should be revised to strengthen and clarify advice relating to:*
  - *the selection and use of alternative proxy target reference points (other than the default proxies already defined in the Policy), taking into account the differing productivities and biological characteristics of various species and species groups*
  - *whether fine scale adjustments (e.g. B48 v B51) are justifiable.*

and

- *…whether there is a need to review and/or develop further advice within the Guidelines on the selection and use of limit reference points, to ensure consistency with the Policy objectives. Stakeholders may give consideration to the following questions:*
  - *Is the proxy setting in the Policy and Guidelines of $0.5B_{MSY}$ appropriate, given that for some species this implies an actual B_{LIM} of less than B_{20}? Should a more conservative approach be taken in which B_{LIM} is generally constrained to a value equal or greater than B_{20}, except where a scientifically defensible case can be made for a lower value.*
  - *Similarly, should alternatives be considered for groups/species on the basis of productivity (e.g. chondrichthyans) or ecological role (e.g. small pelagic fish) and how might these be determined?*

The concept of maximum sustainable yield (MSY) has a long history, beginning in the 1930's with Russell (1931), who discussed the notion of whether it was possible to maintain a maximum catch from a fishery, Hjort et al. (1933), whose publication was entitled "The Optimum Catch", and Graham (1935) who graphically described a yield curve as the rate of change (the production) of a fished population (see Smith, 1994, for a detailed history). The use of equilibrium surplus production models for stock assessment in the 1950's enabled and led to major fisheries management organisations adopting MSY as a fisheries management target (Schaefer, 1954, 1957; Mace, 2001; Smith and Punt, 2001). The scientific community began to question the use of MSY as a management target in the 1970's (e.g. Larkin 1977, Sissenwine 1978). At that time it was realised that a static MSY based on a theory that assumed the fishery was in equilibrium with fishing effort was generally not an appropriate management target because fish populations naturally fluctuate, and cannot produce equilibrium fixed catches in the long-term.

Density dependent recruitment compensation (i.e. stock recruitment steepness), where survivorship of juveniles increases as stock size declines, operates to offset the losses of individuals from a population as the population is reduced naturally or due to fishing and this therefore acts to stabilize the population. This phenomenon must exist to allow naturally stable populations to exist under harvesting, and is the basis for concepts such as surplus production and sustainable harvest (Rose et al. 2001).

Current fisheries management uses MSY more generally in terms of a dynamic fishing mortality rate, F_{MSY}, which should achieve MSY; F_{MSY} is now more generally used as a threshold beyond which fishing mortality should be reduced (Mace, 2001). Many proxies for F_{MSY} have been developed, for example $F_{0.1}$, F_{max}, $F_{30\%}$ and $F_{40\%}$ (different target fishing mortality rates some of which derive from yield per recruit calculations, and others that have a more empirical origin). Of particular interest for the Commonwealth Harvest Strategy Policy (HSP) is $F_{40\%}$, the harvest rate that would result in the spawning stock biomass (SSB) being reduced to 40% of the virgin level (B_0). Clark (1993) showed, using simulations, that for a range of groundfish species, a reliably high annual yield could be achieved by fishing at $F_{40\%}$, which allows for some variability in recruitment; even when that recruitment was serially correlated (periods of low or high recruitment). Fishing at $F_{40\%}$ instead of $F_{35\%}$ didn't change the predicted yield by much but reduced the number of times the stock approached a limit of $B_{20\%}$, set by Clark as a threshold to indicate overfishing and which became a far more widely accepted rule-of-thumb.

Our familiar harvest control rule diagrams with spawning stock biomass (SSB) on the X axis and fishing mortality (F) on the Y axis derive from earlier work such as Serchuk et al. (1997) and Restrepo et al. (1998). Overfishing is indicated by fishing at $F>F_{\mathrm{MSY}}$ (or F_{MSYproxy}), and the stock is considered overfished at $0.5B_{\mathrm{MSY}}$, or $0.5B_{\mathrm{MSYprox}y}$. Our current HSP default proxy for F_{MSY} is $F_{40\%}$, as recommended by Clark (1993) and others, and a corresponding B_{MSY} proxy of $B_{40\%}$. The SSB biomass limit is assumed by the HSP to be $B_{20\%}$, which is 50% of $B_{40\%}$, the proxy for B_{MSY}.

The first major review question is whether a spawning stock biomass target of $B_{40\%}$ would be appropriate across the range of species to which it is applied. As mentioned above, this proxy for MSY was initially derived through simulation analysis of a range of groundfish species (Clark 1993). Groundfish species are a subset of the kinds of organisms that the HSP has been applied to, that include taxa such as molluscs, crustaceans, elasmobranchs (sharks and rays), in addition to finfish. Productivity and therefore SSB at MSY would be expected to vary with life history. Adams (1980) was among the first to investigate such differences, finding that K-selected types (long-lived, late maturing, low M, large body size) would be highly sensitive to overfishing and, once depleted, recovery would require a long time. Winemiller (2005) provides a useful classification of fish stocks based on three major life history strategies: Periodic (long-lived, high fecundity, high recruitment variation), Opportunistic (small, short-lived, high reproductive effort, high demographic resilience) and Equilibrium (low fecundity, large egg size, parental care). Species with different life histories have different responses to fishing pressure, and potentially could be managed according to different reference point targets. There has been a commonly held belief that long-lived K-selected species would tend to have low steepness, implying relatively low productivity, but studies such as Shertzer and Conn (2012) have been unable to find such a relationship.

Guidelines used by NZ fisheries management (Ministry of Fisheries NZ 2008; developed but not yet adopted) use productivity categories as defined by FAO (2001) and Musick (1999) to separately define biomass targets ranging from $B_{25\%}$ for high productivity species to >$B_{45\%}$ for very low productivity species. They also note however, that it is becoming increasingly difficult to justify MSY-compatible biomass targets less than 30-40% B_0. Hilborn and Stokes (2010) however, suggest using historical production levels as a guide to sustainable catches and point out that the dynamics of many species more productive species would entail that 25% B_0 would be consistent with an MSY target.

Within finfish only, several meta-analyses (e.g. Myers 2001, Goodwin et al. 2006) have examined productivity of fish stocks from the RAM Legacy Stock Assessment Database (Myers et al. 1999). Using surplus production models, Thorston (2012) found average B_{MSY}/B_0 values for Pleuronectiformes (flatfish) of 39.5%, Gadiformes (grenadiers, cods, hakes) 43.9%, Perciformes (perch-like fish – many of our commercial species including morwong, whiting, tunas, swordfish) 35.3%, Clupeiformes (herring and anchovy) 26.1%, Scorpaeniformes (gurnards, flathead, rockfish, ocean perch) 46.3% and Other 40.5%. The high value for Scorpaeniformes is unsurprising given work by Dorn (2002) showing little recruitment compensation (low steepness) for US west coast rockfish. The standard deviation of these results was in the order of 0.1 for each group, so an approximate 95% confidence interval of ±0.2 times each estimate applies. There is an assumption that species within these taxonomic groups have similar characteristics, but it is clear that a wide range of life history characteristic types such as those defined by Winemiller (2005) occur within large taxonomic groups such as Perciformes (e.g. whiting and swordfish). Orange roughy and redfish are not within the groups examined – these are in the Order Beryciformes.

For elasmobranchs, Brooks et al. (2010) estimated an analogous form of B_{MSY}/B_0 using numbers of fish rather than biomass termed S_{MER}/S_0. As this was an analysis applicable to data poor species, the required information to determine the target depletion level was based on life history characteristics only – the maximum lifetime reproductive rate. Values for the 11 species examined ranged from 21% for Blue shark to 47% for Short-finned mako. They refer to Au *et al*. (2008) who summarized a likely range of spawning depletion required for optimum safe yields as being between $B_{20\%}$ - $B_{50\%}$, “with the range for sharks probably lying at the upper end of that interval” (Brooks *et al*., 2010, p172). More recent meta-analyses by Zhou et al. (2012) have shown that sustainable exploitation rates for elasmobranchs are less than half natural mortality, while for teleosts they are closer to parity.

A further and related review question is about the appropriateness of the HSP $B_{20\%}$ or ½B_{MSY} limit below which the stock is assessed as being overfished. Beddington and Cook (1983) may have been the first to use the 20% B_0 threshold and probability of falling below it as an indicator of where recruitment declines might be expected to be observable.

Questions about limit reference points for fishing mortality lead to discussion about the level of F that would lead to the population to continue to decline possibly to extinction – termed F_{crash}. Population features that are important in determining F_{crash} and the relationship of F_{crash} to F_{MSY} are the fishery selectivity pattern in relation to maturity and whether stock-recruitment depensation is a possibility (Punt 2000). The ratio of

$F_{\text{crash}}/F_{\text{MSY}}$ decreases with the productivity of the population. An explicit study of the relationship of F_{crash} to $F_{20\%}$ does not appear to have been made.

For productive species where $0.5B_{\text{MSY}}$ is less than $B_{20\%}$ the current HSP suggests it is theoretically possible to set the limit reference point at $0.5B_{\text{MSY}}$. Given the uncertainty inherent in estimation of stock productivity, the precautionary approach (FAO 1995) would firstly require good evidence that $0.5B_{\text{MSY}}$ is indeed below $B_{20\%}$. Some of the most productive fish species, often with highly variable recruitment, are small pelagics, also known as "forage fish" whose abundance levels can naturally vary widely. Such species may have B_{MSY} values much lower than $B_{40\%}$, in which case they may be candidates for limit reference points lower than $B_{20\%}$. However Walters et al. (2005) found that general application of single species MSY to a multispecies ecosystem leads to system degradation, and that forage species may require further protection to maintain the populations of larger piscivores. In the CCAMLR fisheries, for example, the minimum escapement for such forage fish species, such as the mackerel icefish (*Champsocephalus gunnari*) is 75% (that is the TACs are set such that at least 75% of available stocks are left in the water for ecosystem services), which is a very different rule to $B_{75\%}$.

Much has been written about the need to move to ecosystem-based fisheries management (EBFM) to take account of direct and indirect effects of commercial fisheries on the ecosystem that supports the exploited fish populations (e.g. Crowder et al., 2008). While there is general agreement on the principles, implementation of operational procedures based on them is still in progress. Several recent studies (Smith et al. 2011, Pikitch *et al.*, 2012) have used ecosystem models and in some cases empirical data to examine the effects of fishing low trophic level or forage species on predators and other parts of the marine ecosystem. While impacts vary for different species and across different ecosystems, there is an emerging consensus that exploitation rates should be set more conservatively than conventional single species MSY levels for such species. The Marine Stewardship Council identifies criteria for identifying "key" low trophic level species and then requires that default target biomass reference points be set at 75% of B_0, corresponding to exploitation rates at about half F_{MSY}. Pikitch *et al.* (2012), a major report from the Lenfest Forage Fish Task Force, recommend a tiered approach relating to the data availability. Thus, for high data situations they recommend no more than 75% F_{MSY} and no less than 30% B_0 to be left in the ocean. For intermediate data situations these numbers were no more than 50%F_{MSY} and B_{LIM} at least 40%B_0. Finally, for relatively data poor situations they recommended no new forage fisheries and existing fisheries to be restricted to a B_{LIM} no less than 80%B_0. The CCAMLR rule, which relates to taking no more than a defined proportion of current estimates of biomass, takes account of the natural variation of forage fish species. Their dynamics tend to be so variable that they can naturally increase or decrease their stock size by large amounts over relatively short periods. To require that stocks be maintained at 80%B_0 is not something that can necessarily be managed; even the concept of B_0 when applied to such variable species is problematic (see section 2.5.1 above).

Accounting for climate change on marine ecosystems and impacts on commercial fisheries is also a topic of much recent research (e.g. Brown et al. 2010; Plaganyi *et al*., 2012). While an active area of research, climate-linked ecosystem models are not currently in operational use as a fisheries management tool for setting commercial catches. There are a number of example single species commercial fisheries where there has been acceptance of an environmentally induced productivity shift in the population (for a specific Southern and Eastern Scalefish and Shark Fishery, SESSF, example see Wayte, 2013). The recognition of environmentally induced or population density induced variation in such productivity factors as growth and fecundity is growing in importance when conducting single species stock assessments (Whitten *et al*., 2013). These areas are active and relatively new areas of research and no general conclusions have yet been drawn. The expectation is that the marine climate will continue changing, especially in the hot spot areas of the east and west coasts of Australia. Fisheries will undoubtedly change but quite what changes are possible is still to be determined (André *et al*., 2010) so the implications for the HSP are limited to a need to retain some flexibility so that if circumstances in a fishery change significantly the HSP can respond appropriately.

The range of estimates of suitable target biomass and fishing mortality values is very great but the difficulty in estimating the real risks of running relatively high fishing mortality rates at low stock sizes (Beddington *et al*., 2007) suggests that Clark's (1993) suggestion of $B_{40\%}$ rather than something lower is a reasonable compromise. The current default biomass target reference point of $B_{48\%}$ would appear to be highly conservative (biologically) for many species, although it may be quite appropriate for slower growing sharks and rays and may not be sufficiently conservative for some key low trophic level species. For example, the Commonwealth small pelagic fishery (AFMA, 2009) has adopted a biomass level of at least 80% B_0 as the B_{LIM} for each species in this fishery (with higher values in the more data poor situations).

This all means that if MEY or MSY can be reliably estimated from the life history characteristics and fishery data, then there would be no reason not to lower the target reference point. In fact, the objective of optimizing the economic performance of the fishery would require it. But it should also be kept in mind that estimating MEY or MSY can be very difficult and would undoubtedly require dedicated resources for each fishery. In addition, numerous studies show that, especially in mixed fisheries, it is difficult to balance the fishing mortality on an array of species (Walters *et al*., 2005). In New Zealand they use a soft target at $B_{20\%}$ and a hard target of $B_{10\%}$ below which the fishery is closed (Ministry of Fisheries, 2008). New Zealand has many more specifically targeted fisheries and so closing particular fisheries is a reasonable option. Nevertheless, because of these various doubts and uncertainties it would be difficult to argue that there would be no increase in the risk of depletion affecting consequent recruitment levels if the limit biomass reference point was permitted to vary below the current $B_{20\%}$.

3.1.1 DATA POOR STOCKS

A large number of commercially unimportant species, often bycatch or byproduct species, "cannot reasonably be assessed" (Beddington et al. 2007, p1716). Indeed, for such species many stock assessments are not sufficiently informative to support control rules with limit, threshold and target reference points for stock size and fishing mortality (Cadrin and Pastoors 2008). This subject is dealt with in more detail in Chapter 5.

Assessment approaches currently used for extremely data poor stocks depend on the limited data available (Dowling et al 2008; Smith et al 2009). Where a reliable series of catch estimates exist methods such as depletion-corrected average catch (DCAC), depletion-based stock reduction analysis (DBSRA) (Dick and MacCall 2011), and maximum constant yield (MCY) (Ministry of Fisheries NZ 2008) are in operational use in US and NZ fisheries. For species where occurrence distributions and spatial overlap with fisheries are known and there is some information about biological characteristics, risk assessments such as productivity susceptibility analysis (PSA) (Berkson et al. 2011, Cope et al. 2011) and ecological sustainability assessment for fishing effects (SAFE) (Zhou and Griffiths 2008; Zhou et al. 2011) approaches have been used.

4 Buffered Targets or Meta-Rules

4.1 Target reference points in multi-species fisheries

Key Questions in the Discussion Paper:

- *The Review may consider whether further guidance is required on:*
  - *developing and setting target reference points for individual species within multispecies fisheries*
  - *acceptable levels of risk for stocks whose biomass is allowed to vary below B_{MSY}.*

A joint project between the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) is expected to start soon, which may provide further information on these matters.

There is a very large literature on the management of multi-species fisheries and the related ecosystem based fisheries management (Caddy and Mahon, 1995; Link, 2002; Hilborn *et al*., 2004; Haddon, 2007; Smith *et al*., 2007). All concede that multi-species fisheries management is difficult but no universal solution has yet been proposed. A major problem is that the species mix in fishery catches may not necessarily match the mix in combined TACs or in quota holdings. Klaer and Smith (2011) propose characterizing multispecies catch data into primary and companion components. This method provides an empirical means to examine the impact of individual species TAC decisions across all of the quota species in a fishery. The establishment of spatial closures has also been proposed. However:

> *For fisheries that are multi-species … marine reserves have some potential advantages. Their successful use requires a case-by-case understanding of the spatial structure of impacted fisheries, ecosystems and human communities. Marine reserves, together with other fishery management tools, can help achieve broad fishery and biodiversity objectives, but their use will require careful planning and evaluation. Mistakes will be made, and without planning, monitoring and evaluation, we will not learn what worked, what did not, and why. (Hilborn* et al.*, 2004, p198)*

Any potential advantages of spatial closures for fisheries (insurance, protection of habitat, spill over of adults and larvae) can be effectively cancelled out if the fishery involves highly mobile species, or those with limited larval dispersal, or if fishing is not the only potential threat to the system (see chapter 8 for a more detailed discussion). However, for a mixed fishery in which a large number of species are caught but only some are formally managed, usually through quotas but possibly by limiting effort (e.g. the South East Fishery and, currently, the Northern prawn fishery) there is the potential for marine closures to offer some refuge from fishing mortality for many unassessed species. Despite these advantages, there are also possible downsides to imposing closures. If large closures are imposed and catches of the key commercial species are not reduced accordingly then fishing mortality in the areas remaining open will increase, possibly causing harm to the stock still exposed to fishing (Haddon *et al*., 2003). At the same time if there are sufficient closures in a fishery they may affect fishing behaviour and influence the fisheries data used to assess the stocks. Evidence that this is occurring is only now being generated in the SESSF. A current FRDC funded research project is exploring the impact that marine closures (all types) can have on the stock assessment process to determine whether the closures are compromising our understanding of the stock dynamics.

In Australia, the present system for managing multi-species fisheries and other ecosystem-based fisheries management is to assess the key commercial species within the context of a standard harvest strategy with associated assessments and control rules or a system of tiered harvest strategies that treat different species according to how much information is available to assess the stock status. There is also an array of data-poor harvest strategies available but so far, these have not been mixed with more formal harvest strategies (whole fisheries are considered data-poor and treated as such but particular data-poor species within a mixed fishery do not tend to be managed using data-poor harvest strategies). However it should be noted that the tiered harvest strategy framework used in the SESSF already allows for different treatment of species according to the amount of information available (Smith et al. 2008). For any remaining species there is the ecological risk assessment process (Hobday *et al*., 2011; Williams *et al.,* 2011). This entails a hierarchical system of levels entailing different degrees of detail. At the second level in the hierarchy, the approach assesses the relative productivity and susceptibility of each species to the fishing pressure being imposed and classifies each species as low, medium or high risk (see Table 2 in Chapter 5).

Because this remains an area of fisheries management still searching for solutions it is certainly a candidate for greater clarification of options within the HSP. For example, in mixed species fisheries, where the key commercial species are managed using more formal harvest strategies if it was decided that it would be acceptable to manage relatively data-poor species using the data-poor harvest strategies available (Dowling *et al*, 2008; Smith et al 2009) then this option, or others, needs to be made clear in the HSP.

4.2 Buffer Zones

Key Questions in the Discussion Paper:

- *The Review may consider whether 'buffer zones' might be applied to the interpretation of reference points, such that when an indicator moves within a specified range of the reference point level, the reference point level is considered to have been achieved? The use of this approach in other countries (e.g. New Zealand) might provide a useful case study if the Review considers this issue further*.

4.2.1 INTRODUCTION

Target and limit reference points and the related control rules that use these to guide management are usually depicted using a phase diagram that compares fishing mortality against spawning biomass (Figure 2). This type of diagram was originally described by Serchuk *et al*., (1997, 1999) and Restrepo *et al*., (1998). In the case illustrated (Figure 2) the biomass and fishing mortality target and limit reference points are precisely defined. Fishing mortality being constant above the target biomass means that catches will increase with stock size. In the illustration the break-point occurs exactly at the target and there is a linear decline in F with decreasing spawning biomass, down to the limit biomass, after which no targeted fishing should occur. In mixed fisheries there is usually a bycatch TAC set to allow for unavoidable bycatch (to reduce or prevent the need for discarding).

Such control rules (Figure 2) imply that the assessment of the stock biomass levels is relatively precise, which is not the case for any stock assessment, whether it is a sophisticated integrated assessment or a simple analysis of catch rates. The HSP recognizes that the assumption of equilibrium at the target is unrealistic. It states that:

> *…control rules should ensure that the fishery is maintained at (on average), or returned to, a target biomass point B_{TARG} equal to the stock size required to produce maximum economic yield…. … For highly variable species that may naturally (i.e. in the absence of fishing) breach B_{LIM}, the harvest strategy for these species must be consistent with the intent of the Policy (DAFF, 2007, p 23).*

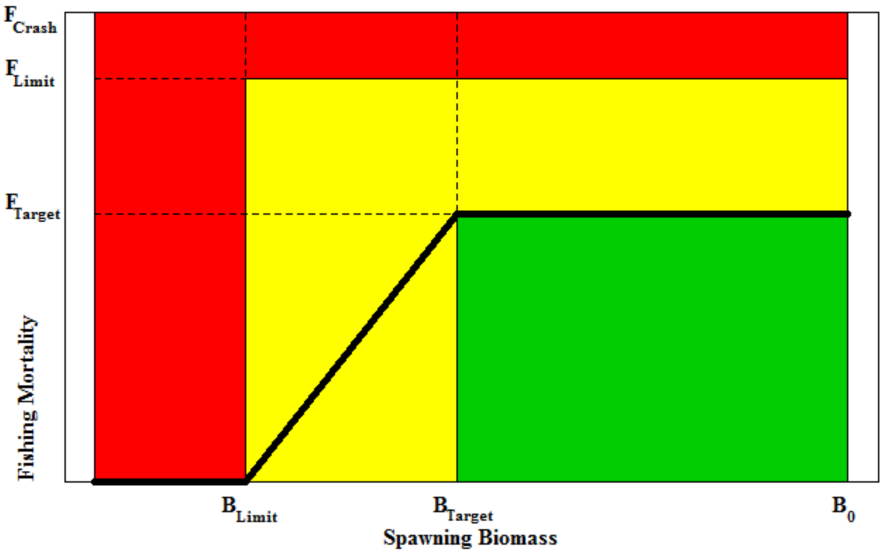


Figure 2. Common relationships between fishing mortality and spawning biomass related reference points; this is not the control rule used in the SESSF. The red area reflects situations where a stock would be experiencing overfishing and be overfished. The green area would be considered as under-fished and under-fishing, while the yellow areas reflect areas where the harvest control rule (thick black line) would act to reduce catches and fishing mortality to move the stock back towards the targets. After Beddington *et al*. (2007). There is a constant target fishing mortality until the biomass breakpoint (in this case the B_{Target}) is reached followed by a linear decline to the B_{Limit}, after which there is no targeted fishing.

Natural variation is expected due to environmental forcing and recruitment variability from year to year so the expectation is that even with a perfectly managed fishery the stock would fluctuate around the target. The HSP states: “For stocks above B_{LIM} but below the level that will produce maximum sustainable yield (B_{MSY}) it is necessary to first rebuild to B_{MSY}. Once stocks are above B_{MSY}, rebuilding shall continue toward B_{TARG}….“ (DAFF, 2007, p24) If a precise harvest control rule were to be interpreted without a buffer or meta-rules the stock would be expected to be below the target, and therefore presumably in need of rebuilding 50% of the time so the recommended TACs would also fluctuate up and down randomly. Given that natural variation is acknowledged in the HSP then ideas of having targets with buffers or meta-rules relate to proposed solutions for dealing with this problem of variation leading to highly variable management.

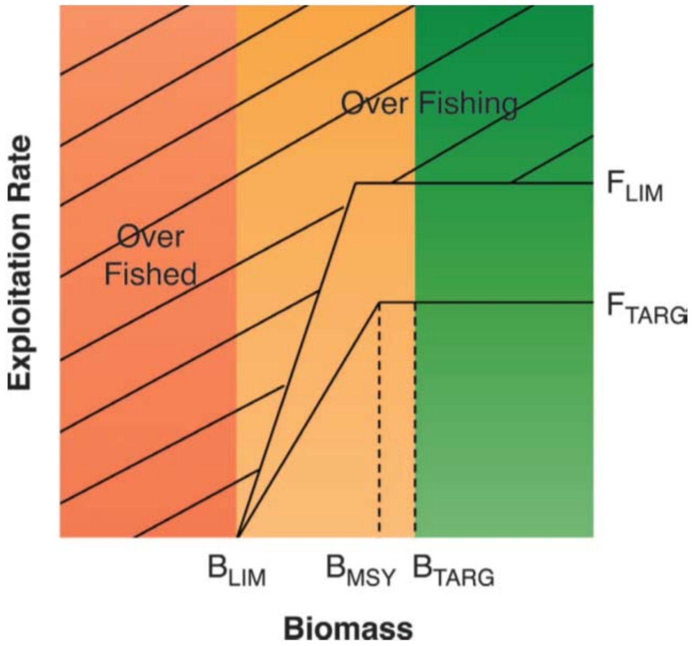


Figure 3. Example of a harvest control rule consistent with Australia's harvest strategy policy (B_{LIM} - limit biomass reference point; B_{MSY} - biomass that corresponds to maximum sustainable yield; B_{TARG} - target biomass reference point; F_{LIM} - limit fishing mortality rate; F_{TARG} - target fishing mortality rate). The HSP specifies B_{TARG} as B_{MEY}, the biomass that corresponds to the maximum economic yield. The control rule specifies that as the biomass reduces below B_{MSY}, F_{TARG} is progressively reduced to zero at B_{LIM} (after Smith, *et al.*, 2008)

A common option when precise targets and inflection points are used in the control rules within a harvest strategy is to apply a meta-rule that says no change to TACs will be made unless the proposed change is at least 10% (or some such value; in the GAB there is a CPUE update rule that is used to account for the very latest catch rates when setting TACs, that requires a minimum change of a 20% increase or decrease in the CPUE for a 10% increase or decrease in a TAC). In the SESSF, there are a few species with relatively large catches so 10% might be a very large number (e.g. 10% of the flathead TAC would be 275 t) so the meta-rule there is before a change to the TAC is made it must be at least a 10% change to the TAC or 50 t, whichever is smaller.

Such meta-rules have the advantage of increasing stability of catches through time. However, there is potential for confusion with this approach because of the way the harvest control rules are actually used to generate Recommended Biological Catches (RBCs) from which a separate process is used to set a Total Allowable Catch. The harvest control rules are well documented in each case but extra clarity and transparency could be achieved if the final step of generating the TACs from the RBCs were as thoroughly documented. The harvest control rules in each formal harvest strategy clearly define the RBC one the assessment has been completed. Without clear documentation of the step from RBC to TAC this permits uncertainty to enter the process.

Meta-rules certainly have a place in the simpler harvest control rules used in fisheries for which there is no formal mathematical model of the stock dynamics. In such fisheries the control rules are precisely specified and without such meta-rules the issues of variable catch levels and change every year would arise. The advent and increase in the number of multi-year TACs will interact with tis, however, and should reduce its importance. The same effects of greater stability could be brought by using buffers around each target reference point for each species. Both such buffers and meta-rules have the same problem of trying to use a single value for all species, even though some species are much more variable than others. For example, depending on the prevalence of scallop beds it is quite possible for the current scallop harvest strategy to have the stock appear to move from above the biomass target to below the biomass target in a single fishing season, even when there are an array of undersize scallop beds waiting to grow into the fishery. The meta-rules currently used in the different fisheries appear to work acceptably well except for some of the more extremely variable species such as squid and scallops.

For those species with more sophisticated stock assessments their control rules can be more sophisticated also and appear more akin to the original proposed by Caddy and Mahon (1995). The implementation of these control rules, however, is less rigid. They may still be specified precisely but their specific detail can effectively add in a buffer to the stock status at which fishing mortality (catches) are reduced to rebuild the stock towards the target. This is exemplified within the SESSF (Day, 2009). The Tier 1 harvest control rule in the SESSF specified limit and target biomass depletion reference points, as well as a target fishing mortality rate. This is represented as a series of values depicted as the series: (B_{LIM}:B_{TARG}:F_{TARG}). Since December 2005, when the Harvest Strategy Policy was first implied in the Ministerial Directive, various values had been suggested and used for the target and breakpoint in the Tier 1 rule (Figure 4).

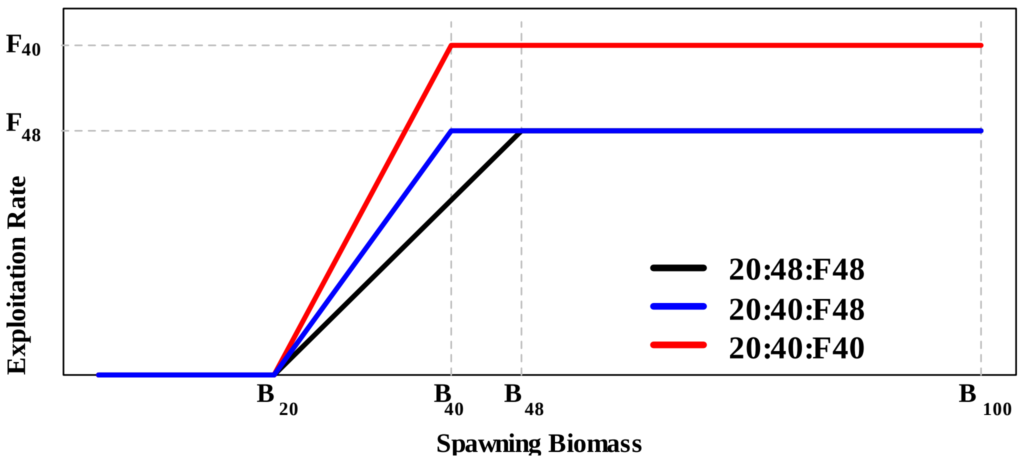


Figure 4. Early alternative Tier 1 control rules used in the SESSF under the HSP in 2006 (after Day, 2009), illustrating different target biomass and fishing mortality levels.

Initially, $B_{40\%}$ was used as a proxy for B_{MSY}, leading to the 20:20:40 rule. A little later $B_{48\%}$ was suggested as a proxy for B_{MEY}, the selected target in the HSP leading to the 20:40:48 and the 20:48:48 rules. The breakpoints at which the impact of the Harvest Control Rule on fishing mortality begins were thus altered. For the 2009 TAC setting session, AFMA directed that the initial trajectory of the 20:40:40 rule (the redline in

Figure 4) up until fishing mortality reached $F_{48\%}$, which meant that the breakpoint in the control rule needed to be estimated as it lay to the left of $B_{40\%}$ (Figure 5).

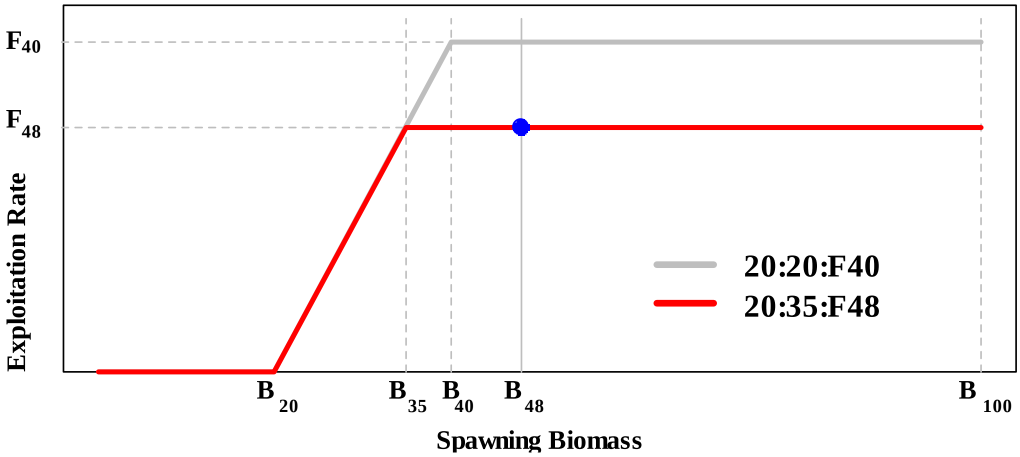


Figure 5. Re-estimated control rule for Tier 1 assessments in the SESSF in 2009, with a breakpoint at $B_{35\%}$ as a modification of the older 20:40:40 rule to become 20:35:48. The blue dot represents the biomass and fishing mortality targets (after Day, 2009).

This 20:35:48 (B_{LIM}:B_{TARG}:F_{TARG}) control rule introduced a large buffer between the target and the breakpoint. This does not mean that the catches (TAC) do not come down if the stock falls below the target biomass, but it does mean that the steepness of reductions in catch only increase once the biomass falls below $B_{35\%}$.

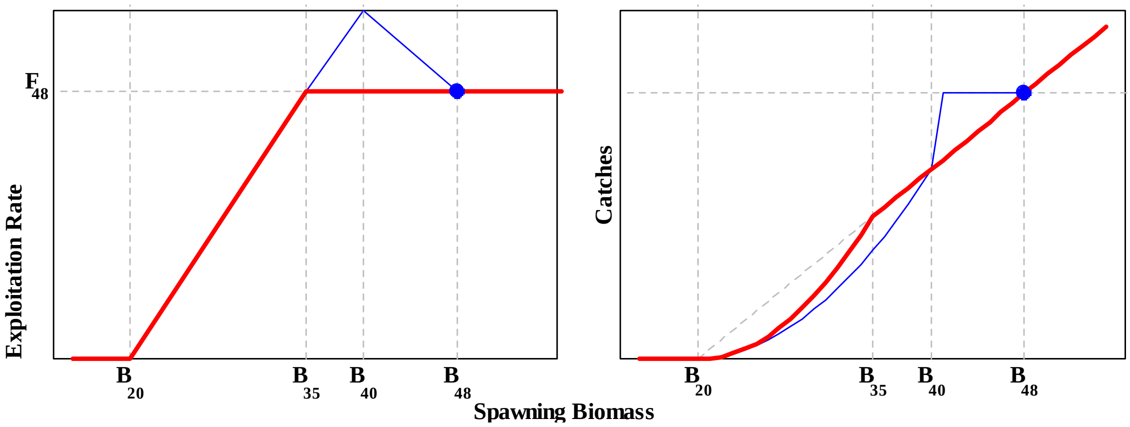


Figure 6. The 20:35:48 Tier 1 control rule in terms of its effect on fishing mortality and on relative catches. A constant fishing mortality implies a constant proportion of the available biomass will be allocated as a TAC, the steep linear decline in the control rule implies an exponential decline in catches the further below the breakpoint at $B_{35\%}$ the biomass becomes. When a buffer is installed in which the TAC is not decreased until, for example, $B_{40\%}$, this would be equivalent to allowing the fishing mortality to increase (blue lines in the plots) and then, past the chosen buffer, to decrease very rapidly when it returned to a linear decline with biomass.

It is thus apparent that a form of buffer around the target reference point can already be introduced into the harvest control rules. If an alternative form of buffer were introduced that kept TACs constant until the buffer range (for example one might use $B_{40\%}$ as a suitable buffer from $B_{48\%}$) then the implication would be that the fishing mortality would be allowed to increase up until the buffer limit and then decrease more rapidly than without the buffer (Figure 6). Such dynamics within the fishery would need to be examined in more detail than the brief consideration given here and, to be in line the HSP it would need to be simulation tested to determine whether such a strategy increased or decreased the risk overall or breaching the limit reference point.

The present arrangements where those harvest strategy control rules in which the break point is clearly defined at the proxy target reference point certainly stabilizes catches and another meta-rule that prevents TACs varying by more than 50% between any two years has also been helpful in preventing serious dislocation and disturbance in the fishery for some relatively unstable species.

The terms of reference for these technical reviews included the identification of relevant research that could be conducted to improve the implementation and operation of the harvest strategy policy. If it was decided to pursue the issue of buffers and meta-rules around the targets then it would be beneficial to use simulation testing (MSE) to consider the effect of such changes to the expected dynamics of different fisheries.

5 Data-Poor Fisheries and Tiered Harvest Strategies

5.1 Introduction

Key questions:

- *Is there a need for further guidance on the development and testing of additional assessment Tiers to allow the use of more appropriate indicators for some particularly data poor stocks?*
- *How can increased precaution be demonstrated with decreased data without a MSE or HS evaluation process? Is the application of discount factors sufficient?*
- *Should there be a greater emphasis on the use of empirical performance measures and related control rules for fisheries with limited data and resourcing?*
- *Is the use of grouped species catch per unit effort (CPUE) data as indicators in some fisheries consistent with the objectives of the Policy and demonstrably precautionary and are there practical alternatives?*
- *How can a transparent and cost-effective, risk-based approach to data collection, research, assessment and decision-making can be integrated into the Policy.*
- *Should and if so how would specific requirements for data specification and provision relevant to harvest strategies be specified in the Policy or Guidelines. This might include specification of minimum documentation standards (e.g. consideration of the point at which additional data collection—monitoring and assessment—is required when catches of non-quota species start significantly increasing due to targeting or other reasons).*

Harvest strategies usually consist of monitoring, assessment and control rules. The assessment component contains a) a performance measure(s) from the system - or a model(s) using data from the system to generate a performance measure(s) - together with b) target and c) limit reference points, against which the performance measure is compared. Here an assessment is used in its broadest definition, being any system that provides information about the status (or a proxy) of the stock. In some cases, the assessment might be a simple linear regression of catch rates, whereas in others it uses a full dynamic stock assessment model.

For data poor fisheries, difficulties can arise in almost every component of the harvest strategy – for example, little or no regular monitoring means time series are rare, the assessment method is undertaken with an unknown degree of uncertainty, reference points are poorly defined and the associated control rules do not necessarily address risk clearly. Yet, an essential component of the present Harvest Policy is the application of a consistent degree of risk across all fisheries, irrespective of fishery type.

This data poor section describes the risk-cost-catch trade-off involved when attempting to manage fisheries with only limited information. The HSP states: “A tiered approach to control rules is encouraged in order to cater for different levels of certainty (or knowledge) about a stock…… Such an approach provides for an increased level of precaution in association with increasing levels of uncertainty about stock status, such that the level of risk is approximately constant across the tiers." (DAFF, 2007, p36) However, the use of a tiered system of harvest strategies highlights an issue of minimum information requirements despite the fact that some fisheries already have few resources to obtain more information, if required.

The second component describes several data poor assessment methods, but placed in the framework of the risk-cost-catch trade-off. Much recent work, both within Australia and internationally has been undertaken, but many of these have yet to be formally published.. Indeed, a FRDC funded project (2012/202) entitled 'Operationalising the risk cost catch trade-off' began in July 2012 in CSIRO and is due to finish in June 2014.

Simulation testing already undertaken shows that the risk level by Tier method is not always predictable and can also be very case specific (Deroba and Bence, 2008; Fay *et al*., 2012). However, undertaking these tests for each fishery or species is impractical and expensive. Generic data poor MSE software is being developed (although mostly still unavailable) which points to one approach. The other is to apply a degree of caution although it may be unclear how to evaluate the risk without simulation tests.

It is important to note that economic reference points are not discussed in this section. Data-poor methods tend to focus mostly on the limit reference points, data-poor target reference points are to be described in the 'Alternative Economic Targets and Reference Points' document.

5.2 Defining Data-Poor

"Data poor" or "data limited" are relative terms (the two terms are used here interchangeably) and are applied to different circumstances in different fisheries (Welch *et al.* 2005). One definition of data-limited fisheries is that they lack sufficient biological information to infer the exploitation status of the targeted stocks (Vasconcellos and Cochrane, 2005; Dowling et al, 2011). Similarly, Punt el al (2011) define data-poor as stocks with catch estimates but little or no information on relative abundance and few or no samples of age and length from the fishery. Richards and Maguire (1998) (cited in Pilling *et al.* (2008)) define fisheries as data poor when the best scientific information available is inadequate to determine meaningful reference points and/or current stock status with respect to such reference points. Thus, a "data poor" fishery is one for which a defensible and quantitative stock assessment cannot be provided because of limitations in the kind and/or quality of the data available (Haddon *et al.* 2005; Kelly & Codling 2006). Therefore, here we define fisheries or species as data poor if information is insufficient to produce a defensible quantitative stock assessment.

While these definitions are largely similar, there are implications that need to be considered when specifying harvest strategies. Clearly, model-derived reference points are not available in most data-poor situations. However, suitable proxies can often be specified for a harvest strategy to be developed for a data-poor fishery. Restrepo *et al.* (1998) describe fishery and stock assessment attributes to delineate data richness (Table 1).

Table 1: Fishery and stock assessment attributes used by Restrepo *et al.* (1998) to delineate data richness (cited Welch *et al.* 2005).

	Data rich	**Data moderate**	**Data poor**
Life history characteristics	Yes	Yes	Unreliable or limited
Fishery dependent data (e.g. logbook catch and effort)	Yes	Yes	Unreliable or limited
Data time series	>20 years	Generally <20 years	Generally <20 years
Fishery independent data (e.g. monitoring)	Yes	Available or limited	No
Stock assessment	Sophisticated	Simple sophisticated	Minimal or lacking
Reliable MSY related quantities	Yes	Limited	No
Stock size estimate	Yes	Yes	No
Fishery parameters (e.g. selectivity, fishing mortality)	Yes	Yes	Unreliable or limited
Control rules	*Fmsy*, *Bmsy* etc	$F_{35\%}$, $B_{35\%}$	M, avg catch etc
Data quality	High	High moderate	Moderate poor
Uncertainty	Accounted for	Reasonable characterisation	Qualitative or lacking

Data limited fisheries often arise because of inherent characteristics such as being new or developing, low value, or the cost of data collection being prohibitive because of geographic spread, a lack of monitoring and enforcement resources, the remoteness of fishing grounds and/or vast coastlines with multiple access points. Specifically data limited fisheries can include, but are not necessarily limited to:

a. new fisheries with no time series of information;
b. large scale but recently developed fisheries where fisheries research and management have lagged exploitation;
c. low-value fisheries for which little data are collected;
d. small-scale developing fisheries with usually several target species of otherwise mixed fisheries;
e. large scale fisheries where the quality of data is poor or variable and difficult to assure (e.g. misreporting and/or discarding);
f. spatially structured fisheries where data collected may not be representative of the whole stock; and
g. near to or totally bycatch species, in a mixed fishery, to which little or no attention is paid.

(Haddon *et al.* 2005; Pilling *et al.* 2008).

Vasconcellos and Cochrane (2005) estimated that 20-30% of the world's capture fisheries were data-limited. Data limitations were more pronounced in invertebrate fisheries, and more among demersal than pelagic finfish fisheries. It was also more prominent in areas with high species diversity and small stocks where fisheries play an important role for food security, such as in many tropical and low-income countries of Africa, Asia, Oceania and the Caribbean. For example, Salas *et al.* (2007) characterise small-scale fisheries in Latin America and the Caribbean as being multi-gear and multispecies, and having low capital and labour intensive, remote landing sites, large numbers of migrant and seasonal workers, and weak market and bargaining power among fishers.

Many data-limited fisheries are also of low economic value, implying limited human resources for undertaking stock assessment (Scandol 2005). While such fisheries may not necessarily be data-poor, stock assessment and complex statistical analysis of trends may not be locally deliverable in an ongoing sense. In such cases an empirical harvest strategy could be developed using quality fishery dependent and/or independent data. However, in many cases fisheries are both data-poor and lacking in local analytical capacity.

5.3 Review of Relevant Research

5.3.1 TIERS AND INDICATORS

Data-poor stocks comprise an important component of the species targeted by the Commonwealth fisheries. Often these are caught within complex, multi-species fisheries and can therefore be both a target and a byproduct within a region. A separate review of bycatch species in Commonwealth fisheries has also been undertaken.

The SESSF have implemented a Tier system to classify their assessment methods from data rich to data poor (Smith *et al*., 2008; Little *et al*, 2011). A Tier 1 assessment is a robust stock assessment, whereas a Tier 3 and 4 uses catch curve analysis to estimate F and a time series of catch rate data respectively. An overview of all the assessment methods used in AFMA's managed fisheries, to which the HSP applies, has shown that eight Tiers – from Tier 0 to 7 can be identified in Commonwealth fisheries (Dowling *et al.* in press).

For some fisheries, where data is very limited a series of catch triggers for levels at which management intervention may be required can be used as the harvest strategy (Dowling *et al*, 2008; Dowling, 2011) and these effectively impose a series of Tiers on such fisheries aimed at increasing information requirements and assessment if a fishery grows.

Many methods used in data poor tiers have been tested using Management Strategy Evaluation (Haddon, 2011, Little *et al*., 2011, Klaer et al, 2012) to compare their management effectiveness and compare their relative risk and uncertainty (Fay *et al*., 2012). Although Tiers are applied in the SESSF they are not the norm across the Commonwealth managed fisheries, where often only one tier is used in each fishery. This is potentially an issue, from both the point of view of consistency among fisheries and also a consistent application of the risk-cost-catch trade-off.

A study on AFMA's information needs (Dichmont *et al.* in press) has developed a Guideline to developing a fishery's information needs where the Tier system is further enhanced from that in use in the SESSF. This work is the output from a meta-analysis across all the Commonwealth's harvest strategies currently in use. It breaks the system into three component - Harvest strategy assessment Tiers (**Table 2**), economic target Tiers (**Table 3**) and ERA/M Tiers. The first two relevant tables are reproduced below. This extension shows that there are two components regarding the Tier assessment system – the stock assessment method to develop the index of abundance and the method to determine the target or MEY. This section only discusses stock assessment rather than economic methods.

The degree to which monitoring supports harvest strategies is clearly illustrated in the way that AFMA has implemented the harvest strategy policy (HSP) across its fisheries. Each tier in **Table 2** defines the types of data that are collected and the form of assessment undertaken to feed into the harvest control rule for that tier. The harvest control rules themselves can vary widely for a given tier, but in all cases should be designed to meet the requirements of HSP to achieve the target maximum economic yield (MEY) while avoiding biologically defined limits (limit reference points or LRPs) with a probability that is defined in the HSP. This second criterion is referred to below as the "risk" criterion. For many fisheries, the performance against the requirements of the HSP of the current harvest strategy (based on the current monitoring strategy) for each target species will have been tested using simulation testing such as management strategy evaluation (MSE) (Smith et al, 1999; Sainsbury et al, 2000).

Table 2: Tier structure for harvest strategies with associated data requirements. Costs included in the original table have been removed.

Tier number	Tier description	Minimum data requirements
0	Robust assessment of F and B based on fishery dependent AND independent data	Time series of independent surveys and verified catch, effort and/or catch rate data. Data required to standardise catch rates (if used).
1	Robust assessment of F and B based on fishery dependent data ONLY	Time series of verified catch, effort and/or catch rate data. Data required to standardise catch rates (if used).
2	Assessment of F and B based on fishery dependent and/or fishery independent data	Time series of catch, effort and/or catch rate data.
3	Empirical estimates of F based on size and/or age data	Time series of catch only. Representative sample of size and, if relevant, age
4	Empirical estimates of • relative biomass based on fishery dependent data • within season changes to relative biomass based on fishery dependent data • relative biomass based on fishery independent surveys	Time series of catch only or time series of fishery dependent data such as catch rates or independent survey data.
5	Empirical estimates of F based on spatial distribution of effort relative to species distribution	Patchy catch and effort data or distribution of catch/effort relative to the species distribution
6	No estimate of biomass and F; use of fishery-dependent species-specific triggers	Patchy catch and/or effort data by species
7	No estimate of biomass and F; use of fishery-dependent triggers for groups of species	Patchy catch and/or effort data by groups of species

Reuter *et al.* (2010) describe a similar system of Tiers for management of Alaskan fisheries, where Tier 1 equates to having point estimates of biomass and biomass at maximum sustainable yield (MSY), together with a probability density function of fishing mortality at MSY. Alaska's Tier 6 is the data-poorest level, with catch history only.

Cadrin *et al.* (2004) and Cadrin and Pastoors (2008) also refer to tiered approaches, viewing the estimation of biological reference points as a hierarchy, ranging from data-poor proxies of relative indices of stock size and exploitation rates, to applying more informative demographic production models such as stochastic, age-based simulations of maximum sustainable yield. Interim limits can be derived from the most reliable tier of approaches, and research programs can be designed to advance the analysis to a more reliable tier for approximating or estimating MSY reference points.

Despite the general principle being agreed, it is not always clear is how to rank these Tiers. There is an implication that risk increases as one moves to more data poor methods, however results from simulation tests of these Tier methods are unpredictable.

In Klaer and Wayte (2011), several forms of uncertainty are described – stock assessment uncertainty, using an inappropriate assessment method, uncertainty in the data used in the assessment, and uncertainty in translating stock assessment result into stock status. These different forms of uncertainty and different assessment methods were tested within an MSE and showed that, for example, an average-length-based harvest strategy can achieve the policy within the correct risk profile (Klaer, Wayte & Fay, 2012), that surplus production methods work well as long as certain conditions are met (but this was not usually the case for the species tested; Klaer & Wayte, 2011) and that a cpue-based Harvest Control Rule worked well but was sensitive to, for example, the choice of parameter values and the reference period for the reference points (Little *et al.*, 2011). On the other hand, Dichmont *et al.* (2006) and Dichmont and Brown (2010) showed that, for the Northern Prawn Fishery and the Queensland spanner crab fishery, simple regressions of catch rate data could perform well at guiding management actions. In the NPF case, the catch rate HCR was compared to surplus production and delay difference methods. In that case, the latter was preferred as risk was more clearly defined but the catch rate method otherwise performed well. The harvest strategies used in some other data-poor fisheries within the Commonwealth were examined within the reducing uncertainty in stock status project using Management Strategy Evaluation, but these were constrained in the range of testing possible simply because of the lack of information (Dowling, 2011; Haddon, 2011; Plaganyi *et al*, 2012). Nevertheless, within those constraints the harvest strategies in use were found to be capable of achieving the intent of the policy even in the data-poor circumstances (Haddon, 2012b).

From a Tier perspective, there is therefore a lot of scope for using or developing different Tier assessment methods. However, the various MSE tests have shown very case specific results indicating that a precautionary system should be applied unless these methods are tested through MSEs.

Bentley and Stokes (2009) compare the assessment versus the procedural[1] paradigms – the latter applies to the Commonwealth HSP. Rather than focusing on the assessment

[1] In New Zealand and South Africa, management strategies are called management procedures. Harvest strategies are called operational management procedures (Rademeyer *et al.*, 2008).

method itself, they propose that harvest strategies are much more likely to apply to data poor fisheries. However, they argue that more attention needs to be given to the method of presenting evaluation results to decision makers, and more attention should be given to the design, evaluation and selection of harvests strategies to be tested. In the USA, development of a standard format for assessments in some cases has been proposed. However, in Australia, each RAG produces its own format, level of output detail etc. and some consistent approach (while still considering the differences between fisheries) might communicate better to the public and other scientists.

Table 3: Level number, description with associated minimum data requirements for the category of the economic component of stock assessments associated with estimating the target reference point for a species or group. Costs included in the original are removed here.

Level number	Level descriptor	Minimum data requirements
1	Full dynamic bio-economic model using a Tier 0-2 assessment	Recent industry level costs and prices. Projected costs and prices over a reasonable projection period. This requires information about projections on exchange rates.
2	B_{MEY} proxy using a Tier 0-4 assessment	Expert driven opinion on previously profitable catch rates that has good stakeholder or scientific backing
3	MEY proxy using a Tier 5-7 assessment	Little or no information on profitable levels

5.3.2 COST-CATCH-RISK TRADE-OFF

The above aspect of Tiers leads directly to the next issue – how is the risk-cost-catch trade-off, as described in Sainsbury (2005), maintained between Tiers, or whether it even should be done. In the SESSF, there has been much debate about discount factors and other methods of developing RBCs per Tier that maintain constant risk between Tiers. There is a gap between the theory of the trade-off and its practical implementation. The tier in current use for a particular species in a given fishery will have been determined by a range of factors, including the monitoring and assessment methods in use prior to implementation of the HSP. However the tier applied to a particular species is a matter of choice and could be varied over time, taking into account the cost-catch-risk (CCR) trade-off. The tiers in **Table 2** span from high information need (Tier 0) to low information need (Tier 7), with costs of both monitoring and assessment varying across tiers. Within constraints, fisheries are able to choose the tier that best suits the needs and capacity of the fishery. While consideration of the costs of monitoring and assessment might tend to favour higher tiers (lower information requirements), this will depend on how precaution is applied in determining the harvest control rules that complete the harvest strategy definition for each tier. This is because higher tiers are associated with higher levels of uncertainty about stock status, requiring more precautionary harvest control rules and hence lower catch levels to meet the risk criterion defined in the HSP. This interplay across tiers between economic costs (of monitoring and assessment) and benefits (derived from catch levels) to achieve an acceptable level of risk is the essence of the CCR trade-off. To date, the quantitative nature of this trade-off has not been explored fully for any fishery.

In an attempt to reduce the risks to the stock associated with using some of the higher tier harvest strategies (i.e. Tiers 3 and 4 in the SESSF rather than the Tier 1) an array of discount factors have been proposed with a larger discount for the higher tiers. An AFMA draft document describing the TAC setting process states: “The application of the discount factor is to be determined on an individual species basis but will be applied unless RAGs advise that alternative equivalent precautionary measures are in place (such as spatial or temporal closures) or that there is evidence of historical stability of the stock at current catch levels.” (AFMA, 2009a, p 5). There is no discount applied to Tier 1 assessments, a 5% discount to the TACs derived from Tier 3 methods, and a 15% discount to the TACs from Tier 4 (it should be noted that these discount levels were chosen arbitrarily). The relative risk of the various tiers used in the SESSF has been examined using management strategy evaluation (MSE) and this has found that the specific outcome is species and fishery dependent (Fay *et al*., 2012).

As part of a meta-analysis of all AFMA’s harvest strategies, Dowling et al. (in press) used a statistical linear model to quantify the risk-cost-catch (RCC) frontier for each of three forms of risk – biological, economic and ecosystem. Although the most parsimonious models were statistically significant, the management and research costs tended to be reactive to risk. For risks to target species, it was not possible to develop a model for proactive use. This shows that the risk-cost-catch trade-off has generally not been applied to AFMA’s fisheries and more work would be required before it could be. The findings showed that the information collection and assessment of a fishery, tended to reflect the history of a fishery rather than a program designed to address a RCC trade-off.

New Zealand uses a very simple harvest strategy for their most data-poor stocks, which only have catch information. They set the maximum constant yield for such species using the average catch from a period when the fishery was relatively stable with no major changes in fishing mortality which is multiplied by a constant (less than 1.0) which is chosen relative to available information based on any knowledge on the stock demographics and the history of the fishery (Ministry for Primary Industries, 2012). The application of the constant c in the $MCY = cY_{AV}$ equation is a form of discount factor to allow for the uncertainty in such a harvest strategy. This approach is, however, purely empirical and is not an attempt to provide for equivalent risk between alternative assessment methods, although the stability of catches does suggest a low risk strategy.

The notion of applying a discount to the recommended catch levels that are produced by data-poor harvest strategies is becoming more common. In a proposed management framework for the Pacific Coast Groundfish Fishery Management Plan (FMP) in the USA it states that two management committees:

> *… further recommended that if the ABC [Allowable Biological Catch] control rule is structured to account for different levels of information available for each stock in the FMP, then the system of uncertainty buffers for each category or “tier” should provide increasing precaution with decreasing levels of information and increasing uncertainty.*
>
> *(PFMC and NMFS, 2010, p 7)*

The intent is to attempt to reduce the risk in accordance with increasing levels of uncertainty in different assessment methods and harvest strategies. This principle is simple to understand but demonstrating that different assessment methods have the perceived relative degrees of risk requires detailed simulation testing. Fay *et al*. (2012) have demonstrated that the relative risks can be greatly affected by what appear to be small details in the different harvest control rules. Without the meta-rule that limits annual changes to the TAC for a stock to no more than 50% the Tier 3 harvest strategy does not always perform better than the Tier 4 harvest strategy. With the meta-rule then the ordering is as might be expected the Tier 3 generally out-performs the Tier 4; although the particular outcome is also species and stock dependent.

5.3.3 DATA-POOR ASSESSMENT METHODS

In the data- and capacity-poor context, most literature has focused on empirical indicators and assessments, and less on control rules and the incorporation of indicators and assessments in a harvest strategy framework. Data-poor assessments have been reviewed extensively elsewhere (see for example Kruse *et al*., 2005b, Pilling *et al*., 2008, Marine and Coastal Fisheries Special Section Volumes 1 and 2 in 2009, 2010). Publications of the US National Oceanic and Atmospheric Administration (e.g. Dick and MacCall, 2010; Berkson *et al.*, 2011) are useful as are those available on the FAO website.

A review of data poor indicators was undertaken in Dowling *et al.* (in press) and key points are provided here. When developing a harvest strategy performance measures, target and limit reference points, or suitable proxies that may be applied to a fishery, have to be identified. In data-limited situations the initial focus will be upon empirical measures of fishery performance. An empirical indicator is calculated directly from a specific set of raw data, and the calculation, may produce one or two parameters that can be easily defined (e.g. nominal CPUE, mean age, mean length). This differs from an estimated or model-derived indicator, which is derived from a range of data sets and is dependent on additional parameters or models that may or may not be available (e.g. biomass, fishing mortality) (Scandol, 2005).

For the simpler empirical reference points, where stock status cannot be directly inferred, target and limit reference points can be replaced by putting thresholds on changes to the empirical indicator (for example, total effort) that would indicate further investigation and analysis, before further changes are allowed. These thresholds are already applied to some of AFMA's harvest strategies (e.g. those in Tiers 5, 6 and 7). Such threshold or trigger levels should, if possible, relate to all possibilities for change to which managers should be alerted. Given a possible suite of indicators and reference points or triggers, and given the characterization of the fishery, consideration must be given to how these could be used as input to a control rule.

Scandol (2003) investigated indicators and reference points based on total catch, catch rate, the distribution of fish length in the catch, as well as various measures of the distribution of age in the catch. It was shown that management strategies based on empirical indicators and reference points could have a high error rate, but that sustainable fisheries could be achieved when suitably conservative choices were selected for the reference points.

Scandol (2005) processed empirical stock status indicators including catch, CPUE, mean age, mean length, recruitment fraction, total mortality and fishery independent surveys using quality control methods that worked by constraining those indicators within stated bounds. Biomass surveys were found to perform best, followed by mean age and length, and recruitment fractions. CPUE and catch had the worst performance but were still acceptable.

A review of data poor methods undertaken in the USA NOAA (Dorn *et al.*, 2011) looked at catch-only methods which included minimal life history information only and methods that include catch, life history and time series of survey indices or length composition data. Most of these packages are freely available on the NOAA website (http://nft.nefsc.noaa.gov/index.html), including PopSim that is a generic age-based MSE operating model. Many of these methods performed well but needed key assumptions to be true for the model to be validly applied. On the other hand, a novel approach is used to assess data rich and poor stocks in the SESSF alongside each other – the so called 'Robin Hood' approach (Punt *et al.*, 2011) – thereby drawing from data rich information and inferring to data poor species.

Punt *et al.* (2001) used Monte Carlo simulation to examine the performance of alternative empirical indicators and associated reference points in terms of their ability to correctly identify the biological conditions that they were designed to measure. Indicators based only on catch rates are shown to be potentially very misleading. In contrast, indicators based on the mean length or mean weight of the catch changed in a more predictable manner with abundance. However, reference points based on these quantities were frequently 'triggered' either too early or too late.

Trenkel and Rochet (2003) compared the performance of population indicators for a Celtic Sea groundfish community based on achieved precision, statistical power and availability and estimation method of reference points. Among the population indicators of intrinsic population growth rate, total mortality, exploitation rate, mean length of catch, and change in fishing mortality to reverse population growth, the mean length of catch was most precisely estimated and the corresponding hypothesis tests had consistently large powers.

Life history characteristics inferred from size-specific catch data (e.g. percentage of mature fish in catch), have been suggested as a way to monitor change in stock status for data-poor species (Reuter *et al.*, 2010; Froese, 2004; Kelly and Codling, 2006). Basson and Dowling (2008) used a simulation approach to consider CPUE and eight size-based indicators: mean, median and 90th percentile length and weight, and the proportion of "big" and "small" fish in the catch. Size based indicators changed less than CPUE in response to changes in fishable abundance and were thus much more sensitive to measurement error or random noise. Further, size-based indicators were shown to be informative only for populations where individual growth was slow. Of the size-based indicators, mean length and weight performed best. The performance of size-based indicators also depended on the stock-recruitment relationship. Using classification trees as control rules, it was demonstrated that there was little to be gained by using more than 4-5 indicators together. The choice of indicators depended on the population dynamics, specifically lifespan and growth. Moreover, even good indicators could perform poorly when used in a badly-designed control rule.

Froese (2004) suggested that assessments could be based on three size-based indices from catch composition data, *Px*: (i) percentage of mature fish in the catch, *Pmat*, with 100% as target; (ii) percent of specimens with optimum length in the catch, *Popt*, with 100% as target; and (iii) percentage of large fish in the catch, *Pmega*, with 0% as target, and 30–40% as representative of reasonable stock structure if no upper size limit exists. Cope and Punt (2009) showed that Froese's (2004) values were not always sufficient to ensure protection from overfishing, since the metrics were intended to avoid growth and recruitment overfishing, but there was no quantitative linkage to stock status and calculation of future sustainable catches. Moreover, their values cannot be interpreted adequately without knowledge of the selectivity pattern. They introduced *Pobj* (the sum of *Pmat*, *Popt*, and *Pmega*) to distinguish selectivity patterns. This approach gives further guidance to interpreting catch length composition data under variable fishery conditions without collecting additional information. It also provides a link to developing harvest control rules that inform proactive fisheries management under data-limited conditions.

McGarvey *et al.* (2005) used a simulation incorporating delay-difference models to evaluate the performance of stock assessment models based on logbook data sets of i) catch in weight and fishing effort, ii) plus catch in numbers, and iii) catch in weight and catch in numbers (no effort). Assessment models utilising catch in numbers substantially improved precision and accuracy in annual population estimates.

Griffiths *et al.* (2007) used catch by length data with anecdotal information to build a size distribution of the true population, which was incorporated into a Bayesian modelling approach to estimate abundance and biomass from gillnet catches in data-limited situations.

All these studies have shown that both within Australia and internationally an extensive research drive on data poor methods have been undertaken. However, most of these are still within the Tier 3-5 range. Few have no catch data, for example, or only group (rather than species) specific data such as the Coral Sea aquarium fishery (Haddon, 2012b).

In particular, while some examples exist (e.g. Wayte and Klaer 2010), there remains a real need to provide general guidance on formulating control rules that link empirical indicators with suitable management responses. Most research has focused on comparing data-poor assessment methods rather than comparing the effectiveness of different data-poor harvest control rules.

5.3.4 DATA RELATED ISSUES

Data related issues are described in the Discussion paper in terms of data requirements, developing fisheries, fisheries data used in the assessment and real time data provision. A further aspect, are data sources and quality. For data poor fisheries, difficulties can arise in almost every component of the harvest strategy – for example, little or no regular monitoring means time series are rare, the assessment method is undertaken with an unknown degree of uncertainty, reference points are poorly defined and the associated control rules do not clearly address risk.

For fisheries, as for natural resource management generally, the purpose of monitoring is to support management strategies, which in turn are designed to achieve management objectives. Monitoring is one of the key steps in the adaptive management cycle, and together with assessment and decision making define a management strategy. Monitoring is key to supporting any adaptive management strategy as it provides the data used to assess the state of the system and to check whether management strategies are achieving their objectives. Monitoring is needed to support both harvest strategies and environmental risk management (ERM). Monitoring strategies cannot be assessed without simultaneously considering their use in supporting management strategies.

In the Guidelines by Dichmont *et al.* (in press), data requirements for each Tier are provided (**Table 2** and **Table 3**). However, the key issue is rather whether there are minimum data requirements in the form of minimum Tiers for specific fisheries. Dichmont *et al.* (in press) discuss this issue, and while they provide guidance on how to approach this issue no clear past precedent could be obtained to provide empirical solutions. However, the review does state that there are certain types of data that all fisheries should collect on a routine basis. A minimum standard is that there be logbooks which collect data on all fishing operations, including where and when they occurred (at the finest spatial and temporal resolution possible), the type of fishing gear used, and a record of the amount of all species (or higher taxa where identification is difficult) retained. Additional (reasonable) requirements for most fisheries are a record of species caught by the gear but not retained, or observed to interact with the gear. These minimum standards are required to determine the nature and level of interactions of the fishery with the ecosystem. These constitute a minimum standard, for all fisheries independent of their scale and impact, that would provide for a defence against claims that a fishery was causing irreversible damage.

Additional minimum standards should apply to some fisheries depending on their scale and likely level of ecological impact. These additional requirements are to assess the impacts of fishing on the fished stock and the ecosystem in which it is a part and include collecting information to help determine the biological status of impacted ecological components. There are several means that could be used to determine to which fisheries minimum requirements apply. This could be on the basis of 1) the value of the fishery, 2) the volume of landings in the fishery, and/or 3) the overall ecological foot print of the fishery (which will in part be determined by the types of gear used in fishing operations). Two options to address these considerations are: the first is to make *a priori* determinations of risk, for example similar to the "fishery risk assessments" adopted by DSEWPaC in marine bioregional planning; the second (and likely preferred) option is to make case-by-case determinations using the steps and methods described in Dichmont *et al.* (in press).

However, the harvest strategies applied to some fisheries already are confined by their inability to collect the information required. At this stage, it is unclear what the consequences of this experience have been to these fisheries.

Implementation of harvest strategies in Commonwealth fisheries has shown that - i) there are additional Tier levels beyond those used in the SESSF acknowledging the large number of target species and types of fisheries managed by AFMA, ii) there are pragmatic harvest strategies that meet the intent of the Policy but that still need clear statements as to how these conform to the policy, and iii) commitments written into the harvest strategies to collect and store data as required to allow the fishery to establish more defensibly its stock status may need additional resources than those already available (Dowling et al, 2008a).

The various MSE tests described above have shown very case specific results indicating that a precautionary system should be applied unless these methods are tested through

MSEs. Thus, a rule of specific to particular fisheries is best could be considered. However, not all fisheries or species within a multi-species fishery can afford an MSE. So something more generic is also needed along with criteria for when to apply which approach. Two approaches are possible:

a) generic MSEs have been developed (NOAA's PopSim; Haddon and Dowling, 2012, and others), but are either at very early stages or require further work. Further research in this area would be of value.

b) A risk-cost-catch trade-off framework where many data poor methods are tested in an MSE framework and then potentially generalised (if at all possible). A start to this process has recently been funded by FRDC (PI Dichmont), but this work will only report at the end of 2014.

Presently, there is little direction on what constitutes a defensible harvest strategy because any such discussion tends to describe more data rich approaches. As more MSE tests are undertaken, this issue will become more clearly defined and some solutions provided. However, there are fisheries or species within multi-species fisheries managed by the Commonwealth that are sufficiently complex that the costs of moving beyond very little data make the move almost impossible. For example, there are minor fisheries of such relatively low value that there are insufficient resources to even enter all data into databases or query those databases and do the analyses necessary to fulfil the existing data-poor HS requirements (Dowling et al, 2008a). Thus, the issue is whether even lower Tiers than those used within AFMA (Table 2) are required and whether these still conform to the intent of the policy. If not, then a funding model needs to be provided that allows all components of those fisheries that implement the harvest strategy to be appropriately resourced. Fulfilling the requirements of the Harvest Strategy Policy for all Commonwealth fisheries has obvious resource requirements.

The hierarchical methods developed in several harvest strategies or within the ERA (Hobday *et al.* 2011) entail small scale fisheries starting at a data poor Tier which consists mostly of empirical triggers. The ERA is explicit in that it provides two options when a risk is shown, using a method that defaults to being precautionary, which is to a) move to a more data rich method and test if this risk still remains or b) mitigate this risk through direct management action. This is the principle behind the assessment Tier system and the hierarchical trigger system used in some fisheries.

6 TAC Setting and Multi-Year TACs

6.1 TAC SETTING AND MULTI-YEAR TACS

The following issues were identified:

- *The Review may consider if criteria should be developed and described in the Guidelines which RAGs can refer to when determining whether and how to apply discount factors to determine TACs in a consistent manner (ABARES, 2011, pp118). Some work has been done in the SESSF and may help inform the Guidelines in this respect.*
- *What empirical indicators might be most appropriate for assessing fishery condition through time when applying MYTACs?*
- *How risks associated with MYTACs might be incorporated into RBCs? The use of multi-year TACs has not been accompanied by an appropriate consideration of risk, to this point in time, noting that longer periods between assessments may increase the risk that changes in stock status occur?*
- *How to determine an appropriate time period for MYTACs and whether the period is dependent on the status of the stock (e.g. very depleted versus near target)?*

6.1.1 TAC SETTING

A key management lever used in Commonwealth fisheries is the application of total allowable catches (TACs) through individual transferable quotas (ITQs). Many of the Australian Commonwealth fisheries are multi-species fisheries and these present further particular problems when setting TACs. The use of ITQ management in multi-species fisheries has been the subject of much debate and the complexities and difficulties of managing multi-species fisheries are well known (Branch 2009; Chu 2009). In these fisheries, a major issue is in setting total allowable catches (TACs) that are directed towards individual species to achieve management outcomes across a range of species. Generally, when TACs are set for individual species, catches of other species are not considered. In multi-species fisheries, there are often technological interactions where fishing effort directed towards one quota species will normally result in a mixed catch of fish that may include other quota species. Fishers can usually ‘target’ to some degree through fishing different areas and depths, seasons, times of day and by modifying gear. But it is the degree to which fishers can target that is the issue. The species mix in catches may not necessarily match the mix in combined TACs or in quota holdings. This difficulty in balancing quotas for multiple species with actual catches may then lead to increased discarding, TAC over-runs, effort restrictions or fishery closures when quota is constrained on some species (Branch et al 2006; Sanchirico et al 2006). This may lead, therefore, to problems with achieving B_{MEY} for multiple species.

While a number of solutions have been proposed or implemented to improve transferability of quota and other incentives to reduce over-quota fishing and discarding, it is surprising that there has been little focus on TAC-setting itself and coordinating this across multiple species/stocks as a means of dealing with some of these issues. Klaer and Smith (2011) analysed data from the trawl sector of the Australian Southern and Eastern Scalefish and Shark Fishery to determine the relationship between primary species and companion species and the implications this has for TAC setting. The primary species is the species being considered when setting an individual species TAC. The companion species are ones that should also be considered when setting the TAC of the primary species, because a considerable proportion of the primary species catch is taken as a companion species non-target catch. The target species in each fishing operation was determined and was used to characterize recent multispecies catch data into primary and companion components. The approach of identifying companion species within a given fishery provides an empirical means to examine the impact of individual species TAC decisions across all of the quota species in a fishery.

6.1.2 MULTI-YEAR TACS

Currently there is a growing use of Multi-Year TACs in those fisheries where they can be implemented. However, this strategy and the various means by which is has been and is being implemented have not been subject to formal management strategy evaluation. In general, multi-year TACs will require a “discount” of some level of catch to balance the greater risk associated with less frequent review and adjustment. There are obvious risks of stock depletion if the multi-year TACs are set too high. There is also a potential loss of yield if good recruitment occurs but is not reacted to for a few years (though potential losses through natural mortality may be offset by potential gains by growth of fish left in the water for longer, this balance will vary by species).

While there is a good deal of debate within various Australian Assessment Groups concerning the implementation of multi-year TACs no clear decisions or standard protocols have yet been adopted with respect to avoiding the potential risks of setting a multi-year TAC so high it leads to depletion. There are a number of examples where fish species have declined rapidly over relatively short numbers of years, for example deepwater flathead in the GAB (Klaer, 2011), and school whiting in the SESSF (Day, 2012). While draft breakout rules have been produced within the SESSF these have not been tested and only relate to catch rates and so are of limited use in those species where catch rates are highly variable. Informal criteria for placing species into multi-year harvest strategies have been developed but limited financial resources are currently restricting the number of Tier 1 assessments able to be conducted and this leads to pressure to maintain TACs in the absence of new information. Even if a species does breach its break out rules there are currently no guarantees that there are sufficient financial resources available to do a more adequate assessment.

There remains debate over the best way to set a multi-year TAC. The options raised include simply applying the current TAC forward for three year, another (only suitable for Tier 1 assessed species) is to set the TAC in each year in line the median projected secure catch from the stock assessment model, another is to apply some arbitrary discount with different figures being suggested in every case discussed. It is therefore very simple to conclude that more simulation testing work needs to be conducted to determine the utility of different criteria for selecting species as suitable for multi-year TACs. The exploration of the risk cost catch trade-off currently underway in a FRDC project should be able to provide insights with respect to this problem of whether multi-year TACs should always be reduced below single year TACs so as to reduce the risk of declines. Any research undertaken on this topic should evaluate the different options for setting multi-year TACs. With reductions in available resources for conducting stock assessments this research program takes on extra urgency.

There is very little literature regarding application of multi-year TACs in other jurisdictions. The Pacific Fishery Management Council allows for multi-years TACs in that assessments are done in year y, and acceptable biological catches (ABCs) are forecast for years y+1 and y+2. The Council then selects the TACs for years y+1 and y+2, usually based on an Allowable Catch Limit (ACL) control rule. However, no formal simulation testing of this strategy has been completed (Andre Punt *pers. comm*.).

In New Zealand, while there doesn't appear to be a formal mechanism for allocating multi-year TACs their management system of identifying the Maximum Constant Yield (MCY) leads, in practice, to stable TACs over many years. Thus a consideration of volume 1 of the stock assessment plenary document for 2012 (Ministry for Primary Industries, 2012) shows that, for example, Alfonsino, Arrow Squid, Barracouta, Blue Cod. Blue Moki, Blue Warehou, and Butterfish have all had the same Total Allowable Commercial Catch (TACC) for ten years of more. While there are some species where the TACC has varied (e.g. Blue Mackerel) there are many more New Zealand fisheries which have exhibited stable TACCs for many years. It is important to note that the MCY calculation accounts for the risk of setting the same catch level over a number of years by resulting in lower catches on average than setting any annual TAC based on updated assessments.

7 Rebuilding Strategies and Bycatch TACs

7.1 Introduction

The following issues were identified:

- *… whether and how the guidelines should be amended to provide further direction on the recovery objective and on whether rebuilding timeframes could be determined in a more species specific manner, giving consideration to the species productivity and other factors which might affect the stock's ability to recover (e.g. climate change, stochastic events, etc.). (DAFF, 2012, p26)*

and

- *… whether and how the advice in the guidelines on formulating rebuilding strategies (and particularly the estimation of incidental catch allowances) should be expanded upon or strengthened, and whether and how the Policy itself should be made more prescriptive in this matter. (DAFF, 2012, p26)*

A primary objective of the Commonwealth Harvest Strategy Policy (HSP) is to maintain key commercial fish stocks at ecologically sustainable levels and within that context, maximize the economic returns to the Australian community (DAFF, 2007, p4). A key commercial species is defined in the HSP as "… a species that is, or has been, specifically targeted and is, or has been, a significant component of a fishery" (DAFF, 2007, p54). To meet this objective, harvest strategies were developed for key commercial species that were "… designed to pursue maximizing the economic yield from the fishery, and ensure fish stocks remain above levels at which the risk to the stock is unacceptably high" (DAFF, 2007, p4). These minimum levels are defined by Limit Reference Points (LRP).

The HSP specifies minimum standards for the Limit Reference Point (LRP) as being: "B_{LIM} (or proxy) equal to or greater than ½ B_{MSY} (or proxy)" and/or "F_{LIM} (or proxy) less than or equal to F_{MSY} (or proxy)" (DAFF, 2012a, p22). In practice, this was operationalized by declaring the spawning biomass that corresponds to the level at which the risk to the stock is unacceptably high as the B_{LIM}, and unacceptably high was "… for example the point at which recruitment overfishing is thought to occur" (DAFF, 2007, p23). While this specific point has been estimated to occur across a wide range of depletion values for a range of species (Myers *et al*., 1994), in Australia it was decided to adopt ½ B_{MSY} as the default depletion level to use as B_{LIM} (Restrepo *et al*, 1998), which defaulted to being represented as $B_{20\%}$. It should be remembered that there is no empirical demonstration that $B_{20\%} = B_{LIM}$, is the same as ½B_{MSY}. In fact, given that *MSY* can easily vary greatly from $B_{40\%}$ if ½B_{MSY} were completely adopted it would be possible to have a limit biomass reference point well below $B_{20\%}$. Even where it is deemed possible to estimate B_{MSY} the limit reference point of $B_{20\%}$ has been retained to avoid the risk of depletion reaching levels that constitute risks to subsequent recruitment. Given the choice of $B_{20\%}$ as the limit the HSP aims to: "… ensure that the stock stays above the limit biomass level at least 90% of the time (i.e. a 1 in 10 year risk that stocks will fall below B_{LIM}). In those circumstances where the depletion level cannot be estimated, the HSP allows for proxies to be used within designed harvest control rules (see section 2.5.1 for comments on the incompatibility of the requirement that current harvest strategies use the present stock status to determine any recommended biological catches and yet the determination of the probability of falling below the limit reference point would require projections forward of any recommended catch levels; the only way to get around this incompatibility is to conduct simulation tests to ensure the harvest strategy adopted fulfils the <10% requirement).

The Harvest Control Rules (HCRs) in each Harvest Strategy adopted in each Commonwealth fishery are designed to reduce fishing mortality if the stock is assessed as declining away from the B_{TARG} towards the B_{LIM} (the default Target Reference Point – TRP – is $B_{48\%}$ which is taken as a proxy for the maximum economic yield, or MEY; = $B_{MSY} \times 1.2$, where $B_{40\%}$ is used as a conservative proxy for B_{MSY}); in this way it aims to prevent overfishing by encouraging the stock to rebuild. If, however, a stock does drop below B_{LIM} then it becomes defined as overfished and an AFMA managed rebuilding strategy must be put in place to rebuild the stock towards B_{TARG}. Below B_{LIM} a stock may also be considered for listing as conservation dependent or a more significant listing level, and such a listing may require the development of a formal recovery plan under the EPBC Act.

In the Commonwealth fisheries there are currently four fish species which are conservation dependent: School shark (*Galeorhinus galeus*), Orange roughy (*Hoplostethus atlanticus;* not on the Cascade Plateau), eastern gemfish (*Rexea solandri*), and southern bluefin tuna *(Thunnus maccoyii*). All of these species were seriously depleted before the implementation of the present HSP and since the introduction of recovery plans targeted fishing is supposed to stop (except for SBT, which is managed under an international harvest strategy). Unfortunately, this means that information and data about these species becomes greatly reduced. This lack of information means the difficulty in managing these species and pushing the recovery plans forward becomes greater. This is an unintended consequence of the HSP. In a cost recovery setting, it becomes even more difficult to fund research on fisheries for which directed commercial activity has ceased.

The Guidelines for Implementing the HSP state that: “For a stock below $\mathrm{B}_{\mathrm{LIM}}$ a rebuilding strategy will be developed to rebuild the stock to $\mathrm{B}_{\mathrm{TARG}}$. Once such a stock is above $\mathrm{B}_{\mathrm{LIM}}$ it may be appropriate for targeted fishing to re-commence in-line with the stock rebuilding strategy and HS.” (DAFF, 2007, p 24)

This present document is concerned with details of the management of those stocks that fall below B_{LIM}, including the different strategies and timeframes for rebuilding. In terms of timeframes for rebuilding the *Guidelines* state: “Typically recovery times are defined as the minimum of 1) the mean generation time plus ten years, or 2) three times the mean generation time.” (DAFF, 2007, p. 44). In addition, in mixed fisheries, to minimize discarding, the rebuilding strategies need to determine what level of incidental bycatch is likely to occur under normal fishing operations where the depleted species is no longer subject to a targeted fishery.

Attempting to meet these guidelines has been problematic in three of the conservation dependent species (the orange roughy fishery has effectively been shut down) as well as other currently depleted species (such as blue warehou, *Seriolella brama*) so the discussion here will focus on research related to these subjects.

7.1.1 POTENTIAL ISSUES OF RELEVANCE TO THE REVIEW

Relating to these issues the discussion document (DAFF, 2012b) listed two areas in which commentary was invited:

"Rebuilding timeframes and strategy:

There has been some debate about the scientific basis for these timeframes, and whether this statement pertains to the timeframe for moving the stock from below B_{LIM} to B_{LIM} (or above), to B_{MSY}, to B_{TARG}, or from B_{LIM} to B_{TARG}. In addition, while the Guidelines state that rebuilding strategies should aim to rebuild stocks to B_{TARG}, this is perhaps inconsistent for multispecies fisheries which are allowed to maintain stocks at below B_{MEY} (i.e. the Policy's B_{TARG}) but always above B_{LIM}. In addition, it is uncertain whether the implicit assumption that all stocks can be rebuilt is in fact correct**.** An important issue is:

Rebuilding strategies for incidental catch: The Policy states that where stocks are below B_{LIM}, *targeted* fishing for that stock shall cease. The Policy states that a '*rebuilding strategy may impose additional constraints on* (incidental catch) *allowance up to and including closure of the fishery*'. However, the Policy does not require that harvest strategies necessarily impose a zero catch limit on stocks below B_{LIM}. Specifically, the Guidelines note that '*Clearly, a zero RBC below B_{LIM} provides the maximum possible recovery rate. However, achieving zero catches in a multi-species fishery may be difficult'* (HSP, p. 44). The Guidelines also state '*the optimal time path to rebuild a stock has an economic component. In determining the optimal time path to rebuild a stock, there is a trade-off between lost profits in the short term and the speed at which the stock is rebuilt*' (HSP, p. 43).

Accordingly, where a commercial stock falls below B_{LIM} targeted fishing must cease but an incidental catch allowance (sometimes referred to, somewhat misleadingly, as a 'bycatch allowance' or 'bycatch TAC') may be put in place as part of a suite of management measures to rebuild the stock. Experience has shown that stocks managed under rebuilding strategies have not always shown the expected rebuilding for recovery within the planned timeframe. For example, while rebuilding strategies were implemented for three species (eastern gemfish, school shark and blue warehou) in 2008, recent assessments and projections suggest that the total fishing mortality of these species has not been reduced sufficiently to allow rebuilding within the specified timeframes (ABARES, 2011). In the case of eastern gemfish, targeting has been prohibited since 1996 but there is still no sign of recovery to previous levels. The possibility of a regime shift is being considered in this case, amounting to a reduction in overall productivity of the stock not necessarily related to fishing.

7.2 Review of Research

Some of the questions asked within the discussion document are more related to policy decisions than to technical questions amenable to research. Thus, for example, the question of whether targeted fishing should cease until a stock has rebuilt to B_{LIM} or B_{TARG} is a policy decision, but the implications of such decisions can be discussed in terms of their implications for the stock and for the internal consistency and other possible implications for the rest of the policy.

7.2.1 REBUILDING FROM B_{LIM} TO B_{TARG} OR TO BACK ABOVE B_{LIM}

The HSP is clear about the targets for rebuilding. It states that "For a stock below B_{LIM}, a stock rebuilding strategy will be developed to rebuild the stock to B_{TARG}. Once such a stock is above B_{LIM} it may be appropriate for targeted fishing to re-commence in-line with the stock rebuilding strategy and Harvest Strategy." (DAFF, 2007, p 4 & 24). This reflects the fact that the harvest control rules that operate within particular fisheries when the stock status falls between B_{TARG} and B_{LIM} constitutes the strategy that aims to rebuild the stock if it falls below B_{TARG}. A separate rebuilding strategy is required when the stock is estimated to be below B_{LIM}, because all targeted fishing is required to stop. Both aspects constitute rebuilding strategies, and it therefore makes sense that the HSP states that rebuilding should aim to return the stock to the TRP of B_{TARG} (=$B_{48\%}$). Confusion appears to have occurred because of the possibility of interpreting the quoted statement as meaning the intent was that there should be no targeted fishing until the species achieved the B_{TARG}. This confusion is really a failure to understand the intent of the HSP with respect to depleted species. A clarification of this intent should remove this potential confusion. The HSP makes two clear statements about depleted and conservation dependent species:

> *Where the biomass of a listed species/stock is rebuilding towards to [sic] B_{TARG}, consideration may be given to deleting the species from the EPBC Act list of threatened species, or amending the category it is in. Deleting a species from the list of threatened species under the EPBC Act is effected via a legislative instrument issued by the Minister for the Environment and Water Resources. Advising the Minister that a recovering species that has rebuilt above B_{LIM} should be considered for delisting will be the responsibility of AFMA on the advice of the AFMA board, however, any person can initiate the process. (DAFF, 2007, p24)*

Similarly, there is the statement in the section on the relationship of the Policy to the EPBC Act:

> *Where the biomass of a listed stock is above* B_{LIM} *and rebuilding towards* B_{TARG}*, consideration could be given to deleting the species from the EPBC Act list of threatened species, or amending the category it is in.*
>
> *The relevant sections of the EPBC Act, primarily Part 13, will apply for any listing, amending, or deletion of a species from the list of threatened species.*
>
> *The best available science will underpin all key decisions in the application of the Policy and relevant provision of the EPBC Act. Stakeholders will be well informed and agencies will ensure transparency. (HSP, p. 7)*

Because this is the basis of the HSP, the assumption is often made that if a species were above the B_{LIM} then the harvest strategy for whatever fishery is involved would be used to manage the fishery as per normal. For this reason, while the quotations above appear relatively clear in their intent, the use of the phrases "...may be given…" and "…could be given…" in lines 2 of each quote are often pointed to by Industry members when this failure to understand the intent of the HSP is mentioned.

While this appears simple to resolve by making the intent of the HSP explicitly clear there are difficulties because the issue is at least partly due to the interaction between the Fisheries and the Environment Acts. While it is clear that targeted fishing can begin, albeit slowly, once a species rises above B_{LIM}, it is not clear whether targeted fishing can occur on conservation dependent species even if they are above B_{LIM}. Clarifying that would appear to be beyond the scope of the HSP review because it involves the EPBC Act. However, if it is the intent of the policy, then it could still be made clear that for those species that do not become conservation dependent, even though they dip below B_{LIM}, targeted fishing will be permitted to re-commence following the stock being assessed as being above the LRP.

This is an important clarification because it would reduce uncertainty over the conditions under which the HSP and its accepted harvest control rules would apply for the provision of management advice.

7.2.2 IN A MIXED FISHERY SHOULD DEPLETED STOCKS ALWAYS BE REBUILT TO B_{TARG}?

The HSP is clear that stocks that fall below the target reference point should be rebuilt to B_{TARG}. However, whether this is always the default target biomass level, $B_{48\%}$, is not made explicit but appears to be assumed. The discussion document (DAFF, 2012b) is correct to point out that the HSP allows for circumstances where the TRP may differ from this default under an array of circumstances where the default B_{MEY} is not the expected yield from a fishery. This issue is covered in sectionon-Stevens act

> *3.3 Multi-species fisheries*
>
> *In fisheries that target or catch a number of species … it will be extremely difficult to maintain all species at the TRP because not all species can be effectively targeted and some species will be caught as incidental catches of the main target species. Importantly, MEY applies to the fishery as a whole and is optimised across all species in the fishery. As a result, some secondary species (e.g. lower value species) may be fished at levels that will result in their biomass remaining below their target biomass reference point (i.e. B_{MEY}). In such circumstances, the estimated biomass of these secondary species **must** be maintained above their limit reference point, $B_{LIM.}$ (HSP, p25)*

The management of secondary species may be conducted using harvest strategies designed for relatively data poor stocks (Dowling *et al*., 2008a), which, for example, may use catch level triggers that lead to increases in the data gathering and possible assessment requirements before further increases are permitted. If this path is adopted this would meet the requirements as listed under the quoted Section 3.3. To date this does not appear to be common in the major Commonwealth fisheries. They are either completely data poor (for example the Western Deepwater Trawl) or, if they are a mixture, the principle economic targets are assessed in some form of tiered assessment arrangement and any remaining secondary species and bycatch species are either dealt with under the lowest tier assessment available in the particular fishery or are included in the Ecological Risk Assessment (Haddon, 2012).

For the major mixed fisheries it would be valuable to conduct research to devise or recommend further data poor stock assessment methods to improve the effectiveness and hence the defensibility of the harvest strategies selected for a fishery.

7.2.3 REBUILDING TIMEFRAMES RELATIVE TO SPECIES' PRODUCTIVITY

In Australia there are guidelines for determining the timeframe over which stocks depleted below B_{LIM} are expected to be rebuilt.

The analysis of rebuilding strategy options and timelines can be complex and is further complicated by the social, economic and policy dimensions of such decisions. …

Typically recovery times are defined as the minimum of 1) the mean generation time plus ten years, or 2) three times the mean generation time. (HSP, 2007, 44)

The notion of developing rebuilding strategies for overfished or depleted stocks is common to other formal harvest strategy policies around the world, for example, rebuilding strategies are part of the requirements for the Magnuson-Stevens Fishery Conservation and Management Act in the USA (US Department Commerce, 2007) as well as in the Harvest Strategy Policy introduced in New Zealand (Ministry of Fisheries, 2008). The details of how rebuilding strategies are implemented differ by country but the intent of moving an overfished stock back towards the target for that fishery is invariably the same. The definition of overfished is usually related to the stock depletion level being below the limit reference point.

In the USA the LRP is known as the MSST – minimum stock size threshold and the technical guidance (Restrepo *et al*, 1998) for implementing their management standards describes how to approach rebuilding strategies for overfished stocks:

… the National Standard Guidelines require that special plans be implemented to rebuild the stocks up to the B_{MSY} level within a time period that is related to the stock's productivity. This document does not propose a default rebuilding plan, because the time to rebuilding may depend on each stock's current level of depletion. Instead, the document presents the four key elements that should be considered in rebuilding plans: An estimate of B_{MSY}, a rebuilding time period, a rebuilding trajectory, and a transition from rebuilding to more optimal management. (Restrepo et al, 1998, p3)

However, in addition it stated:

To the extent possible, the stock size threshold [MSST] *should equal whichever of the following is greater: One-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold ... (Restrepo et al, 1998, p17)*

In the Magnuson-Stevens Act (U.S. Dept of Commerce, 2007), for a fishery that is overfished a plan is required that:

(A) Specify a time period for rebuilding that fishery that shall –

(i) be as short as possible, taking into account the status and biology of any overfished stocks of fish, the needs of the fishing communities, recommendations by international organizations in which the United States participates, and the interactions of the overfished stock of fish within the marine ecosystem; and

(ii) not exceed 10 years, except in cases where the biology of the stock of fish, other environmental conditions, or management measures under an international agreement in which the United States participates dictate otherwise; (US Dept Commerce, 2007, p92)

The guidelines (Restrepo *et al*, 1998) described a rebuilding plan based on these two clauses thus:

> *In the absence of data and analyses that can be used to justify alternative approaches, we recommend that a default rebuilding plan for stocks below the MSST be based upon the precautionary target control rule of Section 3.3 with the following extensions:*
>
> *The maximum rebuilding period,* T_{max}*, should be 10 years, unless* T_{min} *(the expected time to rebuilding under zero fishing mortality) is greater than 10 years, when* T_{max} *should be equal to* T_{min} *plus one mean generation time. (Restrepo et al, 1998, p37)*

This strategy includes reference to the notions of 10 years, or T_{min}, the time to rebuild in the complete absence of fishing, and of adding one mean generation time to T_{min} if 10 years would be insufficient. This appears to be the origin of one of Australia's potential timeframes for rebuilding. Ten years plus the mean generation time suggests that the well-known variability of recruitment events and the obscured but important relationship between spawning biomass and consequent recruitment events (Myers and Barrowman, 1996) has not been accounted for.

New Zealand has elected to base its rebuilding time frames on a notion of T_{min}. The standards document state:

> *The Harvest Strategy Standard specifies that where the probability that a stock is at or below the soft limit [*$B_{20\%}$*] is greater than 50%, the stock should be rebuilt to the target [*$B_{40\%}$*] within a time period between* T_{min} *and 2 ×* T_{min} *(where* T_{min} *is the theoretical number of years required to rebuild a stock to the target with zero fishing mortality).*
>
> *Mathematical projection models will generally need to be developed to estimate* T_{min} *and to compare and contrast alternative rebuilding strategies. These will usually be probabilistic models that incorporate uncertainty in the projections. (Ministry of Fisheries, 2008, p11 – 12)*

In explanation for the notion of T_{min} the same document states:

> T_{min} *reflects the extent to which a stock has fallen below the target, the biological characteristics of the stock that limit the rate of rebuild, and the prevailing environmental conditions that also limit the rate of rebuilding. Allowing a rebuilding period up to twice* T_{min} *allows for some element of socio-economic considerations when complete closure of a fishery could create undue hardships for various fishing sectors and/or when the stock is an unavoidable bycatch of another fishery. (Ministry of Fisheries, 2008, p12)*

There are some depleted species in Australia (e.g. Eastern gemfish; SESSF RAG papers, 2011 and 2012) that, given the previous variation inferred from the Tier 1 assessment, would not recover in a maximum of 10 years plus the mean generation time. For this reason the New Zealand strategy appears more general than that espoused in either the USA or in Australia. The strategy in the USA and Australia appears to default to one where recruitment is expected to be deterministically dependent on spawning stock size or at least considers that recruitment will operate relative to the median expected recruitment. The explicit suggestion of using stochastic projection models is directly related to accounting for the known risks arising from recruitment variability using Monte Carlo simulation methods (Francis, 1992). This latter approach would be more consistent with the emphasis placed in the Australian HSP of using precautionary and risk based strategies.

In those fisheries where specific targeting is a characteristic then the option of closing such a fishery should severe depletion occur is an option that would have little impact on other fisheries (although the closure of the orange roughy fisheries using the 700 m trawl closure has also greatly reduced the catch of other deepwater species such as the various species of oreo). In mixed species fisheries, however, it is only by using mathematical simulation methods that the potential influence of allowing different bycatch TACs can be determined.

The rebuilding strategies in the USA are aimed primarily at the sustainability objective of the fisheries Act while the strategy in New Zealand's Fisheries Act provides for greater flexibility to take economic, social, and cultural needs into account. In a study of the economics outcomes of stock rebuilding (Larkin *et al*., 2007) used simulation models and determined that extending the rebuilding timeframe over the 10 years plus mean generation time could substantially increase annual harvests and economic benefits, depending on the productivity of the stock concerned and the economic discount rate used. The longer timeframes adopted in New Zealand for rebuilding depleted stocks thus allowed for both sustainability and economic objectives to be more balanced. Again, however, this would entail conducting a simulation study and continued monitoring of the depleted stock. It is clear that the need to satisfy the requirements for rebuilding plans leads to a substantial increase in the demands for technical analysis (Restrepo *et al*., 1998) and even with that analysis there remains great uncertainty because of the reduced information available (Punt and Ralston, 2007).

There is also a need to recognize that there are circumstances under which rebuilding would not be expected to occur. The marine environment is not a constant and the east and west coasts of Australia in particular are potential hot spots for significant change (Harris *et al*., 1988; Hobday and Lough, 2011). Within the SESSF there is already an instance where a relatively depleted species that was near the LRP (Jackass Morwong, *Nemadactylus macropterus*) exhibited a 20 year series of below average recruitment. This was eventually characterized as a change in the species productivity due to a regime change or regime shift, or at least an alteration in prevailing conditions that has lasted for decades (Wayte, 2012). There are a number of high profile international instances of species that have become seriously depleted having their fisheries closed only to fail to recover or rebuild (Walters and Maguire, 1996; Fu *et al*., 2001). An array of explanations have been proposed for the failure of the northern cod fishery to recover but the key finding is that the productivity of the stock has shifted to a different level and the recovery, if it ever happens, is not presently predictable. It is in recognition that there are factors other than fishing that can lead to fish stocks declining that has led to fish stocks found below the soft and hard limits in New Zealand to be referred to as depleted rather than overfished. This is more than a detail or nicety of language as it formally recognizes that there are other factors that may need attention when fish stocks decline. Regime shifts are a reality that cannot be dismissed and Wayte (2012) provides a clear example of the evidence required to demonstrate such events.

In addition to the effects of marine climate and changes in the prevailing environmental conditions affecting stock recruitment relationships it is also possible that some species, particularly when they were fished under a basket species category (e.g. gulper sharks) may have been reduced to such a low level that the probability of them recovering would become influenced by random events. There is some confusion in the literature concerning the risk of extinction of marine organisms. At a recent conference on the State of the Oceans, that examined extinction risks (Rogers and Laffoley, 2011) there were numerous declarations about overfishing being a marine population stressor but extinctions being referred to were not of commercially fished species (except for the Chinese Bahaba – *Bahaba taipingensis* – which has become extremely valued in the Chinese medicine field). Nevertheless, more evidence has been compiled (Hutchings and Reynolds, 2004) that demonstrates that few populations recover rapidly with few observed populations changing in abundance over 15 year periods.

> *Reductions in fishing pressure, although clearly necessary for population recovery, are often insufficient. Persistence and recovery are also influenced by life history, habitat alteration, changes to species assemblages, genetic responses to exploitation, and reductions to population growth attributable to the Allee effect, also known as depensation. … Unprecedented reductions in abundance and surprisingly low rates of recovery draw attention to scientist's limited understanding of how fish behaviour, habitat, ecology, and evolution affect population growth at low abundance. (Hutchings and Reynolds, 2004, p 297)*

The assumption with most fishery population models is that at low abundance there will be density dependent effects that increase the survivorship of any recruits that are produced. Other density dependent effects are possible but the main one of interest relates to improved recruitment success (not necessarily more recruits, just more surviving; Myers and Barrowman, 1996). This density-dependent effect has been shown to be strong in some species but also weak in others. Where it is weak the species concerned are far more vulnerable to failing to recover if they become depleted (Keith and Hutchings, 2012). It has been 20 years since the northern cod off Newfoundland was recognized as collapsed and there are still no real signs of recovery.

The species that have been identified as highly depleted in Australia were generally depleted well before the introduction of the current HSP. Application of management strategy evaluations (MSE) to test of the effectiveness of an array of harvest strategies in the present HSP were made in the Reducing Uncertainty in Stock Status project (Dowling, 2011; Haddon, 2011; Klaer and Wayte, 2011; Plaganyi *et al*, 2011, 2012). Those MSE harvest strategy tests indicated that the harvest strategies tested should achieve their aims of preventing declines below the LRP and maintain the stock sizes at productive levels. However, of the MSE analyses conducted only Plaganyi *et al.* (2012) who considered the Coral Sea fishery for sea cucumbers analyzed the effect of systematic environmental changes such as climate change. While the MSE conducted on the scallop harvest strategy concluded that the harvest strategy would achieve the intent of the HSP, it could not predict the sudden death of more than 24,000t of scallops in Bass Strait in 2011 (an event mirrored down the east coast of Tasmania). This is an extreme example of where a non-fishery related phenomenon has a large influence on the state of a fishery stock.

8 Spatial Management

8.1 Introduction

The following issues have been identified:

- *The Review may consider if further guidance is required in relation to how to take into account closed areas and spatial management approaches when designing harvest strategies that are consistent with the Policy objectives.*

There is already a research project underway that is addressing the impact of marine spatial closures on stock assessments and consequently on the harvest strategy policy. There are some species which are relatively data-poor mainly because they are patchily distributed and such patches are heterogeneous in terms of productivity and are often highly variable in abundance due to natural variations (e.g. scallops and squid in the south, and sea cucumbers in the north). Finding limit and target reference points that can be validly applied to such species can be extremely difficult. It is clear that further guidance is required in the HSP with how to deal with such species in a manner considered to be consistent with the intent of the HSP.

8.2 Review of Research

8.2.1 OVERVIEW

Spatial management (e.g. marine closures and rotational harvesting) may be applied in various contexts within a harvest strategy. It can form the main harvest strategy framework (such as in a system of rotational closures), it can be used to augment a harvest strategy framework, or spatial management measures can be invoked as a control rule (see section below on control rules).

Spatial management is often favoured as a more cost-effective regime and/or in the absence of other information allowing alternative management measures. It can be applied to species for which the concept of an equilibrium biomass has limited meaning as a result of life history. It is also a useful approach for artisanal fisheries where monitoring and compliance limitations make TACs or catch controls impractical and data gathering is more challenging (Pilling *et al.* 2008); compliance with closure boundaries is managed in Australia using a satellite Vessel Monitoring System.

Worm *et al.* (2009) emphasise that conventional management tools used for industrial fisheries are generally unenforceable in small-scale artisanal fisheries when implemented in a top-down manner, and describes a system of co-management to rebuild depleted fish stocks on Kenyan coral reefs via a network of closed areas and the exclusion of beach seines. Worm *et al.* (2009) also cite other examples of successful rebuilding from Latin America, where open-access invertebrate fisheries for valuable invertebrates were transformed by the establishment of spatial management units that had exclusive access by local fishing organizations. Such closures can be successful where conventional management tools are likely to fail but if compliance in remote areas is at all an issue, then closures will also be prevented from being effective.

Spatial management has been successfully implemented in the form of a rotational harvest strategy or temporal pulse fishing frameworks for sessile species that have the propensity to experience 100% local depletion. This has been applied to various scallop fisheries (Dowling *et al.* 2008; Valderrama and Anderson 2007; Myers *et al.* 2001) and to sea cucumber fisheries (Dowling *et al.* 2007; Humble and de la Mare 2008), for which the concept of B_{MSY} or B_0 has limited meaning.

The adaptive rotational harvest strategy developed by Humble and de la Mare (2008) closed harvested areas to further fishing until a designated degree of recovery occurred. Instead of a set rotation cycle length, local areas were harvested at a frequency determined by local recovery rates, which may differ over time and by location. Only local density and body mass estimates were required, yet modelling showed that this strategy out-performed one of a constant harvest rate and annual harvest strategy, without requiring estimation of life-history parameters or population abundance on a large scale. Valderrama and Anderson (2007) used an age-structured bio-economic model to demonstrate that economic rents where maximized by engaging in pulse fishing strategies for Atlantic Sea Scallops, whereby fishing only occurs following a multi-year closure period. Closures allowed biomass to accumulate undisturbed for several years in a row, leading to the harvest of premium-size scallops upon reopening of the fishing grounds. Closures also resulted in substantial reductions in operating fishing costs, and the rotational harvesting strategy was found to be robust with respect to a number of assumptions in the model.

Schnute and Richards (2001) agreed that a regulatory scheme that controls fishing mortality with large spatial and temporal fishery closures offers a management strategy more robust to uncertainty than direct control of catch, since only a small component of the stock gets exposed to the fishery. Pitchford *et al.* (2007) used a deliberately simple model, which describes an exploited fishery close to the point where small random perturbations can build up and lead to fishery collapse, to show that closures achieved via marine protected areas (MPAs) can buffer these random effects and alleviate the propensity to collapse. They showed that, compared with harvest control rules based on uncertain estimates of stock size, MPAs can substantially reduce the risk of fisheries collapse for only a very small cost to total yield. It should be remembered, however, that this work used a simple model of a fishery set up at the point of failure.

Rather than imposing a reserve and measuring its effect on profits, Sanchirico *et al.* (2006) examined when no-take zones were economically optimal. Closed areas were an economically optimal solution when the value derived from spillover from the reserve outweighs the value of fishing in the patch. There were circumstances whereby closing low biological productivity areas, and even sometimes low cost areas to fish, can result in greater fishing profits than when both areas are open to fishing.
As opposed to rotational spatial closures or a system of MPAs as the main harvest strategy approach, small, permanent closed areas may be used to augment a harvest strategy in the face of uncertainty (Dowling *et al.* 2008a,b). This is a measure that can be useful when:

- a harvest strategy framework, such as a trigger system, has been formulated, but there remains concern about the extent to which the framework is precautionary, and/or
- the fishery interacts with highly vulnerable species or habitat, and/or

- the fishery is in a developmental state where management should not overly inhibit access and flexibility, and/or
- the fishery may be highly sensitive to small stochastic perturbations (Pitchford *et al.* 2007).

8.2.2 CLOSED AREAS/SEASONS

Spatial management measures may be introduced as control rule responses to trigger levels being reached, particularly for highly vulnerable species or species with a high potential for localized depletion. For example, in a trigger harvest strategy framework, spatial closures or short-term provisions for fishing to cease in a given local area may be a possible response to a Level 1 trigger, if analysis shows that the trigger level has been reached as a result of concentrated fishing in a given area. Reuter *et al.* (2010) concur that closed areas, marine refugia or marine protected areas have been suggested as alternative management strategies to quota management, but point out that complications can arise if and when attempting to integrate their effectiveness into traditional stock assessments.

Spatial control rules are particularly useful for artisanal fisheries, where monitoring and enforcement may be difficult. They also lend themselves easily to community management in an artisanal context (Pilling *et al.* 2008). Matic-Skoko *et al.* (2011) described spatial closures being imposed as a control rule in Mediterranean artisanal fisheries, together with gear restrictions. Without compliance by fishers, however, such spatial control rules will fail.

8.2.3 MOVE-ON PROVISIONS

Often applied to small-scale fisheries on sessile species, "move on" provisions provide precautionary limits and, like daily catch limits, mitigate against localized depletion. They have been applied to beche-de-mer, lobster and trochus in the Australian Coral Sea hand collectibles fishery (Dowling *et al.* 2008a,b). Move-on provisions are typically defined in terms of a catch obtained within a given spatial region within a given time limit. For example, the Australian beche-de-mer move-on criterion is 5 t of combined species catch from one reef annually per permit; subsequent collection may not continue within a 15 nautical mile anchorage.

As with daily catch limits, move-on provisions are often adjunct control rules within, for example, a broader Total Catch or trigger framework. Move-on provisions require trust among fishers, particularly if the provision applies to some daily catch limit that is unable to be externally monitored.

8.2.4 MPAS AS INFORMATION SOURCES FOR MANAGEMENT

This harvest strategy approach involves the comparison of fished and unfished reference sites, typically via the use of Marine Protected Areas (MPAs). With the increasing implementation of MPAs, there is potential for improving decision making in management through comparisons of fished populations with populations in MPAs at spatially explicit scales. This approach is particularly applicable to fisheries targeting, for example, near-shore rocky reef species that exhibit spatial variation in harvest pressure and demographic rates, limiting traditional stock assessment approaches.

McGilliard *et al.* (2011) evaluated the potential use of the ratio of the density of fish outside a marine protected area to that inside it each year (the density ratio, DR) in a control rule to determine the direction and magnitude of change in fishing effort in the next year. Management strategy evaluation was used to evaluate the performance of this DR control rule (DRCR) for a range of movement rates of larvae and adults and other biological scenarios, and determined the parameters of the control rule that maximized cumulative catch (over 95 years) for each scenario.
Wilson *et al.* (2010) used a combination of data-based indicators sampled inside and outside of MPAs as well as model-based reference points for data-poor, sedentary near-shore species in a decision tree model. The model consistently improved total catches while maintaining the biomass and spawning potential ratio at levels within acceptable management thresholds.

The following additional control rules are also applicable in data poor fisheries, noting that these may be used in combination. For example, Welch *et al.* (2005) describes a precautionary approach to management for the data-poor king threadfin fishery taken in the commercial inshore gillnet fishery of northern Queensland, Australia, advocating a phased approach to risk-averse management. Simple assessment of commercial catch and effort data from the fishery did not indicate overexploitation. However, estimation of stock size using models was not possible, and more robust assessments are hampered by limited biological data, an absence of monitoring data, un-validated commercial log-book data, and a creep in fishing effort as technology advances. In such a data poor situation it was recommended that closures be used to protect spawning threadfin aggregations, as well as the use of maximum constant yield (MCY) to set a precautionary limit on annual catches.

8.2.5 ROTATIONAL SPATIAL MANAGEMENT

In a spatial management harvest strategy framework, the control rule is whether and which areas to open or close to fishing in a given year or fishing season. The general aim is to maintain some specified level of stock protection and thus indirectly avoid an explicit biomass based limit reference point. Usually this requires some form of pre-season survey to assess biomass or habitat conditions, and possibly the condition of the species (such as for Australian scallops) (Dowling *et al.* 2008a,b).

8.2.6 SPATIAL/TEMPORAL INCENTIVES TO AVOID THREATENED, ENDANGERED, OR PROTECTED SPECIES

Incentives relating to allowable catch in respect to location can be imposed as an overarching regime in a fishery managed under a catch or effort quota system. Such an approach could also form a control rule in response to a reference point or trigger being reached, particularly in a multispecies fishery. Under such an incentive system, catch or effort would be decremented from an individual's quota at a rate relevant to a location or time in which they are operating, leading to a higher rate of consumption of the operator's allocation in areas where the potential impact on the stock would be greatest (Wilcox *et al.* 2010). This is useful if the species of concern is being caught in a specific season or area to which the incentive can be applied.

8.2.7 ADJUSTMENT OF SEASON LENGTH (E.G. FROM DEPLETION ANALYSIS)

For highly productive, short-lived species subjected to management by a fishing season of fixed duration or via catch or effort quotas, control rules may be implemented to adjust the season length or the TAC or TAE, according to the most recent information available. For example, if the fraction of the designated TAC/TAE is overshot, then the fishery may be closed or the effort is reduced. Such stocks are typically highly variable and the stock abundance may vary about an order of magnitude inter-annually, depending on the recruitment success in a particular year, although Tuck *et al.* (2001) also describe within-season changes to the TAC for the fishery for the longer-lived, less productive Patagonian toothfish. However, this fishery has few participants.

The Australian Arrow Squid harvest strategy is based on a system of real-time within-season management, where assessment approach is one of undertaking spatial and non-spatial depletion analyses. These project and adjust the cumulative catch for the season with a view to determining either season length or total catch or both for the season, and either may be updated during the season (Dowling *et al.* 2008b). Banana Prawns within the Australian Northern Prawn Fishery are also subject to within-season management (Dichmont *et al.* 2006).

9 Other Issues

9.1 Over-ride Rules

The discussion paper identified the following issues:

The Guidelines state that '*both the criteria for invoking exceptional circumstances and the response to them need to be clearly specified and agreed ahead of the need to apply them*', but provide little further guidance. In reality, such circumstances are unpredictable in their timing and nature and therefore may not be amenable to management by pre-determined rules.

- *The Review may wish to consider whether additional guidance can/should be developed around the development of 'metarules' to cope with exceptional circumstances.*

Such circumstances might include where assessments have not been completed due to unforeseen circumstances, where there has been an exceptional change in the nature of the fishery or where there has been a change in the ecological environment of the fishery unrelated to impacts of fishing. (HSP, p. 47)

In the previous discussion on meta-rules it was noted that they could be successful in achieving the intent of the policy while finding a practical way to manage complex situations with many interactions occurring at once. As such meta-rules constitute a back-up plan in rare cases of exceptional situations. Therefore it is again simple to conclude that this is an area that requires further detailed exploration and research.

9.2 Data related issues

The discussion paper identified the following issues:

Data requirements and availability can impact on the effectiveness of harvest strategies. For example, fisheries data used in assessments can be 12–18 months old by the time those assessments are applied within the harvest strategies, which has led to the application of 'recent catch rate multipliers' in the TAC setting processes (e.g. in the SESSF).

- *The Review may consider whether specific requirements regarding data specification and provision, relevant to harvest strategies, need to be specified within the Policy or Guidelines. This might include consideration of the point at which additional data collection (monitoring and assessment) is required when catches of non-quota bycatch species start significantly increasing (due to targeting or other reasons).*

Previous management strategy evaluations (MSE) of various harvest strategies in the SESSF (Wayte, 2009) have included the time delays in their testing and so such delays between data collection and utilization have received some testing. The use of the TAC adjustment rule based on the most recent CPUE analyses has already been tested with MSE (Wayte *et al.*, 2009) and found not to alter the performance of the various harvest strategies procedures within the SESSF in terms of risk to the stock or overall catch levels, although it did significantly increase year-to-year variation in catches.

If the HSP began to require a minimum data requirement to be collected for all key commercial species this would have resource implications that might need to be taken in to account. Without those resources such a requirement could not be met.

10 Research Projects of Potential Value

10.1 Research Currently Under Way

There are already a number of research projects underway that may have implications for the review of the Harvest Strategy Policy. Unfortunately, given the timetable of the Australian research funding cycle a number of these projects have only recently begun. Nevertheless, they may generate outputs of value to the review committee. There are, for example, three FRDC funded projects currently underway:

10.1.1 THE RISK COST CATCH TRADE-OFF.

This work is FRDC project 2012/202, entitled *Operationalising the risk cost catch trade-off*, only started on October 1st 2012 and is due to finish in September 2014. This work will relate directly to the management of all fisheries and assuming the trade-offs can be characterized this work should be especially valuable for the more data-poor species and in making the HSP more internally consistent.

Its objectives are:

1. Extend AtlantisSE to enable the full suite of Commonwealth fishery types (e.g. data poor) to be simulated.
2. Using this modelling platform, define the risk-cost-catch trade-off between target species at different information and Tier levels.
3. In close consultation with managers and industry, develop a set of operational rules and clear quantitative guidelines for assessing the risk-cost-catch trade-off.

10.1.2 THE INFLUENCE OF CLOSURES ON THE HSP

This work is FRDC project 2011/032, entitled: *Incorporating the effects of marine spatial closures in risk assessments and fisheries stock assessments*. This project only started In April 2012 and is due to finish in November 2014. With the recent large increase in the number of spatial closures in the marine environment around Australia this has relevance to all Commonwealth fisheries. There is no doubt that various closures have influences fisher behaviour from the Northern prawn fishery, the SESSF, over to the Northwest Shelf trawl fishery. Exactly what influence that has on our perception of the stock status in each case remains unknown

Its objectives are:

4. Develop criteria and procedures for determining whether current methods for incorporating the effects of marine spatial closures in risk assessments and stock assessments are appropriate for all species.
5. Develop a method for incorporating the effects of marine spatial closures in risk assessments and stock assessments for those species where the current approach is not considered effective.
6. Develop a set of rules for determining TACs or catch limits based on the quantity and quality of data available on the species biology, the characteristics of the closure, and the extent of monitoring inside and outside of the closure.

10.1.3 THE MANAGEMENT OF BYCATCH SPECIES

This work is FRDC project 2011/028, entitled: *Development of robust methods to estimate acceptable levels of incidental catches of different commercial and byproduct species*. This project only formally started on February 1st 2012 and is due to finish on September 30th 2013. The work is of primary interest to both data-poor species and to those highly depleted species which are now subject to bycatch only TACs. The project stems from a series of FRDC funded workshops in 2011 (Haddon, 2012) that considered the problem of how to Analyse Trends in Abundance for Non-Target Species.

Its objectives are:

1. Develop guidelines and tests to determine if incidental catch levels for any species are likely to be unsustainable or contrary to the principles of the Harvest Strategy Policy, with particular reference to species under rebuilding strategies and provide case examples.
2. Conduct risk assessments to determine acceptable levels of incidental catch TACs for species under rebuilding strategies (e.g. School Shark, Blue Warehou and Gemfish as case studies) within the parameters of the Harvest Strategy Policy.
3. Determine whether any of the methods developed under objectives 1 and 2 can apply to relatively data poor species; develop guidelines for application to species for which there is only catch data.
4. Assess the feasibility of extending the methodology above in objective 1 to develop a practical and workable methodology to estimate acceptable capture limits for rare and TEP species.

10.2Research That Would be Useful

10.2.1 MULTI-YEAR TACS

Currently there is a growing use of Multi-Year TACs in those fisheries where they can be implemented. However, this strategy and the various means by which is has been and is being implemented have not been subject to formal management strategy evaluation. There are obvious risks of stock depletion if the multi-year TACs are set too high. Part of the implementation, for example, in the SESSF, is the production of breakout rules to aid deciding whether to break out of the sequence of TACs decided upon at the start of their implementation. While some criteria have been drafted for selecting those species deemed suitable for multi-year TACs these have yet to be tested formally using MSE, and in some cases a lack of resources is putting pressure on the RAG outcomes to maintain TACs in the face of uncertainty.

It is simple to conclude that more simulation testing work needs to be conducted to determine the utility of different criteria for selecting species as suitable for multi-year TACs.

10.2.2 ALTERNATIVE DATA-POOR HARVEST STRATEGIES

For the major mixed fisheries it would be valuable to conduct research to devise or recommend further data poor stock assessment methods of harvest strategies to improve the defensibility of management selected for such fisheries.

11 References

Adams, P.B. (1980) Life history patterns in marine fishes and their consequences for fisheries management. *Fishery Bulletin* **78:** 1–12.

AFMA (2009) Small Pelagic Fishery Harvest Strategy June 2008, revised October 2009. AFMA, Canberra, Australia. 11p.

AFMA (2009a) SESSF Stock Assessment Methods and TAC Setting Process. Version 1.5. September 2009. 8 p.

André, J., Haddon, M., and G. Pecl (2010) Modelling climate-change induced nonlinear thresholds in cephalopod population dynamics. *Global Change Biology* **16**: 2866-2875.

Au, D. W., Smith, S. E., and Show, C. (2008) Shark productivity and reproductive protection, and a comparison with teleosts. In: *Sharks of the Open Ocean,* pp. 298–308. Ed. by M. D. Camhi, E. K. Pikitch, and E. A. Babcock. Blackwell Publishing, Oxford, UK.

Basson and Dowling (2008) Development of a robust suite of stock status indicators for the Southern and Western and the Eastern Tuna and Billfish fisheries. FRDC Project No. 2003/042

Beddington, J.R. and J.G. Cooke (1983) The Potential Yield of Fish Stocks. *FAO Fisheries Technical Paper* **242:** 1-47.

Beddington, J.R., and Kirkwood, G.P.(2005) The estimation of potential yield and stock status using life-history parameters. *Philosophical Transactions of the Royal Society B Biological Sciences* **360(1453):** 163–170. doi:10. 1098/rstb.2004.1582. PMID:15713595.

Beddington, J.R., Agnew, D.J. and C.W. Clark (2007) Current problems in the management of marine fisheries *Science* **316:** 1713:1716

Bentley, N. & Stokes, K. (2009) Contrasting Paradigms for Fisheries Management Decision Making: How Well Do They Serve Data-Poor Fisheries? *Marine and Coastal Fisheries,* **1,** 391-401.

Berkson, J., Barbieri, L., Cadrin, S., Cass-Calay, S.l., Crone, P., Dorn, M., Friess, C., Kobayashi, D., Miller, T.J., Patrick, W.S., Pautzke, S., Ralston, S. and Trianni, M. (2011) Calculating Acceptable Biological Catch for Stocks That Have Reliable Catch Data Only (Only Reliable Catch Stocks – ORCS). NOAA Technical Memorandum NMFS-SEFSC-616, 56p.

Beverton, R.J.H and S.J. Holt (1957) On the dynamics of exploited fish populations. *U.K. Ministry of Agriculture and Fisheries, Fisheries Investigations* (Series 2) **19**: 1 – 533.

Branch T.A. (2009) How do individual transferable quotas affect marine ecosystems? *Fish and Fisheries* **10:**39-57.

Branch T.A., Hilborn R., Haynie A.C., Fay G., Flynn L., Griffiths J., Marshall K.N., Randall, J.K., Scheuerell, J.M., Ward, E.J. and M. Young (2006) Fleet dynamics and fishermen behavior: lessons for fisheries managers. *Canadian Journal of Fisheries and Aquatic Sciences* **63:**1647-1668.

Brooks, E. N., Powers, J. E., and Corte´s, E. 2010. Analytical reference points for age-structured models: application to data-poor fisheries, *ICES Journal of Marine Science,* **67:** 165–175.

Brown CJ, Fulton EA, Hobday AJ, Matear RJ, Possingham HP, Bulman C, Christensen V, Forrest RE, Gehrke PC, Gribble NA et al. (2010) Effects of climate-driven primary production change on marine food webs: implications for fisheries and conservation. *Global Change Biology* **16:**1194-1212.

Butterworth, D.S. and M.O. Bergh (1993) The development of a management procedure for the South African Anchovy resource. P 83-99 *in* Smith, S.J, Hunt, J.J. & D Rivard (eds) Risk Evaluation and Biological Reference Points for Fisheries Management. *Canadian Special Publication of Fisheries and Aquatic Sciences* **120:** 1:442.

Caddy, J.F. and R. Mahon (1995) Reference Points for Fisheries Management *FAO Fisheries Technical Paper* **347** FAO, Rome. 83 p.

Caddy, J.F. and R. McGarvey (1996) Targets or limits for management of fisheries? *North American Journal of Fisheries Management* **16:** 479-487

Cadrin, S.X., Boutillier, J.A., and Idoine, J.S. 2004. A hierarchical approach to determining reference points for Pandalid shrimp. *Canadian Journal of Fisheries and Aquatic Sciences* **61**(8): 1373-1391.

Cadrin, S.X. & Pastoors, M.A. (2008) Precautionary harvest policies and the uncertainty paradox. *Fisheries Research*, **94,** 367-372.

Chu, C. (2009) Thirty years later: the global growth of ITQs and their influence on stock status ion marine fisheries. *Fish and Fisheries* **10:** 217-230.

Clark, W.G. (1993) The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. Pp 233- 246 In *Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations*. Edited by G. Kruse, D.M. Alaska Sea Grant College Program Report No 93-02, University of Alaska Fairbanks. 825p.

Cope, J. M., DeVore, J., Dick, E. J., Ames, K., Budrick, J., Erickson, D. L.,and S. Williams, (2011) An approach to defining species complexes for U.S. west coast groundfishes using vulnerabilities and ecological distributions. *North American Journal of Fisheries Management* **31:** 589–604

Cope, J.M., and Punt, A.E. 2009. Drawing the lines: resolving fishery management units with simple fisheries data. *Canadian Journal of Fisheries and Aquatic Sciences* **66**(8): 1256-1273.

Crowder, L. B., Hazen, E. L., Avissar, N., Bjorkland, R., Latanich, C., and Ogburn, M. B. (2008) The Impacts of Fisheries on Marine Ecosystems and the Transition to Ecosystem-Based Management. *Reviews in Ecology and Evolutionary Systematics* **39:**259–78.

DAFF (2007) Commonwealth Fisheries Harvest Strategy. Policy and Guidelines. Department of Agriculture, Fisheries and Forestry. 55p.

DAFF (2012) Review of the Commonwealth Fisheries Harvest Strategy Policy and Guideline (the Review). Discussion Paper Version 14 – September 2012. Department of Agriculture, Fisheries and Forestry. 34p.

DAFF (2012a) Terms of Reference for the Review of the Commonwealth Fisheries Harvest Strategy Policy. Department of Agriculture, Fisheries and Forestry. 2p.

Day, J. (2009) Modified breakpoints for the Tier 1 harvest control rule. Pp 153-157 *in* Tuck, G.N (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2008. Part 2.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 331p.

Day, J. (2012) School whiting (*Sillago flindersi*) : further exploration of fixed projection catches, potential indicators and alternative harvest strategy analyses. Pp 290-329 *in* Tuck, G.N (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2011. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 377p.

Deroba, J. J., and J. R. Bence. (2008) A review of harvest policies: Understanding relative performance of control rules. *Fisheries Research* **94**: 210-223.
Dichmont, C.M. & Brown, I.W. (2010) A Case Study in Successful Management of a Data-Poor Fishery Using Simple Decision Rules: the Queensland Spanner Crab Fishery. *Marine and Coastal Fisheries,* **2,** 1-13.
Dichmont, C.M., Deng, A., Punt, A.E., Venables, W. & Haddon, M. (2006) Management strategies for short lived species: The case of Australia's Northern Prawn Fishery: 2. Choosing appropriate management strategies using input controls. *Fisheries Research*, **82,** 221-234.
Dichmont, C.M., Smith, A.D.M., Dowling, N.A., Power, D., Smith, A.D.M. & Galeano, D. (*In Press*) Designing information requirements for the management of Commonwealth fisheries (ed. A.F.M. Authority).
Dick, E.J. and MacCall, A.D. (2010) Estimates of sustainable yield for 50 data-poor stocks in the Pacific Coast Groundfish Fishery Management Plan. *NOAA Technical Memorandum* NMFS-SWFSC-460, 208p
Dick, E.J., and MacCall, A.D. (2011) Depletion-based stock reduction Analysis: a catch-based method for determining sustainable yields for data-poor fish stocks. *Fisheries Research* **110(2):** 331–341. doi:10.1016/j.fishres.2011.05.007.
Dorn, M.W. 2002. Advice on West Coast rockfish harvest rates from Bayesian meta-analysis of stock–recruit relationships. *North American Journal of Fisheries Management* **22(1):** 280–300. doi:10.1577/1548-8675(2002) 022 <0280:AOWCRH> 2.0.CO;2.
Dorn, M.W., Berkson, J., Punt, A.E. & Stokes, K. (2011) Assessment Methods for Data-Poor Stocks Report of the Review Panel Meeting. *Assessment Methods for Data-Poor Stocks*, pp. 24. National Marine Fisheries Service, Santa Cruz, California.
Dulvy, N.K., Ellis, J.R., Goodwin, N.B., Grant, A., Reynolds, J.D., Jennings, S., 2004. Methods of assessing extinction risk in marine fishes. *Fish and Fisheries* **5 (3)**: 255–276.
Dulvy, N. K. & Forrest, R. E. (2010). Life histories, population dynamics and extinction risks in chondrichthyans. In Sharks and Their Relatives, Vol. II (Carrier, J. C., Musick, J. A. & Heithaus, M. R, eds), pp. 639–679. Boca Raton, FL: CRC Press.
Dowling, N.A., Dichmont, C.M., Venables, W., Smith, A.D.M., Smith, D.C., Power, D. & Galeano, D. (in press) From low- to high-value fisheries: is it possible to quantify the trade-off between management cost, risk and catch? *Marine Policy*.
Dowling, N., Haddon, M., Smith, D.C., Dichmont, C.M. & Smith, A.D.M. (2011) Harvest Strategies for Data-Poor Fisheries: A Brief Review of the Literature. CSIRO Marine and Atmospheric Research, Hobart. 43p.
Dowling, N. A. and Smith, D. C. 2007. Development of Harvest Strategies for AFMA’s Small Fisheries. Final report for Project 2006/820 to the Australian Fisheries Management Authority, Canberra.
Dowling, N.A., D.C. Smith, I. Knuckey, A.D.M. Smith, P. Domaschenz, H.M. Patterson, and W. Whitelaw. (2008a). Developing harvest strategies for low-value and data-poor fisheries: Case studies from three Australian fisheries. *Fisheries Research* **94:** 380-390.
Dowling, N. A., D. C. Smith, and A. D. M. Smith. (2008b). Finalisation of harvest strategies for AFMA’s small fisheries. Final report for Project 2007/834 to the Australian Fisheries Management Authority, Canberra.
Dowling, N. (2011) Management strategy evaluation testing of the management strategies used with North West slope trawl fisheries. RUSS. CSIRO, Hobart. 87p.

Engers, R.J. Marasco, C. Pautzke, and T.J.I. Quinn. (1993) University of Alaska, Alaska Sea Grant Report 93-02, Fairbanks, Alaska. pp. 233–246.
FAO (1985) *FAO. The First 40 Years.* Food and Agricultural Organization of the United Nations, Rome.
FAO (1995) *Code of Conduct for Responsible Fisheries*. Food and Agricultural Organization of the United Nations, Rome. 41p.
FAO (1996) *Precautionary Approach to Capture Fisheries and Species Introductions*. FAO Technical Guidelines for Responsible Fisheries 2. Food and Agricultural Organization of the United Nations, Rome. 55p.
FAO (1997) *Fisheries Management.* FAO Technical Guidelines for Responsible Fisheries 4. Food and Agricultural Organization of the United Nations, Rome. 84p.
FAO (2001) BAYES-SA, Bayesian stock assessment methods in Fisheries management – User manual. www.FAO.ORG Corporate Document Repository Y1958E.
Fay,G., Little, L.R., Tuck, G.N., Haddon, M. and N. Klaer (2012) Maintaining risk equivalancy among fishery harvest control rules in Southeast Australia. (*In Review)*
Francis, R.I.C.C. (1992) Use of risk analysis to assess fishery management strategies: A case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. *Canadian Journal of Fisheries and Aquatic Science*, **49**: 922-930.
Froese R. 2004. Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries* **5**: 86–91.
Fu, C., Mohn, R. and L.P. Fanning (2001) Why the Atlantic cod (*Gadus marhua*) stock off eastern Nova Scotia has not recovered *Canadian Journal of Fisheries and Aquatic Sciences* **58:** 1613 – 1623
Garstang, W. (1900) The impoverishment of the sea – A critical summary of the experimental and statistical evidence bearing upon the alleged depletion of the trawling grounds. *Journal of Marine Biological Association of the United Kingdom* **6**: 1-69.
Garcia, S.M. (1994) The precautionary principle: its implications in capture fisheries management. *Ocean & Coastal Management* **22**: 99-125.
Goodwin, N.B., Grant, A., Perry, A.L., Dulvy, N.K., Reynolds, J.D. (2006) Life history correlates of density-dependent recruitment in marine fishes. *Canadian Journal of Fisheries and Aquatic Sciences* **63**:494–509.
Graham, M. (1935) Modern theory of exploiting a fishery, an application to North Sea Trawling. *Journal de Conseil International pour l'Exploration de la Mer* **10:** 264-274.
Griffiths, S.P., Kuhnert, P.M., Venables, W.N., and Blaber, S.J. 2007. Estimating abundance of pelagic fishes using gillnet catch data in data-limited fisheries: a Bayesian approach. Canadian Journal of Fisheries and Aquatic Sciences **64**: 1019-1033.
Gulland, J.A. (1965) Estimation of mortality rates. Annex to Arctic Fisheries Working Group Report (meeting in Hamburg, January 1965). International Council for the Exploration of the Sea, Document 3 (mimeo), Copenhagen. (Cited in Megrey, 1989).
Haddon, M. (2007) Fisheries and their management. Pp 515-532. *In Marine Ecology* (eds) S.D. Connell & B.M. Gillanders. Oxford University Press. 630 p.
Haddon, M. (2011) *Management Strategy Evaluation testing of the Management Strategies used with South-Eastern Scallop Fisheries.* Report prepared for DAFF: part of the Reducing Uncertainty in Stock Status project. CSIRO Wealth from Oceans Flagship. 100 p.

Haddon, M. (2012) Using Innovative Techniques to Analyse Trends in the Abundance for Non-Target Species. FRDC TRF 2010/057, Fisheries Research Development Corporation and CSIRO, Hobart. 117p.

Haddon, M. (*ed)* (2012b) *Reducing Uncertainty in Stock Status: Harvest Strategy Testing, Evaluation, and Development. General Discussion and Summary.* CSIRO Marine and Atmospheric Research. 37 p.

Haddon, M., Buxton, C., Gardner, C. and N. Barrett (2003) The effect of introducing MPAs in a commercial fishery: A rock Lobster example. P 428-436. In *Aquatic Protected Areas - What works best and how do we know?* (eds. Beumer, J., Grant, A. and D.C. Smith) Proceedings of the World Congress on Aquatic Protected Areas - Cairns, Australia; August, 2002.

Haddon, M. and N.A. Dowling (2012) Exploring Data-Poor Harvest Strategies Excel Workbook: User Manual. CSIRO, Hobart. 48pp DRAFT.

Haddon, M., Ziegler, P., Lyle, J. & Burch, P. (2005) Using a spatially structured model to assess the Tasmanian fishery for banded morwong (Cheilodactylus spectabilis). *Fisheries Assessment and Management in Data-Limited Situations,* **21,** 737-756.

Harrington, J.J., Semmens, J.M. and M. Haddon (2007) Spatial distribution of commercial dredge fishing effort: application to survey design and the spatial management of a patchily distributed benthic bivalve species *Marine and Freshwater Research* **58**: 756-764.

Harris, G.P., Davies P., Nunez, M., Meyers, G. (1988) Interannual variability in climate and fisheries in Tasmania. *Nature* **333:** 754–757.

Hilborn, R. (2012) The evolution of quantitative marine fisheries management 1985 – 2010 *Natural Resource Modeling* **25:** 122-143.

Hilborn, R., and Stokes, K. 2010. Defining overfished stocks: have we lost the plot? Fisheries (Bethesda, Md.), 35(3): 113–120. doi:10.1577/1548-8446-35.3.113.

Hilborn, R., Stokes, K., Maguire, J-J., Smith, T., Botsford, L.W., Mangel, M., Orensanz, J., Parma, A., Rice, J., Bell, J., Cochrane, K.L., Garcia, S., Hall, S.J., Kirkwood, G.P., Sainsbury, K., Stefansson, G., and C. Walters (2004) When can marine reserves improve fisheries management? *Ocean and Coastal Management* **47:** 197-205

Hilborn, R. and C.J. Walters (1992) *Quantitative Fisheries Stock Assessment: Choice, dynamics and uncertainty*. London: Chapman & Hall.

Hjort, J., Jahn, G. and Ottestad, P. 1933. The optimum catch. *Hvalradets Skrifter* **7**: 92-127.

Hobday, A.J., Lough, J.M. (2011) Projected climate change in Australian marine and freshwater environments. *Marine and Freshwater Research* **62**: 1000-1014.

Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Turnbull, C., Walker, T.I., Wayte, S.E., Webb, H., Williams, A., Wise, B.S. & Zhou, S. (2011) Ecological risk assessment for the effects of fishing. *Fisheries Research,* **108,** 372-384.

Humble, S.R., and de la Mare, W. 2008. An adaptive harvest strategy for data-poor fisheries on sedentary species: Application to the giant red sea cucumber *Parastichopus californicus* fishery in British Columbia. Reconciling Fisheries with Conservation, Vols I and II **49**: 1263-1266.

Hutchings, J.A. and J.D. Reynolds (2004) Marine fish population collapses: Consequences for recovery and extinction risk. *Bioscience* **54:**297-309

Keith, D.M. and J.A. Hutchings (2012) Population dynamics of marine fishes at low abundance. *Canadian Journal of Fisheries and Aquatic Sciences* **69:** 1150-1163.

Kelly, C.J. & Codling, E.A. (2006) 'Cheap and dirty' fisheries science and management in the North Atlantic. *Fisheries Research*, **79,** 233-238.

Klaer, N. (2011) Deepwater flathead (*Neoplatycephalus conatus*) stock assessment based on data up to 2009/10 – development of a preliminary base case. Pp 329-341 *in* Tuck, G.N (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2010. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 374p.

Klaer, N. and D.C. Smith (2012) Determining primary and companion species in a multi-species fishery: implications for TAC setting. *Marine Policy*. **36 (3):**606-612.

Klaer, N. & Wayte, S. (2011) Demersal MSE for trawl fish in the Southern and Eastern Scalefish and Shark Fishery and other likespecies. *Reducing uncertainty in stock status* (eds M. Haddon & J. Larcombe). Department of Agriculture, Fisheries and Forestry.

Klaer, N.L., Wayte, S.E. & Fay, G. (2012) An evaluation of the performance of a harvest strategy that uses an average-length-based assessment method. *Fisheries Research*, **134-136,** 42-51.

Kruse, G.H., Gallucci, V.F., Hay, D.E., Perry, R.I., Peterman R.M., Shirley, T.C. Spencer, P.D., Wilson, B. and Woodby, D. (eds.) 2005b. Fisheries assessments and management in data-limited situations. Alaska Sea Grant College Program, University of Alaska Fairbanks. 958 pp.

Larkin, P.A. (1977) An epitaph for the concept of maximum sustainable yield. *Transactions of the American Fisheries Society* **106**: 1-11.

Link, J.S. (2002) What does ecosystem-based fisheries management mean? *Fisheries* **27:** 18-21

Little, L.R., Wayte, S.E., Tuck, G.N., Smith, A.D.M., Klaer, N., Haddon, M., Punt, A.E., Thomson, R., Day, J. & Fuller, M. (2011) Development and evaluation of a cpue-based harvest control rule for the southern and eastern scalefish and shark fishery of Australia. *ICES Journal of Marine Science*, **68,** 1699-1705.

Ludwig, D., Hilborn, R. and C.J. Walters (1993) Uncertainty, Resource Exploitation, and Conservation: Lessons from History. *Science* **260**: 17 & 36.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. *Canadian Journal of Fisheries and Aquatic Sciences* **51:** 110-122.

Mace, P. M. 2001. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries* **2:** 2–32.

Mace, P.M. and M.P. Sissenwine (1993) How much spawning per recruit is enough? p 101-118 *in* Smith, S.J, Hunt, J.J. & D. Rivard (*eds*) Risk Evaluation and Biological Reference Points for Fisheries Management. *Canadian Special Publication of Fisheries and Aquatic Sciences* **120:** 1-442.

Mangel, M., Brodziak, J., and Dinardo, G. (2010) Reproductive ecology and scientific inference of steepness: a fundamental metric of population dynamics and strategic fisheries management. *Fish and Fisheries.* **11:** 89-104.

Matic-Skoko, S., Staglicic, N., Pallaoro, A., Kraljevic, M., Dulcic, J., Tutman, P., and Dragicevic, B. (2011) Effectiveness of conventional management in Mediterranean type artisanal fisheries. Estuarine, *Coastal and Shelf Science* **91**(2): 314-324.

McGarvey, R., Punt, A.E., and Matthews, J.M. (2005) Assessing the information content of catch-in-numbers: A simulation comparison of catch and effort data sets. *Fisheries Assessment and Management in Data-Limited Situations* **21**: 635-657.

McGilliard, C.R., Hilborn, R., MacCall, A., Punt, A.E., and Field, J.C. (2011) Can information from marine protected areas be used to inform control-rule-based management of small-scale, data-poor stocks? *ICES Journal of Marine Science* **68**(1): 201-211.

Megrey, B.A. (1989) Review and comparison of age-structured stock assessment models from theoretical and applied points of view. *American Fisheries Society Symposium* **6**: 8-48

Ministry of Fisheries (2008) *Harvest Strategy Standard for New Zealand Fisheries*. Ministry of Fisheries, New Zealand Government. 25p.

Ministry of Fisheries. (2008b). Draft operational guidelines for New Zealand's harvest strategy standard. Ministry of Fisheries NZ Report.

Ministry for Primary Industries (2012) Report from the Fisheries Assessment Plenary, May 2012: stock assessments and yield estimates. Part 1: Introductory Sections to Jack Mackerel. Compiled by Ministry for Primary Industries Fisheries Science Group. 410 p.

Musick, J.A. 1999. Criteria to define extinction risk in marine fishes. *Fisheries* **24**: 6-14.

Myers, R.A. 2001. Stock and recruitment: generalizations about maximum reproductive rate, density dependence, and variability using meta-analytic approaches. *ICES Journal of Marine Science* **58**:937-951.

Myers, R.A. and N. Barrowman (1996) Is fish recruitment related to spawner abundance? *Fisheries Bulletin* **94:** 707-724

Myers, R.A., Bowen, K.G. and Barrowman, N.J. 1999. Maximum reproductive rate of fish at low population sizes. *Canadian Journal of Fisheries and Aquatic Sciences* **56:** 2404–2419.

Myers, R.A., Fuller, S.D., and Kehler, D.G., 2000. A fisheries management strategy robust to ignorance: rotational harvest in the presence of indirect fishing mortality. *Canadian Journal of Fisheries and Aquatic Sciences* **57:**2357-2362.

Myers, R.A., Rosenberg, A.A., Mace, P.M., Barrowman, N., and V.R. Restrepo (1994) In search of thresholds for recruitment overfishing. *ICES Journal of Marine Science* **51**: 191-205.

Overholtz, W.J., Edwards, S.F. and J.K.T. Brodziak (1993) Strategies for rebuilsing and harvesting New England groundfish resources. *Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations.* Alaska Sea Grant College Program. AK-SG-93-02. 507-527

Pikitch, E., Boersma, P.D., Boyd, I.L., Conover, D.O., Cury, P., Essington, T., Heppell, S.S., Houde, E.D., Mangel, M., Pauly, D., Plagányi, É., Sainsbury, K., and Steneck, R.S. (2012) *Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs*. Lenfest Ocean Program. Washington, DC. 108 pp.

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAllister, M.K., Pope, J., and K.J. Sainsbury. (2004) Ecosystem based fishery management. Science, 305: 346–347.

Pilling, G.M., Apostolaki, P., Failler, P., Floros, C., Large, P.A., Morales-Nin, B., Reglero, P., Stergiou, K.I. & Tsikliras, A.C. (2008) Assessment and management of data-poor fisheries. *Advances in fisheries science: 50 years on from Beverton and Holt.***,** 280-305.

Pitchford, J.W., Codling, E.A., and Psarra, D. 2007. Uncertainty and sustainability in fisheries and the benefit of marine protected areas. *Ecological Modelling* **207**: 286-292.
Plagányi, É.E., Skewes, T.D., Dowling, N.A. and M. Haddon (2012) Risk management tools for sustainable fisheries management under changing climate: a sea cucumber example. *Climate Change* DOI 10.1007/s10584-012-0596-0.
Prager, M.H., Porch, C.E., Shertzer, K.W., and J.F. Caddy (2003) Targets and limts for management of fisheries: A simple probability-based approach *North American Journal of Fisheries Management* **23:** 349-361
Punt, A.E. 2000. Extinction of marine renewable resources: a demographic analysis. *Population Ecology* **42**: 19.
Punt, A.E., Campbell, R.A., and Smith, A.D.M. (2001) Evaluating empirical indicators and reference points for fisheries management: application to the broadbill swordfish fishery off eastern Australia. *Marine and Freshwater Research* **52**(6): 819-832.
Punt, A.E. and S. Ralston (2007) A management strategy evaluation of rebuilding revision rules for overfished roskfish stocks *Biology, Assessment, and Management of North Pacific Rockfishes. Alaska Sea Grant College Program. AK-SG-07-01:* 329 - 351
Punt, A.E., Smith, D.C. & Smith, A.D.M. (2011) Among-stock comparisons for improving stock assessments of data-poor stocks: the "Robin Hood" approach. *ICES Journal of Marine Science,* **68,** 972-981.
Rademeyer, R.A., Butterworth, D.S. & Plaganyi, E.E. (2008) A history of recent bases for management and the development of a species-combined Operational Management Procedure for the South African hake resource. *African Journal of Marine Science,* **30,** 291-310.
Restrepo, V.R. and J.E. Powers (1999) Precautionary control rules in US fisheries management: specification and performance. *ICES Journal of Marine Science* **56:** 846-852
Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, and J. F. Witzig. (1998) Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson- Stevens Fishery Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-31. U.S. Dept. Commerce, Washington, D.C. 54 p.
Reuter, R.F., Conners, M.E., Dicosimo, J., Gaichas, S., Ormseth, O., and Tenbrink, T.T. (2010) Managing non-target, data-poor species using catch limits: lessons from the Alaskan groundfish fishery. *Fisheries Management and Ecology* **17**(4): 323-335.
Richards, L.J. & Maguire, J.J. (1998) Recent international agreements and the precautionary approach: new directions for fisheries management science. *Canadian Journal of Fisheries and Aquatic Sciences,* **55,** 1545-1552.
Rose, K. A., Cowan, J. H., Winemuller, K. O., Myers, R. A. and Hilborn, R. 2001. Compensatory density-dependence in fish populations: controversy, understanding and prognosis. *Fish and Fisheries* **2:**293-327.
Russell, E.S. (1931) Some theoretical considerations on the ”overfishing” problem. *Journal du Conseil International pour l’Exploration de la Mer* **6**: 3-20.
Rogers, A.D. and D, d’A, Laffoley (2011) *International Earth System Expert Workshop on Ocean Stresses and Impacts*. Summary Report IPSO Oxford.

Sainsbury, K. (2005) Cost-effective management of uncertainty in fisheries. *Outlook 2005*. Australian Bureau of Agricultural and Resource Economics, Canberra, A.C.T.

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

Salas, S., Chuenpagdee, R., Seijo, J.C., and Charles, A. (2007). Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. *Fisheries Research* **87**(1): 5-16.

Sanchirico J. N., Holland D., Quigley K. and M. Fina (2006) Catch-quota balancing in multispecies individual fishing quotas. *Marine Policy* **30:**767-785.

Scandol, J.P. 2003. Use of cumulative sum (CUSUM) control charts of landed catch in the management of fisheries. *Fisheries Research* **64**: 19-36.

Scandol, J. 2005. Use of quality control methods to monitor the status of fish stocks. Fisheries Assessment and Management in Data-Limited Situations **21**: 213-233.

Schaefer, M.B. (1954) Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bulletin of the Inter-American Tropical Tuna Commission* **1:** 25-56.

Schaefer, M.B. (1957) A study of the dynamics of the fishery for Yellowfin tuna in the Eastern Tropical Pacific Ocean. *Bulletin of the Inter-American Tropical Tuna Commission* **2:** 247-285.

Schnute, J.T., and Richards, L.J. 2001. Use and abuse of fishery models. *Canadian Journal of Fisheries and Aquatic Sciences* **58**(1): 10-17.

Serchuk, F.M., Rivard, D., Casey, J. and Mayo, R. 1997. Report of the ad hoc working group of the NAFO Scientific Council on the precautionary approach. NAFO SCS Document 97/12.

Serchuk, F.M., Rivard, D., Casey, J. and Mayo, R. (1999) A conceptual framework for the implementation of the precautionary approach to fisheries management within the Northwest Atlantic Fisheries Organization (NAFO). *Proceedings 5th NMFS NSAW. NOAA Technical Memorandum NMFS-F/SPO-40 17p.*

Sissenwine, M.P. 1978. Is MSY an adequate foundation for optimum yield? *Fisheries* **3:** 22-42.

Shertzer, K.W. and Conn, P.B.. (2012). Spawner recruit relationships of demersal marine fishes: prior distribution of steepness. *Bulletin of Marine Science* **88**: 39–50.

Smith, A.D.M., Brown, C.J., Bulman, C.M., Fulton, E.A., Johnson, P., Kaplan, I.C., Lozano-Montes, H., Mackinson, S., Marzloff, M., Shannon, L.J. and Y.-J. Shin, J. Tam (2011) Impacts of fishing low-trophic level species on marine ecosystems. *Science*, 333: 1147-1150

Smith, A.D.M., Fulton, E.J., Hobday, A.J., Smith, D.C., and P. Shoulder (2007) Scientific tools to support ther practical implementation of ecosystem-based fisheries management. *ICES Journal of Marine Science*, **64:** 633–639

Smith, A.D.M. and A.E. Punt (2001) The gospel of maximum sustainable yield in fisheries management: birth, cruifixion and reincarnation. *Conservation of Exploited Species*. Reynolds, J.D., Mace, G.M., Redford, K.H. and J.G Robinson (*eds*). The Zoological Society of London, Cambridge University Press. 505 p.

Smith, D.C., Punt, A.E., Dowling, N.A., Smith, A.D.M., Tuck, G.N. and I.A. Knuckey (2009) Reconciling approaches to the assessment and management of data-poor species and fisheries with Australia's Harvest Strategy Policy. *Marine and Coastal Fisheries: Dynamics, Management and Ecosystem Science* **1:** 244-254

Smith, A.D.M., Sainsbury, K.J. & Stevens, R.A. (1999) Implementing effective fisheries-management systems - management strategy evaluation and the Australian partnership approach. *ICES Journal of Marine Science,* **56,** 967-979.

Smith, A.D.M., Smith, D.C., Tuck, G.N., Klaer, N., Punt, A.E., Knuckey, I., Prince, J., Morison, A., Kloser, R., Haddon, M., Wayte, S., Day, J., Fay, G., Pribac, F., Fuller, M., Taylor, B., Little., R (2008) Experience in implementing harvest strategies in Australia's south-eastern fisheries. *Fisheries Research* **94:** 373-379.

Smith, S.J., Hunt, J.J., and D. Rivard (1993) Risk Evaluation and Biological Reference Points for Fisheries Management. *Canadian Special Publication of Fisheries and Aquatic Sciences* **120:** 1:442.

Smith, T.D. (1994) *Scaling Fisheries: The science of measuring the effects of fishing, 1855 – 1955.* New York. Cambridge University Press.

Thorston, J.T., Cope, J.M., Branch, T.A. and Jensen, O.P. 2012. Spawning biomass reference points for exploited marine fishes, incorporating taxanomic and body size information. *Canadian Journal of Fisheries and Aquatic Sciences* **69:**1556-1568.

Trenkel, V.M., and Rochet, M.J. 2003. Performance of indicators derived from abundance estimates for detecting the impact of fishing on a fish community. *Canadian Journal of Fisheries and Aquatic Sciences* **60**(1): 67-85.

Tuck, G., Smith, T., Constable, A., He, X., Kuikka, S. and Klaer, N. 2001. Initial evaluation of management strategies for the Macquarie Island toothfish fishery. pp 162-218 *In* 'Ecologically sustainable development of the fishery for Patagonian toothfish (*Dissostichus eleginoides*) around Macquarie Island: population parameters, population assessment and ecological interactions'. X. He, A. Constable, K. Sainsbury and W. de la Mare (eds). Fisheries Research and Development Corporation Report 97/122, Canberra, Australia.

U.S. Department of Commerce (2007) Magnuson-Stevens Fishery Conservation and Management Act. As amended through January 2007. 170p.

Valderrama, D., and Anderson, J.L. 2007. Improving utilization of the Atlantic sea scallop resource: An analysis of rotational management of fishing grounds. *Land Economics* 83(1): 86-103.

Vasconcellos, M. (2003) An analysis of harvest strategies and information needs in the purse seine fishery for the Brazilian sardine. *Fisheries Research,* **59,** 363-378.

Vasconcellos, M., and Cochrane, K. 2005. Overview of world status of data-limited fisheries: Inferences from landings statistics. *Fisheries Assessment and Management in Data-Limited Situations* **21**: 1-20.

Walters, C.J., Christensen, V., Martell, S.J. and J.F. Kitchell. 2005. Possible ecosystem impacts of applying MSY policies from single species assessment. *ICES Journal of Marine Science*. **62:**58-568.

Walters, C.J., Hilborn, R., and V. Christensen (2008) Surplus production dynamics in declining and recovering fish populations *Canadian Journal of Fisheries and Aquatic Sciences* **65:** 2536-2551.

Walters, C.J. and J-J, Maguire (1996) Lessons from stock assessment from the northern cod collapse *Reviews in Fish Biology and Fisheries* **6:** 125-137

Wayte, S.E. (*ed.*) (2009) Evaluation of new harvest strategies for SESSF species. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 137p.

Wayte, S.E. (2013) Management implications of including a climate-induced recruitment shift in the stock assessment for the jackass morwong (*Nemadactylus macropterus*) in south-eastern Australia. *Fisheries Research* http://dx.doi.org/10.1016/j.fishres.2012.07.009, in press.

Welch, D.J., Garrett, R.N., and Gribble, N.A. 2005. Fisheries uncertainty: A tropical Australian data-poor fishery. *Fisheries Assessment and Management in Data-Limited Situations* **21**: 533-552.

Wetzel, R. and Punt, A.E. 2011. Model performance for the determination of appropriate harvest levels in the case of data-poor stocks. Fish. Res., 110, pp. 342–355

Whitten, A.R., Klaer, N.L., Tuck, G.N., and R.W. Day (2013) Accounting for cohort-specific variable growth in fisheries stock assessments: a case study from south-eastern Australia. *Fisheries Research.(In Press)*

Wilcox, C., Dowling, N. and Pascoe, S. 2010. Predicting the impact of hook decrements on the distribution of fishing effort in the ETBF. Report to the Fisheries Research and Development Corporation, Canberra, Australia

Williams, A., Dowdney, J., Smith, A.D.M., Hobday, A.J. and M. Fuller (2011) Evaluating impacts of fishing on benthic habitats: A risk assessment framework applied to Australian fisheries. *Fisheries Research* **112:** 154-167

Wilson, J.R., Prince, J.D. and Lenihan, H.S. 2010. A management strategy for sedentary nearshore species that uses Marine Protected Areas as a reference. *Marine and Coastal Fisheries: Dynamics, Management and Ecosystem Science* **2:**14-27.

Winemiller KO (2005) Life history strategies, population relation, and implications for fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 872–885.

Worm, B., Hilborn, R., Baum, J.K., Branch, T.A., Collie, J.S., Costello, C., Fogarty, M.J., Fulton, E.A., Hutchings, J.A., Jennings, S., Jensen, O.P., Lotze, H.K., Mace, P.M., McClanahan, T.R., Minto, C., Palumbi, S.R., Parma, A.M., Ricard, D., Rosenberg, A.A., Watson, R., and Zeller, D. 2009. Rebuilding Global Fisheries. *Science* 325(5940): 578-585

Zhou, S. and Griffiths, S. (2008) Sustainability assessment for fishing effects (SAFE): a new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl. *Fisheries Research* **91**, 56–68.

Zhou, S., A.D.M. Smith and M. Fuller (2011) Quantitative ecological risk assessment for fishing effects on diverse data-poor non-target species in a multi-sector and multi-gear fishery. *Fisheries Research*, 112: 168-178

Zhou, S., S. Yin, J.T. Thorson, A.D.M. Smith and M. Fuller (2012) Linking fishing mortality reference points to life history traits: an empirical study. *Canadian Journal of Fisheries and Aquatic Sciences* (in press)

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

YOUR CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

FOR FURTHER INFORMATION

Wealth From Oceans Flagship
Malcolm Haddon
t +61 3 6232 5097
e Malcolm.haddon@csiro.au
w www.csiro.au

16 Appendix 4: Economic Issues

Vieira, S. and S. Pascoe (2012) *Technical Reviews for the Commonwealth Harvest Strategy Policy: Economic Issues.* FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, and CSIRO Wealth from Oceans, Brisbane. p53.

Australian Government

Department of Agriculture, Fisheries and Forestry

ABARES

Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: economic issues

Simon Vieira (Australian Bureau of Agricultural and Resource Economics and Sciences)

Sean Pascoe (CSIRO Wealth from Oceans National Research Flagship)

Research by the Australian Bureau of Agricultural and Resource Economics and Sciences and CSIRO

May 2013

FRDC

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

FRDC project no. 2012/225

Cataloguing data
Vieira, S & Pascoe, S, 2013, *Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: Economic issues, ABARES*, Report to client prepared for the Fisheries Research and Development Corporation, Canberra, May.

ISBN 978-1-74323-133-3

Internet
Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: economic issues, is available at: daff.gov.au/abares/publications.

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)
Postal address GPO Box 1563 Canberra ACT 2601
Switchboard +61 2 6272 2010|
Facsimile +61 2 6272 2001
Email info.abares@daff.gov.au
Web daff.gov.au/abares

Acknowledgements
This project was funded by the Fisheries Research and Development Corporation. This report has benefitted from review and constructive criticism of previous drafts by K. Cochrane (Department of Ichthyology and Fisheries Science, Rhodes University), R. Curtotti, M. Harris, P. Morris, I. Stobutzki and P. Ward (ABARES) and members of the Harvest Strategy Policy Review Steering and Advisory Committees.

Contents

Tables

Figures

Boxes

Project details

FRDC project number:	2012/225
Project title:	A technical review of formal fisheries harvest strategies
Principal investigator:	Simon Vieira[a] and Sean Pascoe[b]
Subproject title:	Technical reviews of the Commonwealth Harvest Strategy Policy: economic issues
Principal-investigators' affiliation:	a. Australian Bureau of Agricultural and Resource Economics and Sciences, Department of Agriculture, Fisheries and Forestry b. Commonwealth Scientific and Industrial Research Organisation
Principal-investigators' address:	a. 18 Marcus Clarke Street (GPO Box 1563, Canberra ACT 2601) b. 41 Boggo Road, Dutton Park QLD 4102 (PO Box 2583, Brisbane QLD 4001)
Principal-investigators' telephone:	a. ph. 02 6272 2291 b. ph. 07 3833 5966

Objective

Alternative indicators and approaches to better setting economic target reference points and meeting the economic objective of the *Commonwealth Fisheries Harvest Strategy: policy and guidelines.*

Outcomes achieved to date

The project reviewed the operationalisation of the harvest strategy policy's maximum economic yield objective across Commonwealth fisheries. To do this, a review of the relevant literature was undertaken to provide a detailed description of the challenges that have occurred. The report provides an outline of key economic definitions and concepts, the general experiences and challenges of operationalising maximum economic yield in Commonwealth fisheries. It then draws on the literature to list the potential options that are available to improve the way in which Commonwealth fishery management meets the intent of the policy.

Non-technical summary

The key objective of Australian Commonwealth fisheries management for key commercial species as defined in the *Commonwealth Fisheries Harvest Strategy: policy and guidelines* (referred to as 'the policy' throughout) is that Commonwealth fisheries be managed sustainably and the net economic returns to the Australian community are maximised (DAFF 2007). This is interpreted in the policy as maximum economic yield (MEY), which is the level of catch and fishing effort that maximises sustainable economic profits in the industry over time. To this end, the biomass associated with maximum economic yield (B_{MEY}) is recommended as the target reference point to be used for key commercial species in all Commonwealth fishery harvest strategies.

MEY ensures that all inputs used in fishing are used at their optimal level, including the fishery resource itself. A key component of the economic surplus generated is resource rent, which represents the return generated by the fish stock—a key input into the production process. How much (if any) resource rent is realised by the community directly is a separate issue: the concept of MEY is concerned with maximising its generation.

A key challenge in achieving MEY is determining the actual harvest target itself. MEY is more than just a catch target—it also relates to a stock size and level of fishing effort that enables the catch to be taken. Estimating MEY requires some form of a bioeconomic model, which in turn requires detailed information on the biology of the species, technical interactions between fishing gears and catches (especially in mixed fisheries), cost structures of the fishing fleet and market conditions. In many cases, information on one or more of the required model components is not available, such that bioeconomic modelling is unable to be undertaken.

Recently, there has also been some confusion over what sectors need to be considered when estimating MEY using a bioeconomic model. In particular, a small number of researchers have proposed that downstream businesses such as wholesalers, processors and retailers should be included in the definition, and that the impacts of upstream businesses supplying the fishing industry should also be considered. The effect of their inclusion is higher catch and effort levels in the fishery, but lower industry profits compared to the definition of MEY above. However, the use of greater levels of inputs in fishing beyond what is optimal not only reduces rent generation but also diverts resources from other sectors of the economy where they could be used to greater benefit. Further, empirical analysis has demonstrated that in most cases, improved profitability in fisheries leads to improved economic activity in regional communities (counter to the previous arguments).

While the estimation of MEY has its own set of challenges, implementation of the policy in Commonwealth fisheries has also demonstrated further challenges associated with operationalising MEY as a management target. Some issues have arisen for certain fishery types while other issues have been more general, occurring across fishery types. These issues are summarised here, together with potential options that may assist in resolving them.

General challenges

Detailed biological and economic information is often not readily available to construct bioeconomic models. Proxy measures of the target reference point as recommended in the policy are available for fisheries that possess indicators of stock biomass but do not have access to a bioeconomic model. However, there has been evidence of a general misunderstanding of the circumstances under which a bioeconomic model should be developed instead of using proxy reference points. Further uncertainty has also existed around the circumstances under which alternative proxies (those that differ to the policy's recommendations) should be developed. A broader lack of stakeholder understanding regarding MEY, the information required to target it and the most cost effective approaches to obtaining that information have also been key issues that have affected the operationalisation and stakeholder support of MEY.

These challenges highlight the potential benefits that might eventuate from providing greater practical guidance on best practice approaches to operationalising MEY. Further, a multifaceted approach to improving stakeholder knowledge could also be pursued to improve MEY operationalisation. Potential options include the formation of an economic technical working group to deal with issues around MEY, ensuring the availability of economic advice to fishery managers and resource assessment groups, as well as improving definitions and guidelines in the policy and allowing these to be updated with new information when it becomes available. More generally, research into issues around the estimation and implementation of MEY is ongoing and will provide further guidance on how to operationalise MEY.

Data-poor fisheries

As the policy was developed with a focus on biomass reference points, application of the policy to data-poor stocks has been difficult. As a consequence, economic considerations have received far less attention relative to biological objectives for these stocks. Given that many data-poor fisheries are of low value, the application of any approach in a data-poor environment requires careful consideration of the tradeoffs between the costs, benefits and risks associated with reducing management uncertainty. Greater practical guidance in this regard may be useful.

Application of approaches developed by Zhou et al. (2012) to estimate MEY proxies represents one relevant option to improve MEY management for data-poor fisheries that could be associated with a relatively low cost. This approach provides rules of thumb for determining MEY proxies for single stock fisheries using information that is readily available for low information fisheries.

Further building on current biologically focused data-poor approaches to better incorporate economic information may also be an option. Furthermore, a range of other indicators exist that provide information about the potential excess level of fishing capacity in data-poor fisheries. These do not necessarily equate to either biological or economic reference points, but contribute to an estimation of fishery level performance (rather than individual species reference points). Data envelopment analysis may be a particularly relevant approach here given that it only requires catch and effort data.

Multispecies fisheries

The policy recognises that in multispecies fisheries MEY should be applied to the fishery as a whole and not necessarily to individual species (that is, optimised across all species). Deriving models to identify conditions for MEY in multispecies fisheries in such a way is difficult. While it has been done well in the Northern Prawn Fishery, this required significant time and resources. Furthermore, the fishery's model includes only three species. For other multispecies fisheries such as the Southern and Eastern Scalefish and Shark Fishery, the large number of species and limited biological information are significant constraints.

Research is currently underway that is focused on developing rules of thumb to guide the setting of MEY proxies in the multispecies context and extends the approaches developed in Zhou et al. (2012). Alternative options include the use of aggregated yield functions (where total catch is combined across all species) to determine target fishery effort levels. Approaches focused on fishing capacity measures may also provide similar guidance.

Highly variable stocks

For short-lived, essentially annual species, the optimal harvesting strategy requires that the stock available in a given year be fished down until it is unprofitable, provided that subsequent recruitment and sustainability is not affected. While economic theory assumes that operators in such a fishery will stop harvesting when it is optimal to do so, this is generally not the case. In Australian fisheries, this is partly due to crew and skippers being paid a share of revenue, creating revenue maximising incentives (rather than profit maximising incentives). Furthermore, high levels of profit generated at the start of a fishing season in a highly variable fishery are likely to attract excess capacity and promote a subsequent race to fish, lowering overall net economic returns within a given year.

To improve MEY management in highly variable fisheries, assessment of the levels of excess capacity is an option, although is complicated in such fisheries. Some excess capacity is optimal in 'average' years to allow sufficient capital to take advantage of the high years, although determining this optimal level of excess capacity is problematic. Other approaches focused on ensuring management arrangements provide fishers with efficient incentives may also be useful.

Fisheries with market power

Where fisheries have some degree of market power such that price varies with the quantity landed, the definition of MEY may need to be modified. In such fisheries, maximising industry profit results in lower quantities of fish being made available to consumers at a higher average price, in turn resulting in a net loss of benefits to society. Therefore, maximising net economic returns requires maximising the sum of both producer and consumer surplus. This results in a higher level of catch (and effort) than that which maximises industry profits alone. However, the number of fisheries where a significant degree of market power exists is small. Therefore, the default position that management should take to target MEY for most Commonwealth fisheries is to assume prices are fixed in the short term with respect to catch, as has usually been done.

Internationally shared stocks

The policy does not prescribe arrangements for stocks targeted by domestic fisheries that are managed by international management bodies or arrangements or for stocks managed under a joint authority. Therefore, there has been some uncertainty around what approaches should be taken where the policy has been applied to such fisheries with the intent to achieve MEY. Given that domestic catches are typically influenced by external negotiations, a focus on arrangements that promote cost minimisation is warranted. Also, domestic target reference points may be better expressed in terms of capacity utilisation.

1 Introduction

The *Fisheries Management Act 1991* requires that the management of Commonwealth fisheries pursue five legislated objectives. Summarised, these include ensuring efficient and cost-effective management arrangements, management consistent with ecologically sustainable development principles, accountability, achieving management cost recovery targets and '*maximising net economic returns to the Australian community from the management of Australian fisheries*'.

The *Commonwealth Fisheries Harvest Strategy: policy and guidelines* (referred to here as 'the policy') intends to ensure that Commonwealth fishery harvest decisions are made in a fashion that is consistent with these objectives (DAFF 2007). The policy's overarching objective requires '*the sustainable and profitable utilisation of Australia's Commonwealth fisheries in perpetuity through the implementation of harvest strategies that maintain key commercial stocks at ecologically sustainable levels and within this context, maximise the economic returns to the Australian community*' (DAFF 2007, p. 4). To achieve this, the policy requires that harvest strategies seek to '*maintain fish stocks, on average, at a target biomass point (B_{TARG}) equal to the stock size required to produce maximum economic yield (B_{MEY})*' with a proxy of 1.2 B_{MSY} (biomass at maximum sustainable yield) recommended as the target if B_{MEY} is unknown (DAFF 2007), p. 4). Furthermore, the policy's guidelines identify some key operational issues relating to the targeting of B_{MEY} and provide advice on how these issues should be dealt with.

Despite this, the targeting of maximum economic yield (MEY) in Commonwealth fisheries has faced challenges on multiple fronts. A lack of relevant biological and economic data has been a key issue. There have also been practical implementation challenges stemming from limited knowledge and understandings amongst relevant stakeholders. More specific issues have also arisen on a fishery-by-fishery basis for fisheries that are data-poor, catch multiple species, target highly variable stocks, exhibit a degree of market power (through an ability to influence price) and catch internationally shared stocks. Many Commonwealth fisheries exhibit more than one of these characteristics.

This report reviews relevant literature to provide a detailed description of the challenges to operationalising MEY and, where possible, identify potential approaches to resolving these issues. To do this, key economic definitions and concepts are first outlined. General experiences operationalising MEY in Commonwealth fisheries are then discussed. Finally, issues relevant to particular types of fisheries (e.g. international, mixed species fisheries, highly variable stocks and fisheries with market power) are addressed.

2 Economic definitions and understandings

A key constraint to operationalising MEY has been a lack of stakeholder understanding regarding the concept and its implications for fishery management (AFMA 2011). This partly reflects the novelty of MEY as an objective, a lack of economic training amongst stakeholders and a low level of stakeholder access to relevant technical expertise. While it is beyond the scope of the current review to fill this information gap, its focus warrants some explanation of the concept.

The net economic return objective

A commercial fishery's net economic return is its revenue earned from fishing, less the costs of fishing. This revenue reflects the quantity of fish caught across the fishery multiplied by the average market price received for that catch. Similarly, the costs of fishing reflect the quantities of inputs (e.g. labour, fuel and capital) used in the fishery multiplied by the market prices paid to use or employ those inputs. Costs of fishing also include the costs of management, which are largely recovered from commercial fishers in Commonwealth fisheries. While the definition of a fishery's costs is not always straightforward[1], the concept of net economic return itself is fairly uncomplicated as it ultimately reflects fishery-wide profitability.

The assumed link between a fishery's net economic return and the benefit it generates for a community occurs through the market. Market prices received by the fishery for its output (if supplied to the domestic market) and paid by the fishery for its inputs reflect their value to the community. For example, the market price for fish is determined by the willingness of consumers to pay, in conjunction with the market supply of fish. A consumer's willingness to pay for a good reflects the benefit they expect to derive from consuming it, and they will consume it if their willingness to pay is equal to or higher than the market price. Community benefit that accrues to consumers, known as consumer surplus, is represented by the difference between their willingness to pay and the market price. Similarly, the market price paid for an input is determined by the current supply of that input and its current demand, the latter being a function of the productive benefits that can be generated from that input for the community.

In measuring community benefit, net economic return provides an indication of the level of inputs that should be devoted to fishing. For example, if fishing becomes unprofitable, it indicates that fewer inputs should be devoted to producing catch in the fishery. Furthermore, it suggests that those inputs have a more beneficial (or productive) use for the community if employed in another sector of the economy.

The link between net economic return and community benefit is not always clear-cut. For example, net economic returns in export-focused fisheries partially reflect benefits that accrue to non-domestic consumers. Additionally, net economic returns typically do not capture costs

[1] For example, capital costs include 'capital opportunity cost' and 'capital depreciation costs', costs which are not readily measured on a market. The opportunity cost is the foregone earnings that could have been realised if an input such as capital was put to its next best alternative use. For example, unpaid owner- or family-labour also requires the estimation of a 'labour opportunity cost'. It will reflect the income that could have been earned by the relevant person engaged in that unpaid labour.

associated with the environmental impacts of fishing. Such impacts, therefore, require the use of other indicators to measure overall fishery management performance[2]. While such issues exist, net economic return still provides an accessible and easily understood indicator of community benefit.

Resource rent is a key component of a fishery's net economic return. It reflects the return to the owner of the fishery resource, and represents the value generated by the fish stock as an input into the production process (Coglan & Pascoe 1999). A key reason for pursuing MEY is to maximise the resource rents generated from a fishery. A separate issue relates to what share of the total resource rent generated in a fishery is captured by the community (as opposed to those catching the fish). Resource rent capture in other resource based industries (e.g. mining) is a contentious and highly politicised issue (Ashiabor & Saccasan 2011). The policy and the concept of MEY is instead concerned with the generation rather than allocation of resource rent.

Although net economic return has been defined here in terms of a commercial fishery, the concept also applies to non-commercial use values (e.g. recreational fishing, charter fishing, diving) and non-use values (e.g. the value attached to knowing a fish species exists). The difference is that these values are not revealed in the market. Non-market valuation techniques are available to estimate a net economic return equivalent but are often associated with limitations (Vieira et al. 2009). The use of these measures in allocating fisheries resources between commercial, recreational and conservation sectors has had little practical application, as the measures themselves are generally poorly understood by non-economists and in many cases are mistrusted (Bateman et al. 2000). However, examples exist that demonstrate how these techniques could be applied for fishery resource allocation purposes (Berman et al. 1997)

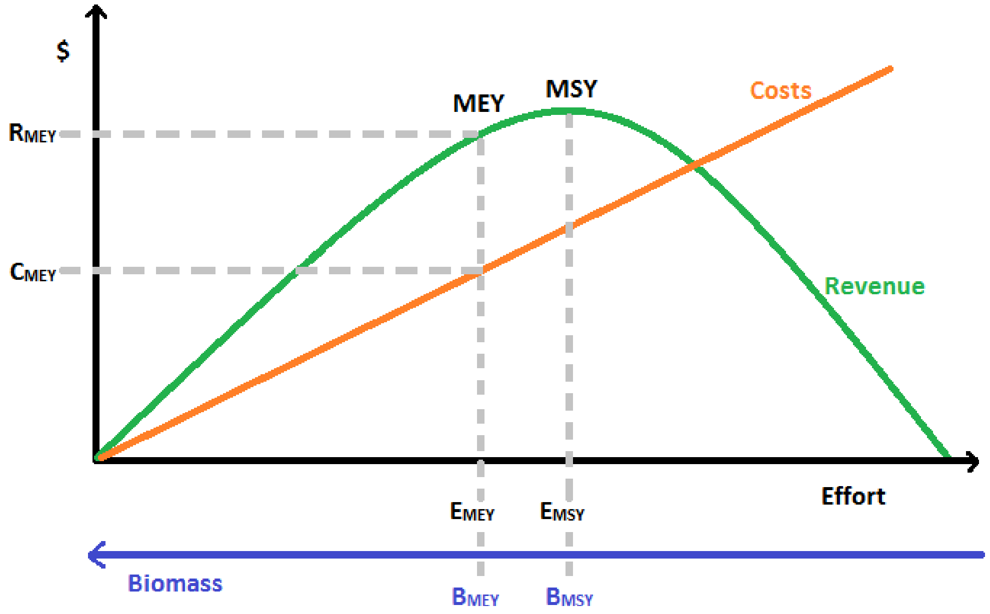
Maximum economic yield

For a commercial fishery, net economic returns are maximised at MEY, a point associated with a conjointly occurring level of sustainable catch, fishing effort and stock biomass (Box 1). The concept was introduced by Gordon (1954) and Scott (1955). Clark (1973) and Clark and Munro (1975) made significant contributions to developing the concept further.

Achieving MEY involves a trade-off between higher revenues (through higher catches) and lower harvesting costs (through lower effort and more abundant stocks, which allows fish to be caught more easily, reducing the unit cost of capture). The latter ‘stock effect’ is the fundamental reason that MEY is associated with a more conservative (higher) level of biomass relative to maximum sustainable yield (MSY) (Grafton et al. 2007). In being more conservative, MEY is also advantageous in that it ensures that stocks will be more resilient to negative environmental shocks. Similarly, higher profitability at MEY means that industry will be more resilient to negative changes in economic conditions. The MEY concept is presented in Box 1.

[2] These costs can be directly incorporated into an economic analysis through the use of non-market values. However, these are generally costly to estimate. A range of multicriteria approaches also exists that allows economic performance to be combined with ecological and social performance (see Dichmont et al. [2013] for a recent example for Queensland fisheries).

Box 1 Demonstrating maximum economic yield using a simple static, single period, single species model



The horizontal axis measures fishing effort (e.g. trawl hours) while the vertical axis measures the dollar value shown on both the revenue and cost curves. Increases in effort are shown as movements along the horizontal axis and are associated with declines in fishery stock biomass.

The revenue curve shows the relationship between biomass, effort and revenue for a fishery. Every point along the revenue curve represents a revenue amount that is associated with a biologically sustainable catch. It is a function of the stock's stock–recruitment relationship, the fishery's harvest function (how catches vary with effort) and the price received for catch (which is assumed here to be constant). As effort increases, the level of sustainable revenue that is earned increases up until a point where lower stock levels start to constrain catches and, therefore, revenue. This turning point occurs at the maximum sustainable yield (MSY). Here the largest total revenue is generated but not the largest possible net economic return.

The total cost curve shows the relationship between costs and different levels of effort and biomass. Costs increase with increasing effort (as more inputs are employed in the fishery) and with lower biomass levels (as fish become more difficult to catch). Maximum economic yield (MEY) occurs at the level of effort (E_{MEY}) and biomass (B_{MEY}) where net economic returns—the difference between total revenue and total cost—are maximised. This occurs with revenue R_{MEY} and total cost C_{MEY}.

The reader is referred to Kompas and Gooday (2005) and Kompas et al. (2011) for a more detailed non-technical description.

The setting of a fishery's harvest levels is equivalent to an investment decision about how many fish should be conserved to contribute to future stocks and catches (Clark & Munro 1975). The expected values of future revenues and costs from fishing need to be considered in this context by accounting for the fact that a dollar earned today will typically be valued more than a dollar earned in the future (this is not considered in Box 1). This is because a dollar earned today is immediately available to generate further economic returns.

The discounting of revenues and costs addresses these issues and involves multiplying the expected value of future revenues and costs by a discount rate that converts all future values into present dollar terms. This dynamic treatment of MEY has implications for the optimal MEY as well as the path that should be taken to this optimal point and is synonymous with maximising the flow of the present value of economic profits over time. It generally results in a higher level of catch and effort and a lower level of biomass than the static MEY levels. The divergence between the static and dynamic MEY levels depends on the discount rate used—the lower the discount rate, the closer the two MEY points. Kompas et al. (2011) provide more detail on these topics.

The concept of economic efficiency measures a fishery's net economic value compared to its potential (Gooday 2004). While managing a fishery at MEY means that 'fishery-level efficiency' is being achieved (the appropriate level of inputs are employed, such that there is not excess capacity), achieving full economic efficiency also requires 'vessel-level efficiency' (vessels harvest in a profit maximising manner) and 'management efficiency' (required management services are provided at least cost) (Kompas et al. 2011). It is often assumed that vessel-level efficiency will be achieved through vessel operators making profit maximising decisions, however, this may not always be the case. For example, revenue based share payments to skippers and crew can provide revenue maximising incentives (McConnell & Price 2006). The fishery management instrument used in a fishery can also distort the incentives of vessel operators (Gooday 2004). However, it should be noted that having a MEY management target will have economic benefits no matter what management instrument is applied.

A related concept is optimal fishing capacity. For a fishery, capacity utilisation (CU) measures the ratio of a fishery's actual catch to its potential catch given the set of fixed assets (e.g. vessels and the given stock size). CU scores range from zero to one, with CU < 1 indicating the existence of excess capacity. That is, the same catch could have been taken with a smaller fleet. Capacity underutilisation is an indicator of less than optimal economic performance—a fleet that is fully utilised will be more economically efficient than one with substantial underutilisation. The exception to this is in the case of highly variable stocks where some level of excess capacity is economically efficient to ensure that good years are captured. Target levels of CU can provide a short term measure of economic performance, but do not necessarily infer sustainability or a long run optimal catch level.[3]

Recently, there has been some debate about the concept of MEY. One area of debate has focused on whether B_{MEY} will always be greater than B_{MSY} for a single stock fishery (Clark et al. 2010a, 2010b; Grafton et al. 2012; Grafton et al. 2010). The two key influencing factors are the growth rate of the fish stock and the discount rate that is applied to future revenues and costs—a slow growth rate and a high discount rate will move B_{MEY} closer to B_{MSY}, and, in the view of Clark et al. (2010a), potentially beyond B_{MSY}. While this debate has interesting theoretical implications, the practical implications are that fishery managers should apply recommended MEY catch and effort settings cautiously for slow growing species to ensure stock sustainability.

[3] Excess capacity is essentially a short-run indicator and needs to be assessed in the context of current management or environmental conditions. For example, reduced quotas to allow stock recovery may result in excess capacity in the short term, but as stocks increase, capacity utilisation is likely to also increase. In contrast, overcapacity represents a longer term measure, and reflects fleet capacity relative to the management objective(s). Assessing overcapacity, however, requires the use of bioeconomic models.

There has also been confusion over what sectors need to be included in MEY calculations, with Christensen (2009) and Wang and Wang (2012) arguing that downstream businesses such as wholesalers, processors and retailers should be included. Doing so results in fishery catch and effort levels that are higher than traditional MEY levels. Not only would such an approach reduce rent generation, as noted by Kompas et al. (2011 pg 11) it would imply the use of

> …more vessels, days at sea, gear, crew, bait and all of the other inputs used in fishing – resources that could be used instead in alternative employment. This is what economists mean by efficiency for the economy as a whole. If too many resources are being expended in fishing, too little are being used elsewhere.

Norman-Lopez and Pascoe's (2011) contribution to this debate involved an analysis of the net economic effects of achieving MEY for several Australian fisheries. They showed that although losses occur across sectors in the short term with a move to MEY, a net economic benefit to society results in the long term.

3 General challenges to operationalising maximum economic yield

What the literature tells us

The estimation of MEY requires the use of a bioeconomic model that summarises the biological characteristics of a fish stock together with the economic characteristics of the fishery that harvests it. These models are typically designed to derive the optimal biomass, catch and effort levels that achieve MEY. Many bioeconomic models presented in the literature focus on the economic optimal in a theoretical context, but empirical applications to existing fisheries also exist. Applications have covered a wide range of issues and scenarios including mixed target species fisheries (Bertignac et al. 2000; Bjørndal et al. 2012; Placenti et al. 1992; Punt et al. 2011), achieving ecosystem-based objectives (Fulton et al. 2007; Kasperski & Wieland 2010; Ryan et al. 2010) and low-information fisheries (Chae & Pascoe 2005; Resosudarmo 1995).

Most Commonwealth fisheries have no bioeconomic models, while those that do exist are old and unlikely to reflect the current biological understanding, consider current technologies or reflect current economic conditions (Table 1). The Northern Prawn Fishery (NPF) is the only case where a bioeconomic model has become a formal part of the management process (Dichmont et al. 2010; Punt et al. 2011). Experiences there suggest that developing bioeconomic models to feed into management decision processes has its own set of challenges. For example, the acceptance of a model by industry and managers will be greatly influenced by data quality (and quantity) (Dichmont et al. 2010).

Table 1 Most recent bioeconomic models for Commonwealth fisheries

Commonwealth fishery	2009–10 GVP ($'000)	Most recent bioeconomic model	Reference
Northern Prawn	88 828	2011	(Punt et al. 2011)
Torres Strait	11 617	2012 (lobster) 1993 (prawns)	(Plagányi et al. 2012) (Reid et al. 1993)
SESS Commonwealth Trawl Sector	56 720	2006 (5 species only)	(Kompas & Che 2006)
SESS Commonwealth Gillnet and Hook sectors	24 550	2006 (shark and ling)	(Kompas & Che 2006)
SESS Commonwealth GAB Trawl Sector	8 977a	2012 (deepwater flathead and bight redfish)	(Kompas et al. 2012)
Eastern Tuna and Billfish—longline and minor line	30 140	None	
Southern Bluefin Tuna	38 095	1991	(Kennedy & Pasternak 1991)
Western Tuna and Billfish	1 656b	None	
Bass Strait Scallop	6 400	None	
Southern Squid Jig	93	None	
Other fisheries	60 295	None	

Note: GVP = gross value of production. a 2008–09 GVP estimate because 2009–10 data is confidential. b 2007–08 GVP estimate because 2009–10 confidential.

Source: (ABARES 2011)

More recently, management strategy evaluation (MSE) approaches have also been used to inform management strategies against a MEY objective. The MSE approach is a framework that models a fishery's various characteristics (biological, management, monitoring, economic) taking into account various sources of uncertainty. This enables potential approaches to management to be tested against pre-specified objectives (Holland 2010). In doing so, management strategies can be developed that are robust to uncertainty but also allows informed and desired trade-offs between management objectives (Rademeyer et al. 2007).

Examples of MSEs that incorporate economic factors exist for fisheries in Australia (Dichmont et al. 2008; Plagányi et al. 2012), the European Union (Bjørndal et al. 2004; Christensen 1997); New Zealand (Holland et al. 2005) and Antarctica (Hoshino et al. 2010). These have looked at the influence of management strategies on fishery profitability, fleet structure, fisher behaviour, employment and activity in other support sectors (such as the processing sector). More generally, MSEs provide the opportunity to assess performance against economic management objectives together with other relevant management objectives.

For Commonwealth fisheries, bioeconomic models and MSEs incorporating bioeconomics are currently the only two approaches that have been applied to determine harvest levels consistent with targeting MEY. The majority of recent economic research on Commonwealth fisheries to date has provided a retrospective view of fishery performance including economic surveys (George et al. 2012), analysis of historical drivers of profit (Skirtun & Vieira 2012), historical productivity (Perks et al. 2011) and efficiency (Kompas et al. 2004; New 2012; Pascoe et al. 2012). However, such approaches don't provide advice on management settings to achieve MEY.

Defeo and Seijo (1999) demonstrate a potential approach to estimating fishing mortality at MEY (F_{MEY}). It uses yield-mortality models to generate a biological production curve that incorporates both natural and fishing related mortality for the entire fish stock. Incorporation of average revenue and cost parameters allows the generation of an estimate of F_{MEY}. The authors note advantages of using such an approach over catch-effort surplus production model approaches typically used in bioeconomic models, including improved certainty given that each component can be measured with some certainty relative to effort, which can be difficult to standardise. Although the method still requires estimates of virgin biomass, natural and total mortality by age class and revenue and cost parameters, it represents an alternative approach that is relatively less data intensive that could be explored.

The alternative to estimating MEY reference points is to use proxies as recommended in the harvest strategy policy. Recent analysis presented by Zhou et al. (2012) attempts to provide rules of thumb for low-information fisheries regarding the selection of MEY proxies based on a fishery's characteristics . This work represents a significant step towards improving the reliability of proxies for MEY for all fisheries more generally. Indeed, the work suggests that the proxies currently recommended in the policy could be improved (for more details, refer to Section 5 on 'Data-poor stocks').

Current guidelines and assumptions

While the policy recommends MEY as a harvest strategy target, there is little advice in the policy's guidelines on how the target should be estimated and implemented. It points out that bioeconomic optimisation models are used to estimate MEY and provides a very general discussion of how MEY has been targeted in the NPF. It also provides the estimated B_{MEY} for a small number of Commonwealth stocks. The only other advice offered is that targeting MEY should occur over the medium term (3–5 years) based on expectations around the variability of factors that influence MEY. It is also noted that the cost of using a bioeconomic model may exceed the benefit of having an estimated MEY target, particularly if reliable proxies are available (DAFF 2007).

What the issues have been

A review of Australian Fisheries Management Authority's (AFMA's) arrangements for obtaining scientific and economic information highlights some of the key issues regarding the operationalisation of MEY (AFMA 2011). An overall finding was that research processes had not evolved with the fisheries management environment and, in particular, the novel focus on MEY. The key issues were a general lack of stakeholder understanding regarding MEY, the information required to target it and the most cost effective approaches to obtaining that information. There was also evidence of a general misunderstanding of the circumstances under which a bioeconomic model should be developed instead of using proxy reference points. Further uncertainty also existed around the circumstances under which alternative proxies (those that differ to policy recommendations) should be developed.

A more focused synopsis of the challenges that arise when targeting MEY is provided by Dichmont et al. (2010) who drew on experiences in the NPF. Their discussion focuses on six key challenges:

- **Specifying the model**—Dichmont et al. (2010) note that modelling MEY is complicated by the many factors that affect it. They point out that a key factor that is often not well captured is fleet dynamics, particularly in terms of fleet responses to regulatory change and, for multispecies fisheries, targeting behaviour changes.

- **Defining the boundaries**—MEY optimises economic returns to the fishery and excludes sectors linked to the fishery such as the processing sector. If MEY is achieved over time with reductions in a fishery's catch, it also reduces economic activity in these downstream sectors. *Although the result of* such action is that '*resources previously consumed in fishing are freed up to be used more productively in other sectors*' (Dichmont et al. 2010), doing so can be politically difficult.

- **The best model outcome may not always be practical**—bioeconomic models can produce a result that '*although potentially optimal in the "model world" is generally unacceptable in real life*' (Dichmont et al. 2010 pg. 17) as they may not capture factors relevant to the interests of industry or the community. This implies that careful design of the model is required, to include relevant constraints to account for these factors and/or careful interpretation of its outputs.

- **The need for accurate economic data**—economic parameters (such as output and input prices) will be a key determinant of MEY results but are highly variable and can create high levels of uncertainty regarding optimal harvest paths. Additionally, once economic cost data are obtained costs need to be appropriately incorporated into the model. Decisions such as how to separate fixed and variable costs are not necessarily straightforward. These data issues mean that regular revision of MEY results and management advice may be required.

- **A good target is not enough**—changes in things such as fisher behaviour, cost structure, stock biology and the regulatory environment will mean that the MEY path and target will need to be re-estimated regularly to allow optimal performance to be approximated.

- **Implementation in a co-management arena**—targeting of MEY in the NPF has been challenging, given the poor understanding of the concept possessed by most stakeholders. The relative variability of economic parameters and, therefore, MEY has also had negative implications for industry support of MEY. The authors note that 'Education of stakeholders about the reason for using MEY as a management target is critical, as is sharing of knowledge and experiences in modelling MEY' (Dichmont et al. 2010), p. 20).

Overall, the authors state that approaches to developing bioeconomic models and to targeting MEY have been ad hoc given the lack of information that exists on applying MEY in practice. They point out the importance of using an adaptive management framework and 'that operationalising MEY is not simply a matter of estimating the numbers but requires strong industry commitment and involvement' (Dichmont et al. 2010 pg. 1), which requires a balanced combination of education and consultation.

The experiences in the NPF outlined by Dichmont et al. (2010) have presented many challenges. As a result, it has taken many years to develop the current NPF bioeconomic model and approach. Similarly, the development of relationships and trust with key stakeholders to garner their cooperation and support has also taken substantial time. This trust has benefited not only the implementation of MEY, but also access to the economic data required to pursue it. The NPF is also the most valuable single-method Commonwealth fishery (ABARES 2011). So while it provides a good example of how MEY can be targeted, the approach used by this fishery may be beyond the financial capability of most Commonwealth fisheries. For most other Commonwealth fisheries, MEY will need to be pursued at lower cost and, therefore, with greater uncertainty.

In the Southern and Eastern Scalefish and Shark Fishery (SESSF), MEY has been estimated for selected stocks targeted in the Commonwealth Trawl Sector and Gillnet, Hook and Trap Sector (Kompas et al. 2011). However, as the bioeconomic model used stock models that were developed in isolation of the fishery's accepted stock assessment models, the MEY targets were not applied. This demonstrates a point noted by Larkin et al. (2011): MEY is more likely to be achieved when economic information is incorporated into stock assessment models for fish stocks during their initial development.

Since the introduction of the harvest strategy policy, the Great Australian Bight Trawl Sector (GABTS) of the SESSF is the only Commonwealth sector that has developed a bioeconomic model to determine total allowable catches (TACs) for its key target species—deepwater flathead and bight redfish (Kompas et al. 2012). The bioeconomic model was integrated with the accepted stock assessment models for both species. Estimation of the model involved close collaboration with scientists and industry to obtain relevant data. The authors noted that the model would benefit from further work to capture supply dependent market price sensitivities, a major influence on the expected revenue and, therefore, profit associated with different catch levels. This obviously has implications for the final MEY estimates of the model.

For the remaining SESSF species, proxy target reference points for MEY have been applied as recommended by the policy. While this should be considered an appropriate approach for stocks where bioeconomic models are not available (given the approach's low cost), the policy's recommended proxy of 0.48 B_0 (i.e. 48 per cent of unfished biomass) or 1.2 B_{MSY} has generally been applied across the board, irrespective of a stock's biological and economic characteristics (with the exception of tiger flathead as explained below). There are likely to be some cases where informed adjustment of the target proxy according to a stock's characteristics may lead to improved performance against the MEY objective.

Alternative options and approaches

Setting targets

It is expected that knowledge and experience in operationalising MEY will grow with the estimation of MEY for more Commonwealth stocks and ongoing research on alternative approaches to targeting MEY. As knowledge increases, it is likely that better informed decisions around the selection of appropriate MEY proxies will be possible. Communicating research results to RAGs, management advisory committees (MACs) and AFMA will be a priority. The updating of the policy's guidelines with new research findings may also assist with targeting MEY. If proxies can be set more reliably, the relative benefits of using a bioeconomic model to accurately estimate MEY are likely to be reduced.

Where the development of a bioeconomic model is being considered, there has to be acknowledgement that the model (like any stock assessment model) is going to be updated and improved as techniques and data availability improves. Communication of this to stakeholders is essential to manage expectations around what can be delivered in the first instance.

For low-value fisheries, the application of proxies will continue to be the only feasible option for targeting MEY. While the policy allows for the recommended B_{MEY} proxy of $0.48B_0$ to be altered to better achieve a stock's MEY given its characteristics, this has rarely been done. One example where it has been done is for tiger flathead in the SESSF. Shelf Resource Assessment Group (RAG) members incorporated some assumed economic parameters (e.g. prices received for catch and per unit effort costs based on ABARES survey results) into the stock assessment to provide an estimate of likely profitability under different biomass ratios relative to B_{MSY} (Galeano D. 2011, pers comm.). The RAG was then able to select the biomass ratio that was expected to be associated with the highest fishery profitability, an outcome that is consistent with the economic intent of the policy. Guidance on the appropriate setting of proxies provided by recent work on data-poor fisheries (Zhou et al. 2013) and current work on mixed-species fisheries may also better allow such adjustment of proxies in the future (refer to Sections 4 and 5 for more information).

While biologically focused MSEs have been applied in Commonwealth fisheries such as the Bass Strait Central Zone Scallop Fishery (Haddon 2011) and the Small Pelagic Fishery (Giannini et al. 2010), the addition of economic parameters to the MSEs could have provided information about the relative profitability of different management strategies. The advantages of undertaking bioeconomic assessments in tandem with MSEs and stock assessments in terms of reduced research costs and accessing data can be significant (Larkin et al. 2011).

Data

Options also exist to more easily obtain relevant economic data to support targeting of MEY. Aggregated annual price information for fishery species is often readily available from ABARES. More detailed monthly export price data can also be used to augment information on catch prices for export focused fisheries. The greater challenge is obtaining boat cost information, which is generally confidential. ABARES surveys key Commonwealth fisheries (Table 2) and provides estimates of boat-level costs. Given that the ABARES surveys rely on finalised profit and loss statements, there is a delay in getting this information. However, these surveys can still provide detailed information on fishery revenues and costs at relatively low cost.

The NPF industry undertakes its own economic survey to update its bioeconomic model due to lags between ABARES' surveys and the timing of the annual stock assessment process, illustrating the advantages of obtaining industry buy-in for targeting MEY. This requires a high amount of industry support and trust; the strong engagement of the NPF industry in the management process has assisted in the implementation of MEY in that fishery.

Where survey information is not available, approaches outlined in Zhou et al. (2012) to estimate fishery level costs based on easily observed fishery characteristics (such as fishing method, vessel size and days fished) may also provide an option (refer to section on data-poor stocks for more detail).

Table 2 Commonwealth fisheries recently surveyed by the Australian Bureau of Agricultural and Resource Economics and Sciences

Fishery	2005–06	2006–07	2008–09	2009–10	2010–11
Bass Strait Central Zone Scallop Fishery				✓	✓
Northern Prawn Fishery	✓	✓	✓	✓	
Commonwealth Trawl Sector of SESSF	✓	✓	✓	✓	✓
Gillnet Hook and Trap Sector of SESSF	✓	✓	✓	✓	✓
Torres Strait Prawn Fishery	✓	✓			
Eastern Tuna and Billfish Fishery	✓	✓	✓	✓	✓

SESSF = Southern and Eastern Scalefish and Shark Fishery

Processes

Dichmont el al. (2010) suggest that the approach taken to implementing MEY in Commonwealth fisheries to date has been ad hoc. This suggests that there may be benefits to providing greater practical guidance on best practice; in particular, around the circumstances under which an MEY target should be estimated and how it should be developed. This could be in the form of a checklist or set of principles that, if used appropriately, could assist in addressing issues created by the low input of economic expertise into RAG processes and allow for a more cost-effective approach to implementing MEY.

AFMA's framework for delivering cost-effective research (AFMA 2008) also provides a broader overarching framework that can be drawn upon to make decisions on what research activities should be pursued at the fishery level to meet the MEY objective. A key element of the framework is the recognition that management decisions need to be made in the face of some level of uncertainty and there needs to be some consideration of risk. This framework is structured around four key questions, three of which are most relevant here, and include:

1) What decisions will AFMA need to make about a fishery?

2) What options are available to AFMA to ensure that the risks of not achieving objectives are within 'acceptable' levels?

3) Is purchasing research the most cost effective option to make a management decision?

Regarding the MEY objective, the answer to the first question is that AFMA needs to make harvest-level decisions that meet the MEY objective. For the second question, the options currently are, in order of decreasing certainty and decreasing research cost:

- develop a bioeconomic model of the stock or fishery to estimate an MEY target
- use additional information to adjust the policy's recommended proxies for MEY
- adopt the policy's recommended proxies.

Each option involves trade-offs between the risks of not achieving the MEY objective (associated with lost economic returns) and research costs. The process of selecting an option should also be undertaken on the basis of substantial industry consultation. As has already been suggested, the last two low-cost options will potentially become more reliable and beneficial with time as more research is undertaken to estimate MEY for a wider variety of fishery types and scenarios.

The third question provides the impetus to compare the costs and benefits of the options to pursue MEY with the intention of ensuring that the option likely to deliver the greatest net benefit is selected. The costs of pursuing alternative options will involve both up-front costs and ongoing costs. The up-front costs for the investment in a bioeconomic model to estimate MEY are likely to be relatively high. Ongoing costs include two components. The first component relates to the cost of monitoring performance and updating the target, which would once again be higher with a bioeconomic model. However, the second ongoing cost is the cost associated with not achieving MEY and the losses in net economic returns that result. The latter costs would be expected to be higher where options that exhibit higher uncertainty (such as proxies) are implemented to target MEY.

It should be noted that RAGs and MACs have found the framework outlined in AFMA (2008) difficult to apply in practice at the fishery level and investment decisions on acquiring economic and scientific information have remained inconsistent (AFMA 2011).

Stakeholder knowledge

Improving stakeholder understanding of MEY should be a focus that occurs on two fronts. First, in terms of providing a better understanding of the MEY concept and what it is trying to achieve. A greater understanding amongst stakeholders will provide for a more engaged debate and discussion around how to achieve MEY. The second front is in terms of understanding what managing to MEY means in a practical sense for fishery management decision making.

Achieving this increased understanding is a key issue and a multifaceted approach is likely needed. Some potential options include:

- **The formation of an economic technical working group**—as recommended by the *Review of AFMA's arrangements for obtaining and using scientific and economic information and advice* (AFMA 2011) this group would focus on identifying where bioeconomic models would be cost-effective; establishing processes to ensure cost-effective collection of relevant economic data; considering the use of proxies for B_{MEY} and determining the required information to do this; and considering which RAGs require economic expertise. While this recommendation from the review had broad support, it has not yet been implemented.

- **Ensuring availability of economic expertise and advice**—in the absence of a technical working group, efforts to ensure economists are available to provide input to the RAG processes may improve decision making with reference to the MEY target. Economists with an adequate understanding of MEY as a concept and an ability to communicate effectively with all stakeholders (particularly those with a non-economist background) offer the greatest opportunity for providing input to RAG processes. For the actual estimation of MEY, this additionally requires a more technical level of expertise. Similarly, there may be benefits associated with providing fishery managers with relevant economic training. These requirements, together with the small pool of fishery economists within Australia, mean that this is not necessarily a straightforward outcome to achieve.

- **Improving definitions, explanations and guidelines in the policy**—while definitions are already provided in the policy's guidelines, the lack of understanding amongst stakeholders suggests that there may be merit in revisiting these. More broadly, there may be benefits to having the guidelines updated more regularly as new research is completed to inform the policy, such as work on datapoor fisheries and mixed species fisheries.

Given the short amount of time in which MEY has been an explicit management target, understandings regarding some of the specific issues that occur on a fishery by fishery basis are also relatively poor. The remaining sections of this paper consider some of these issues and what the potential options may be for dealing with them.

4 Data-poor species

What the literature tells us

There is recognition that improved decision support methods and tools are needed for the general management of data-poor fisheries (Defeo & Seijo 1999; Dowling et al. 2008; Johannes 1998; Kelly & Codling 2006). While the literature provides some examples of such approaches for data-poor fisheries, the majority have a biological focus, with few covering economic factors and, more specifically, MEY management.

Zhou et al. (2012) provide one of the few examples of research with a focus on MEY reference points for data-poor fisheries. Their research developed a rule-of-thumb–based approach to determining MEY proxy reference points based on easily observed fishery characteristics. The MEY reference points are presented in terms of a ratio to a known equivalent (effort- or biomass-based) MSY reference point (e.g. $B_{MEY} = 1.2B_{MSY}$). This work builds on additional work presented by the authors focused on determining biological reference points (including B_0, MSY, B_{MSY} and F_{MSY}) for data-poor stocks.

The approach developed to derive MEY proxy ratios involved two stages. For the first stage, a relationship between MSY and MEY reference points was estimated using a simulation method. Key fishery bioeconomic parameters were allowed to vary randomly across simulations within some assumed acceptable ranges. The relevant parameters were:

- intrinsic growth rate
- catchability
- carrying capacity
- costs
- output price
- discount rate.

Out of a total of 10,000 simulations, 5897 had parameter value combinations that were deemed to be realistic and acceptable. The optimal MEY-MSY ratio (in terms of both effort and biomass) was then estimated for the combination of parameter values that occurred in each accepted simulation. Regression analysis was then used to quantify the relationship between the estimated MEY-MSY ratios and the parameter values that occurred across all simulations.

The estimated relationship demonstrated that the cost share of revenue (defined as the cost per unit catch divided by the price) served as the most important and influential parameter on the optimal MEY proxy ratio. This result is presented by the authors in terms of a decision tree that guides how the MEY proxy ratio should be set using information about a fishery's cost share. The derived decision trees for the optimal MEY proxy ratio in terms of biomass and effort are summarised in Table 3.

Given the importance of fishery cost share, the second stage of the analysis focused on approaches to estimating a fishery's cost share given that such information is typically not readily available for data-poor fisheries. Vessel level cost data from 16 Australian fisheries were used to quantify relationships between key costs (variable costs, repairs and maintenance, fixed costs, capital costs) and easily observed fishery characteristics (e.g. approximate vessel size, fishing method, days fished and management instrument). The estimated relationships then provided a means to estimating a fishery's cost share based on these easily observed characteristics also using a decision tree. Vessel length, fishery type and the price received for landed fish were shown to be the major influences on cost shares. In summary, with knowledge of key variables for a particular fishery, a fleet's likely cost share can be estimated, followed by its likely optimal biomass (B_{MEY} to B_{MSY}) or effort (E_{MEY} to E_{MSY}) ratio as is shown in Table 4.

Table 3 Summary of regression tree results showing the likely optimal maximum economic yield ratios in terms of biomass (B_{MEY}/B_{MSY}) and effort (E_{MEY}/E_{MSY}) for different fishery cost shares. For example, if a fishery's cost share of revenue is greater than 45 per cent and less than 55 per cent, the ratio of B_{MEY} to B_{MSY} would be 1.23 and the ratio of E_{MEY} and E_{MSY} would be 0.77.

Cost share	Optimal B_{MEY}/B_{MSY} ratio	Optimal E_{MEY}/E_{MSY} ratio
< 0.25	1.05	0.95
> 0.25, < 0.35	1.12	0.88
> 0.35, < 0.45	1.17	0.83
> 0.45, < 0.55	1.23	0.77
> 0.55, < 0.65	1.28	0.72
> 0.65, < 0.75	1.33	0.67
> 0.75, < 0.85	1.38	0.62
> 0.85	1.45	0.55

Note: the above decision tree results were derived using a 5 per cent discount rate. However, various discount rates were tested by Zhou et al. (2012).

Source: (Zhou et al. 2012)

Table 4 Summary of regression tree results for cost share and the determination of E_{MEY}/E_{MSY} ratio

Main fishing gear	Vessel length class	Average first sale price of fish landed ($)	Estimated cost share of revenue at MSY	Cost share class	E_{MEY}/E_{MSY} at 5% discount rate
Longline	< 13.5 m	Any	0.85	> 0.85	0.55
Active gear	> 13.5 m	< 15.5	0.86	> 0.85	0.55
Active gear	> 13.5 m	> 15.5	0.77	> 0.75, < 0.85	0.62
Active gear	< 13.5 m	> 10.5	0.66	> 0.65, < 0.75	0.67
Active gear	< 13.5 m	< 10.5	0.72	> 0.65, < 0.75	0.67
Other static gear	> 20.5 m	Any	0.73	> 0.65, < 0.75	0.67
Other static gear	[13.5–20.5 m]	Any	0.56	> 0.55, < 0.65	0.72
Dive	< 13.5 m	Any	0.48	> 0.45, < 0.55	0.77

Source: (Zhou et al. 2012)

The approach was tested on two fisheries for which MEY had previously been estimated. Application to the NPF gave a proxy B_{MEY}/B_{MSY} ratio of 1.38 (across all species). This compared to bioeconomic model based estimates for the fishery's three key species of 1.15, 1.255 and 1.38 (Punt et al. 2011), which the authors concluded was consistent for one species and not substantially greater for the other two. Application to the Commonwealth Trawl Sector (CTS) also derived a ratio of 1.38 that compared to previously estimated ratios ranging from 1.06 (flathead) to 1.53 (orange roughy) and an average ratio of 1.26 across species (Kompas & Che

2006), representing an overestimate for some stocks and an underestimate for others. However, given that the approach was developed for single-stock fisheries, such divergences are expected as both fisheries catch multiple species (and for the CTS, using multiple gears). The overfished status of some of these stocks may have also contributed.

More generally, the distribution of optimal ratios for the likely range of fishery parameter values suggests that the harvest strategy policy's recommended proxy values for B_{MEY} may more appropriately be 1.3–1.4 B_{MSY} as opposed to the currently recommended 1.2 B_{MSY}. This higher 1.3-1.4 B_{MSY} ratio is expected to be more relevant to the 'average' stock type. The authors also suggest that optimal effort levels are most likely to fall between 55 per cent and 65 per cent of MSY effort (Zhou et al. 2012).[4]

Where reliable proxies cannot be derived, harvest control rule evaluation using MSE can be useful in testing the likely effectiveness of data-poor harvest strategies (Smith et al. 2009). Most MSE applications to Australian fisheries have not explicitly included economic factors. However, Plagányi et al.'s (2012) application of MSE to the Torres Strait Rock Lobster Fishery provides an example where economic objectives were incorporated. This evaluation tested a range of management scenarios against biological, economic, cultural and social objectives. In terms of economic factors, the MSE evaluated the likely impact of different quota management arrangements on processing sector activity, employment, fleet structure, efficiency and profitability. While some data collection was undertaken, significant assumptions about key economic parameters were still required and tested. The analysis provides a good example of how the trade-offs between economic profitability objectives (such as MEY) and other biological, social and cultural objectives can be quantified and presented in an economic data-poor setting.

While data-poor fishery management against economic objectives is not well covered in the literature, experiences meeting biological objectives are; these can provide guidance on how to better meet economic objectives. Dowling et al. (2008) worked with Commonwealth fishery managers and stakeholders to develop harvest strategies that would apply in data-poor contexts. The authors identified four broad principles that should be followed for the pragmatic development and implementation of harvest strategies in data-poor fisheries. These include:

- developing sets of triggers with conservative response levels, with progressively higher data and analysis requirements at higher response levels
- identifying data gathering protocols and subsequent simple analyses to better assess the fishery
- archiving biological data for possible future analysis
- using spatial management, either as the main aspect of the harvest strategy or to augment other measures.

The authors provide no discussion of the link between these principles and economic objectives. While examples of trigger-based approaches that implicitly consider economic factors do exist, these don't explicitly include economic analysis. Examples include the data-poor Spanner Crab

[4] More recent preliminary analyses focusing on multispecies measures have found that both economic and biological information is an important determinant of B_{MEY}/B_{MSY} ratios. Optimal ratios within multispecies fisheries ranged from 0.5 for species with a small revenue share (of total revenue), slow growth and high catchability; to 1.7 for species with higher revenue shares, moderate growth rates and low catchability.

Fishery in Queensland, Australia (Dichmont & Brown 2010; O'Neill et al. 2010), and the banana prawn component of the NPF.

Kelly and Codling (2006) propose the use of simple empirical indicators as an approach for informing harvest strategy rules in North Atlantic fisheries that have unreliable data. Drawing on the field of process management and work by Scandol (2003, 2004) who used a similar approach for fisheries in New South Wales, Australia, the suggested approach uses direct empirical measures of stocks status to simply track whether 'things are getting worse', or are 'out of control'. They note that the approach would not replace traditional stock assessments, but 'would allow a rationalisation of the cost of the current system while fulfilling the requirement for stock monitoring and advice provision', particularly for data-poor fisheries. Similar principles might potentially be applicable to economic objectives for low value data-poor stocks.

Bentley and Stokes (2009a, 2009b) call for a shift of focus for data-poor fisheries from assessment to procedural based approaches, drawing on experiences in New Zealand. Furthermore, they recommend generic management procedures that depend on easily observed characteristics of a fishery, including biological, economic and social attributes. The authors demonstrate the potential benefits of monitoring even in low-value fisheries and show, in principle, the gains that can be made through the use of management procedures that include adaptive monitoring.

Current guidelines and assumptions

The harvest strategy policy's guidelines state that '[i]*n cases where* B_{MEY} *is unknown, a proxy of* $1.2B_{MSY}$ *(or a level 20 per cent higher than a given proxy for* B_{MSY}*) is to be used*' (DAFF 2007), p. 22). Furthermore, in cases where B_{MSY} is unknown, the policy's guidelines suggest a proxy for B_{MSY} be 40 per cent of adult virgin biomass (B_0). Applying the B_{MEY} proxy to the latter B_{MSY} proxy results in a target of 48 per cent of B_0. The guidelines also state that '*AFMA may approve the use of an alternative proxy for* B_{MEY}' and, further, that '*alternative approaches to setting proxies for reference levels will need to be formulated and applied using the available information*' (DAFF 2007), p. 36). Despite this, there have been few cases where alternative proxies have been developed.

More generally, a tiered approach to control rules that caters for different levels of stock uncertainty is recommended. Furthermore, where economic data are minimal, it is recommended that decision rules may need to be empirical and involve monitoring of fishery profitability, productivity indices, or profit decompositions or through analysis of other indicators such as latent effort and analysis of sale and lease prices of fishing rights (DAFF 2007).

What the issues have been

As noted by Dowling et al. (2008), the policy was developed with a focus on biomass, which has made applying the policy to data-poor stocks difficult. Where harvest strategies have been developed for data-poor stocks, their design has focused on biological requirements (i.e. to prevent overfishing) (Smith et al. 2009). The low gross value of production (GVP) of many data-poor stocks means that such an approach is likely to be consistent with the intent of the policy, but is dependent on the degree to which including an economic objective and measures to meet it impose additional research and management costs on the fishery.

The SESSF harvest strategy uses tiers for different levels of uncertainty. It is one of the few fisheries that attempts to target MEY for relatively data-poor species, currently assessed under Tiers 3 and 4 (AFMA 2009). Tier 3 applies to stocks for which catch, age composition and basic biological parameters are available to generate catch-curves. These allow current fishing mortality (F_{CUR}) to be compared to limit (F_{20}) and target (F_{48}) reference levels. Tier 4 applies where only catch and effort data are available. Statistically standardised catch rates are compared to target and limit catch rates, which are assumed to correspond to B_{MEY} and B_{LIM}, respectively. However, the setting of the target catch rate is quite subjective, being the average catch rate that occurred in a reference period when the species was considered to be fully fished, catch rates were relatively stable and the fishery was considered profitable and sustainable.

For both Tier 3 and Tier 4, the link between their respective target reference points and fishery profitability has not been explored. For the majority of Tier 3 and 4 species that exhibit a low value, a high uncertainty, low cost approach is justified. However, some lower tier species are associated with high GVP such as blue-eye trevalla, which has accounted for up to $5.0 million or 5 per cent of SESSF GVP (2006–07). If such species cannot be assessed at a higher tier, improving the reliability of the reference points used in these lower tiers may be beneficial.

Overall, while the approaches taken to managing data-poor Commonwealth fisheries since the implementation of the policy have been arguably pragmatic in meeting sustainability requirements in some cases (Dowling et al. 2008), the development of data-poor harvest strategies have typically been unsuccessful in addressing the MEY objective. This partly reflects a lack of understanding on how this objective can be met under these settings.

Alternative options and approaches

Given that many data-poor fisheries are low value, the application of any approach in a data-poor environment requires careful consideration of the trade-offs between the costs, benefits and risks associated with reducing management uncertainty. Practical guidance on the appropriate level of research investment for data-poor stocks and what constitutes meeting the MEY objective for such stocks may also be warranted.

Application of the approaches used in Zhou et al. (2012) to develop MEY proxies represents one relevant option that could be associated with a relatively low cost. Further development of the approach may improve its reliability and usability. A second related project that is currently underway aims to develop the approach to estimate MEY proxies for stocks in multispecies fisheries, making the approach more relevant to Commonwealth fisheries, which are typically multispecies.

Building on current data-poor approaches such as the SESSF Tier 3 and Tier 4 assessment approaches to better incorporate economic factors may also be an option. In the case of Tier 3 species, the approach used by Defeo and Seijo (1999) (discussed here on page 10) has similar data requirements and may offer an alternative approach to developing harvest controls for these species that moves beyond simply using the recommended policy proxies.

A range of other indicators exist that provide information about the potential excess level of capacity in fisheries when bioeconomic models are not available. These do not necessarily equate to either biological or economic reference points, but contribute to an estimation of fishery level performance (rather than individual species reference points). The use of data envelopment analysis (DEA) to estimate capacity utilisation and the level of excess capacity has been used to assess fishery performance in a wide range of fisheries (Dupont et al. 2002; Färe et al. 2000; Hoff & Frost 2007; Lindebo et al. 2007; Pascoe et al. 2003; Pascoe & Tingley 2006;

Tingley & Pascoe 2005; Tingley et al. 2003; Tsitsika et al. 2008; Vestergaard et al. 2003). An advantage of DEA approaches is that they can be used when only catch and effort data are available (e.g. Tingley et al. 2003), but 'better' estimates can be derived including prices (e.g. Lindebo et al. 2007) and costs (e.g. Pascoe & Tingley 2006).

5 Mixed species

What the literature tells us

The additional complexity in determining MEY in fisheries characterised by technical interactions (i.e. the same gear catches several species simultaneously) has been long established in the fisheries economic literature (e.g. Anderson 1975; Clark 1976; Silvert & Smith 1977).[5] This is further complicated when different fisheries (in terms of gear types) are spatially overlayed, catching different combinations of the same sets of species. In such a case, deriving estimates of MEY requires taking into account the impacts of one fishery on the other, as well as the effects of a given level of effort on the sustainable yields of all species caught (Anderson 1975). A result of this is that each species' biomass at fishery MEY will be less than or equal to its individual B_{MEY} level if each was caught independent of the others (Duarte 1992).

This is illustrated for a four-species fishery in Figure 1. The upper panel shows a fishery's revenue earned from four individual species and its total costs for different effort levels. The lower panel depicts total revenue (summed across the four species), total costs and total profit. For each effort level, each species will be associated with a given biomass level (with effort and biomass being inversely related). The level of fishing effort that maximises total sustainable fishery profits is around six units (shown by the dark green vertical line). At this level of effort, each species is associated with a given biomass that achieves fishery-wide MEY (denoted B_{FMEY}). For example, species 1 is fished beyond its MSY such that its $B_{FMEY} < B_{MSY}$ on a 'single species' basis, species 2 is close to its B_{MSY} (such that $B_{FMEY} \approx B_{MSY}$), and B_{FMEY} for species 3 and 4 are below B_{MSY} and close to what may be considered their single species B_{MEY}. In this example, profits are also maximised at a level close to maximum sustainable revenue, although this is not always the case.

Deriving general analytical models to identify conditions for MEY in multispecies fisheries has been described as a formidable, if not impossible task (Chaudhuri 1986; Silvert & Smith 1977). Most attempts to estimate MEY in multispecies fisheries have been empirically based, using bioeconomic models to estimate MEY across the set of species in the catch (e.g. Holland & Maguire 2003; Placenti et al. 1992; Sandberg et al. 1998; Ward 1994). In Australia, multispecies bioeconomic models have been developed for several fisheries and used to provide management advice and estimates of fishery-level MEY (e.g. Kompas & Che 2006; Kompas et al. 2009; Punt et al. 2011; Punt et al. 2002).

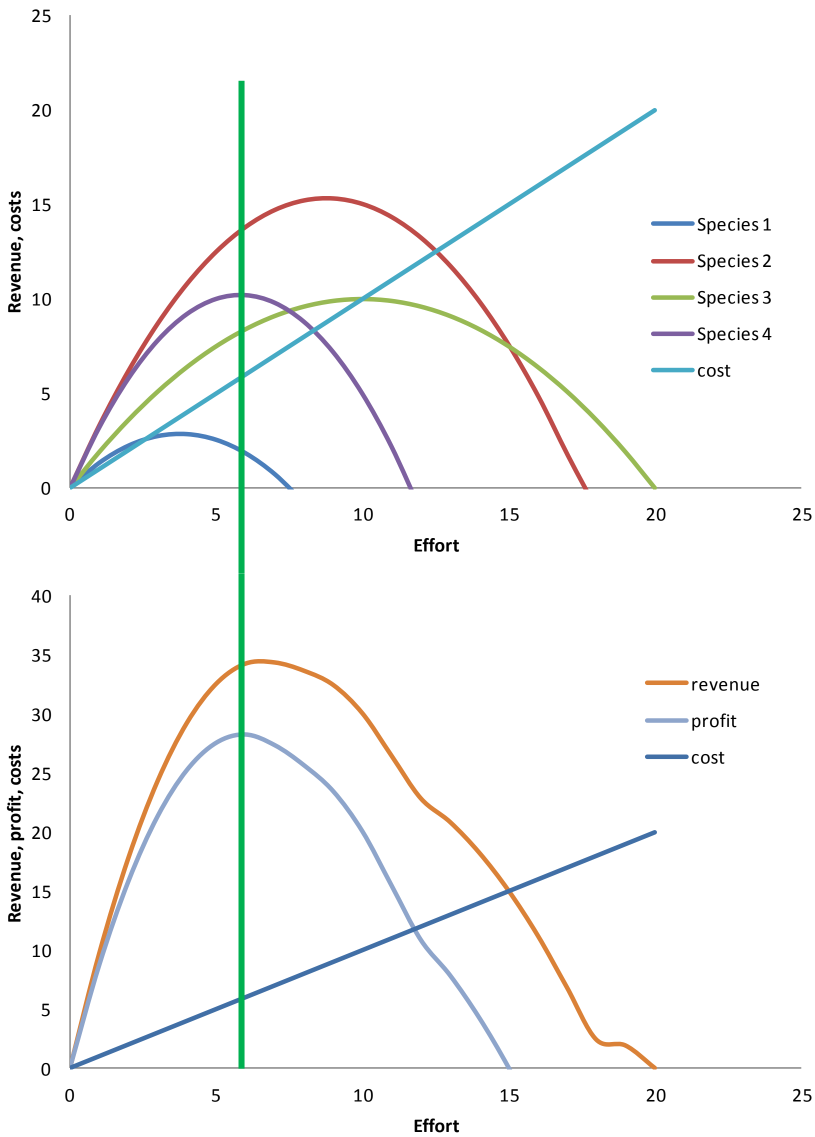
The development of bioeconomic models requires considerable biological information on each individual species, which is often unavailable. In some data poor fisheries where only catch and effort data are available (plus some indicative economic variables), aggregated yield functions have been used. That is, total catch of all species is modelled as a function of total effort. These have been deployed largely in developing countries (e.g. Lorenzen et al. 2006) but have also been used in more developed countries where fisheries are based on a large number of species,

---

[5] This section will focus on species that have technical interactions rather than biological interactions. That is, the species are caught together as either 'target' and 'byproduct' species, or as a mixed-bag of species with no specific target. Numerous other studies exist looking at fisheries with biological interactions e.g. predator–prey interactions. These contain similar challenges in determining MEY, although most models assume that the species can be separately targeted (e.g. Anderson 1975; May et al. 1979; Silvert & Smith 1977).

each contributing a relatively small proportion to revenue (e.g. Chae & Pascoe 2005; Jin et al. 2012).

Figure 1 Example of multispecies definition of MEY based on four individual species caught together based on concepts presented in Anderson (1975) and Clark (1976). The upper figure illustrates the individual sustainable revenue curves (i.e. sustainable yield times price) for a given level of fishing effort. In the lower figure, the fishery total revenue curve is derived by the vertical summation of the individual species revenue curves shown in the upper figure. Total profits are derived from total revenue less total costs at each level of effort.



True joint production in fisheries—where species are caught in fixed proportions—is relatively rare. The relatively small numbers of studies that have empirically tested for joint production in fisheries have found that the ability to target some individual species may be limited, but not impossible. Most fisheries are characterised by a mix of both substitution relationships (where fishers can target and substitute between species) and complementarity relationships (where catches are taken in combination under joint production) (Pascoe et al. 2007; Pascoe et al. 2010; Squires 1987). Studies of fisher behaviour also suggest that apparent targeting behaviour (or lack of) may be an artefact of the management schemes, and changing management may change this relationship as fishers respond to the new incentives created (Christensen & Raakaer 2006). In such cases, changes in catch composition can be achieved through either gear change or spatial fishing pattern changes.

Several empirical models have addressed the spatial component of mixed fisheries through modelling the fishery at the 'metier' level (Pascoe & Mardle 2001; Pelletier et al. 2009; Ulrich et al. 2002). Metiers are defined as a fishing activity that is defined spatially (i.e. a given location), using a given gear and catching a given combination of species. The models estimate catches, costs and profits based on effort allocation across these different metiers, capturing both multigear interactions as well as mixed species (technical interactions).

Current guidelines and assumptions

The harvest strategy policy's guidelines (DAFF 2007) recognise that MEY applies to the fishery as a whole (i.e. optimised across all species) and not necessarily to individual species, and that secondary (lower valued) species may be fished at levels that result in biomass levels lower than their own individual B_{MEY}.

The guidelines stress, however, that all species should be maintained above their limit reference point (generally taken as 20 per cent of the unfished biomass). The guidelines also stress that consideration should also be given to:

- demonstrating that economic modelling and other advice supports such actions
- confirming that no cost-effective alternative management option is available (i.e. gear modifications or spatial management) that can more effectively separate the species
- ensuring the associated ecosystem risks have been considered in full.

What the issues have been

Estimating MEY in multispecies fisheries in Australia has been complex. The work in the NPF is the culmination of over 30 years of bioeconomic analysis involving mostly Commonwealth Scientific Industrial Research Organisation (CSIRO) and ABARES.[6] The most recent versions of the model (Punt et al. 2011) represent a substantial investment by scientists, managers and industry (Dichmont et al. 2010), but is based on only three species.

In contrast, modelling work in the SESSF has been less successful due to the large number of species in the fishery, and the number of different gears that catch these species in differing combinations. An analysis of catch combinations in the fishery (Klaer & Smith 2012) suggests that a substantial proportion of most quota species in the SESSF are caught as byproduct when targeting other species. Further, nearly all species are caught to varying degrees with all other species (Klaer & Smith 2012). This in itself is not an issue, as other bioeconomic models with similar levels of technical interaction have been developed and successfully deployed (Pascoe & Mardle 2001; Pelletier et al. 2009; Ulrich et al. 2002). In these models, however, key biological parameters were available for almost all of the species, with the residual species included as fixed proportions in order to determine the full fishery revenue.

[6] The first bioeconomic modelling analysis in the fishery was undertaken by Clark and Kirkwood (1979).

In the case of the SESSF (e.g. Kompas & Che 2006), the reverse is the situation—with only a relatively small proportion of the key species having appropriate biological parameters available for bioeconomic analysis. This limits the usefulness of the model as a management tool, especially in relation to estimating target reference points. However, the cost of determining appropriate biological parameters for all species in the fishery is likely to be prohibitive.

Developing appropriate bioeconomic models to allow multispecies estimates of MEY is complex, but a more fundamental problem is the general lack of bioeconomic models for most Commonwealth fisheries (multispecies or otherwise). With the exception of the NPF, activity in developing bioeconomic models has been sporadic and usually linked to particular research projects than undertaken as ongoing investments in fisheries management.

Alternative options and approaches

A Fisheries Research and Development Corporation (FRDC) project (FRDC 2011/200) is underway, with a focus on MEY proxies for species (particularly secondary, non-target species) in multispecies fisheries. As reported by Zhou et al. (2012) (a previous FRDC project, 2010/044), which had a single species focus, the aim of the project is to develop rules of thumb to guide the modification of the currently applied 'B_{MEY}=1.2 B_{MSY}' proxy, but in the multispecies context. The general results from the multispecies project are likely to be available in mid-2013, but preliminary results suggest that the additional complexity of multispecies fisheries makes deriving robust rules of thumb substantially more complicated than for single species fisheries.

An alternative option is to consider the use of aggregated yield functions (where catch across species is aggregated) in cases where only total catch and effort information is available. While these are less than ideal at identifying target reference points at the species level, they may be beneficial in identifying target effort levels for the fishery as a whole. Applications elsewhere have found that the estimate of effort at fishery level MEY is less sensitive to assumptions about the combined yield function than catch-based target reference points (Chae & Pascoe 2005).

Abandoning the use of MEY as a target reference point would not resolve these issues. Biological reference points such as MSY result in similar problems. While MSY may be easier to determine, it would still result in a set of incompatible reference points, resulting in discarding, biological overexploitation of some species as well as levels of fishing effort that result in lower net economic returns. Further, if individual species MSY were considered acceptable in the absence of credible multispecies bioeconomic models, then individual species MEY estimates could be readily derived using data-poor methods. These would have the same consequences as the individual species MSY in terms of being incompatible, although the loss in economic returns may not be as great. In any case, achieving MSY or single species–based MEY reference points at an individual level in a multispecies fishery will not be possible for all species, so management would be destined to fail.

A range of other indicators exist that provide information about the potential excess level of capacity in multispecies fisheries (Pascoe 2007). The use of DEA to measure capacity utilisation has already been discussed for data-poor fisheries. These approaches do not necessarily equate to either biological or economic reference points, but contribute to an estimation of fishery level performance (rather than individual species reference points). Target levels of CU could be introduced as a proxy measure of short term economic performance for multispecies fisheries, but do not necessarily infer sustainability or a long run optimal level of output (see footnote 3).

6 Highly variable stocks

What the literature tells us

Highly variable stocks are referred to here as those stocks that exhibit substantial variation in biomass between years and for which the relationship between biomass in the current period and biomass in the next period is relatively weak. Most of the fisheries economic literature regarding such stocks is concerned more with the choice of management instrument rather than the appropriate level of harvest. Several authors have compared the use of taxes versus catch quotas (Androkovich & Stollery 1991; Hannesson & Kennedy 2005; Weitzman 2002), input controls versus catch quotas (Kompas et al. 2008; Yamazaki et al. 2009), or constant versus variable escapement targets (Clark & Kirkwood 1986; Reed 1979).

Relatively few studies have addressed the issue directly regarding optimal catch levels given variable stocks. Clark and Kirkwood (1986) found that a constant low catch may result in loss of benefits when recruitment was high without necessarily preventing stock collapse when recruitment was low. As a result, higher catch rates were optimal even though these also involved a higher risk of stock collapse. In this regard, information on recruitment was important, such as stock surveys. Without such information, a risk averse strategy would result in lower catch rates and lower benefits to the industry (Clark & Kirkwood 1986). Other studies have included stochastic variation in stock levels to estimate optimal catch and effort levels given stock uncertainty (e.g. Kugarajh et al. 2006; Pascoe & Mardle 2001).

An alternative to setting target reference points with highly variable stocks was to determine viable sets of catch or effort levels that were considered acceptable given this uncertainty. Models using the viability analysis approach are relatively limited in fisheries (Béné et al. 2001; Doyen et al. 2012; Eisenack et al. 2006), and are based on achieving a given level of economic performance and not necessarily maximising economic performance.

Of more importance in the Australian fisheries context are not just variable stocks, but highly variable stocks of short-lived species such as prawns, squid, scallops and small pelagics. Recruitment in these fisheries is often environmentally driven, and the ability to forecast recruitment is limited. Studies elsewhere have focused on estimating fixed capacity/effort levels that maximise the net present value over time given highly variable stocks from year to year (e.g. Maravelias et al. 2010). Other studies suggest an adaptive management approach is more appropriate, with in-season updating and pre-season surveys being critical components (Hoshino et al. 2012). Simulations within a management strategy evaluation framework suggest that in-season updating of a catch target provides greater benefits than a fixed effort target with a trigger mechanism to stop fishing if necessary, with both having the same potential downside risks (i.e. in terms of percentage of years that a loss would be made and the magnitude of any losses) (Hoshino et al. 2012).

For short-lived, essentially annual species, fishery production is essentially a 'fish down' operation. That is, provided that subsequent recruitment is not affected (i.e. spawning has taken place or a minimum level of escapement has been allowed for), the optimal strategy is to fish down the available stock until it is no longer economically viable to continue fishing. The criterion for maximising economic profits in such a case is to harvest until marginal revenue (the revenue earned from an additional unit of effort) is equal to marginal cost (the cost of the additional unit of effort). This is illustrated in Figure 2 for an annual fishery in both a good and poor year. Marginal revenue declines with effort as the available stock is fished down and the criterion is met at around 12 units of effort (blue vertical line) in the good year and 5 units (red vertical line) in the poor year. This equates to the levels that maximise economic profits in each year.

In such a case, MEY should be achieved without the need for additional intervention. In theory, fishers should have no incentive to continue fishing beyond the point where marginal revenue equals marginal cost, as to do so would result in the additional cost exceeding the value of their additional catch.[7] In such a case, management needs only to focus on ensuring that subsequent years' recruitment is not jeopardised by ensuring sufficient escapement of spawners.

In practice, however, high levels of economic profit generated in the start of the year are likely to attract additional resources into the fishery, with a subsequent race to fish. This is likely to result in considerable excess capacity. The effect of these additional fixed costs in the fishery is to lower the level of profits, although the point at which these profits are optimised is the same (Figure 3). A mechanism to rationalise excess capacity in the fishery is consequently still required if economic returns are to be maximised.

[7] In practice this is not always the case as will be discussed later.

Figure 2 Maximum economic yield (MEY) for a short-lived species. Total fishery profits are optimised with marginal revenue per unit of effort equal to cost per unit of effort. As catch rates decline over the year, there is a natural 'stopping' point that is essentially equivalent to MEY. This point adjusts with stock abundance automatically correcting for good or bad years.

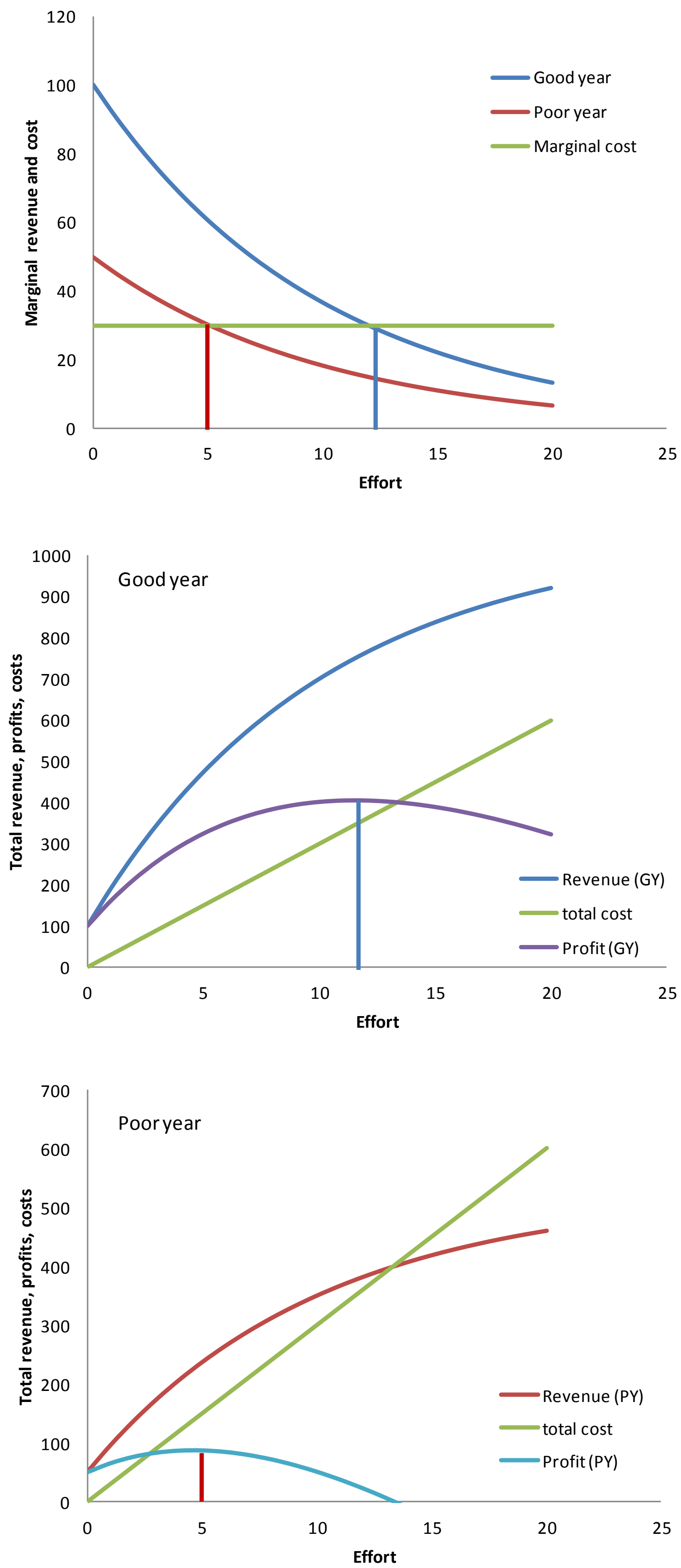
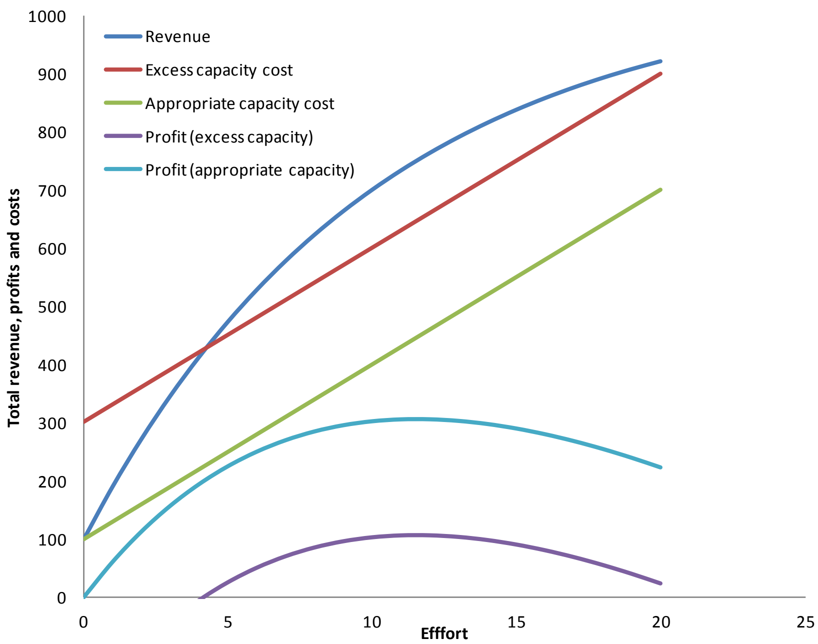


Figure 3 The impact of excess capacity on fishery profit. Excess capacity results in higher total costs and lower profits due to the fixed cost component. However, as marginal costs per unit of effort are the same, the optimal effort level is the same in both cases.



Current guidelines and assumptions

The harvest strategy policy's guidelines (DAFF 2007) recommend an adaptive management strategy through:

- conducting pre-season surveys to provide estimates of abundance that then determines the harvest control rule response
- undertaking within-season monitoring and the use of catch triggers (e.g. as used in the banana prawn component of the NPF)
- allowing a set number of spawning events prior to harvest (e.g. as used in the Bass Strait Central Zone Scallop Fishery).

The aim of the pre-season survey is to provide an estimate of the initial stock size, from which catch or effort targets can be set.

What the issues have been

To date, MEY has only been applied as a functional target reference point to tiger prawn stocks and the blue endeavour prawn stock in the NPF. So experiences with applying MEY to highly variable stocks have been limited. However, recent work in the same fishery to investigate the appropriate setting of a TAC for the fishery's highly variable banana prawn stocks has provided some insights. Over recent years (while still an input-controlled fishery), trigger reference points have been imposed on this component of the fishery.

In theory, as illustrated above, trigger points should not be necessary as fishers should stop fishing once it becomes unprofitable. The trigger point applied in the NPF was a proxy for this condition, but did not vary from year to year with changes in fuel costs and prices. Analysis of logbook information suggests that many fishers stopped fishing before the trigger point was reached, consistent with profit maximising behaviour and reflecting individual variations in costs. Some fishers, however, continued to fish until the forced closure, and individuals have expressed a desire to continue to fish beyond this point. While lower cost producers could potentially fish longer than higher cost producers, much of the push to extend fishing time relates to the incentives created by the crew share system and the need to retain good crew. Crew (including hired skippers) are generally paid a percentage of catch revenue, and hence have an incentive to fish even if marginal revenue is less than marginal costs. Changing the crew payment system to one based on a percentage of profits rather than revenue would better align the crew incentives with those of the vessel owners and fishery managers. Profit-based crew payment systems are common worldwide (McConnell & Price 2006), and Australia is in the minority using revenue-based crew share payments.

The trigger-based method also encourages the race to fish, in that expectations of early closure encourage all fishers to operate. While individually they may operate as profit maximisers, the greater involvement of capital in the fishery may reduce the overall level of economic profits achieved (as per Figure 3).[8] This is less of an issue for the NPF as the fleet has been reduced to a level at which excess capacity is likely to be minimal. A recent MSE of management options for the banana prawn fishery concluded that a trigger reference point may be developed that is consistent with MEY and may perform better than current trigger mechanisms in terms of maximising industry profits (Buckworth et al. 2013).

The proposed move to individual transfer quotas in the NPF has caused further difficulty in that a TAC is required for banana prawns. Pre-season surveys in the fishery have been undertaken by CSIRO for several years. These have mostly been designed to provide information for the tiger prawn component of the fishery, but also provide an index of banana prawn availability. Attempts at estimating a banana prawn TAC using these data, however, have proven difficult, and would have potentially resulted in a substantial loss of economic profits if actually implemented. More recently, attention has focused on improving the ability to forecast using rainfall information (current CSIRO project), although the relationship between catch and estimates of availability has appeared unreliable in recent years (although this could also be due to changes in economic conditions in the fishery).

It is important to separate the use of a management target from the management instrument used to achieve the target. In the case of the NPF, estimating a TAC for MSY is just as difficult as estimating a TAC for MEY.

Alternative options and approaches

Assessment of levels of excess capacity remains an option, although this is also complicated in highly variable fisheries. Some excess capacity is optimal in 'average' years to allow sufficient capital to take advantage of the high years, although determining this optimal level of excess capacity is problematic (Squires et al. 2003).

[8] The impact of this on overall fisheries performance is uncertain. Boats that operate in the banana prawn fishery also operate in the tiger prawn fishery, so fixed costs are still incurred irrespective of whether they operate in the banana prawn fishery or not. However, excess capacity could still exist in the banana prawn component of the fishery if fewer boats could still take the same the level of catch over a longer period of time.

For many highly variable, short-lived species, it is likely that MEY can be achieved by ensuring appropriate incentives are in place (rather than attempting to impose a particular catch or effort limit), provided that escapement is sufficient to reduce the impact of the catch on subsequent recruitment (e.g. through ensuring that spawning as already taken place). This includes removing incentives created under the race to fish to harvest the animals at too small a size (e.g. by imposing pre-season closures). While beyond the control of managers, but within the control of industry, changing the way in which crew are paid from a revenue share model to a profit share model would also help align incentives in the fishery.

Without some form of property right, however, incentives still exist to race to fish. An option may be to introduce some form of individual quota share, and encourage fishers to pool quota and profit share. This will create incentives to reduce fishing capacity while ensuring that all fishers retain benefits from their allocation. Again, this is an industry solution rather than a solution that can be imposed by management. Potentially, the fishery would be self regulating in terms of fishing effort and arbitrarily high TACs could be set to establish quota shares.

7 Market power

What the literature tells us

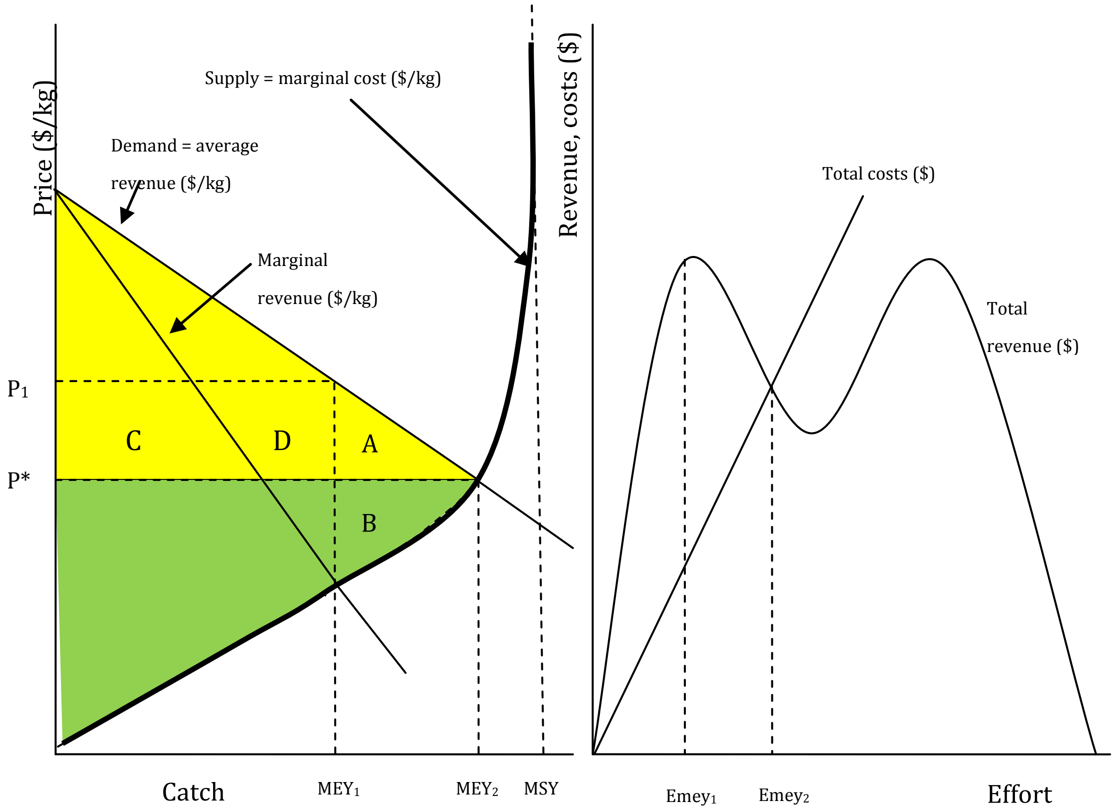
Most bioeconomic modelling analyses assume that prices are independent of the quantity landed, such that a constant price can be imposed in the model (e.g. Kompas et al. 2010; Punt et al. 2011). This assumption is largely supported by demand studies of fish species that conclude that prices are relatively inflexible[9] with regard to quantity supplied at the fishery level (e.g. Bose 2004; Burton 1992; Fousekis & Revell 2005; Jaffry et al. 1999; Smith et al. 1998),[10] although more recent analyses suggest that prices for some species are more responsive to quantity landed in the longer term, even if relatively unresponsive in the short term (e.g. Andersen et al. 2008; Pascoe & Revill 2004).

The ability to affect the price through varying the catch has implications for the definition of MEY. In Figure 4 (a), the traditional supply and demand model is presented for the case of a price setting fishery with a downward sloping demand curve. That is, the unit price it receives (which represents average revenue, defined as total revenue divided by catch) decreases as the quantity supplied by the fishery increases. The marginal revenue curve (which shows the extra revenue earned with each additional unit of output) lies below the average revenue curve. The industry supply curve is given by the marginal cost of sustainable catch (defined as the extra cost associated with an additional unit of catch) which is shown to increase. This differs from the marginal cost per unit effort in the traditional model (which is generally assumed to be constant), as the sustainable catch per unit of effort decreases as effort increases, with fish becoming more difficult to catch with decreasing biomass. Hence the marginal cost per unit of sustainable catch increases as catch increases, and as it cannot increase beyond maximum sustainable yield (by definition), the marginal cost curve asymptotes at this point.

The fishing industry would maximise its profit at the point where its marginal cost is equal to marginal revenue, depicted by MEY_1 in Figure 4(a). This is equivalent to the point $Emey_1$ in Figure 4(b). At this level of output, prices are P_1. However, while producer profits are maximised here, society's total benefits (the sum of consumer and producer surplus) are not. Rather, these total benefits are maximised where average revenue equals marginal cost, with a higher production quantity (MEY_2) and a lower price (P^*). The benefits to society at this optimal production point are depicted by the shaded areas in Figure 4(a). The yellow area represents consumer surplus, which is the difference between what consumers are willing to pay and what they are required to pay. The green area is producer surplus—the difference between the price received and the marginal cost of production.

[9] Price flexibility is measured as the percentage change in price given a 1 per cent change in quantity supplied. The own-price flexibility is the inverse of the price elasticity, which is the percentage change in quantity demanded due to a 1 per cent change in price. The measure of price flexibility is more appropriate when dealing with highly perishable products with (to some extent) exogenously determined output, as the price adjusts to clear the market. Fisheries falls into this category as output is a function of stock and fleet size, and the price adjusts depending on the resultant catch (although there is feedback in that effort is likely to decline at lower price levels). A product's price is inflexible if it does not change with quantity supplied (which is equivalent to a perfectly elastic demand).
[10] A review of studies of price elasticities (c.f. price flexibilities) has also concluded that fish prices, in general, are elastic (i.e. inflexible) (Asche et al. 2007).

Figure 4 Effects of variable prices on optimal output. Figure 4(a) represents the traditional market model (i.e. supply and demand) and illustrates the degree to which consumer benefits are affected by fisheries production decisions. Figure 4(b) represents the fishery-centric bioeconomic model with variable prices. In such a model maximum economic yield (MEY) may result in a lower revenue than lower catch levels.



Note: **MSY Maximum sustainable yield. MEY1** Maximum economic yield where producers maximise profit. **Emey1** The effort level associated with MEY1. **P1** The price that occurs with MEY1 catch. **MEY2** Catch where benefits to both consumers and producers are maximised. **P*** the price associated with MEY2. **Emey2** the effort level associated with MEY2.

Ignoring consumer surplus and producing at MEY_1 maximises benefits to the industry and represents a net transfer of benefits from consumers to producers. That is, producers capture additional producer surplus benefits associated with areas C and D in Figure 4 (a) at the lower MEY_1 quantity (given that the higher price P_1 prevails). These are benefits that would be captured by consumers if the efficient MEY_2 catch was produced. In addition, by not producing at MEY_2, areas A and B are not captured by anyone and represent an actual loss of benefits to society, traditionally referred to as a net 'deadweight' loss.[11] Therefore, in order to maximise the benefits to society as a whole, the more appropriate target is the natural 'market' equilibrium given by MEY_2 (Anderson 1973, 1980), with the equivalent level of effort $Emey_2$ in Figure 4 (b). At this point, the sum of consumer and producer surplus is maximised (Turvey 1964). However, industry profits are less than they might be at lower effort and catch levels.

[11] In contrast, when producers are price takers and prices are relatively inflexible (i.e. invariant to the quantity supplied), the demand curve is effectively flat, and consumer surplus does not exist. Hence, maximising producer benefits in such a case is an appropriate strategy for achieving MEY.

With globalisation of world fisheries markets, the ability of fishers (or even a fishery at an aggregate level) to influence their price is limited for most species. Too high a price would attract imports, while higher prices overseas would attract exports. Conditions under which the scenario depicted in Figure 4 could occur are limited, and rely on the case where the fishery was the main (or ideally sole) supplier to a domestic market with little competition from imports.

As noted previously, relatively few bioeconomic models include price variability as a component. Many of these ignored consumer surplus implications (e.g. Danielsson et al. 1997; Gillig et al. 2001; Õnal et al. 1991; Shalliker 1987), although others considered consumer surplus as a key component of economic benefits from fisheries management when estimating optimal yields (e.g. Blomo et al. 1982; Cook 1990; Edwards & Murawski 1993; Grafton et al. 2012).

Current guidelines and assumptions

The policy (DAFF 2007) does not refer to issues of market power. Implicit in the guidelines is that MEY is defined in terms of industry profitability only. Descriptions in the policy refer to variations in prices only in the context of inter-annual variability, and assume that price is exogenously determined (external to the fishery).

What the issues have been

For most Commonwealth fisheries, the assumption of exogenous prices (and associated with this the assumption of perfectly elastic demand, or inflexible prices) is reasonable. Most fisheries produce products that compete either on the domestic market with other domestically produced and/or imported substitutes, or on the export market with other countries; in both cases, market share is generally small.

There are, however, a small number of fisheries in which price–quantity relationships may be an important consideration when determining MEY targets. In particular, the recent shift in the supply of banana prawns from the NPF to the domestic market is believed to have had an adverse impact on its own price (Buckworth et al. 2013).

Anecdotal evidence suggests that the recent reopening of the Bass Strait Central Zone Scallop Fishery and the subsequent increase in fresh scallops on the domestic market has also potentially had an influence on market prices—both for this fishery as well as the adjacent Victorian and Tasmanian State fisheries (AFMA 2010). However, this effect has not been formally quantified

Alternative options and approaches

Incorporating the effects of changes in quantity on price and subsequently the appropriate definition of MEY first requires an understanding of the demand relationship for the species (including cross-species price interactions); second, it requires a bioeconomic model with an integrated demand component in order to determine the appropriate target reference point. From the diagrammatic model in Figure 4, the optimal yield will generally lie somewhere between the catch that maximises industry profits, and MSY. The more inflexible the price, the closer the optimal yield will equate to that which maximises industry profits.

Given that most empirical studies (in Australia and elsewhere) have found that fish prices are generally inflexible, a default position may be to estimate MEY as the yield that maximises industry profits at the prevailing price—as is current practice. However, where there is evidence of flexibility, research needs to be undertaken to derive more appropriate catch–price relationships to further refine the model and ensure that the target reference point reflects the yield that maximises total benefits to the broader society (industry and consumers).

8 Internationally shared fisheries

What the literature tells us

Most studies of international fisheries have focused on approaches to estimate non-cooperative (or cooperative) outcomes between fishing nations under different conditions (Abbott et al. 2010; Bailey et al. 2010; e.g. Klieve & MacAulay 1993; Lindroos 2004; McWhinnie 2009; Munro 2009). These have included theoretical studies to identify the necessary conditions for 'international MEY-like' catch levels to evolve across nations (Chiarella et al. 1984), assuming all nations share the same objective of maximising economic returns. These conditions are relatively restrictive, requiring homogeneity in technology (the fishing fleets of all nations use similar technology) and also the absence of market externalities (i.e. each nation's catch is sold on its respective domestic market with no import competition from other harvesting nations) (Chiarella et al. 1984). Subsequent studies have focused on asymmetry in production as a more realistic assumption (i.e. differences in harvesting costs), and concluded that the 'natural' state of international fisheries is effectively the open-access situation (Munro 2009) and shared stocks are more prone to overexploitation (McWhinnie 2009).

For high-valued, highly migratory species such as tuna, cooperation between coastal states has been improving since the early 1990s (Munro 1990). However, where formal allocations are made between member states, these are often based on historical catch levels rather than a specific target reference point (Grafton et al. 2011). The Commission for the Conservation of Southern Bluefin Tuna (CCSBT) has, in some instances, failed to provide an agreed total quota and allocation due to differences in objectives of the member countries (Kurota et al. 2010). In international waters, new individuals can enter the fishery and potentially undermine any allocations agreed between co-operating parties. For example, in the case of Southern Bluefin Tuna, non-members of the CCSBT have previously taken as much as one third the total harvest (Polacheck et al. 1999).

A substantial complication in the management of international fisheries is the problem of disparate social-value systems, which in turn may be driven by local needs and dependencies on the marine environment (Crutchfield 1973). In the case of Australian fisheries, the stated objective is the maximisation of the net economic returns from the resource. However, for other adjacent jurisdictions, the management objective may be substantially different. The objectives of international fishery management must be modified to accommodate different national objectives (Crutchfield 1973).

The fisheries economic literature has not addressed the issue of how to best use any allocation once determined. From an economic perspective, when output is given exogenously, economic returns can only be maximised through minimising the cost of production. These maximum returns to the state may (but most likely will not) equate to what could be achieved if a global maximum economic yield is imposed in the fishery as a whole. While considerable work has been undertaken on cost minimisation by individual fishers (e.g. Jensen 2002; Nostbakken 2006), most of the relevant literature relates to capacity and capacity utilisation described in previous sections (e.g. for data-poor species fisheries).

Current guidelines and assumptions

The policy does not prescribe management arrangements in the case of species managed by international management bodies and/or arrangements or for fisheries managed under a joint authority. However, the policy states that the Australian Government will negotiate with the relevant bodies to ensure sustainable fisheries (DAFF 2007). In this sense, the policy recognises implicitly that an MEY target is an unrealistic expectation for such fisheries at the international level. However, as noted above, maximising economic returns from the Australian allocation is still achievable, but is not identified as a target for these Australian fisheries in the policy. This notwithstanding, the Australian share of the fishery is subject to the *Fisheries Management Act 1991* that still specifies maximising the net economic returns as an overall management objective.

What the issues have been

For all intents and purposes, the Australian components of international fisheries have been managed as any other fishery. The exception is that catch and/or effort limits are exogenously determined or, at the very least, influenced by negotiations with international agencies or joint authorities.

The fact that international stocks are being shared with other countries implies that the returns to targeting a biomass level will be dependent on the relative share of catch. If the Australian share dominates, then management actions may have some power to influence stock size (and future economic returns). But if Australia only takes a small share of the international catch, then its influence over future stock levels (and the fishery's profitability) is reduced. In the latter case, a biomass target for the domestic fishery is not going to be appropriate. In such cases, it has then been unclear how harvest strategies can best meet the MEY intent of the policy.

For example, the Eastern Tuna and Billfish Fishery targets some stocks for which the Australian catch makes up a relatively small proportion of the total international catch. The fishery's harvest strategy control rules utilise a target catch rate that is equivalent to the rate that prevailed during a historically profitable period (1997 to 2001). However, this period was also associated with a relatively favourable terms of trade (high fish prices, low fuel prices). This means that achieving the same catch rate now may not necessarily result in positive profits and, therefore, may not be consistent with targeting MEY (Ward et al. 2013).

Alternative options and approaches

In cases where catch is determined under a separate international negotiation process, target reference points for management of the Australian component may be better expressed in terms of capacity utilisation (instead of biomass). As noted previously, underutilised capacity represents an opportunity for a more efficient fleet configuration, although some underutilisation is desirable given fluctuations in stock and price conditions from year to year. Identifying an optimal level of underutilisation in such fisheries is an area for future research.

Related to the use of capacity utilisation measures is the use of profit functions (e.g. Pascoe et al. 2011) and cost functions (e.g. Asche et al. 2009) to identify optimal levels of individual catch, and from this the possible extent of excess capacity.

While not a reference point per se, the harvest strategy policy could also advocate the use of management instruments that encourage cost minimisation, such as individual transferable quotas.

9 References

ABARES 2011, Australian Fisheries Statistics 2010, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Abbott, JK, Garber-Yonts, B & Wilen, JE 2010, 'Employment and renumeration effects of IFQs in the Bering Sea/Alutian Islands crab fisheries', Marine Resource Economics, vol. 25, no. 4, pp. 333-54.

AFMA 2008, A framework for delivering cost effective research information for AFMA's fisheries, Australian Fisheries Management Authority, Canberra.

—— 2009, Harvest Strategy Framework for the Southern and Eastern Scalefish and Shark Fishery, Australian Fisheries Management Authority, Canberra.

—— 2010, 17th Meeting of ScallopRAG, Melbourne, 4 May 2010, Australian Fisheries Management Authority, Canberra.

—— 2011, Review of AFMA's Arrangements for Obtaining and Using Scientifics and Economic Information and Advice, Report of the Expert Panel, Australian Fisheries Management Authority, Canberra.

Andersen, TB, Roll, KH & Tveterås, S 2008, 'The price responsiveness of salmon supply in the short and long run', Marine Resource Economics, vol. 23, no. 4, pp. 425-37.

Anderson, LG 1973, 'Optimum economic yield of a fishery given a variable price of output', Journal of the Fisheries Research Board of Canada, vol. 30, no. 4, pp. 509-18.

—— 1975, 'Analysis of Open-Access Commercial Exploitation and Maximum Economic Yield in Biologically and Technologically Interdependent Fisheries', Journal of the Fisheries Research Board of Canada, vol. 32, no. 10, pp. 1825-42.

—— 1980, 'Necessary components of economic surplus in fisheries economics', Canadian Journal of Fisheries and Aquatic Sciences, vol. 37, no. 5, pp. 858-70.

Androkovich, RA & Stollery, KR 1991, 'Tax versus quota regulation: a stochastic model of the fishery', American Journal of Agricultural Economics, vol. 73, no. 2, pp. 300-8.

Asche, F, Bjorndal, T & Gordon, DV 2007, 'Studies in the Demand Structure for Fish and Seafood Products', in A Weintraub, C Romero, T Bjorndal, R Epstein & J Miranda (eds), Handbook Of Operations Research In Natural Resources, Springer US, vol. 99, pp. 295-314.

—— 2009, 'Resource Rent in Individual Quota Fisheries', Land Economics, vol. 85, no. 2, pp. 279-91.

Ashiabor, H & Saccasan, M 2011, The Political economy of Australia's proposed resource rent taxation regime, Cheltenham, UK : Edward Elgar Publishing, 2011, <http://hdl.handle.net/1959.14/146263>.

Bailey, M, Rashid Sumaila, U & Lindroos, M 2010, 'Application of game theory to fisheries over three decades', Fisheries Research, vol. 102, no. 1-2, pp. 1-8.

Bateman, IJ, Langford, IH, Nishikawa, N & Lake, I 2000, 'The Axford debate revisited: a case study illustrating different approaches to the aggregation of benefits data', Journal of Environmental Planning and Management, vol. 43, no. 2, pp. 291-302.

Béné, C, Doyen, L & Gabay, D 2001, 'A viability analysis for a bio-economic model', Ecological Economics, vol. 36, no. 3, pp. 385-96.

Bentley, N & Stokes, K 2009a, 'Contrasting Paradigms for Fisheries Management Decision Making: How Well Do They Serve Data-Poor Fisheries?', Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, vol. 1, no. 1, pp. 391-401.

—— 2009b, 'Moving Fisheries from Data-Poor to Data-Sufficient: Evaluating the Costs of Management versus the Benefits of Management', Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, vol. 1, no. 1, pp. 378-90.

Berman, M, Haley, S & Kim, H 1997, 'Estimating net benefits of reallocation: discrete choice models of sport and commercial fishing', Marine Resource Economics, vol. 12, pp. 307-28.

Bertignac, M, Campbell, HF, Hampton, J & Hand, AJ 2000, 'Maximizing resource rent from the Western and Central Pacific tuna fisheries', Marine Resource Economics, vol. 15, no. 3, pp. 151-78.

Bjørndal, T, Gordon, DV & Bezabih, M 2012, 'Measuring potential profits in a bioeconomic model of the mixed demersal fishery in the North Sea', Journal of Bioeconomics, vol. 14, no. 2, pp. 1-20.

Bjørndal, T, Gordon, DV, Kaitala, V & Lindroos, M 2004, 'International management strategies for a straddling fish stock: A bio-economic simulation model of the Norwegian spring-spawning herring fishery', Environmental and Resource Economics, vol. 29, no. 4, pp. 435-57.

Blomo, VJ, Nichols, JP, Griffin, WL & Grant, WE 1982, 'Dynamic modeling of the eastern Gulf of Mexico shrimp fishery', American Journal of Agricultural Economics, vol. 64, no. 3, pp. 475-82.

Bose, S 2004, 'An empirical investigation of price-quantity relations of the quota species of Australia's South East Fishery', Marine Resource Economics, vol. 19, pp. 161–72.

Buckworth, RC, Ellis, N, Zhou, S, Pascoe, S, Deng, RA, Hill, FG & O'Brien, M 2013, Comparison of TAC and current management for the White Banana Prawn fishery of the Northern Prawn Fishery, CSIRO Marine and Atmospheric Research, Brisbane.

Burton, MP 1992, 'The demand for wet fish in Great Britain', Marine Resource Economics, vol. 7, no. 1, pp. 57-66.

Chae, DR & Pascoe, S 2005, 'Use of simple bioeconomic models to estimate optimal effort levels in the Korean coastal flounder fisheries', Aquatic Living Resources, vol. 18, no. 2, pp. 93-101.

Chaudhuri, K 1986, 'A bioeconomic model of harvesting a multispecies fishery', Ecological Modelling, vol. 32, no. 4, pp. 267-79.

Chiarella, C, Kemp, MC, Van Long, N & Okuguchi, K 1984, 'On the economics of international fisheries', International Economic Review, vol. 25, no. 1, pp. 85-92.

Christensen, A-S & Raakaer, J 2006, 'Fishermen's tactical and strategic decisions: A case study of Danish demersal fisheries', Fisheries Research, vol. 81, no. 2â€"3, pp. 258-67.

Christensen, S 1997, 'Evaluation of management strategies: a bioeconomic approach applied to the Greenland Shrimp Fishery', ICES Journal of Marine Science: Journal du Conseil, vol. 54, no. 3, pp. 412-26.

Christensen, V 2009, 'MEY= MSY', Fish and Fisheries, vol. 11, no. 1, pp. 105-10.

Clark, CW 1973, 'The economics of overexploitation', Science (New York, NY), vol. 181, no. 4100, p. 630.

—— 1976, Mathematical Bioeconomics: The Optimal Management of Renewable Resources, John Wiley and Sons, USA.

Clark, CW & Kirkwood, GP 1979, 'Bioeconomic model of the Gulf of Carpentaria prawn fishery', Journal of the Fisheries Board of Canada, vol. 36, no. 11, pp. 1304-12.

—— 1986, 'On uncertain renewable resource stocks: Optimal harvest policies and the value of stock surveys', Journal of Environmental Economics and Management, vol. 13, no. 3, pp. 235-44.

Clark, CW & Munro, GR 1975, 'The economics of fishing and modern capital theory: a simplified approach', Journal of Environmental Economics and Management, vol. 2, no. 2, pp. 92-106.

Clark, CW, Munro, GR & Sumaila, UR 2010a, 'Limits to the privatization of fishery resources', Land Economics, vol. 86, no. 2, pp. 209-18.

—— 2010b, 'Limits to the privatization of fishery resources: reply', Land Economics, vol. 86, no. 3, pp. 614-8.

Coglan, L & Pascoe, S 1999, 'Separating resource rents from intra-marginal rents in fisheries' economic survey data', Agricultural and Resource Economics Review, vol. 28, no. 2.

Cook, BA 1990, 'Maximum Social Returns for Canada's Pacific Halibut Fishery', North American Journal of Fisheries Management, vol. 10, no. 1, pp. 11-8.

Crutchfield, JA 1973, 'Economic and Political Objectives in Fishery Management', Transactions of the American Fisheries Society, vol. 102, no. 2, pp. 481-91.

DAFF 2007, Commonwealth fisheries harvest strategy: policy and guidelines, Department of Agriculture Fisheries and Forestry, Canberra.

Danielsson, A, Stefansson, G, Baldursson, FM & Thorarinsson, K 1997, 'Utilization of the Icelandic cod stock in a multispecies context', Marine Resource Economics, vol. 12, pp. 329-44.

Defeo, O & Seijo, CJ 1999, 'Yield-mortality models: a precautionary bioeconomic approach', Fisheries Research, vol. 40, no. 1, pp. 7-16.

Dichmont, CM & Brown, IW 2010, 'A case study in successful management of a data-poor fishery using simple decision rules: the Queensland spanner crab fishery', Marine and Coastal Fisheries, vol. 2, no. 1, pp. 1-13.

Dichmont, CM, Deng, A, Punt, AE, Ellis, N, Venables, WN, Kompas, T, Ye, Y, Zhou, S & Bishop, J 2008, 'Beyond biological performance measures in management strategy evaluation: Bringing in economics and the effects of trawling on the benthos', Fisheries Research, vol. 94, no. 3, pp. 238-50.

Dichmont, CM, Pascoe, S, Kompas, T, Punt, AE & Deng, R 2010, 'On implementing maximum economic yield in commercial fisheries', Proceedings of the National Academy of Sciences, vol. 107, no. 1, pp. 16-21.

Dowling, NA, Smith, DC, Knuckey, I, Smith, ADM, Domaschenz, P, Patterson, HM & Whitelaw, W 2008, 'Developing harvest strategies for low-value and data-poor fisheries: case studies from three Australian fisheries', Fisheries Research, vol. 94, no. 3, pp. 380-90.

Doyen, L, Thebaud, O, Bene, C, Martinet, V, Gourguet, S, Bertignac, M, Fifas, S & Blanchard, F 2012, 'A stochastic viability approach to ecosystem-based fisheries management', Ecological Economics.

Duarte, CC 1992, 'Targeted versus nontargeted multispecies fishing', Environmental and Resource Economics, vol. 2, no. 3, pp. 259-81.

Dupont, DP, Grafton, RQ, Kirkley, J & Squires, D 2002, 'Capacity utilization measures and excess capacity in multi-product privatized fisheries', Resource and Energy Economics, vol. 24, no. 3, pp. 193-210.

Edwards, SF & Murawski, SA 1993, 'Potential economic benefits from efficient harvest of New England groundfish', North American Journal of Fisheries Management, vol. 13, no. 3, pp. 437-49.

Eisenack, K, Scheffran, J & Kropp, JP 2006, 'Viability analysis of management frameworks for fisheries', Environmental Modeling & Assessment, vol. 11, no. 1, pp. 69-79.

Färe, R, Grosskopf, S & Kirkley, J 2000, 'Multi-Output Capacity Measures and Their Relevance for Productivity.', Bulletin of Economic Research, vol. 52, pp. 101-13.

Fousekis, P & Revell, BJ 2005, 'Retail Fish Demand in Great Britain and its Fisheries Management Implications', Marine Resource Economics, vol. 19, pp. 495–510.

Fulton, EA, Smith, ADM, Smith, DC & van Putten, IE 2007, 'Human behaviour: the key source of uncertainty in fisheries management', Fish and Fisheries, vol. 12, no. 1, pp. 2-17.

George, D, Vieira, S & New, R 2012, Australian fisheries surveys report 2011, results for selected fisheries 2008-09 to 2010-2011, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, February.

Giannini, F, Hobsbawn, PI, Begg, GA & Chambers, M 2010, Management strategy evaluation (MSE) of the harvest strategy for the Small Pelagic Fishery, Bureau of Rural Sciences, Canberra.

Gillig, D, Griffin, WL & Ozuna, T 2001, 'A Bioeconomic Assessment of Gulf of Mexico Red Snapper Management Policies', Transactions of the American Fisheries Society, vol. 130, no. 1, pp. 117-29.

Gooday, P 2004, Economic aspects of fisheries policy, ABARE eReport 04.18, Canberra.

Gordon, HS 1954, 'The economic theory of a common-property resource: the fishery', The Journal of Political Economy, vol. 62, no. 2, pp. 124-42.

Grafton, QR, Kompas, T, Che, TN, Chu, L & Hilborn, R 2012, 'BMEY as a fisheries management target', Fish and Fisheries.

Grafton, RQ, Hannesson, R, Shallard, B, Sykes, D & Terry, J 2011, 'The economics of allocation in tuna regional fisheries management organizations', in RL Allen, J Joseph & D Squires (eds), Conservation and Management of Transnational Tuna Fisheries, pp. 155-62.

Grafton, RQ, Kompas, T & Hilborn, R 2010, 'Limits to the privatization of fishery resources: Comment', Land Economics, vol. 86, no. 3, pp. 609-13.

Grafton, RQ, Kompas, T & Hilborn, RW 2007, 'Economics of overexploitation revisited', Science, vol. 318, no. 5856, pp. 1601-.

Hannesson, R & Kennedy, J 2005, 'Landing fees versus fish quotas', Land Economics, vol. 81, no. 4, pp. 518-29.

Hoff, A & Frost, H 2007, 'Optimal vessel quotas and capacity of a Danish trawler fleet segment: A dual approach', Marine Resource Economics, vol. 22, no. 1, pp. 1-14.

Holland, DS 2010, Management strategy evaluation and management procedures: tools for rebuilding and sustaining fisheries, OECD Publishing.

Holland, DS, Bentley, N & Lallemand, P 2005, 'A bioeconomic analysis of management strategies for rebuilding and maintenance of the NSS rock lobster (Jasus edwardsii) stock in southern New Zealand', Canadian Journal of Fisheries and Aquatic Sciences, vol. 62, no. 7, pp. 1553-69.

Holland, DS & Maguire, J-J 2003, 'Optimal effort controls for the multispecies groundfish complex in New England: what might have been', Canadian Journal of Fisheries and Aquatic Sciences, vol. 60, no. 2, pp. 159-70.

Hoshino, E, Hillary, RM & Pearce, J 2010, 'Economically optimal management strategies for the South Georgia patagonian toothfish fishery', Marine Resource Economics, vol. 25, no. 3, pp. 265-80.

Hoshino, E, Milner-Gulland, EJ & Hillary, RM 2012, 'Bioeconomic adaptive management procedures for short-lived species: A case study of Pacific saury (Cololabis saira) and Japanese common squid (Todarodes pacificus)', Fisheries Research, vol. 121-122, no. 0, pp. 17-30.

Jaffry, SA, Pascoe, S & Robinson, C 1999, 'Long run price flexibilities for high valued UK fish species: a cointegration systems approach', Applied Economics, vol. 31, no. 4, pp. 473 - 81.

Jensen, CL 2002, 'Applications of dual theory in fisheries: a survey', Marine Resource Economics, vol. 17, no. 4, pp. 309-34.

Jin, DI, Kite-Powell, H, Hoagland, P & Solow, A 2012, 'A Bioeconomic Analysis of Traditional Fisheries in the Red Sea', Marine Resource Economics, vol. 27, no. 2, pp. 137-48.

Johannes, RE 1998, 'The case for data-less marine resource management: examples from tropical nearshore finfisheries', Trends in Ecology & Evolution, vol. 13, no. 6, pp. 243-6.

Kasperski, S & Wieland, R 2010, 'When is it Optimal to Delay Harvesting? The Role of Ecological Services in the Northern Chesapeake Bay Oyster Fishery', Marine Resource Economics, vol. 24, pp. 361-85.

Kelly, CJ & Codling, EA 2006, '"Cheap and dirty" fisheries science and management in the North Atlantic', Fisheries Research, vol. 79, no. 3, pp. 233-8.

Kennedy, JOS & Pasternak, H 1991, 'Optimal Australian and Japanese harvesting of southern bluefin tuna', Natural Resource Modeling, vol. 5, no. 2, pp. 213-38.

Klaer, NL & Smith, DC 2012, 'Determining primary and companion species in a multi-species fishery: Implications for TAC setting', Marine Policy, vol. 36, no. 3, pp. 606-12.

Klieve, H & MacAulay, TG 1993, 'A game theory analysis of management strategies for the southern bluefin tuna industry', Australian Journal of Agricultural and Resource Economics, vol. 37, no. 1, pp. 17-32.

Kompas, T & Che, N 2006, 'A Stochastic Bioeconomic Model of a Multi-species and Multifleet fishery: An Application to the South East Trawl Fishery', ABARE report to the Fisheries Resources Research Fund, Canberra.

Kompas, T, Che, N, Chu, L & Klaer, N 2012, Transition to Maximum Economic Yield goals for the Great Australian Bight trawl fishery, funded by the Fisheries Research and Development Corporation, Canberra.

Kompas, T, Che, TN & Grafton, RQ 2004, 'Technical efficiency effects of input controls: evidence from Australia's banana prawn fishery', Applied Economics, vol. 36, no. 15, pp. 1631-41.

—— 2008, 'Fisheries instrument choice under uncertainty', Land Economics, vol. 84, no. 4, pp. 652-66.

Kompas, T & Gooday, P 2005, Maximum economic yield, efficiency and fisheries management, ABARE Report to the Fisheries Resources Research Fund, Canberra.

Kompas, T, Grafton, RQ & Che, N 2011, Maximum Economic Yield in Fisheries Management, ABARES technical report 11.3, Canberra.

Kompas, T, Grafton, RQ, Che, N & Gooday, P 2009, Development of methods and information to support the assessment of economic performance in Commonwealth fisheries, ABARES.

Kompas, T, Grafton, RQ & Che, TN 2010, 'Bioeconomic losses from overharvesting tuna', Conservation Letters, vol. 3, no. 3, pp. 177-83.

Kugarajh, K, Sandal, L & Berge, G 2006, 'Implementing a Stochastic Bioeconomic Model for the North-East Arctic Cod Fishery', Journal of Bioeconomics, vol. 8, no. 1, pp. 35-53.

Kurota, H, Hiramatsu, K, Takahashi, N, Shono, H, Itoh, T & Tsuji, S 2010, 'Developing a management procedure robust to uncertainty for southern bluefin tuna: a somewhat frustrating struggle to bridge the gap between ideals and reality', Population Ecology, vol. 52, no. 3, pp. 359-72.

Larkin, SL, Alvarez, S, Sylvia, G & Harte, M 2011, Practical Considerations in Using Bioeconomic Modelling for Rebuilding Fisheries, OECD Publishing.

Lindebo, E, Hoff, A & Vestergaard, N 2007, 'Revenue-based capacity utilisation measures and decomposition: The case of Danish North Sea trawlers', European Journal of Operational Research, vol. 180, no. 1, pp. 215-27.

Lindroos, M 2004, 'Restricted coalitions in the management of regional fisheries organizations', Natural Resource Modeling, vol. 17, no. 1, pp. 45-69.

Lorenzen, K, Almeida, O, Arthur, R, Garaway, C & Khoa, SN 2006, 'Aggregated yield and fishing effort in multispecies fisheries: an empirical analysis', Canadian Journal of Fisheries and Aquatic Sciences, vol. 63, no. 6, pp. 1334-43.

Maravelias, CD, Hillary, R, Haralabous, J & Tsitsika, EV 2010, 'Stochastic bioeconomic modelling of alternative management measures for anchovy in the Mediterranean Sea', ICES Journal of Marine Science: Journal du Conseil, vol. 67, no. 6, pp. 1291-300.

May, RM, Beddington, JR, Clark, CW, Holt, SJ & Laws, RM 1979, 'Management of multispecies fisheries', Science, vol. 205, no. 4403, pp. 267-77.

McConnell, KE & Price, M 2006, 'The lay system in commercial fisheries: Origin and implications', Journal of Environmental Economics and Management, vol. 51, no. 3, pp. 295-307.

McWhinnie, SF 2009, 'The tragedy of the commons in international fisheries: An empirical examination', Journal of Environmental Economics and Management, vol. 57, no. 3, pp. 321-33.

Munro, GR 1990, 'Extended jurisdiction and the management of Pacific highly migratory species', Ocean Development & International Law, vol. 21, no. 3, pp. 289-307.

—— 2009, 'Game theory and the development of resource management policy: the case of international fisheries', Environment and Development Economics, vol. 14, no. 01, pp. 7-27.

New, R 2012, 'Management changes and vessel-level technical efficiency in the Eastern Tuna and Billfish Fishery: a stochastic frontier analysis', paper presented to Australian Agricultural and Resource Economics Society 2012 Conference (56th), Fremantle, Australia, February 7-10, 2012.

Norman-Lopez, A & Pascoe, S 2011, 'Net economic effects of achieving maximum economic yield in fisheries', Marine Policy, vol. 35, no. 4, pp. 489-95.

Nostbakken, L 2006, 'Cost structure and capacity in the Norwegian pelagic fisheries', Applied Economics, vol. 38, no. 16, pp. 1877-87.

O'Neill, MF, Campbell, AB, Brown, IW & Johnstone, R 2010, 'Using catch rate data for simple cost-effective quota setting in the Australian spanner crab (Ranina ranina) fishery', ICES Journal of Marine Science: Journal du Conseil, vol. 67, no. 8, pp. 1538-52.

Õnal, H, McCarl, BA, Griffin, WL, Matlock, G & Clark, J 1991, 'A Bioeconomic Analysis of the Texas Shrimp Fishery and Its Optimal Management', American Journal of Agricultural Economics, vol. 73, no. 4, pp. 1161-70.

Pascoe, S 2007, 'Capacity analysis and fisheries policy: theory versus practice', Marine Resource Economics, vol. 22, pp. 83–7.

Pascoe, S, Coglan, L, Punt, AE & Dichmont, CM 2012, 'Impacts of Vessel Capacity Reduction Programmes on Efficiency in Fisheries: the Case of Australia's Multispecies Northern Prawn Fishery', Journal of Agricultural Economics, vol. early view (online).

Pascoe, S, Kirkley, J, Greboval, D & Morrison-Paul, C 2003, Measuring and Assessing Capacity in Fisheries. 2: Issues and Methods, FAO, Rome.

Pascoe, S, Koundouri, P & Bjorndal, T 2007, 'Estimating targeting ability in multi-species fisheries: a primal multi-output distance function approach', Land Economics, vol. 83, no. 3, pp. 382-97.

Pascoe, S & Mardle, S 2001, 'Optimal fleet size in the English Channel: a multi-objective programming approach', European Review of Agricultural Economics, vol. 28, no. 2, pp. 161-85.

Pascoe, S, Punt, AE & Dichmont, CM 2010, 'Targeting ability and output controls in Australia's multi-species Northern Prawn Fishery', European Review of Agricultural Economics, vol. 37, no. 3, pp. 313-34.

Pascoe, S & Revill, A 2004, 'Costs and benefits of bycatch reduction devices in European brown shrimp trawl fisheries', Environmental & Resource Economics, vol. 27, no. 1, pp. 43-64.

Pascoe, S & Tingley, D 2006, 'Economic capacity estimation in fisheries: A non-parametric ray approach', Resource and Energy Economics, vol. 28, no. 2, pp. 124-38.

Pascoe, S, Vieira, S, Dichmont, CM & Punt, AE 2011, 'Optimal vessel size and output in the Australian northern prawn fishery: a restricted profit function approach', Australian Journal of Agricultural and Resource Economics, vol. 55, no. 1, pp. 107-25.

Pelletier, D, Mahevas, S, Drouineau, H, Vermard, Y, Thebaud, O, Guyader, O & Poussin, B 2009, 'Evaluation of the bioeconomic sustainability of multi-species multi-fleet fisheries under a wide range of policy options using ISIS-Fish', Ecological Modelling, vol. 220, no. 7, pp. 1013-33.

Perks, C, McGill, K & Curtotti, R 2011, 'Vessel-level productivity in Commonwealth fisheries', paper presented to Australian Agricultural and Resource Economics Society 2011 Conference (55th), Melbourne, Australia, February 8-11, 2011.

Placenti, V, Rizzo, G & Spagnolo, M 1992, 'A bio-economic model for the optimization of a multi-species, multi-gear fishery: the Italian case', Marine Resource Economics, vol. 7, no. 4, pp. 275-95.

Plagányi, É, Deng, R, Dennis, D, Hutton, T, Pascoe, S, van Putten, I & Skewes, T 2012, An Integrated Management Strategy Evaluation (MSE) for the Torres Strait tropical rock lobster Panulirus ornatus fishery, CSIRO, Brisbane.

Polacheck, T, Klaer, NL, Millar, C & Preece, AL 1999, 'An initial evaluation of management strategies for the southern bluefin tuna fishery', ICES Journal of Marine Science: Journal du Conseil, vol. 56, no. 6, pp. 811-26.

Punt, AE, Deng, R, Pascoe, S, Dichmont, CM, Zhou, S, Plagányi, ÉE, Hutton, T, Venables, WN, Kenyon, R & van der Velde, T 2011, 'Calculating optimal effort and catch trajectories for multiple species modelled using a mix of size-structured, delay-difference and biomass dynamics models', Fisheries Research, vol. 109, no. 1, pp. 201-11.

Punt, AE, Smith, ADM & Cui, G 2002, 'Evaluation of management tools for Australia's South East Fishery. 1. Modelling the South East Fishery taking account of technical interactions', Marine and Freshwater Research, vol. 53, no. 3, pp. 615-29.

Rademeyer, RA, Plagányi, AE & Butterworth, DS 2007, 'Tips and tricks in designing management procedures', ICES Journal of Marine Science: Journal du Conseil, vol. 64, no. 4, pp. 618-25.

Reed, WJ 1979, 'Optimal escapement levels in stochastic and deterministic harvesting models', Journal of Environmental Economics and Management, vol. 6, no. 4, pp. 350-63.

Reid, C, Collins, P & Battaglene, T 1993, Torres Strait prawn fishery: an economic analysis, ABARE, Canberra.

Resosudarmo, BP 1995, 'The construction of a bioeconomic model of the Indonesian flying fish fishery', Marine Resource Economics, vol. 10, pp. 357-72.

Ryan, RW, Holland, DS & Herrera, GE 2010, 'Bioeconomic equilibrium in a bait-constrained fishery', Marine Resource Economics, vol. 25, no. 3, pp. 281-93.

Sandberg, P, Bogstad, B & RÃ¸ttingen, I 1998, 'Bioeconomic advice on TACâ€"the state of the art in the Norwegian fishery management', Fisheries Research, vol. 37, no. 1, pp. 259-74.

Scandol, JP 2003, 'Use of cumulative sum (CUSUM) control charts of landed catch in the management of fisheries', Fisheries Research, vol. 64, no. 1, pp. 19-36.

—— 2004, A framework for the assessment of harvested fish resources in NSW, vol. 15, NSW Department of Primary Industries.

Scott, A 1955, 'The fishery: the objectives of sole ownership', The Journal of Political Economy, vol. 63, no. 2, pp. 116-24.

Shalliker, J 1987, 'Fleet structures model: predictive modelling of the UK sea-fishing fleet', Journal of the Operational Research Society, pp. 1007-14.

Silvert, W & Smith, WR 1977, 'Optimal exploitation of a multi-species community', Mathematical Biosciences, vol. 33, no. 1-2, pp. 121-34.

Skirtun, M & Vieira, S 2012, Understanding the drivers of profitability in Commonwealth fisheries: assessing the influence of recent government policies,, report to client prepared for the Fisheries Resources Research Fund, Canberra.

Smith, D, Punt, A, Dowling, N, Smith, A, Tuck, G & Knuckey, I 2009, 'Reconciling approaches to the assessment and management of data-poor species and fisheries with Australia's Harvest Strategy Policy', Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, vol. 1, no. 1, pp. 244-54.

Smith, P, Griffiths, G & Ruello, N 1998, Price Formation on the Sydney Fish Market, ABARE, Canberra.

Squires, D 1987, 'Public regulation and the structure of production in multiproduct industries: an application to the New England otter trawl industry', RAND Journal of Economics, vol. 18, no. 2, pp. 232-47.

Squires, D, Omar, IH, Jeon, Y, Kirkley, J, Kuperan, K & Susilowati, I 2003, 'Excess capacity and sustainable development in Java Sea fisheries', Environment and Development Economics, vol. 8, no. 01, pp. 105-27.

Tingley, D & Pascoe, S 2005, 'Eliminating excess capacity: implications for the Scottish fishing industry', Marine Resource Economics, vol. 20, pp. 407–24.

Tingley, D, Pascoe, S & Mardle, S 2003, 'Estimating capacity utilisation in multi-purpose, multi-métier fisheries', Fisheries Research, vol. 63, no. 1, pp. 121-34.

Tsitsika, EV, Maravelias, CD, Wattage, P & Haralabous, J 2008, 'Fishing capacity and capacity utilization of purse seiners using data envelopment analysis', Fisheries Science, vol. 74, no. 4, pp. 730-5.

Turvey, R 1964, 'Optimization and suboptimization in fishery regulation', The American Economic Review, pp. 64-76.

Ulrich, C, Le Gallic, B, Dunn, MR & Gascuel, D 2002, 'A multi-species multi-fleet bioeconomic simulation model for the English Channel artisanal fisheries', Fisheries Research, vol. 58, no. 3, pp. 379-401.

Vestergaard, N, Squires, D & Kirkley, J 2003, 'Measuring capacity and capacity utilization in fisheries: the case of the Danish Gill-net fleet', Fisheries Research, vol. 60, no. 2-3, pp. 357-68.

Vieira, S, Schirmer, J, Loxton, E & Australia, W 2009, Social and economic evaluation methods for fisheries: a review of the literature, Fisheries Research Division, WA Marine Research Laboratories.

Wang, YG & Wang, N 2012, 'A Retrospective Evaluation of Sustainable Yields for Australia's Northern Prawn Fishery', Fisheries, vol. 37, no. 9, pp. 410-6.

Ward, JM 1994, 'The bioeconomic implications of a bycatch reduction device as a stock conservation management measure', Marine Resource Economics, vol. 9, no. 3, pp. 227-40.

Ward, P, Marton, N, Moore, A, Patterson, H, Penney, A, Sahlqvist, P, Skirtun, M, Stephan, M, Vieira, S & Woodhams, J 2013, Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: Implementation Issues, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) report to client prepared for the Fisheries Research and Development Corporation, Canberra.

Weitzman, ML 2002, 'Landing Fees vs Harvest Quotas with Uncertain Fish Stocks', Journal of Environmental Economics and Management, vol. 43, no. 2, pp. 325-38.

Yamazaki, S, Kompas, T & Grafton, RQ 2009, 'Output versus input controls under uncertainty: the case of a fishery', Natural Resource Modeling, vol. 22, no. 2, pp. 212-36.

Zhou, S, Pascoe, S, Dowling, N, Haddon, M, Klaer, N, Larcombe, J, Smith, ADM, Thebaud, O & Vieira, S 2012, Quantitatively defining biological and economic reference points in data poor and data limited fisheries, CSIRO Marine and Atmospheric Research, Canberra, Australia. .

17 Appendix 5: Review of Implementation

Ward, P., Marton, N., Moore, A., Patterson, H., Penney, A., Sahlqvist, P., Skirtun, M., Stephan, M., Vieira, S. and J. Woodhams (2013) A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy, FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

Australian Government
Department of Agriculture, Fisheries and Forestry
ABARES

Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: implementation issues

Peter Ward, Nic Marton, Andy Moore, Heather Patterson, Andrew Penney, Phil Sahlqvist, Maggie Skirtun, Mary Stephan, Simon Vieira & James Woodhams

Research by the Australian Bureau of Agricultural and Resource Economics and Sciences

June 2013

FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

FRDC project no. 2012/225

Cataloguing data
Ward, P, Marton, N, Moore, A, Patterson, H, Penney, A, Sahlqvist, P, Skirtun, M, Stephan, M, Vieira, S & Woodhams, J 2013, Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: implementation issues, ABARES, Report to client prepared for the Fisheries Research and Development Corporation, Canberra, June.

ISBN: 978-1-74323-129-6

Internet
Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: implementation issues is available at: daff.gov.au/abares/publications.

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)
Postal address GPO Box 1563 Canberra ACT 2601
Switchboard +61 2 6272 2010|
Facsimile +61 2 6272 2001
Email info.abares@daff.gov.au
Web daff.gov.au/abares

Acknowledgements
This project was funded by the Fisheries Research and Development Corporation and the Australian Government Department of Agriculture, Fisheries and Forestry. The authors are grateful for the guidance provided by members of the review's advisory committee: Ian Thompson, Ilona Stobutzki, Jo-Anne McCrea, Geoff Richardson, Beth Gibson, Craig Ingram, Tooni Mahto, Jeff Moore, Brian Jeffriess, Trixi Madon, Patrick Hone, Nick Rayns and David Smith. Stuart Curran, Anthony de Fries, Tim Karlov, Sandy Morison, Brad Milic, Mariana Nahas, Claire Taylor, other Australian Fisheries Management Authority fishery managers and other Commonwealth Scientific and Industrial Research Organisation scientists provided information and advice on sections of this report. ABARES staff involved in this project are listed in Appendix B.

Contents

Tables

Figures

Project details

FRDC project number:	**2012/225**
Project title:	A technical review of formal fisheries harvest strategies
Subproject title:	A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy 2007
Principal investigator:	Peter Ward
Affiliation:	Australian Bureau of Agricultural and Resource Economics and Sciences, Department of Agriculture, Fisheries and Forestry
Address:	18 Marcus Clarke Street (GPO Box 1563, Canberra ACT 2601 Australia)
Telephone:	Ph. 02 6272 4163, Fax 02 6272 2104

Objective

To undertake a detailed review of the extent and effectiveness of implementation of the *Commonwealth Fisheries Harvest Strategy: policy and guidelines* (DAFF 2007) and harvest strategies across Commonwealth fisheries, including the identification of potential performance measures.

Outcomes achieved to date

The project reviewed the implementation of the policy across Commonwealth fisheries, jointly managed and international fisheries, compiled detailed case studies of harvest strategies in eight Commonwealth fisheries and proposed criteria that might be used to measure the policy's performance in the future. This report also describes changes in economic performance and biological status to which the implementation of harvest strategies is likely to have contributed. It was not possible to separate the influence of harvest strategies from the effects of other factors on fishery performance for all Commonwealth fisheries.

Summary

Scope

This review focuses on technical aspects of the implementation of the *Commonwealth Fisheries Harvest Strategy: policy and guidelines* (Commonwealth Fisheries Harvest Strategy Policy or the policy) (DAFF 2007). The review includes information on whether fishery management actions and decisions have been consistent with the policy, challenges encountered in implementing the policy, and changes in the biological and economic status of fisheries that might be attributed to the policy's implementation.

A harvest strategy is a formal system for managing a fishery. Harvest strategies consist of reference points that reflect management objectives, indicators that measure status against those reference points, a process for assessing stocks, and monitoring the fishery and control rules designed to modify fishing activities in response to indicators and thereby meet those management objectives. Harvest strategies are often tested using management strategy evaluation (MSE) to ensure that the decision rules have a high probability of achieving the objectives under a wide range of plausible scenarios.

Implementation of the Commonwealth Fisheries Harvest Strategy Policy

The policy's overriding objective is to maintain key commercial fish stocks at ecologically sustainable levels and, within this context, maximise economic returns to the Australian community. It requires the implementation of fishery harvest strategies that maintain stocks at a desired state (target reference point) that is equivalent to the stock size or biomass (B) that will produce the maximum economic yield (MEY). The policy also requires stocks to be above a limit reference point beyond which the biological risk to the stock is considered too high. The proxy for the limit reference point is at least one-half of the biomass that would produce the theoretical maximum sustainable yield (MSY) in the absence of fishing. If B_{MSY} has not been estimated, then the proxy for B_{MSY} is assumed to be 40 per cent of the unfished biomass ($0.40B_0$), with the proxy limit being $0.20B_0$. The proxy for the target reference point is 20 per cent above the biomass that will produce MSY ($1.20B_{MSY}$) or $0.48B_0$.

Since the policy's introduction in 2007, the Australian Fisheries Management Authority (AFMA) has implemented harvest strategies for 72 fish stocks that are managed in 12 of the 13 active Commonwealth fisheries (harvest strategies have been developed, but not implemented, for several stocks in one fishery—the relatively small Coral Sea Fishery; Table 1). The policy requires harvest strategies to be implemented for all key commercial species, which are defined as 'a species that is, or has been, specifically targeted and is, or has been, a significant component of the fishery' (DAFF 2007). The fish stocks under harvest strategies include all quota-managed species and several other commercial species, including rebuilding stocks that were previously commercial species (e.g. eastern gemfish). Harvest strategies have been implemented for several byproduct species (e.g. squid in the Northern Prawn Fishery). There are other species that are sometimes retained for sale, but are not under harvest strategies (e.g. ocean jacket in the Southern and Eastern Scalefish and Shark Fishery [SESSF] Commonwealth Trawl and Scalefish Hook sectors.

In several fisheries, multiple stocks or species are managed together as a single entity. The eastern and western stocks of jackass morwong, for example, are assessed as separate stocks but are managed under a single total allowable catch (TAC). Similarly, there are several fisheries where multiple species are managed together (e.g. scampi consist of at least three species in the North West Slope Trawl Fishery). These problems arise through uncertainty about stock structure or species identification, or are a legacy of past management arrangements. Grouping different species or stocks under single assessments and harvest strategies inevitably results in increased uncertainty because of the different productivity and status of each species or stock. Uncertainty in assessments could be reduced by regularly verifying the composition of catches and encouraging management at the individual stock level.

Fishery performance

The economic performance of many Commonwealth fisheries and the biological status of fish stocks have improved since the late 2000s. The number of Commonwealth stocks classified as not overfished, for example, increased from 21 in 2007 to 38 in 2011, and the number classified as not subject to overfishing increased from 37 to 55 (Table 1). Many improvements in stock status are likely to be due to the implementation of harvest strategies. During this period economic returns improved in major Commonwealth fisheries, including the Northern Prawn Fishery and the Commonwealth Trawl Sector. However, it is difficult to separate the influence of harvest strategies from the effects of other factors during this period, particularly fishing effort reductions that have resulted from structural adjustment. In combination with harvest strategies and other management measures, improved data, research and assessment have reduced uncertainty in the biological status of many stocks. Other factors influencing economic performance (generated net revenues) include fluctuating demand for seafood, fluctuating currency exchange rates, changing operating costs and implementing management measures (e.g. fishery closures and state marine parks).

Many of the impediments to implementing the policy are related to cost (specifically for improved monitoring and assessment), human resources and data availability, and not due to problems with the policy itself. Sophisticated stock assessments, which require the collection of additional data, might not be justified for low-value fisheries. Priorities for harvest strategy implementation have therefore tended to reflect the economic value of stocks rather than the level of risk. There is a need to encourage the further development of generic and cost-effective approaches for small fisheries and data-poor stocks, including the implementing risk-based approaches and prioritising the implementation of harvest strategies for data-poor fisheries that interact with high-risk species. Ecological risk assessments can be used to identify high-risk species, enabling ecological risk management programs or harvest strategies to be developed, which involve a combination of monitoring, mitigation and adaptive management.

Reference points

About two-thirds of the harvest strategies implemented in Commonwealth fisheries specify target and limit reference points. The harvest strategies implemented in most Commonwealth fisheries are consistent with the policy. For large, data-rich fisheries with quantitative assessments, harvest strategies have been designed and tested to directly achieve the policies objective of MEY.

The harvest strategies of most low-value fisheries or data-poor fisheries have triggers instead of reference points—for example, the Western Deep Water Trawl Sector. The triggers are intended to activate a process of data collection and assessment in response to an indicator (e.g. catch) reaching a pre-agreed level. However, the most appropriate levels of triggers for many of these fisheries are unknown and have not been MSE tested. Some triggers are not regularly monitored, or the data required for assessments or implementing management measures when a trigger is reached may not be routinely collected, and such assessments may not be feasible within a suitable timeframe. Further work is needed to evaluate trigger-based harvest strategies and to demonstrate their effectiveness in achieving the policy's objectives.

Statistical models that combine biological and economic information are necessary for determining MEY and estimating the levels of biomass, fishing effort and catch that correspond to MEY. These bioeconomic models have been used to estimate B_{MEY} for six Commonwealth stocks (in the SESSF Great Australian Bight Trawl Sector and tiger prawn subfishery of the Northern Prawn Fishery). Bioeconomic models require reliable data on market prices, operating costs, a quantitative stock assessment model and experts to run those analyses, and they need to forecast prices and economic conditions accurately. These data are difficult to collect for many fisheries. Instead of estimating B_{MEY}, most harvest strategies use the policy's proxies for target reference points, which are based on biological quantities instead of economic quantities (e.g. $1.20B_{MSY}$). Low-cost alternatives to bioeconomic modelling using available economic information and assessments are needed. The policy's B_{MEY} proxy for the target reference point also needs to be validated for a wide variety of fishery types and species.

In addition to maintaining stocks at the biomass that will produce MEY, the policy states that MEY should be optimised across all species. Fishery-wide MEY has been estimated for two fisheries (SESSF Great Australian Bight Trawl Sector and the tiger prawn subfishery of the Northern Prawn Fishery). It has not been estimated for other Commonwealth fisheries for the same reasons that stock-specific MEYs have not been estimated—inadequate economic data, no quantitative assessment models, insufficient capacity or insufficient funding.

Many harvest strategies rely on catch-per-unit effort (CPUE) reported by commercial fishers. These harvest strategies assume that standardised CPUE is a reliable index of stock biomass and that the selected reference period represents MEY or the unfished stock. CPUE is often also the main abundance index used in quantitative assessment models. Fishery-independent surveys can be a reliable alternative or adjunct to commercial CPUE. Examples of such surveys in Commonwealth fisheries include acoustic surveys for orange roughy. The Small Pelagic Fishery has run daily egg production surveys to collect data for estimates of current spawning biomass. The Bass Strait Central Zone Scallop Fishery's harvest strategy involves preseason surveys. Trawl surveys have been established in several valuable fisheries, including the Northern Prawn Fishery, SESSF Commonwealth Trawl Sector and Great Australian Bight Trawl Sector. However, it takes many years of surveying to compile a time series that can be used as an index of trends in abundance, and those estimates may only be robust for a few, frequently caught species. For fisheries where such surveys are not possible or are considered unaffordable, there is a need for additional work on developing reliable commercial CPUE indices.

Ecological role

The policy recognises that more conservative reference points might be required for keystone species that are important in the maintenance of trophic relationships or communities. The Macquarie Island Toothfish Fishery, which adapted its harvest strategy from the international Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), takes into account the ecological role of harvested species. In recognition of the important role of forage fish in food webs, the harvest strategy for the Small Pelagic Fishery stipulates that the harvest of small pelagic species should not exceed 20 per cent of the most recent estimate of abundance, with this being progressively scaled down by 0.25 per cent per year since the last assessment, down to 7.5 per cent.

Risk and uncertainty

The Commonwealth Fisheries Harvest Strategy Policy requires that harvest strategies achieve comparable (low) levels of risk across all categories of information availability. Many harvest strategies include control rules that explicitly increase the level of caution as uncertainty in stock status increases.

Multiyear TACs have been introduced in several fisheries to reduce annual assessment costs, and to provide the industry with stability and certainty about short-term catch levels. Multiyear TACs are often based on projections of future stock status under various scenarios. Nevertheless, it may be necessary to determine whether discounts should be applied to multiyear TACs to achieve acceptable levels of risk over extended periods and to provide further guidance on setting break-out rules for multiyear TACs.

Harvest strategy control rules generate a recommended biological catch (RBC). Limiting total fishing mortality to the RBC should move the stock's biomass towards the target reference point. TACs are usually based on these RBCs. However, there have been situations where assessments were not accepted, resulting in TACs being based on other considerations or rolled over from a previous year. Sometimes the TAC that is rolled over is based on a previous assessment that has similar problems to the assessment that has not been accepted (e.g. redfish). The policy does not provide guidance on setting TACs in the absence of an agreed assessment, other than advocating a risk-management approach where exploitation rates are steadily reduced as time elapses since the last assessment.

Rebuilding overfished stocks

Harvest strategies are likely to have prevented many stocks from falling below their limit reference points and becoming overfished. However, several stocks that were depleted to below these limits before the policy was adopted have not subsequently rebuilt, despite the requirement to not allow targeted fishing and setting incidental catch allowances. The reasons why these stocks have not rebuilt are not clear, but may include the possibility that ongoing catches exceed levels that will facilitate rebuilding or changes in stock productivity caused by ecological factors, such as changes in the marine environment or climate, that affect spawning success.

The reference points of most harvest strategies are fixed at estimated theoretical equilibrium levels and do not reflect the dynamic nature of fish stocks. Fixed reference points cannot reflect environmentally induced productivity changes. Apparent changes in productivity have resulted in the revision of reference points for eastern jackass morwong to reflect the understanding that the productivity of this stock has decreased. Criteria for identifying productivity shifts and the development of non-equilibrium reference points might help in these situations. Regardless, there is need for firmer guidance on setting incidental catch allowances and managing the catches of companion species.

In several cases, reduced abundance or the effects of mandatory and voluntary restrictions on fishing activities may have reduced the availability or quality of fishery-dependent data that are often crucial for stock assessments and to monitor rebuilding. Rebuilding timeframes may have sometimes been too optimistic because stock productivity has been overestimated or a return to average historical levels of recruitment has been assumed (e.g. eastern gemfish). Furthermore, the policy's guidelines are not entirely clear as to whether the formula for calculating the rebuilding timeframe refers to rebuilding from the current biomass to the limit reference point, or whether it refers to another reference point (e.g. B_{MSY} or B_{MEY}) or from the limit reference point to B_{MEY}.

Testing and evaluation

The Commonwealth Fisheries Harvest Strategy Policy states that harvest strategies should be formally tested to demonstrate that they are highly likely to meet the policy's core elements. MSE involves computer simulations of harvest strategies for a range of uncertainties, including model structures, and the assumptions in assessments, parameter values, fishing activities, reporting and management decisions. It has demonstrated that the harvest strategies of most Commonwealth fisheries are robust to uncertainty. Most of the testing has been at a generic level that is relevant to species with similar biological characteristics. However, MSE results can be significantly different among species within the same fishery and so there may be a need for testing at the species level as well as generically. Insufficient information has precluded testing of the harvest strategies of some small fisheries and data-poor stocks, alternative targets in multispecies fisheries, discount factors and some multiyear TACs. These aspects of current harvest strategies still require testing.

Managing fishing mortality

Stock assessments attempt to take into account fishing-induced mortality from all sources. Commonwealth TACs are then derived by harvest control rules that may include deductions of other sources of fishing mortality from the RBC (e.g. estimates of state and recreational catches, catches in other Commonwealth fisheries and Commonwealth discards). For several stocks, reliable estimates have not been available for significant sources of mortality (e.g. recreational catches of silver trevally). For some stocks, state catches have been deducted from RBCs and, in the absence of state–Commonwealth catch-sharing arrangements, the TAC available to Commonwealth fishers has been reduced. For example, the annual state catch of school whiting has ranged between 750 tonnes and 1400 tonnes in recent years—more than one-half of the RBC. State catches are deducted from the RBC, so that the TAC available to Commonwealth fisheries is less than one-half of the RBC. However, state catches are sometimes not actively managed, resulting in the possibility that escalating state catches can result in unpredictable reductions in Commonwealth TACs. Improved stability in Commonwealth fisheries could be achieved through negotiation of catch-sharing arrangements with relevant states and territories.

Temporal and spatial management

Several fisheries have attempted to deal with the effects of spatial management measures, such as marine reserves and closures for protected species, that have been implemented outside the harvest strategy. However, the treatment of closures in harvest strategies has been inconsistent across fisheries. In particular, it has been difficult to determine how RBC estimation and TAC calculations should take closed areas into account, and to identify appropriate reference points in open areas for fisheries or species affected by closures. Research is underway on how RBCs might account for these effects. This research will contribute to the development of guidance on how harvest strategies should deal with closures, including possible modifications to reference points and harvest strategies applied to remaining open areas.

Jointly managed stocks and international fisheries

The policy does not prescribe management arrangements for jointly managed stocks or stocks managed by regional fisheries management organisations (RFMOs). Australia's domestic policy settings have been advocated where relevant at various RFMOs, including the Western and Central Pacific Fishery Commission (WCPFC). International harvest strategies have been implemented by RFMOs for several stocks (e.g. southern bluefin tuna; Table 2). Those harvest strategies are consistent with many aspects of the Commonwealth Fisheries Harvest Strategy Policy. However, there are often delays within RFMOs in adopting new approaches to fishery management because of diverse aspirations among members.

AFMA has developed and implemented harvest strategies for the domestic components of several international fisheries that do not have harvest strategies (e.g. the Eastern Tuna and Billfish Fishery [ETBF]), which is considered to be a subcomponent of the international Western and Central Pacific Fishery. However, the implementation of harvest strategies for the domestic component of several ETBF stocks has been delayed by uncertainty about the extent to which fishing activity in the wider western Pacific affects ETBF stocks, and vice versa. The policy states that 'in the absence of agreement [on RFMO catch level decisions], Australia's domestic catch allocation decision would be consistent with the agreed whole of government position' (DAFF 2007). For these stocks, AFMA has applied a TAC that was based on historical catch levels in the fishery.

Table 1 Summary of the implementation of the Commonwealth Fisheries Harvest Strategy Policy, Commonwealth fisheries, as at December 2012

Fishery	Implementation year	No. of stocks under a harvest strategy[a]	Target reference point(s)	Limit reference point(s)	MSE or testing	Fishing mortality status[a,b]		Biomass status[a,b]		Economic status	
						2007	2011	2007	2011	2007–08	2010–11
Bass Strait Central Zone Scallop Fishery[c]	2009	1	Not defined	One 'viable area' containing at least 500 t	Haddon 2011	0 0 1 1	0 0 1 1	1 0 0 1	0 1 0 1	Fishery was closed	Negative NER
Coral Sea Fishery	2008	Not defined	Not defined	Not defined	Plagányi et al. 2011b	0 9 1 10	0 2 7 9	0 10 0 10	0 7 2 9	Low catch and effort suggest low NER	Catch and effort increased substantially; NER uncertain
Macquarie Island Fishery	Mid 1990s (adopted CCAMLR control rules in 2010)	1	$0.50B_0$	$0.20B_0$	Fay & Tuck 2011	0 0 1 1	0 0 1 1	0 0 1 1	0 0 1 1	NER uncertain	NER are likely to be positive
Norfolk Island Fishery	No harvest strategy because there is no offshore fishery	n.a.	n.a.	n.a.	n.a.	– – – –	– – – –	– – – –	– – – –	No offshore fishery	No offshore fishery
Northern Prawn Fishery[c]	2007	6	Dynamic MEY for tiger prawn subfishery; banana prawn subfishery has a target of 'adequate escapement'	Tiger and blue endeavour prawns 0.5BMSY; red-legged banana prawns 0.5BMSY	Dichmont et al. 2008; preliminary MSE completed for banana prawn during 2012	0 4 4 8	0 1 5 6	0 4 4 8	0 1 5 6	NER were negative in 2005–06; economic performance is likely to have improved in 2007–08	Positive and increasing NER for tiger prawn; stocks building towards B_{MEY}
North West Slope Trawl Fishery[c]	2008 (revised in 2011)	11	Not defined	Not defined	Dowling 2011	0 1 1 2	0 0 1 1	0 2 0 2	0 0 1 1	Low fishery GVP; low catch and effort suggest low NER	Low fishery GVP; low catch and effort suggest low NER

Fishery	Implementation year	No. of stocks under a harvest strategy[a]	Target reference point(s)	Limit reference point(s)	MSE or testing	Fishing mortality status[a,b]		Biomass status[a,b]		Economic status	
						2007	2011	2007	2011	2007–08	2010–11
Small Pelagic Fishery	2008 (rev 2009)	7	Tier 1 0.2–0.1B depletion; Tier 2 0.075B depletion	Not defined (highly variable stocks)	Giannini et al. 2010	0 3 3 6	0 0 7 7	0 3 3 6	0 1 6 7	High latent effort suggests low NER	High latent effort suggests low NER
SESSF[d] Commonwealth Trawl and Scalefish Hook sectors (CTS)[c]	Implementation of SESSF Harvest Strategy Framework commenced in 2005d	27	Tier 1: B_{MEY} or $1.2B_{MSY}$ or $0.48B_0$; Tier 3: proxy equivalent to FB_{MEY}; Tier 4: CPUE[e] (fully fished, sustainable) or one-half of the unfished CPUE	Tier 1 $0.5B_{MSY}$ or $0.2B_0$; Tier 3 $F0.5B_{MSY}$ (or proxy); Tier 4 proxy of $0.4CPUE_{TARG}$	Punt & Smith 1999; Smith et al. 2008; Wayte 2009; Smith 2009; Little et al. 2011; Klaer & Wayte 2011; Fay et al. 2013	1 8 18 27	2 4 22 28	6 11 10 27	6 6 16 28	NER became positive in 2005–06 and increased in 2006–07 due to higher fish prices	Increases in productivity and NER suggest a move toward MEY; key stocks close to B_{MEY}
SESSF East Coast Deepwater Trawl Fishery		1				0 0 1 1	0 0 1 1	0 1 0 1	0 0 1 1	High latent effort suggests low NER	High latent effort suggests low NER
SESSF Great Australian Bight Trawl Sector[c]		3	Same as SESSF CTS; MEY estimated for deepwater flathead and Bight redfish; orange roughy is under the ORCP			0 0 3 3	0 0 4 4	0 1 2 3	0 1 3 4	NER estimates not available	NER are likely to be positive and to have increased. Key stocks above B_{MEY} targets
SESSF Shark Gillnet and Shark Hook Sectors[c]		4	Same as SESSF CTS			0 3 1 4	1 1 2 4	1 2 1 4	1 1 2 4	Positive NER	Positive NER
Southern Squid Jig Fishery[c]	2007	1	–	–	–	0 1 0 1	0 0 1 1	0 1 0 1	0 0 1 1	High latent effort suggests low NER	Increased effort suggests increased profitability, but NER likely to remain low

Fishery	Implementation year	No. of stocks under a harvest strategy[a]	Target reference point(s)	Limit reference point(s)	MSE or testing	Fishing mortality status[a,b]		Biomass status[a,b]		Economic status	
						2007	2011	2007	2011	2007–08	2010–11
Western Deepwater Trawl Fishery[c]	2008 (revised in 2011)	10	–	–	–	0 0 3 3	0 0 3 3	0 3 0 3	0 3 0 3	High latent effort suggests low NER	High latent effort suggests low NER
Total	12 of 13 fisheries with harvest strategies	72 stocks under harvest strategies	48 stocks with target reference points	50 stocks with limit reference points	n.a.	1 29 37 67	3 8 55 66	8 38 21 67	7 21 38 66	n.a.	n.a.

– = not defined; B = spawning stock biomass; B_0 = unfished biomass; CCAMLR = Commission for the Conservation of Antarctic Marine Living Resources; CCSBT = Commission for the Conservation of Southern Bluefin Tuna; CPUE = catch-per-unit-effort (standardised); $CPUE_{TARG}$ = target catch-per-unit-effort (standardised); F = fishing mortality rate; FB_{MEY} = fishing mortality rate that will produce B_{MEY}; GVP = gross value of production; MSE = management strategy evaluation; n.a. = not applicable; NER = net economic returns; OCS = Offshore Constitutional Settlement; ORCP = *Orange Roughy Conservation Programme*; SESSF = Southern and Eastern Scalefish and Shark Fishery

Notes:

[a] The stocks classified in annual *Fishery status reports* (Woodhams et al. 2012) sometimes differ from those recognised by the Australian Fisheries Management Authority (AFMA). For example, AFMA has implemented harvest strategies for 27 stocks in the SESSF Commonwealth Trawl Sector. By contrast, the *Fishery status reports* classifies the status of those 27 stocks, plus an additional stock (ocean jacket), which meets Australian Bureau of Agricultural and Resource Economics and Sciences criteria for inclusion in status reporting. The North West Slope and Western Deepwater trawl fisheries have developed harvest strategies for many stocks that are not currently fished and are not assessed in *Fishery status reports*. Between 2007 and 2011, several stocks ceased being classified in the *Fishery status report* (e.g. deepwater prawns in the North West Slope Trawl Fishery), while additional stocks have been added (e.g. Australian sardine in the Small Pelagic Fishery). Some 'stocks' also contain multiple stocks or multiple species (e.g. the east and west stocks of jackass morwong are managed under a single total allowable catch and are reported as a single stock in the *Fishery status reports* and in the present report.

[b] Assessments usually estimate spawning stock biomass (the mass of reproductively mature individuals in the population). For brevity, we refer to 'biomass' instead of 'spawning biomass' throughout this report.

Fishing mortality status classification (Woodhams et al. 2012):

0	number of stocks classified as subject to overfishing
1	number of stocks where fishing mortality status was classified as 'uncertain'
2	number of stocks classified as not subject to overfishing
3	total number of stocks assessed

Biomass status classification (Woodhams et al. 2012):

0	number of stocks classified as overfished
1	number of stocks where biomass status was classified as 'uncertain'
2	number of stocks classified as not overfished
3	total number of stocks assessed

[c] Indicates fisheries that were reviewed as a case study.

[d] The SESSF's Harvest Strategy Framework Tier 2 has been phased out.

[e] In this report the term, CPUE is used to refer to standardised catch per unit of fishing effort. Annual CPUE values are often averaged over several years or fishing seasons.

Source: Woodhams et al. (2012) and www.afma.gov.au

Table 2 Summary of the implementation of harvest strategies, jointly managed and international fisheries, as at December 2012

Fishery	Implementation year	No. of stocks under a harvest strategy[a]	Target reference point(s)	Limit reference point(s)	MSE or testing	Fishing mortality status[a,b]		Biomass status[a,b]		Economic status	
						2007	2011	2007	2011	2007–08	2010–11
South Tasman Rise Trawl Fishery	n.a.	Fishery is currently closed	n.a.	n.a.	n.a.	0 0 3 3	0 0 1 1	1 2 0 3	1 0 0 1	Fishery closed since 2007	Fishery closed since 2007
Torres Strait Finfish Fishery	n.a.	0	n.a.	n.a.	Begg 2006	0 1 1 2	0 0 2 2	0 1 1 2	0 0 2 2	Low GVP; NER likely to be low	Low GVP; NER likely to be low
Torres Strait Tropical Rock Lobster Fishery	2010	1	$0.65SB_0$ (or F=0.15)	$0.20B_0$	Under development	0 0 1 1	0 0 1 1	0 0 1 1	0 0 1 1	NER not available but GVP declined	Increased GPV suggests NER are likely to have increased
Torres Strait Prawn Fishery	2011	2	$0.28B_0$ for tiger prawns	$0.20B_0$ for tiger prawns; 620 t trigger for endeavour prawns	No testing	0 2 1 3	0 0 2 2	0 2 1 3	0 0 2 2	NER were negative in 2005–06 and latent effort remained high in 2007–08	NER were negative in 2008–09; are likely to have remained low
Torres Strait Beche-de-mer Fishery	n.a.	0	n.a.	n.a.	Plagányi et al. 2011a	0 4 0 4	0 0 5 5	2 2 0 4	1 1 3 5	Uncertain but NER likely to be low	NER are likely to have increased but still likely to be low

Fishery	Implementation year	No. of stocks under a harvest strategy[a]	Target reference point(s)	Limit reference point(s)	MSE or testing	Fishing mortality status[a,b]		Biomass status[a,b]		Economic status	
						2007	2011	2007	2011	2007–08	2010–11
Torres Strait Trochus Fishery	n.a.	0	n.a.	n.a.	Plagányi et al. 2011a	0 1 0 1	0 0 1 1	0 1 0 1	0 1 0 1	Uncertain but NER likely to be low	NER are likely to have increased but still likely to be low
Eastern Tuna and Billfish Fishery[c]	2010 (for swordfish and striped marlin only)	2	Expected CPUE[d] and size at SPR_{40}	Not defined	Kolody et al. 2010	2 2 1 5	1 1 3 5	0 2 3 5	0 1 4 5	Negative NER	NER are negative but improving
Skipjack Tuna Fishery	2008	2	Not defined	Not defined	No testing	0 0 2 2	0 0 2 2	0 0 2 2	0 0 2 2	No fishing activity	No fishing activity
Western Tuna and Billfish Fishery	Developed, not implemented yet	5	Expected CPUE and size at SPR_{40}	Not defined	Kolody et al. 2010	0 3 2 5	1 2 3 6	0 2 3 5	0 2 4 6	High latency and low catch suggest low NER	High latency and low catch suggest low NER
Antarctic Waters Fishery	Developed, but yet to be implemented; currently CCAMLR Harvest Strategy for new and exploratory fisheries	1	Not implemented	Not implemented	Constable & de la Mare 1996; de la Mare et al. 1998; Candy & Constable 2008; Welsford 2012	– – – –	1 0 0 1	– – – –	1 0 0 1	NER likely to be low	No fishing activity
Heard Island and McDonald Islands Fishery	CCAMLR Harvest Strategy for toothfish and mackerel icefish since mid-1990s	2	$0.50SB_0$ for toothfish; $0.75SB_0$ for icefish	$0.20SB_0$ for toothfish; zero commercial RBC for icefish if assessment predicts less than 1000 t or if yield is less than 100 t		0 0 2 2	0 0 2 2	0 0 2 2	0 0 2 2	NER are likely to be positive	NER are likely to be positive

Fishery	Implementation year	No. of stocks under a harvest strategy[a]	Target reference point(s)	Limit reference point(s)	MSE or testing	Fishing mortality status[a,b]		Biomass status[a,b]		Economic status	
						2007	2011	2007	2011	2007–08	2010–11
Southern Bluefin Tuna Fishery	CCSBT management procedure implemented in 2011–12 season	1	Interim rebuilding target of $0.20SB_0$ by 2035	Not defined	CCSBT 2011	1 0 0 1	0 1 0 1	1 0 0 1	1 0 0 1	Low latent quota suggests positive NER	Positive NER, expected to have increased
Total	5 of 12 fisheries with a harvest strategy	16 stocks under harvest strategies	n.a.	n.a.	n.a.	3 13 13 29	3 4 22 29	4 12 13 29	4 5 20 29	n.a.	n.a.

B = spawning stock biomass; B_0 = unfished biomass; CCAMLR = Commission for the Conservation of Antarctic Marine Living Resources; CCSBT = Commission for the Conservation of Southern Bluefin Tuna; CPUE = catch-per-unit-effort (standardised); $CPUE_{TARG}$ = target catch-per-unit-effort (standardised); F = fishing mortality rate; FB_{MEY} = fishing mortality rate that will produce B_{MEY}; GVP = gross value of production; MSE = management strategy evaluation; n.a. = not applicable; NER = net economic returns; RBC = recommended biological catch; SPR_{40} = 40% of spawning potential ratio; t = tonne

Notes: The harvest strategy policy does not prescribe management arrangements for jointly managed or international fisheries. However, the policy notes that the Australian Government will advocate the principles of the policy within all jointly managed fisheries (DAFF 2007). Australian Fisheries Management Authority (AFMA) has developed and implemented harvest strategies for the domestic components of several international fisheries, e.g. Eastern Tuna and Billfish Fishery. For several other stocks, stock-wide harvest strategies have been implemented by RFMOs, e.g. southern bluefin tuna. The details of those international and subcomponent domestic harvest strategies are presented in this table.

[a] The stocks classified in annual *Fishery status reports* (Woodhams et al. 2012) sometimes differ from those recognised by AFMA. For example, AFMA has implemented harvest strategies for 27 stocks in the SESSF Commonwealth Trawl Sector. By contrast, the *Fishery status reports* classifies the status of those 27 stocks, plus an additional stock (ocean jacket), which meets Australian Bureau of Agricultural and Resource Economics and Sciences criteria for inclusion in status reporting. The North West Slope and Western Deepwater trawl fisheries have developed harvest strategies for many stocks that are not currently fished and are not assessed in *Fishery status reports*. Between 2007 and 2011, several stocks ceased being classified in the *Fishery status report* (e.g. deepwater prawns in the North West Slope Trawl Fishery), while additional stocks have been added (e.g. Australian sardine in the Small Pelagic Fishery). Some 'stocks' also contain multiple stocks or multiple species (e.g. the east and west stocks of jackass morwong are managed under a single total allowable catch and are reported as a single stock in the present report.

[b] Assessments usually estimate spawning stock biomass (the mass of reproductively mature individuals in the population). For brevity, we refer to 'biomass' instead of 'spawning biomass' throughout this report.

Fishing mortality status classification (Woodhams et al. 2012):

0 number of stocks classified as subject to overfishing
1 number of stocks where fishing mortality status was classified as 'uncertain'
2 number of stocks classified as not subject to overfishing
3 total number of stocks assessed

Biomass status classification (Woodhams et al. 2012):

0 number of stocks classified as overfished
1 number of stocks where biomass status was classified as 'uncertain'
2 number of stocks classified as not overfished
3 total number of stocks assessed

[c] Indicates fisheries that were reviewed as a case study.

[d] In this report the term, CPUE is used to refer to standardised catch per unit of fishing effort. Annual CPUE values are often averaged over several years or fishing seasons.

Source: Woodhams et al. (2012) and www.afma.gov.au

Introduction

Background

The *Commonwealth Fisheries Harvest Strategy: policy and guidelines* (Commonwealth Fisheries Harvest Strategy Policy, or the policy) (DAFF 2007) was developed in response to a 2005 Ministerial Direction, which required the Australian Fishery Management Authority (AFMA) to:

> '...take a more strategic, science-based approach to setting total allowable catch and/or effort levels in Commonwealth fisheries, consistent with a world's best practice Commonwealth Harvest Strategy Policy that has the objectives of managing fish stocks sustainably and profitably, putting an end to overfishing, and ensuring that currently overfished stocks are rebuilt within reasonable timeframes...' (DAFF 2007)

The objective of the harvest strategy policy is:

> '...the sustainable and profitable utilisation of Australia's Commonwealth fisheries in perpetuity through the implementation of harvest strategies that maintain key commercial stocks at ecologically sustainable levels and within this context, maximise the economic returns to the Australian community. (DAFF 2007)

The present report was initiated to inform an Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) review of the policy, which was scheduled to report to ministers in 2013 (DAFF 2012a). An overarching report (Penney et al. 2013) synthesises the conclusions of the present review of implementation with other technical work, which provides background documents in support of the policy review. The other technical work includes a literature review of international harvest strategy policies (McIlgorm 2013), reviews of reference points, data-poor stocks,[1] buffered targets, total allowable catches (TACs), rebuilding strategies and spatial management (Haddon et al. 2013) and economic issues (Vieira & Pascoe 2013), and management strategy evaluation (MSE; Haddon 2013). The policy review has also been informed by public consultation, which was based on a discussion paper (DAFF 2012b) that sought input on the policy, its guidelines and their implementation.

Aims

The terms of reference for the Commonwealth Fisheries Harvest Strategy Policy review includes the following items:

> 3. The implementation of the policy, including:
>
> whether decisions and actions made by AFMA and the Australian Government have been consistent with the policy
>
> any issues identified with applying the policy to stocks shared with other Australian jurisdictions
>
> trends in biological and economic performance of fisheries managed under the policy
>
> whether the policy has affected the efficiency, certainty and transparency of fisheries management and stakeholder confidence in fisheries management arrangements
>
> how the policy has been used by Australia in international fisheries management bodies/arrangements
>
> how implementation of the policy has been reported. (DAFF 2012a)

---

[1] The terms 'stock', 'species' and 'species groups' are used interchangeably in this report.

This report addresses several of the items listed in the terms of reference; it examines the consistency of harvest strategies with the policy, and reviews trends in fishery performance and the policy's application to stocks that straddle jurisdictions and international boundaries. The public consultation process provides insights into how the policy's implementation has contributed to the efficiency, certainty and transparency of fisheries management and stakeholder confidence.

The report focuses on Commonwealth fisheries where the Australian Government has sole management responsibility. The Australian Government is also involved with other parties in managing straddling stocks and highly migratory species. In this report, jointly managed and international fisheries are defined as those fisheries where the Australian Government does not have exclusive fishery management responsibility. They include fisheries that are managed through a joint authority (with Australian states or the Northern Territory), straddling stocks, highly migratory species and international fisheries that are managed through regional fishery management organisations (RFMOs) or bilateral arrangements with other nations—for example Torres Strait fisheries. Jointly managed and international fisheries are included in this report because the Australian Government advocates the principles in those situations and AFMA has implemented harvest strategies for the domestic components of several international fisheries.

The various technical reports show that the Commonwealth Fisheries Harvest Strategy Policy meets or exceeds the standards of relevant international obligations and continues to represent world's best practice in most respects. Noting this general success, the present report identifies challenges in implementing the policy so that these might be considered within the policy review. This includes informing the policy review on the extent and effectiveness of the implementation of the policy, and evaluating the resulting outcomes in meeting policy objectives. Specifically, the report describes changes in biological status (the number of overfished stocks, overfishing and rebuilding) and economic performance.

We also suggest criteria that might be considered in future evaluations of the policy's performance. These range from the number of fish stocks and fisheries with harvest strategies, to statistics on the biological status of stocks and economic performance of fisheries, the number with reference points, and more detailed questions on the attributes of individual harvest strategies.

Methods

The Commonwealth Fisheries Harvest Strategy Policy applies to key commercial stocks taken in Commonwealth fisheries. However, it was not feasible within the time available to review details of the implementation of the policy for each of the 100 or more commercial stocks across the 24 Commonwealth fisheries. Instead we selected eight fisheries as case studies (Table 3). Those fisheries were chosen to represent many of the key attributes expected to influence the implementation of the Commonwealth Fisheries Harvest Strategy Policy, which were identified in the discussion paper (DAFF 2012b). The case studies also list other Commonwealth fisheries likely to share characteristics and policy implementation issues with that case study, and summary tables outline aspects of the policy's implementation.

Each case study includes a description of how the Commonwealth Fisheries Harvest Strategy Policy has been implemented in the fishery concerned, what worked and any difficulties encountered with implementation. This is structured in terms of the key components of harvest strategies that are specified by the policy—reference points, indicators, control rules and management strategy evaluation (MSE). Data and assessments are also key components of harvest strategies; these are reviewed under the 'Indicators' subsection of each case study. The cases studies include comments on how harvest strategies have been applied and subsequent changes in the fishery's performance (in terms of the biological status of stocks and economic returns) that might be attributed to the harvest strategies.

The focus of this report is on Commonwealth fisheries where the Australian Government has sole management responsibility. However, we summarise attributes of harvest strategy implementation in jointly managed and international fisheries, and include a case study of one international fishery, the Eastern Tuna and Billfish Fishery (ETBF).

We take care not to extend the review into areas of fishery management that are outside the policy, including specific fishery management actions, such as the form of management controls (e.g. input versus output controls) or allocation decisions. Also, this review does not address technical areas, such as assumptions in stock assessment models, which are common to other fisheries, regardless of whether they are managed through the policy.

The report's discussion highlights key conclusions of the case studies and relates this to the information on all fisheries provided in summary tables. The discussion is structured in terms of how the harvest strategies reflect the requirements of the policy, issues with the implementation of the policy and harvest strategies, and improvements in the biological and economic performance of the fisheries that might be associated with actions taken under the policy.

Most of the information used in this report was obtained from the AFMA website (www.afma.gov.au), resource assessment group (RAG) and management advisory committee (MAC) reports, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) *Fishery status reports* (Woodhams et al. 2012), and through direct communication with AFMA fishery managers, RAG chairs and relevant scientists, including Commonwealth Scientific and Industrial Research Organisation (CSIRO). The review of MSE and the attributes of several harvest strategies were informed by Haddon (2013).

Information on fishery performance was obtained from annual *Fishery status reports* (e.g. Woodhams et al. 2012) and economic surveys (e.g. George et al. 2012). The stocks classified in *Fishery status reports* sometimes differ from those recognised by AFMA. For example, AFMA has implemented harvest strategies for the 27 stocks in the SESSF Commonwealth Trawl Sector.

By contrast, the *Fishery status reports* classify the status of those 27 stocks, plus an additional stock (ocean jacket), which meets ABARES criteria for inclusion in status reporting. The North West Slope and Western Deepwater trawl fisheries have developed harvest strategies for many stocks that are not currently fished and are not assessed in *Fishery status reports*. Between 2007 and 2011, several stocks ceased being classified in the *Fishery status report* (e.g. deepwater prawns in the North West Slope Trawl Fishery), while additional stocks have been added (e.g. Australian sardine in the Small Pelagic Fishery). Some 'stocks' also contain multiple stocks or multiple species (e.g. the east and west stocks of jackass morwong are managed under a single TAC and are reported as a single stock in the *Fishery status reports* and in the present report).

Table 3 List of fisheries and stocks that are presented as case studies in this report, including characteristics that may affect the implementation of the Commonwealth Fisheries Harvest Strategy Policy

Fishery	Attributes							Characteristics of interest to the review of implementation of harvest strategy policy
	Landings (2011) (t)	GVP (2010–11) ($ million)	Data availability	Max. ages of target species (years)	Jurisdictions	Spatial or temporal issues	Biomass status[a,b]	
Northern Prawn Fishery	8 335	94.9	Rich	1–2	Commonwealth	Within season management for the banana prawn subfishery	0 1 5 6	High biological productivity, high GVP, data rich, bioeconomic model output controls
SESSF: Commonwealth Trawl and Scalefish Hook sectors	12 330	51.0	Poor to rich	4–150	Commonwealth and states	Voluntary and mandatory closures for protected species, marine parks and reserves	6 6 16 28	Multispecies fishery; substantial range in biological productivity and data available for assessments
SESSF: Great Australian Bight Trawl Sector	2 280	11.1	Poor to rich	6–150	Commonwealth	Continental shelf, upper slop and deepwater subfisheries	0 1 3 4	Multispecies fishery; bioeconomic model
SESSF: Shark Gillnet and Shark Hook sectors	1 834	16.5	Poor to rich	16–50	Commonwealth	Closures for protected species	1 1 2 4	Multispecies fishery; spatial and temporal closures for protected species interactions
Western Deepwater Trawl Fishery	13	Confidential	Poor	13–150	Commonwealth	Possible substructuring of some stocks	0 3 0 3	Low GVP, limited fishing activity, data poor
Southern Squid Jig Fishery	650	1.6	Poor	1	Commonwealth	Fishing activity occurs over a small portion of the species' distribution	0 0 1 1	Short-lived species, low GVP, data poor, within-season management, significant catches in other fisheries (735 t in CTS, 14 t in GABTS)
Bass Strait Central Zone Scallop Fishery	405	2.95	Medium	~16 (recent estimates suggest 5–8 years)	Commonwealth and states	Spatial management	0 1 0 1	Highly variable, spatial management, states may harvest the same stock

Fishery	Attributes							Characteristics of interest to the review of implementation of harvest strategy policy
	Landings (2011) (t)	GVP (2010–11) ($ million)	Data availability	Max. ages of target species (years)	Jurisdictions	Spatial or temporal issues	Biomass status[a,b]	
Eastern Tuna and Billfish Fishery	4 775	29.2	Medium	9–30	Commonwealth and international	Uncertainty over connectivity with the broader region for several stocks	0 4 1 5	Internationally shared stocks

CTS = Commonwealth Trawl and Scalefish Hook sectors; GABTS = Great Australian Bight Trawl Sector; GVP = gross value of production; t = tonne

Notes: All GVP estimates are for the 2010–11 financial year. All other statistics are for the 2011 calendar year. Statistics were sourced from Woodhams et al. (2012).

[a] The stocks classified in annual *Fishery status reports* (Woodhams et al. 2012) sometimes differ from those recognised by AFMA. For example, AFMA has implemented harvest strategies for 27 stocks in the SESSF Commonwealth Trawl Sector. By contrast, the *Fishery status reports* classifies the status of those 27 stocks, plus an additional stock (ocean jacket), which meets Australian Bureau of Agricultural and Resource Economics and Sciences criteria for inclusion in status reporting. The North West Slope and Western Deepwater trawl fisheries have developed harvest strategies for many stocks that are not currently fished and are not assessed in *Fishery status reports*. Between 2007 and 2011, several stocks ceased being classified in the *Fishery status report* (e.g. deepwater prawns in the North West Slope Trawl Fishery), while additional stocks have been added (e.g. Australian sardine in the Small Pelagic Fishery). Some 'stocks' also contain multiple stocks or multiple species (e.g. the east and west stocks of jackass morwong are managed under a single total allowable catch and are reported as a single stock in the *Fishery status reports* and in the present report.

[b] Assessments usually estimate spawning stock biomass (the mass of reproductively mature individuals in the population). For brevity, we refer to 'biomass' instead of 'spawning biomass' throughout this report.

Biomass status classification (Woodhams et al. 2012):

0 number of stocks classified as overfished
1 number of stocks where biomass status was classified as 'uncertain'
2 number of stocks classified as not overfished
3 total number of stocks assessed

Source: Woodhams et al. (2012) and www.afma.gov.au

Fishery case studies

Northern Prawn Fishery

Fishery characteristics

The Northern Prawn Fishery (NPF) was the highest value single-gear fishery managed by the Australian Government in 2010–11, with a gross value of product (GVP) of $94.8 million (30 per cent of total Commonwealth fishery GVP). The value of the fishery has been historically variable, and tied to catch quantities (influenced by environmental variables, particularly for white banana prawns), market competition and exchange rates. The fishery is managed under a harvest strategy with a maximum economic yield (MEY) objective, which was adopted in 2008.

The NPF is a multispecies, trawl fishery. Several tiger, endeavour and banana prawn species are taken, with the banana and tiger prawn species being the most valuable components of the fishery. Byproduct species include bugs, scampi and squid.

The fishery has two distinct seasons—a banana prawn season and a tiger prawn season. These reflect the main species targeted, as well as differences in management and vessel operations between the seasons. These are distinct subfisheries and each has reference points, triggers and decision rules. The tiger prawn subfishery is relatively data rich, with a highly refined, multispecies, bioeconomic assessment, incorporating tiger prawns as the primary target and endeavour prawns as an important byproduct (AFMA 2011d).

The bulk of the catch in the banana prawn subfishery is white banana prawn; however, there is also a smaller fishery for red-legged banana prawn, predominately located in the Joseph Bonaparte Gulf. Historically, there has been no formal stock assessment model for white banana prawns, due to difficulties in determining a clear stock–recruitment relationship, resulting from the influence of environmental factors—in particular, rainfall. The white banana prawn subfishery is managed using catch, catch rates and season length to achieve an adequate level of escapement to minimise biological risk to productivity. There is some catch of tiger prawns during the banana prawn season and catch triggers are in place to manage this catch. Recently, there has been research to develop a catch-prediction model for white banana prawns to forecast yields for the following season; however, this remains a challenge. There is a stock assessment for red-legged banana prawns, which provides estimates of the biomass of the stock. Catch-rate–based decisions rules are used to manage the red-legged banana prawn component of the subfishery for the following season(s).

While the two subfisheries use similar gear (demersal otter trawl), the way in which the vessels use the gear can be quite different. The tiger prawn subfishery is predominately a demersal trawl fishery, closely associated with the bottom, whereas white banana prawns are often taken through the targeting of aggregating prawns nearer the surface, referred to as 'boils'.

The management of the NPF has been explicitly targeting MEY in the tiger prawn subfishery since 2004 and management has also focused on rebuilding of the tiger prawn stocks (from below S_{MSY}). The NPF is currently managed using a suite of input (effort) controls and the current NPF harvest strategy is based on these. However, the fishery is expected to transition to output controls (TACs) in coming years (expected to be in 2014). Significant research and management resources have been invested in recent years to facilitate this transition. The potential for improved performance against the MEY objective under output controls (TACs and individual transferable quota [ITQs]) is complicated by the two distinct subfisheries, the differences in the biology of the target species, and the differences in fishery operations and assessment approaches. This review is limited to the implementation of the current NPF harvest strategy based on input controls; it does not offer an evaluation of, or compare, input and output controls.

Harvest strategy attributes

Background

The two subfisheries (tiger and banana) have separate harvest strategies. The harvest strategy for the tiger prawn subfishery targets MEY—defined as maximising the net present value of the flow of profits in the subfishery for an indefinite period (Dichmont et al. 2012). This is one of the few Commonwealth fisheries where a MEY-based target has been quantitatively estimated. The effort level to achieve this target is calculated every two years (E_{MEY}), with the catch of prawns in a given season managed though season length, spatial extent and gear controls.

The harvest strategy for NPF tiger prawn subfishery is unique in that it targets a dynamically estimated MEY, and depends on projected future prices and costs as well as biological status (biomass). The approach uses a seven-year projection window within which a dynamic path to MEY is calculated. The effort level for each of the seven years is set so that profits are maximised and yields are sustainable (biomass limits are avoided). In practice, the assessment is undertaken every two years, so only the first two years of the projected effort levels are ever used for setting total allowable effort.

The banana prawn subfishery harvest strategy is designed to achieve 'adequate escapement' of banana prawns. This is achieved through a catch-rate threshold (kilograms [kg] per boat per day), which was based on expert opinion and past experience. If catch rates fall below this threshold, the season is closed. In addition, the take of tiger prawns during the banana prawn season is regulated by a catch threshold, the setting of which is informed by the tiger prawn stock assessment.

Reference points and indicators

Target reference points

i. The tiger prawn subfishery (tiger and endeavour prawns) target is a dynamic (i.e. not fixed) MEY, estimated through a bioeconomic model. The aim of the harvest strategy is to optimise the effort during a seven-year moving window to maximise profits from tiger and endeavour prawns.

ii. The banana prawn subfishery targets 'adequate escapement'. This is pursued through regulating season length using catch and catch-rate triggers. Triggers were developed based on historical data.

Limit reference points

i. The limit reference point for stocks in the tiger prawn subfishery is 0.5 of the spawning stock size at maximum sustainable yield (0.5SMSY). Note, for tiger prawns, 0.5SMSY is likely to be less than B20. Stocks are regarded as below the limit reference point when the five-year moving average of SY/SMSY falls below 0.5. Targeted fishing of a species is to cease at that point.

ii. There is no explicit limit reference point for banana prawns. The banana prawn season length is shortened if the banana prawn catch rate falls below the threshold (e.g. 500 kg/day/vessel) or the tiger prawn catch exceeds the trigger (e.g. 6.6 tonnes [t]/week).

iii. A limit reference point for red-legged banana prawns is specified at 0.5SMSY. The assessment model computed that the limit reference point of 0.5BMSY was equal to 390 kg/day. The limit reference point is triggered as soon as the stock falls below 0.5BMSY for two years in a row.

Harvest control rules

The fishery is currently input controlled, with control rules used to regulate effort. Significant resources have been invested in understanding how the fishery could transition to output controls (TACs and ITQs). Preliminary reports have recently been drafted that investigate the impact of catch quantity on prawn price and the ability of assessments to predict white banana prawn biomass. A number of studies have also been undertaken to understand the profitability of the fishery under input and output controls. This work has then been used to explore possible management structures that can achieve the harvest strategy policy objective of MEY. As stated above, this case study makes no comparison of the merits (or otherwise) of input or output controls.

The bioeconomic assessments for the tiger and endeavour prawns are reasonably robust. The biological stock assessment models that are incorporated into this are based on substantial data and have previously been subject to international review. The red-legged banana prawn stock assessment is not as robust, with relatively large uncertainties in assessment outputs. As noted previously, there has been no formal stock assessment for white banana prawns and, while a number of assessment approaches have been developed, none are currently accepted by the RAG as a mechanism for managing the fishery so work is ongoing.

There are also control rules related to byproduct species, including scampi and squid.

Management strategy evaluation and testing

The objectives and structure of the current tiger prawn subfishery harvest strategy have been informed by a number of rounds of testing within an MSE framework (Dichmont et al. 2006, 2008).

Harvest strategy application

There have been several iterations of the tiger and banana prawn subfishery harvest strategies and the structure of the current harvest strategies has evolved from earlier versions. MEY was established as the overall management objective for the tiger prawn subfishery in 2004, before the Commonwealth Fisheries Harvest Strategy Policy.

Fishery performance

Tiger prawn stocks within the NPF were classified by ABARES as overfished between the late 1990s and early 2000s. Precursors to the current tiger prawn harvest strategy were used successfully to rebuild the biomass of these stocks. The blue endeavour prawn stock was classified as uncertain with respect to both biomass and fishing mortality status before 2009. Status of this stock was resolved in 2009 with updates to stock assessment models, and the stock has since been classified as not overfished and not subject to overfishing. There is no accepted assessment for red endeavour prawns and this stock has been classified as uncertain since 1994.

Both red-legged and white banana prawns have been classified as not overfished and/or not subject to overfishing since 1992.

The byproduct species, subject to trigger-based harvest strategies, are not currently assessed within the ABARES *Fishery status reports*.

Net economic returns (NER) in the fishery have improved significantly since 2004, from a decadal minimum of –$15.3 million in 2004–05—becoming positive in 2007–08 before further increasing to $21.5 million in 2010–11 (preliminary estimate). This improvement was associated with increasing revenue and relatively stable costs. The increases in revenue were driven by increased catches of banana prawns, with tiger prawn revenues being relatively low in historical terms. Recent profitability increases have also been driven by increases in economic productivity in both components of the fishery and have allowed the fishery to cope with falling market prices (Skirtun & Vieira 2012). The positive NER and recent productivity improvements are also likely to have been contributed to by the 2006 structural adjustment package, which removed the least productive vessels from the fishery (Pascoe et al. 2012). These improvements have been maintained following the buyback (Skirtun & Vieira 2012).

The tiger prawn stocks have been rebuilding towards S_{MEY} with the most recent assessment indicating that both species are above S_{MSY} but still below S_{MEY} at the end of 2011 (noting that the objective is to maximise profits across the suite of species and not necessarily achieve S_{MEY} for each species). This rebuilding is also likely to have contributed to increasing profitability in the fishery. When combined with increases in economic productivity, this suggests that the fishery has been moving steadily towards MEY since 2004 and that management is meeting the MEY objective.

The species-specific B_{MSY} and B_{MEY} has been estimated for both tiger prawn species. For grooved tiger prawns, B_{MEY} was $1.55B_{MSY}$ and for brown tiger prawns, B_{MEY} was $1.40B_{MSY}$. The policy proxy for B_{MEY} is $1.2B_{MSY}$.

Similar fisheries

There are a number of other fisheries that have developed effort-based harvest strategy approaches. The Southern Squid Jig Fishery (SSJF) is managed via input controls due to an uncertain stock–recruitment relationship. However, the level of data and assessment is much less in the SSJF, as a result of the low and variable levels of effort, and the low value of the fishery.

The NPF is one of only two Commonwealth fisheries with a bioeconomic model that estimates MEY and has optimised a multispecies MEY target (the other being the Great Australian Bight Trawl Fishery). Other multispecies fisheries currently use biomass proxies for MEY for each target species.

Conclusions

The NPF is an example of a valuable and currently profitable fishery where the economic returns from investing in research and management are high. Significant resources have been invested in fishery monitoring, assessment and—for the tiger prawn fishery—estimating MEY and implementing it as a target. For most other Commonwealth fisheries that have a lower GVP, the economic returns from bioeconomic modelling and estimation of MEY are likely to be lower. Therefore, while the NPF approach and experience offers some insights into the direct estimation and implementation of MEY, the relevance of the approach taken in the NPF to other lower value Commonwealth fisheries may be limited.

Dichmont et al. (2010) outline the challenges that have been encountered in implementing MEY in the NPF:

- **Specifying the model**. MEY is complicated by the many factors (such as fleet dynamics) that affect it and it may be difficult to capture these factors.
- **Defining the boundaries**. MEY is optimised for the fishery as a way of ensuring that a society's resources are put to their most productive use. However, this will have impacts on sectors that are dependent on, but outside, the fishery.
- **The best outcome may not always be practical**. Unconstrained models may provide an optimum that does not capture factors relevant to the interests of industry, the community, or practical issues requiring careful design or interpretation.
- **The need for accurate economic data**. Economic parameters are highly variable, creating high uncertainty, and correctly incorporating data into the model is not always straight forward. This means regular model revision will be required.
- **A good target is not enough**. Changes in factors such as fishery behaviour, fishery cost structure and the fishery's regulatory environment will mean that the optimal MEY path may need to be re-estimated regularly.
- **Implementation in a co-management arena**. Poor understanding of the concept by most stakeholders and variability of economic parameters has had negative implications for industry support of MEY. The education of stakeholders should be a high priority.

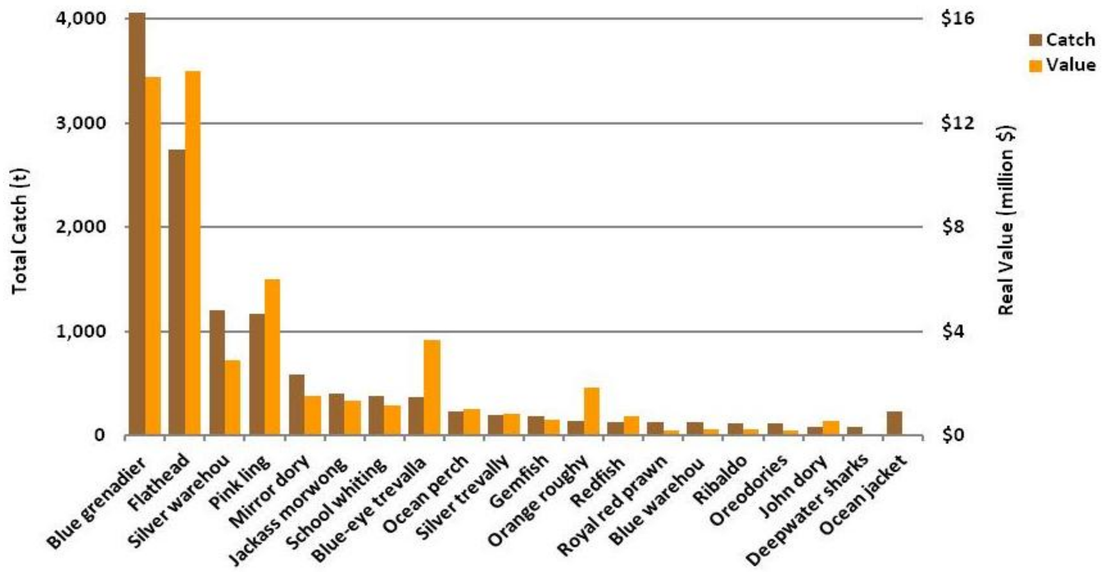
Commonwealth Trawl and Scalefish Hook sectors

Fishery characteristics

The Commonwealth Trawl and Scalefish Hook sectors (CTS) of the Southern and Eastern Scalefish and Shark Fishery (SESSF) land more than 30 fish species. These are managed as 27 commercial stocks, ranging from key commercial species that make up most of the catch, to byproduct species that contribute low or sporadic catches. The species differ substantially in productivity, ranging from royal red prawn (maximum age of four years) to orange roughy and oreos that may live for 150 years (references cited in Woodhams et al. 2012).

The CTS is an economically valuable fishery, with a long history of fishing, research and assessment. It provides a case study for reviewing the implementation of the Commonwealth Fisheries Harvest Strategy Policy in a high-value, multispecies fishery, including the challenges of implementing the policy across a range of species. Species range from economically valuable, data-rich species (e.g. flathead) to less valuable commercial species (e.g. john dory) and byproduct (e.g. ocean jacket) with low information. Six species (blue grenadier, flathead, silver warehou, pink ling, mirror dory and jackass morwong) contributed 80 per cent of the volume of landings and 75 per cent of the value in recent years (Figure 1).

Figure 1 Average annual catch and value of the top 20 species caught in the Commonwealth Trawl and Scalefish Hook sectors across the 2010-11 and 2011-12 fishing seasons



Note: Eastern gemfish, blue warehou and orange roughy are managed under incidental catch allowances. Ocean jacket is a non-quota species, but is included because it contributes significant catches.

Source: Woodhams et al. (2012)

The policy recognises that species caught together in a fishery will have different biological characteristics, and that it may not be possible to maintain all species at B_{MEY} (or the default $0.48B_0$). In other words, the harvesting of one species in a multispecies fishery at levels set in accordance with its target reference point could lead to harvests inconsistent with the default target reference points for other commercial species. Lower value species may have to be maintained at lower levels, provided that the key commercial species are managed at B_{MEY} and the biomass of lower value species is always maintained above the default limit of $0.20B_0$.

Harvest Strategy attributes

Background

The harvest strategy policy has been implemented in the CTS using the SESSF's harvest strategy framework (AFMA 2009a). The framework consists of several types of harvest strategies ('tiers') that are designed to deal with the different levels of information available for the types of species under quota in the CTS (Appendix D). The framework was developed in 2005, predating the release of the Commonwealth Fisheries Harvest Strategy Policy in 2007, and it has evolved since then.

The SESSF framework includes three assessment tiers (1, 3 and 4; Tier 2 has been phased out) with associated rules, which are designed to enable stock assessments and management advice at different levels of data quality or knowledge about the stock. Each tier of the framework consists of a collection of formulas ('harvest control rules') that use the levels of different indicators (fishing mortality rates or indices of biomass) relative to reference points to derive an annual recommended biological catch (RBC).

Reference points and indicators

The policy's default proxies ($1.20B_{MSY}$ or $0.48B_0$) are used as the biomass target reference point for eight of the nine commercial stocks that currently have quantitative Tier 1 assessments. Similarly, the policy's default proxies of $0.50B_{MSY}$ or $0.20B_0$ are used as the biomass limit reference point for Tier 1 species. Tier 1 assessments involve integrated stock assessment models (e.g. Stock Synthesis version 3) to fit multiple data series statistically, such as commercial CPUE, size or age composition of catches, discard rates, biological information (size at maturity, growth parameters) and, where available, data from fishery independent surveys. The models generate various indicators of stock status, including estimates of current, historical and unfished biomass and fishing mortality rates, which are compared to reference points.

For flathead, the fishery's most valuable species, updated stock assessments estimated biomass at maximum sustainable yield (B_{MSY}) to be $0.30B_0$ in 2011 (Klaer 2010a,b). Application of the Commonwealth Fisheries Harvest Strategy Policy proxy of $1.20B_{MSY}$ to this value would have given an MEY target of $0.36B_0$. However, additional economic analysis of stock assessment outputs was undertaken with revenue and cost parameters during the ShelfRAG meeting. This demonstrated that a $0.40B_0$ target was likely to be more profitable and consistent with the intent of the policy (D. Galeano, AFMA, pers. comm., 2011). ShelfRAG subsequently recommended setting the target reference point for flathead at a higher level, at $0.40B_0$ (AFMA 2012a). Bioeconomic modelling has not been conducted for any other CTS stocks.

Orange roughy are managed through the *Orange Roughy Conservation Programme* (AFMA 2006). This program aims to maintain orange roughy biomass on the Cascade Plateau at or above $0.60B_0$, which is more conservative than the policy's default limit reference point.

The target reference point for the CTS's three Tier 3 species is the fishing mortality rate that will reduce spawning biomass to the policy's default proxy of 48 per cent of the unfished level ($0.48B_0$). This rate of fishing mortality is referred to as F_{48}. The Tier 3 limit reference point (F_{20}) is the fishing mortality rate that will reduce the spawning biomass to the policy's default proxy of $0.20B_0$ (Appendix D). Tier 3 assessments involve catch-curve analyses of the age (or size) composition data of catches to provide estimates of current fishing mortality rates (Wayte, & Klaer 2011).

The remaining 15 CTS stocks are managed through Tier 4 harvest control rules. Tier 4 assessments evaluate trends in CPUE[2] from catch-and-fishing-effort data reported in logbooks. Tier 4 target reference points are based on a historical reference period when catches and CPUE were stable, and the stock is considered to have been fully exploited and likely near B_{MSY} (Appendix D). The default reference period is 1986–1995, when the time series of CPUE data commences. Other periods have been selected for several species that are considered not to have been fully exploited at the beginning of the time series. The target CPUE and target catch are halved when the stock is considered to be mostly unexploited during the reference period. CPUE is assumed to be proportional to stock biomass, so that CPUE during the reference period is assumed to correspond to B_{MEY} (proxy of $0.48B_0$, which is equivalent to $1.20B_{MSY}$). The Tier 4 target reference point is then the average CPUE during the reference period; and the limit is 40 per cent of this target CPUE, which approximates $0.20B_0$.

There is increasing debate over whether CPUE is a reliable index of stock biomass for several Tier 4 species, particularly where structural adjustment or other operational changes have resulted in low fishing effort, avoidance or substantial shifts of fishing effort to other areas that might not accounted for in the standardisation process. Other situations where CPUE might not be a reliable indicator of abundance include multispecies stocks,[3] where component species or stocks might have different productivity and subject to different exploitation rates (e.g. deepwater sharks).

A fishery-wide MEY is yet to be estimated for the CTS, and developing an estimate for such a spatially heterogeneous, multispecies and multigear fishery is difficult. Issues with setting B_{MEY} target reference points for individual species in a multispecies fishery have been noted and discussed by SESSFRAG (AFMA 2011a). Research started in 2012 to develop approaches to setting alternative target reference points in multispecies fisheries, including the CTS (FRDC Project 2011/200). In the meantime, SESSFRAG requested RAGs to estimate RBCs for low-value species based on a $0.40B_0$ target (instead of $0.48B_0$). Simplified approaches like this to setting alternative target reference points could be preferable to bioeconomic modelling, particularly when taking into account the complexities and the uncertainty that are likely to be associated with optimisation for a diverse fishery like the CTS with numerous commercial species.

Harvest control rules

Recommended biological catches

All assessment tiers generate an RBC and limiting total fishing mortality to the RBC should move stock biomass towards the target reference point. The quantitative Tier 1 stock assessment models predict an RBC for the upcoming year, as well as long-term RBCs. The models are often used to generate projections of predicted future biomass at alternative catch levels and under various alternative assumptions.

Tier 3 assessments estimate RBCs by multiplying the current average catch by the ratio of the target fishing mortality rate to the actual fishing mortality rate. The time period used to estimate fishing mortality is the same as that used to estimate current catch (AFMA 2009a).

---

[2] In this report, the term 'catch-per-unit-effort' (CPUE) is used to refer to standardised catch per unit of fishing effort. Annual CPUE values are often averaged over several years or fishing seasons. In the CTS, for example, annual CPUEs are usually averaged over four years.

[3] Multispecies stocks are sometimes referred to as 'basket stocks'.

For Tier 4 assessments, the RBC is estimated as the target catch multiplied by the ratio of the average CPUE of the most recent four years and the target CPUE (the value of the CPUE limit is first subtracted from those two quantities).

Discount factors
The level of precaution applied in harvest control rules (TAC calculations) is intended to increase from Tier 1 to Tier 4, reflecting the increasing level of uncertainty in assessments and reference points at each of these tier levels. A default 5 per cent deduction or 'discount factor' is applied to RBCs derived from Tier 3 assessments. A default 15 per cent discount is applied to Tier 4 RBCs. RAGs have sometimes recommended the waiving of default discount factors. The justification for this has varied with the species and the situation. In some cases, there has been broad acceptance that significant spatial closures (usually implemented for other species or objectives) give equivalent or additional precaution to that provided by a discount factor. Concerns have been raised about the circularity in arguing that stability in recent CPUE justifies waiving the discount factor, when these assessments are based on CPUE, which was the reason for having a default discount factor in the first place.

The SESSFRAG originally recommended the values of discount factors, noting that they were provisional pending further analysis of the levels that will provide comparable levels of risk across the tiers. In 2012, SESSFRAG sought to better define circumstances in which discount factors could be waived. Using MSE, Fay et al. (2013) found that the actual value of discount factors required to obtain equivalent risk varied among species and stock status. They suggested that stability in CPUE did not warrant the waiving of discount factors and that uncertainties in the relationship between CPUE and biomass required additional precaution for setting TACs for data-poor species.

Total fishing mortality
The Commonwealth Fisheries Harvest Strategy Policy requires that all sources of mortality are used in determining TACs. RBCs are translated into TACs through a set of rules, which include deductions for expected mortalities due to discarding, research quota, state commercial catches and recreational catches. Recreational catches are significant for several CTS species (e.g. silver trevally and jackass morwong). However, estimates of recreational catches are not always available or considered to be reliable, and assessments and RBC calculations do not always include estimates of recreational catches.

Information on stock abundance in the most recent fishing season is not usually available for assessments. The SESSF framework includes a latest CPUE multiplier rule to adjust TACs according to trends in recent CPUE. The rule adjusts the TAC by the ratio of recent CPUE and the average CPUE that was used in the original TAC calculation. MSE has shown that this rule does not reduce the likelihood of achieving the target biomass, but it does increase the variability in TACs (Wayte 2009). Rules are also applied to limit small and large changes in TACs between fishing seasons, and to allow limited overcatch or undercatch of the TAC to be carried over between fishing seasons.

TACs are almost always based on the RBCs that were generated by the assessments and harvest strategy control rules, and adjusted by meta-rules. However, there have been situations where assessments are not accepted, resulting in TACs being based on other considerations or 'rolled over' from a previous year. In 2011, for example, SlopeRAG did not accept the 2011 assessment of pink ling (AFMA 2012e). Instead they recommended an interim TAC of 1000 t, which was between the long-term RBCs of the 2011 assessment and the previous assessment. Other examples include the situations described above where RBCs are considered unrealistic—mirror dory, or where Tier 3 and Tier 4 assessments have produced quite different RBCs. The 2012–13

TAC for redfish was based on Tier 3 assessments undertaken in 2009, so the more recent concerns about the robustness of assessments should also apply to this TAC. The policy does not provide guidance on setting TACs in the absence of an agreed assessment, other than the policy's guidelines advocating a risk-management approach where exploitation rates are reduced as uncertainty around stock-status increases.

Multiyear TACs

Multiyear TACs have been introduced for several species that have shown stable fisheries and stock status for recent periods. Multiyear TACs are intended to reduce assessment costs and provide the fishing industry with stability and certainty about medium-term catch levels. Stokes (2010) proposed general criteria for selecting stocks that might be eligible for multiyear TACs. As yet, an interannual TAC discount has not been applied to take into account the increasing uncertainty in stock status with time since the last assessment. However, multiyear TACs are usually set at lower levels than single-year TACs, to account for increasing uncertainty.

Despite indications of recent stability in stock status, it remains possible for stocks to change unexpectedly as a result of environmentally induced changes in productivity (e.g. unusually strong or weak-year classes recruiting to the fishery). This can result in the stock status moving outside the range predicted by stock assessments, necessitating a re-estimation of the RBC. There is also potential for fishing mortality to increase above expected levels, even though Commonwealth catches remain within the multiyear TAC, as a result of increases in state catches of the species during the period. Additional breakout rules are intended to cater for unexpected situations. For example, the standardised CPUE for silver warehou, for which a multiyear TAC had been established, declined below the lower 95 per cent confidence interval of CPUE predicted by the Tier 1 stock assessment in 2011. This triggered a full update of the Tier 1 assessment, which indicated a decline in stock biomass and resulted in an RBC reduction of 22 t. Application of the small change limiting rule resulted in no change to the TAC (AFMA 2012e).

Rebuilding stocks

For all tiers, the RBC is recommended to be zero where the indicator is below the limit reference point (i.e. the species is classified as 'overfished'). This reflects the Commonwealth Fisheries Harvest Strategy Policy's requirement for no targeted fishing on overfished stocks and the need to reduce fishing mortality to a level that facilitates rebuilding within required timeframes. Incidental catch allowances are set in the CTS to cover the unavoidable bycatch of rebuilding stocks that may occur when fishers are targeting other species. The SESSF framework does not specify guidelines for setting incidental catch allowances and, in some cases, this allowance may be above the levels estimated by assessments that would allow recovery of the stock in accordance with the adopted rebuilding strategy (e.g. school shark). Companion species analyses (Klaer 2011a) have been used to determine the proportion of the catch of a species that is targeted. Other, more sophisticated analyses are being developed where it is particularly important to assess the level of any residual bycatch—for example, school shark and blue warehou (Klaer 2012c, AFMA 2013b).

Whereas unavoidable bycatch needs to be provided for, the main driver should be ensuring that the level of fishing mortality, including discards, allows rebuilding of the stock within the acceptable timeframes. Projections from eastern gemfish assessments, for example, suggested that there was a low probability of rebuilding to the limit reference point within the specified timeframe if total fishing mortality is 100 t—the recommended incidental catch allowance. However, these projections were potentially optimistic in assuming that recruitment rates will return to levels predicted from the stock–recruitment relationship. There was also concern that recent fishing mortality (landings and discards) for eastern gemfish has been double the incidental catch allowance (Woodhams et al. 2012).

Additional measures might be needed to reduce fishing mortality where assessments suggest that rebuilding is not occurring under current management arrangements or that rebuilding is unlikely to occur within the specified timeframe. The process should be guided by the rebuilding needs of the stock. AFMA and industry have worked to substantially reduce the catch of these stocks through a range of mechanisms, in addition to the incidental catch allowance. Ultimately, however, an effective reduction of fishing mortality for rebuilding stocks is crucial to ensure that overfishing does not continue and reductions in the catches of associated species may be required.

Projections of the eastern, western and southern stocks of orange roughy indicated that those stocks may take many years to recover despite no commercial catches. However, recent evidence suggests that eastern orange roughy may recover sooner than expected

Management strategy evaluation and testing

Harvest strategies developed under the SESSF framework have been subject to extensive MSE. Rather than evaluating one or more tiers for every stock, the MSEs have covered species that are typical of particular life histories, data availability or fishery types. For example, Wayte (2009) tested Tier 1 harvest control rules for three types of species: a short-lived, highly productive species with high recruitment variability (whiting); a very long-lived species with low natural mortality (orange roughy); and a species between these two extremes (flathead). Wayte evaluated the performance of harvest control rules in moving biomass away from limit reference points and towards targets, and demonstrated that the framework was robust to uncertainties in data inputs and assessment approaches.

Klaer & Wayte (2012) went further by determining what levels of data collection were required to meet the policy's objectives. They concluded that all SESSF harvest strategies achieved the objective of not allowing the stock to fall below the limit reference point more than 10 per cent of the time. Klaer & Wayte (2012) reported that the harvest strategies were robust to spatial substructuring and the sampling bias that may derive from such substructuring.

Harvest strategy application

Species and stocks

The SESSF framework applies to all sectors and all species or stocks under quota in the SESSF, as well as western gemfish. Harvest strategies were developed and implemented for all 27 CTS quota species by the 2008 deadline. Initially, each of the 27 quota species was assessed every year. As assessments have stabilised, it has been possible to set multiyear TACs for some species, so that assessments and harvest strategies are not run every year.

The framework is usually applied to each individual stock. For groups of species that are managed through a single TAC, the framework is applied to the entire group of species (e.g. 'other oreodories').

Several 'single species stocks' actually consist of multiple species. For example, the 'flathead' catch is mostly tiger flathead (*Neoplatycephalus richardsoni*), but it also includes several other flathead species. The assessment uses biological parameters derived from tiger flathead, but the RBC calculation is based on catches of all flathead species and the TAC applies to the species mix. This is justified by the relatively low proportion of other flathead species in the catch (AFMA 2013b). There is a need to regularly verify that other flathead species do not comprise a significant proportion of the catch.

For several species (e.g. jackass morwong), two or more stocks are managed under a single TAC. In this situation, the harvest strategy framework (including assessments) is usually applied separately to each stock and a single TAC is subsequently derived from the sum of those RBCs.

Harvest strategies are applied to several species (e.g. john dory) that are rarely targeted, but are frequently caught by trawlers fishing for other commercial species. Harvest strategies or reference points have not been developed for byproduct species, such as angel sharks, gurnards and ocean jacket. However, ShelfRAG has monitored the CPUE of ocean jacket since 2010, as this species has contributed substantial catches at times and is often discarded in large quantities. In recent years, ocean jacket was the fishery's tenth most important species by volume, with landings averaging 230 t per year.

Tier level
The RAGs explicitly decide which assessment approach, and thus which tier level, is to be used for each species. This is largely based on a consideration of data availability and model fits. The decision on the tier level to be used is made before RBCs are generated. CSIRO has developed an automated system of classifying whether age, size and discards data are representative of each time–area strata for each species to help guide the tier selection process (Upston & Klaer 2012).

Tier 4 assessments are routinely conducted for all Tier 3 species, to inform conclusions on biomass status (they complement the estimates of fishing mortality provided by the Tier 3 analyses). Those comparisons have produced very different RBCs for several species, including john dory, mirror dory and redfish. In principle, Tier 3 catch-curve analyses incorporate a wider range of data types than Tier 4 CPUE-based assessments. However, catch-at-age data can also be non-representative, particularly where few samples are collected. The RBC is calculated as the current catch multiplied by the ratio of the target and current fishing mortality rates, but it has been found that as the current fishing mortality rate approaches zero, the ratio exponentially increases to infinity (Klaer 2012a). The resulting high RBCs are not regarded as sustainable or achievable; they merely indicate that higher catches are possible in the short term. In the case of john dory and redfish, the Tier 3 RBCs were not accepted. Instead, the 2011–12 TACs were rolled over to the next fishing season while further assessment work was attempted.

Timing of assessments
There is a time lag of 12 months or more between data collection and setting TACs for the next fishing season. For example, fisheries data for 2010 are not available for analysis until mid-2011; assessments are completed and RBCs are recommended in late 2011, and TACs for the 2012–13 fishing season are then confirmed before the season commences in May 2012. Application of the latest CPUE multiplier rule is intended to alleviate this problem. For several species, Tier 1 models are used to predict status in subsequent seasons, although the reliability of predictions depends on assumptions about the value of projection parameters in the intervening period (e.g. catch levels, recruitment).

Short-lived species, like eastern school whiting and blue warehou, present further challenges to the policy's application. Estimates of eastern school whiting biomass have varied considerably between successive assessments, largely as a result of whiting's late age of recruitment to the fishery (2–3 years) and variability in recruitment for this short-lived species (7 years; Day 2012). Consequently, ShelfRAG has based RBCs for this species on analyses of the performance of different levels of fixed catch for an 18-year projection period. With a constant catch of 1700 t per year, for example, the probability of the spawning stock biomass falling below the $0.20B_0$ limit reference point was less than 10 per cent (Day 2012). ShelfRAG recommended a long-term RBC of 1660 t for 2012–13 because of uncertainty in biomass estimates and to minimise TAC variations (AFMA 2012a). This approach is consistent with the Commonwealth Fisheries

Harvest Strategy Policy, but its performance in maximising economic yields and preventing overfishing will depend on whether the model projections encapsulate the full range of uncertainty in population dynamics and the stock's responses to fishing.

In 2010, ShelfRAG recommended a two- or three-year TAC for flathead, and the South East Management Advisory Committee subsequently supported a two-year TAC. Good catches were reported in subsequent years and the multiyear TAC's break-out rules were not triggered. An assessment was not conducted in 2012 because of budget constraints. Without an assessment, ShelfRAG was not prepared to vary the TAC, so the recommendation was to rollover the existing TAC for a third year (AFMA 2013b). The policy requires harvest strategies to reflect a precautionary approach, with increasing uncertainty in assessments resulting in increasingly conservative management. However, a discount was not applied to the flathead TAC to take into account the increasing uncertainty in stock status with time since the last assessment. For flathead, the inability to undertake an assessment may have resulted in biomass exceeding the target reference point and the fishery foregoing potential catches. Guidance on setting TACs in the absence of assessments may also be required in situations where biomass is in danger of falling below a reference point.

Modifications
In 2008, the harvest control rules for Tier 3 and Tier 4 were altered to ensure that the target and limit reference points were consistent with the requirements of the Commonwealth Fisheries Harvest Strategy Policy. Smith (2009) identified improvements to the framework's harvest control rules, including discount factors between tiers, inflexion points between reference points and changes to control rules to avoid potential unintended 'ratchet effects'. His recommendations were evaluated with further MSE testing. In 2010, the cap on the maximum catch was removed from the Tier 4 harvest control rule because it could sometimes have unintended consequences and that the 50 per cent change limiting rule was sufficient. In 2012, CSIRO proposed a threshold to limit the size of the RBC multiplier produced by Tier 3 assessments. This involved assigning the current fishing mortality rate to be the Tier 3 estimate or 10 per cent of the species' natural mortality rate (M/10), whichever was the smallest value (Klaer 2012a).

Fishery performance

Biological status

The status of many quota species in the CTS improved following the structural adjustment and the implementation of harvest strategies. During 2007–2011, the number of CTS stocks classified as above the $0.20B_0$ limit reference point ('not overfished') increased from 10 to 15, and the number of stocks classified as 'uncertain' declined from 11 to 6 stocks (Woodhams et al. 2012).[4] The number of stocks classified as 'overfished' remained at six during this period. The status of five of the overfished stocks remained unchanged; one stock (smooth oreodory) moved from 'overfished' in 2007 to 'not overfished' in 2011, while the biomass status of blue warehou was classified as 'uncertain' in 2007 and then subsequently classified as 'overfished'.

The reclassification of biomass status from 'uncertain' to 'not overfished' cannot be directly attributed to the implementation of the harvest strategy framework. Instead, it is likely due to

[4] Woodhams et al. (2012) also report on the status of ocean jacket, but this species is not included in these statistics because it is not under quota and not managed through a harvest strategy.

improved data and assessments. Nevertheless, harvest strategies are likely to have contributed to the reclassification of all five of those uncertain stocks as 'not overfished'. Similarly, harvest strategies have probably helped to maintain many stocks as 'not overfished' during 2007–11 by preventing their biomass from falling below limit reference points.

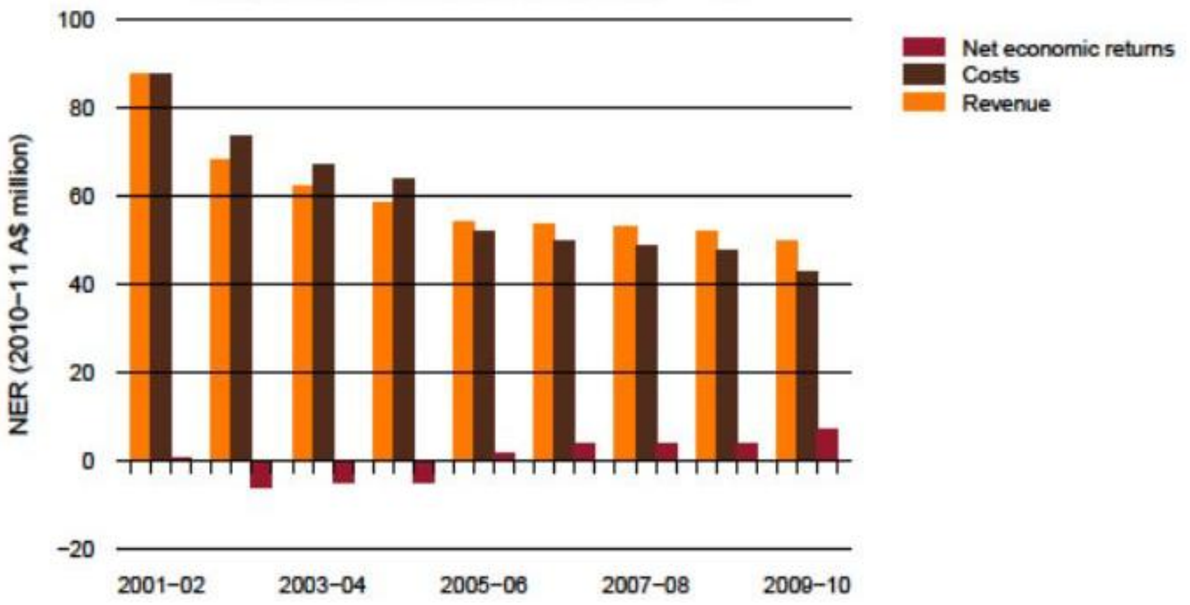
Furthermore, harvest strategies have been used in this fishery since 2005, and status shows improvements since then. In 2005, 10 CTS stocks were classified as 'not overfished' (compared to 15 in 2011), 7 were classified as 'uncertain' (6 in 2011) and 10 were 'overfished' (compared to 6 in 2011; Woodhams et al. 2012).

Blue warehou has been classified as 'overfished' since 2008 ('uncertain' in 2007), whereas oreodories, which were previously classified as 'overfished', have been classified as 'not overfished' since 2008. Several other CTS stocks have classified as 'overfished' since before the implementation of harvest strategies, including eastern gemfish, gulper sharks and orange roughy in all zones except the Cascade Plateau (Woodhams et al. 2012).

Economic performance

NER in the CTS have been estimated each year since the late 1990s. Overall costs and revenues steadily declined in the early 2000s (Figure 2). However, these stabilised after the 2006 structural adjustment, which resulted in a substantial reduction in the number of vessels and fishing effort. NER (profits) were negative in this fishery before structural adjustment, then positive in 2005–06 and have continued to increase since then (Figure 2). While it is difficult to separate the effects of harvest strategy implementation from the effects of the structural adjustment, both initiatives are likely to have contributed to this fishery's improved biological status and economic performance.

Figure 2 Trends in the economic performance of the Commonwealth Trawl Sector



Note: NER = net economic returns

Source: Woodhams et al. (2012)

This conclusion is confirmed by Skirtun and Vieira (2012), who show that improvements in CTS profits are partly a result of improved economic productivity. They note that improvements in recent years are consistent with regulatory and structural change in the fishery. These include the structural adjustment and harvest strategies, with stock biomass of most key species being maintained at, or moving towards, B_{MEY}. Skirtun and Vieira conclude that the CTS is likely to have moved towards MEY.

Similar fisheries

All Commonwealth trawl fisheries are multispecies fisheries, targeting a suite of key commercial species, and also catching less valuable 'byproduct' species. Case studies are provided in this report for two other trawl fisheries—the Great Australian Bight Trawl Sector and the Western Deepwater Trawl Fishery. The challenges with implementing the policy in these trawl fisheries apply similarly to the North West Slope Trawl Fishery and East Coast Deepwater Trawl Sector. Optimising MEY across all species in such fisheries is difficult. The tiger prawn subfishery of the Northern Prawn Fishery and the Great Australian Bight Trawl Sector are the only Commonwealth fisheries that have attempted to optimise MEY across commercial species, and both those fisheries target a relatively small suite of commercial species.

Conclusions

The CTS has successfully developed and implemented harvest strategies for 27 stocks, which cover a wide range of economic value, productivity, biological status and assessment uncertainty. The harvest strategies have been tested; they are well documented and are largely consistent with the Commonwealth Fisheries Harvest Strategy Policy. The harvest strategies have become central to the fishery's management, being used as the basis for setting annual TACs and for reporting biological status. The harvest strategies are likely to have contributed to the improvements in stock status, the fishery's economic performance, efficiency, certainty and transparency of fisheries management, and stakeholder confidence in management arrangements since 2005.

Many of the problems encountered in implementing the policy in the CTS are related to uncertainty in assessments for data-poor species. Uncertainties in assessments of many Tier 1 species are better understood. The uncertainties in Tier 1 assessments largely stem from data quality and the reliance on commercial CPUE as the prime index of abundance.

Additional guidance may be required on the application of discount factors that take into account uncertainty that is inherent in the different assessment methods, in multiyear TACs and in the increasing uncertainty with the time since the last assessment.

For key commercial species, there is potential to improve economic performance with the estimation of B_{MEY} rather than using the default proxies. Augmenting current stock assessments with economic survey data to generate bioeconomic models may provide a cost-effective means of achieving this. The results of work aimed at developing target reference point proxies for data-poor fisheries (Zhou et al. 2012) may present other options.

The Commonwealth Fisheries Harvest Strategy Policy states that 'maximising the profit of the combined catch … may be a complex task given the uncertainty of the catch composition between shots or seasons, but is one that must be faced irrespective of the [target reference point]' (DAFF 2007). Target reference points for individual species that are consistent with fishery-wide MEY are yet to be developed for this fishery. In the interim, the CTS has begun to consider B_{MSY} and $0.40B_0$ as proxy targets for low-value commercial species in recognition of the fact that the fishery's performance against an MEY objective is driven mainly by its key commercial species.

Great Australian Bight Trawl Sector

Fishery characteristics

The Great Australian Bight Trawl Sector (GABTS) is part of the SESSF. In shelf waters, trawling is usually conducted at 120–160 m, targeting mainly deepwater flathead and Bight redfish. For upper continental-slope trawling, other target species include blue grenadier, western gemfish and pink ling, though there has been relatively little fishing at these depths in recent years. Key byproduct species include ocean jacket, angel shark, yellow-spotted boarfish and jackass morwong. Substantial discarding is reported for some of these byproduct species.

The GVP in the GABTS was $11.1 million in 2010–11 (real terms, 2010–11 dollars). Of this, deepwater flathead contributed $6.7 million (60 per cent of total GVP) and Bight redfish contributed $1.5 million (13 per cent). After the 2006–07 peak ($20.2 million), GVP declined substantially to $9.5 million in 2008–09 recovering only slightly in 2009–10 to $12.1 million.

The deepwater component of the GABTS historically targeted orange roughy. In 1988, 68 per cent of the GABTS total effort was on the continental slope. However, there is now little effort at these depths, following the listing of orange roughy as conservation dependent under the *Environment Protection and Biodiversity Conservation Act 1999* and the 2007 closure of most of the orange roughy fishing grounds (> 750 m depth).

The NPF and GABTS are the only Commonwealth fisheries that estimate of B_{MEY}, rather than the policy default target of $1.2B_{MSY}$.

Harvest strategy attributes

Background

The Commonwealth Fisheries Harvest Strategy Policy has been implemented in the GABTS using the SESSF's harvest strategy framework, described the in CTS chapter, since 2008 (AFMA 2009a). In brief, the framework includes three assessment tiers with associated control rules. The rules are designed to enable stock assessments and management advice at different levels of data quality or knowledge about the stock. Each tier of the framework consists of a collection of formulas (harvest control rules) that use the levels of different indicators (fishing mortality rates or indices of biomass) relative to reference points to derive an annual RBC. To date, only Tier 1 and Tier 4 assessments have been used in the GABTS.

Reference points and indicators

Since the implementation of the Commonwealth Fisheries Harvest Strategy Policy, the target for deepwater flathead and Bight redfish has been the policy proxy of MSY × 1.2 ($0.48B_0$), with a limit reference point of $0.2B_0$. However, a study has been conducted by the Australian National University and the CSIRO using a bioeconomic model to estimate B_{MEY} for the two primary target species in the GABTS—Bight redfish and deepwater flathead (Kompas et al. 2012). The multispecies bioeconomic model estimated target reference points of $0.43B_0$ for deepwater flathead and $0.41B_0$ for Bight redfish. The estimated B_{MEY} target for Bight redfish was accepted by the Great Australian Bight Resource Assessment Group (AFMA 2011b) and used to set the TAC for the 2012–13 fishing season. The estimated B_{MEY} target for deepwater flathead was used to set the RBC for the 2013–14 fishing season. The MEY targets developed for the GABTS are static (calculated at a simple point in time) and no integrated model has been developed to allow the regular recalculation of MEY through time.

In addition to Bight redfish and deepwater flathead, catches of orange roughy, school shark, gummy shark, sawshark and elephant fish are managed through TACs derived from the SESSF framework. Consistent with the Commonwealth Fisheries Harvest Strategy Policy, RBCs for these species are based on achieving a default target reference point of $0.48B_0$ as a proxy for B_{MEY}.

The GABTS has implemented a development strategy for species not currently under a TAC, with increasingly stringent, tiered data collection and assessment processes occurring at specified catch triggers (AFMA 2008). This strategy is designed to improve information and assessment as catch increases. Species currently under catch triggers in the GABTS are western gemfish, blue grenadier, ling, blue-eye trevalla, ribaldo and hapuka. For species such as ocean jackets, which was the third highest species by weight caught in the GABTS in 2011, there is no harvest strategy or triggers to manage catches, or any requirement for stock assessment or review.

Harvest control rules

The SESSF Harvest Strategy Framework, which is described in the CTS chapter, is applied to the GABTS and includes general control rules such as the latest CPUE multiplier rule, and the large and small change limiting rule. Multiyear TACs have been implemented for Bight redfish and deepwater flathead, with breakout rules based on the results of annual fishery-independent trawl surveys or, where these are not available, standardised CPUE. These rules also set the conditions under which a full stock assessment would be required earlier than the predetermined interval (AFMA 2008). The current TAC for Bight redfish is set for three years, and assessments are updated every second year. Deepwater flathead are moving from a two-year TAC to a single-year TAC for the 2013–14 fishing season.

Quantitative Tier 1 assessments are conducted for deepwater flathead and Bight redfish in the GABTS, which estimate biomass and fishing mortality rates for these important target species. Fishery-independent surveys also provide estimates of relative abundance and are used in the Tier 1 assessments. The surveys have been completed each year since 2005, except in 2010 and 2012. The Tier 1 assessments account for fishing mortality from the GABTS and there appears to be no other Commonwealth fisheries that catch either species. However, Bight redfish are caught in commercial and recreational fisheries in Western Australia. It is believed that the level of catch in both those sectors is low, but the Western Australian Department of Fisheries has a project underway to confirm this.

Orange roughy in the GABTS are managed under the *Orange Roughy Conservation Programme* (AFMA 2006), which determines research and incidental catch allowances for various fishing zones within the GABTS.

Management strategy evaluation and testing

The CTS chapter describes the MSE of the SESSF framework. The types of species covered by that testing are analogous to the commercial species in the GABTS and the conclusions are broadly applicable to the GABTS. The flathead-like species modelled by Wayte (2009) is likely to be a good proxy for deepwater flathead, with Bight redfish sitting somewhere between flathead and a species like orange roughy.

Harvest strategy application

Harvest strategies have been implemented for the two main target species (deepwater flathead and Bight redfish). There are no harvest strategies for lower value species such as ocean jacket, western gemfish, pink ling, blue grenadier and angel shark, though catch triggers are in place for some of these species.

Several GABTS species are also taken in other Commonwealth fisheries and it is uncertain whether they are part of the same stock harvested in the GABTS. For example, gemfish are captured in the CTS and GABTS, and it remains unclear how many stocks are fished by these fisheries and where the boundaries between the stocks lay. There is a need to resolve stock structure or to at least the sensitivity of assessments to uncertainty in stock structure.

Fishery performance

Both target species are assessed to be above B_{MSY} (Klaer 2011b, 2012b), with deepwater flathead just below the B_{MEY} target and Bight redfish well above B_{MEY}. Both stocks have been in a 'fish down' to target, which is consistent with the policy. However, in 2010 it became apparent that deepwater flathead have been depleted through the late 1990s and again in the mid 2000s to around B_{LIM} (Klaer 2010a). The stock was most likely subject to overfishing at this time but was only identified be the assessment after the event. The stock has since recovered to within an acceptable range of the target. Bight redfish are technically in a fish-down phase to B_{MEY}. However, given the small market for Bight redfish, market prices are highly sensitive to supply and so industry has implemented self-imposed trip limits to control the supply of Bight redfish to markets.

The *Fisheries status reports* have classified deepwater flathead and Bight redfish as not overfished and not subject to overfishing since 2007. The 2010 assessment (Klaer 2010a) suggested that deepwater flathead was above both B_{MSY} and B_{MEY}. However, the 2012 assessment (Klaer 2012b) suggested that the stock has decreased to just below the target $0.37B_0$. The Klaer (2009) and Klaer (2011b) assessments both indicate that Bight redfish are well above both B_{MSY} and B_{MEY}.

Orange roughy stocks in the GABTS appear to have been depleted during the 1980s (Woodhams et al. 2012), well before the implementation of the policy. Implementation of harvest strategies for these stocks has probably prevented further overfishing, but rebuilding is likely to take decades. Reduced data may result in increasing uncertainty in assessments. Limited data on biomass results in orange roughy in the GABTS being classified as 'uncertain' as to whether this stock is overfished. The species remains depleted throughout much of the CTS.

Estimates of NER for the GABTS are not available. However, in comparison to other fisheries, it generates a relatively high GVP with relatively few vessels. This suggests that the sector is likely to be achieving positive NER. Following a peak in the sector's real GVP in 2006–07 of $20.2 million in 2006–07 (2010–11 dollars), GVP has declined to $13.9 million in 2007–08 and $9.5 million in 2008–09. Since then, GVP has recovered slightly to $11.1 million in 2010–11. While rising fuel prices in recent years have negatively affected profitability, increases in fish prices have counteracted this impact. Relatively lower effort levels in 2010–11 suggest that NER may have improved, but recent reports of low fish prices, high fuel prices and reduced stock availability in 2011–12 (Great Australian Bight Fishing Industry Association, pers. comm., 2012) suggest reduced profitability.

As discussed above, the most recent stock assessments indicate that the biomass of key species is above or close to B_{MEY}. As noted by Kompas et al. (2012), the accuracy of the MEY target for each species could be improved with better information on how prices for each species are influenced by catch levels. However, assessment results indicate that the economic performance of the fishery is not constrained by stock biomass and that, depending on the sensitivity of prices to supply, there may be potential for increased profits. Given that the bioeconomic model was only recently completed, it is too early to assess its impacts on the sector's economic performance.

Overall, changes in GVP and profitability in the GABTS since the introduction of the sector's harvest strategy are likely to have resulted more from external factors (output and input prices) rather than as a result of improved TAC setting under the sector's harvest strategy.

Similar fisheries

Case studies are provided in this report for two other trawl fisheries—the Western Deepwater Trawl Fishery and the CTS. Implementation of the Commonwealth Fisheries Harvest Strategy Policy in the GABTS has many issues in common with the CTS. The challenges with implementing the policy in these trawl fisheries apply similarly to the North West Slope Trawl Fishery and East Coast Deepwater Trawl Sector. Optimising MEY across all species in such fisheries is difficult. The NPF is the only other Commonwealth fisheries that have attempted to optimise MEY across key commercial species.

Conclusions

The GABTS harvest strategy appears to work well for stocks that are commercially important and are regularly assessed. The implementation of the bioeconomic model for this fishery was delayed, but it has produced harvest strategy targets that have been accepted for management decision-making. The utility of the model outputs would have been further improved if it was a fully integrated assessment with the ongoing Tier 1 assessments, allowing for regular updates of MEY estimates. The development process may have been improved, had issues around price sensitivities for Bight redfish been identified earlier and captured in the model. It highlights the importance of getting the model right initially for lower value fisheries where the funding to continually update and revise a model may not be available or justified.

For GABTS stocks that are less valuable, but consistently targeted, there is little if any biological or economic assessment. Developing assessments for species that are low value, but sometimes captured in high volume, would provide additional certainty for these stocks. However, the benefits from having greater certainty need to be balanced against the costs of undertaking such assessments.

Shark Gillnet and Shark Hook sectors

Fishery characteristics

The Shark Gillnet and Shark Hook sectors (SGSHS) operate in southern Australia, targeting sharks. These sectors of the SESSF generated a GVP of $16.5 million in 2010–11. The key target species of today's fishery is gummy shark, valued at $14.6 million in 2010–11. Key byproduct species include sawshark and elephant fish. Elephant fish are also a popular target of recreational anglers. School shark was historically the key target of the commercial fishery, but this changed as the biomass was fished down (Thomson & Punt 2009). School shark has been classified as 'overfished' and subject to overfishing in the *Fishery status reports* since 2009 (Woodhams et al. 2012). It is currently listed as conservation dependant under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and is subject to a rebuilding strategy.

The SGSHS is a key component of the Gillnet, Hook and Trap Sector (GHaT), accounting for around two-thirds of the GHaT's GVP. The Scalefish Hook Sector makes up the remainder. The GHaT has consistently generated positive net economic returns over the last decade.

Most of the catch in the SGSHS is taken with gillnet fishing gear. Longline fishing gear is used by a relatively small number of operators. Operations in the gillnet component of the fishery have been increasingly impacted by measures to reduce interactions with species protected under the EPBC Act, particularly Australian sea lion and dolphins. A system of spatial closures is in place in the fishery to reduce these interactions. Closures exist around sea lion colonies and catch triggers are in place to trigger further closures, based on the level of interactions. Additionally, a large area in waters of South Australia (27 239 km^2) has been closed since September 2011 as a result of increased detection of dolphin interactions in that area.

Harvest strategy attributes

Background

The SESSF Harvest Strategy Framework (HSF), which is described in the SESSF Commonwealth Trawl Sector chapter, applies to the SGSHS. RBCs from assessments are implemented through RAG, MAC and AFMA Commission processes as TACs for the four key commercial species—gummy shark, school shark, sawshark and elephant fish.

TACs were first implemented in the SGSHS in 2001. Fully quantitative, Tier 1–style assessments have informed the setting of TACs in the fishery for gummy shark and school shark since this time. Tier 4 assessments were first undertaken for elephant fish and sawshark in 2009.

Implementing the harvest strategy is becoming increasingly difficult in this component of the SESSF. The robustness of the school shark assessment is impacted by the availability of reliable catch-and-effort data for the species. The Tier 4 assessments for sawshark and elephant fish are not currently believed to be reliable. The RBC for gummy shark has been rolled over since its initial estimation implementation for the 2011–12 season.

School shark are often caught in association with gummy shark, so the ability of the fishery to limit catches of school shark to levels that will allow recovery is impacted by the level of effort dedicated to catching gummy shark.

Management arrangements related to gear and spatial closures that have been introduced to manage interactions with protected and listed species, such as school shark, are likely to affect data for stock assessments. Furthermore, these measures are likely to be having an impact on the profitability of the fishery for gummy shark.

Reference points and indicators

School shark is under a rebuilding strategy, which aims to rebuild the stock to the limit reference point within a 'biologically meaningful timeframe'. The policy's proxies for reference points are used for gummy shark ($0.48P_0$), elephant fish and sawshark. For gummy shark, the unfished biomass is expressed as 'equivalent pup production'.

Gummy shark and school shark are assessed through the equivalent of Tier 1 stock assessments. Elephant fish and sawshark are assessed as Tier 4 stocks within the SESSF HSF.

Harvest control rules

Control rules for gummy shark, elephant fish and sawshark are the same as those discussed under the SESSF HSF in the SESSF Commonwealth Trawl Sector case study. The RBC from the 2010 gummy shark assessment was first implemented in the 2011–12 season. There has been no updated assessment since 2010 and the RBC is likely to be rolled over for the second time for the 2013–14 season (first rolled over in 2012–13). The impacts of spatial management, gear changes and avoidance are yet to be fully considered within the assessment framework.

The RBC for school shark is currently zero. A rebuilding strategy for school shark has been in place since 2008. The most recent (2009) stock assessment indicates that biomass is below the limit reference point (8–17 per cent of initial pup production across models). This assessment indicated that catches of 26 t or less would be required to rebuild the stock to the limit reference point ($0.20P_0$) within 32 years.[5] Reported catch has been substantially above 26 t since the implementation of the rebuilding strategy, with 163 t reported in the 2011–12 fishing season (Woodhams et al. 2012). As school shark are now a byproduct species (contributing around $1.2 million or 9 per cent of the value of the fishery in 2010–11), taken during the course of fishing for gummy shark, school shark mortality is tied to effort directed at gummy shark. The 2009 assessment was rerun in 2012, with updated catch data and allowing the model to estimate productivity (as opposed to being a fixed value in earlier assessments). This rerun predicted catches of about 125 t would allow recovery in 32 years. The reliability of this re-assessment is expected to be evaluated by the RAG in 2013.

Bycatch TACs for school shark have been falling year on year and were 150 t in 2012–13. At its last meeting, SharkRAG discussed increasing the bycatch TAC to accommodate the total incidental catch of the stock (including an estimate of discards).

The active avoidance of school shark (and, to some degree, elephant fish and sawshark) in the fishery, changes to gear and recent spatial management controls have affected the reliability of CPUE data and assessments, and the ability of research agencies to undertake assessment updates.

---

[5] 32 years is not specified in the rebuilding strategy as the timeframe to reach the limit reference point, one mean generation time plus ten years (equaling 32 years in the case of school shark) is a 'typical' recovery timeframe provided for by the Commonwealth Fisheries Harvest Strategy Policy. SharkRAG will be discussing the appropriateness of this rebuilding timeframe during 2013.

The RBCs for sawshark and elephant fish have historically been set using the Tier 4 assessment methodology. SharkRAG has expressed concern over the reliability of the Tier 4 assessments in recent years (2011 and 2012) due to the ability of the standardisation process to account for avoidance behaviour of fishers and has not accepted the outcomes (RBCs) from these assessments.

The RAG has discussed using alternative targets for secondary or byproduct stocks. ShelfRAG and South East Management Advisory Committee are likely to consider appropriate targets for byproduct species in coming years.

Management strategy evaluation and testing

There has been no formal MSE or testing of the gummy shark and school shark assessments and harvest strategies. The harvest strategy framework of this fishery is the same as that for the broader SESSF. As such, testing of the Tier 4 methodology discussed in the SESSF CTS chapter is relevant to this fishery as well.

Harvest strategy application

Four species are currently assessed within the fishery and all are managed under the SESSF HSF. Implementation of the framework relies on an RAG-agreed assessment to suggest an RBC. Data quality issues are impacting the application of that framework for three of the four stocks. While elephant fish and sawshark may not currently be considered key commercial species for gillnet operators, they are likely to be economically important byproducts for the broader SESSF (particularly the CTS), justifying their continued assessment. Increasing proportions of the catch of these stocks are being landed by trawl operators in the SESSF in recent years. The Tier 4 assessments for elephant fish and sawshark are becoming increasingly unreliable and were not used by the RAG for RBC recommendations for the 2013–14 season.

RAG participants have expressed concern about the stock assessment for school shark. The ability of the 2009 assessment to provide a reliable indication of biomass of the stock has been questioned, and a number of members and observers on the RAG do not consider the assessment to be reliable. This has implications for understanding and agreeing on the status of the stock, and recommending future catch levels.

Fishery performance

The biological status of gummy shark and sawshark remains unchanged since the introduction of the SESSF HSF (2005) and the Commonwealth Fisheries Harvest Strategy Policy (2007). School shark has been classified as 'overfished' since ABARES commenced reporting status in 1992, except in 2004 when it was classified as 'uncertain' (Woodhams et al. 2012). School shark has been classified as 'subject to overfishing' since 2009. Measures implemented under the framework and policy have not achieved demonstrable rebuilding of this stock. Elephant fish was first classified as 'not overfished' and 'not subject to overfishing' in 2009, having previously been classified as 'uncertain'. The development of a Tier 4 assessment (under the SESSF HSF) for this species informed this change in status. However, further deterioration in data availability may affect the status classification of the elephant fish in coming years.

NER in the GHaT (including the scalefish line sector) have been positive since 1999–2000 and particularly strong in recent years. In real terms, the average NER between 1998–99 and 2006–07 were $1.4 million (2010–11 dollars). NER increased from $1.6 million in 2006–07 to $4.3 million in 2007–08, before peaking in 2008–09 at $6.3 million. Preliminary (nonsurvey based) estimates indicate that NER in 2009–10 decreased to $2.2 million. These increases in NER occurred at around the same time as the introduction of the HSF (2005) and the

Commonwealth Fisheries Harvest Strategy Policy (2007). However, the 2006 structural adjustment package probably increased profitability as well.

A profit decomposition of the gillnet sector of the GHaT (Skirtun & Vieira 2012) showed that the key driver of recent profitability in the sector was improved economic productivity. This was primarily linked to the structural adjustment package, which is likely to have removed the least efficient vessels from the sector (Skirtun & Vieira 2012). Stable TACs and biomass for gummy shark suggest that the harvest strategy's contribution to the improvement in profitability may have been minimal.

Gummy shark is the current driver of the sector's overall economic performance. The most recent assessment indicates that the biomass of subpopulations is close to, or above, the target reference point (Punt & Thomson 2011). If the target (the policy proxy of B_{48}) accurately reflects B_{MEY} for this species, this would suggest that biomass is not currently constraining NER and that there may be potential for greater NER to be earned in the sector. However, this could well be at the expense of recovery of school shark.

School shark was the second most valuable species in the sector in 2010–11. If school shark stocks could be rebuilt towards target levels, it is possible that higher NER could be earned in the sector. However, realisation of the economic benefits from efforts to rebuild the stock may take some time, given the low productivity of the species.

Reducing marine mammal interactions in the sector is likely to continue to affect future economic performance, particularly as a result of excluding the fishery from certain areas.

Similar fisheries

There are a number of other Commonwealth-managed stocks where incidental catch allowances are set at the level of unavoidable catch while targeting other species, including eastern gemfish and blue warehou. The policy does not currently provide guidance on how such stocks should be managed.

There are a number of stocks and fisheries where changes in gear, the spatial extent of the fishery, availability of quota, discard levels or avoidance by fishers has impacted the ability of the RAG to develop indices of abundance, undertake assessments and derive defensible recommendations on fishing mortality levels. The majority of stocks for which this issue has been discussed are either Tier 3 or 4 stocks, or stocks that have been or continue to be overfished.

Conclusions

Fishing for the primary target species (gummy shark) in the SGSHS in recent years has made it difficult to control mortality levels of school shark. A rebuilding strategy has been agreed for school shark, and it is informed by stock assessment outcomes. Incidental catch allowances for school shark in recent years have been set at the level of the unavoidable catch when targeting gummy shark. The Commonwealth Fisheries Harvest Strategy Policy needs to provide more guidance on how mortality levels for overfished stocks should be set, when constraining the catch of these overfished stocks is likely to impact fishing for other key species.

The indices of abundance for several SGSHS stocks are no longer considered to be reliable. Further guidance is needed on the criteria for considering whether an abundance index is reliable and how to recommend catch levels in the absence of a robust assessment.

Management intervention to address the bycatch of marine mammals is affecting how and where the fishery operates. This is likely to impact the fishery's profitability. It may also concentrate fishing effort in areas with no closures or force fishers to use different gear types with different selectivity characteristics. The effects of these management interventions on stock assessments should be explored.

Western Deepwater Trawl Fishery

Fishery characteristics

The Western Deepwater Trawl Fishery (WDTF) and North West Slope Trawl Fishery (NWSTF) are Commonwealth fisheries that operate off the coast of Western Australia. The WDTF has no clear target species but can be characterised as a byproduct/mixed-species fishery taking a wide range of species in low volumes (Moore et al. 2007a, b). In recent years, the WDTF has targeted bugs (*Ibacus* spp.), which now form the majority of the catch. Between one-third and one-half of the total catch is discarded, about one-quarter of which is unidentified. The WDTF is characterised by two distinct areas: north and south of 27°S (Moore et al. 2007a). The NWSTF fishes for scampi and deepwater prawns off the Kimberley Coast.

Both fisheries are predominantly opportunistic with a diverse range of vessels, making it difficult to characterise vessels, trawl types or fishing methods. There is no formal management plan; both fisheries are informally managed via limited entry and various other management measures, including catch triggers. Few vessels have operated in either fishery in recent years.

Harvest strategy attributes

Background

The GVP for the WDTF and NWSTF remain confidential due to the small number of active vessels. Because the number of active vessels in both fisheries have declined during the past decade, GVP is also expected to have declined. These characteristics require low-cost management approaches. There is little or no research funding available and the fishery is quite data poor, with almost no biological information or quantitative stock assessments. As a result, the harvest strategy for the WDTF and NWSTF relies on low-cost indicators and spatial closures rather than data-intensive and more expensive stock assessment–based approaches.

For data-poor fisheries, the policy provides requires scientifically defensible proxies for reference points and corresponding control rules that will achieve the intent of the policy. In the case of the WDTF and NWSTF, these proxies and control rules have been developed as part of the harvest strategy. When these triggers are reached in either fishery, the introduction of output controls may be required. However, this would require sufficient information to enable appropriate quota levels to be estimated and the associated costs may not be justified given the current low value of these fisheries.

Reference points and indicators

For opportunistic data-poor fisheries such as the WDTF and NWSTF, there is a high degree of uncertainty about how to define a reference point compatible with the MEY objective of the Commonwealth Fisheries Harvest Strategy Policy (Dowling et al. 2008). As an alternative, two catch triggers have been developed to invoke further data collection, analysis and reporting, should the fishery expand to reach these catch levels (AFMA 2011c). For example, when the total annual catch of a key commercial species is greater than the highest historical catch of that species (reference period 2000–10) for two consecutive years standardised, a trigger is activated. The trigger requires a standardised CPUE analysis to be undertaken for that species, and consultation with experts and review target based on the results of the CPUE standardisation. A second trigger can be activated when the total annual catch of a key commercial species is greater than two times the highest historical catch of that species (for the reference period) and the annual CPUE is greater than or equal to the average CPUE (for the reference period). This will require the same response as in trigger one combined with ongoing monitoring. If catches are two times the highest historical catches and CPUE is less than the historical average for the reference period, further measures come into play such as limiting catch and instigating quantitative stock assessments. These triggers were developed as a low-cost approach to set out a response to increasing catches in each fishery.

The limit reference points for species in the WDTF and NWSTF are based on CPUE indicators derived from the average annual nominal CPUE for a reference period. Average CPUE for this period is considered to represent a proxy for unfished biomass. Under the policy, a stock size corresponding to 20 per cent of unfished biomass is a suitable proxy.

Harvest control rules

There are no TACs set in either the WDTF or NWSTF, and both fisheries rely on catch triggers to initiate further management responses when certain catch levels are reached. The episodic and non-target nature of the WDTF can result in large changes in CPUE between years. The limit control rule should ensure that stocks stay above the limit at least 90 per cent of the time (i.e. a one-in-ten-year risk that stocks will fall below). Therefore, a management response will be triggered when the CPUE indicator breaches the limit for two consecutive years.

There is currently no RAG or management advisory group for this fishery to review data or to make recommendations to the AFMA Commission.

Management strategy evaluation and testing

An MSE approach was used to test the catch trigger harvest strategy regime for the NWSTF and WDTF, using scampi as a case study (Dowling 2011b). The majority of the scenarios successfully maintained or recovered the spawning biomass above the limit reference point, more than 90 per cent of the time as required by the policy. The exception was when the stock was assumed to have been heavily fished historically and the triggers were inappropriate for the life history of the stock (i.e. such that only Level 1 was ever triggered; Dowling 2011).

Harvest strategy application

The harvest strategy for the WDTF and NWSTF was implemented in 2008 and revised in 2011. The harvest strategy was revised as a result of cessation of a temporary closure in the NWSTF and ongoing negotiations on state–Commonwealth catch-sharing arrangements for both fisheries.

Fishery performance

The WDTF and NWSTF are low-value, low-effort, data-poor fisheries with no target reference points. Judging performance for such a fishery is difficult because there are few benchmarks for comparison. The status for three stocks assessed by the ABARES *Fishery status reports* for the WDTF has remained the same since the implementation on the harvest strategy. The status for scampi species in the NWSTF changed from ‘uncertain’ to ‘not overfished’ and ‘not subject to overfishing’ in 2009, and has remained so to date.

No economic surveys have been undertaken for the NWSTF. In 2010–11, seven permits were issued in the NWSTF, with only one vessel fishing. This indicates latent effort and potentially low NER. The lack of an explicit economic target, or supporting analyses and data means that the fishery’s performance against the economic objective is uncertain. The low value of the fishery does not justify the expense of economic surveys or assessments.

Economic surveys of the WDTF have not been conducted. The number of vessels operating in the fishery has decreased during the past decade. In 2010–11, there 11 permits were issued and only 2 operating vessels. This low effort, low catch and low activation of fishing permits in this fishery indicate that NER were likely to be relatively low.

The harvest strategy has been tested via MSE and found to be robust in the majority of cases. The fishery also has mechanisms for review and adaptation to allow it to respond to changes in catch and catch-series trends.

Similar fisheries

The WDTF and NWSTF provide examples of very low-effort, low-value and data-poor fisheries. Implementation of the Commonwealth Fisheries Harvest Strategy Policy in the WDTF and NWSTF has some issues in common with low-value, low-information secondary species caught in several other SESSF fisheries.

Conclusions

The WDTF and NWSTF harvest strategy seems appropriate given the currently low value and low fishing effort of these fisheries. The use of catch triggers that invoke a decision rule that requires progressively increased data and analysis is likely to be a low-cost and low-risk approach to managing this type of fishery. MSE showed that the harvest strategy would maintain or recover the biomass of WDTF and NWSTF stocks above the limit reference point, more than 90 per cent of the time, as required by the policy. This suggests that approach employed in this harvest strategy is valid and appropriate.

Southern Squid Jig Fishery

Fishery characteristics

The Southern Squid Jig Fishery (SSJF) targets a single species, Gould's squid using a single fishing method (jigging). The species is broadly distributed across southern and south-eastern Australia, but current information on Gould's squid genetics suggests a single stock within Australian waters. Multiple cohorts have been identified in commercial trawl catch from the SSJF management area (Virtue et al. 2011) and multiple cohorts are likely to be harvested in the jig fishery during any particular season.

Fishing effort in the SSJF tends to concentrate in a few areas of the managed waters, particularly off central and western Victoria near Queenscliff and Portland. In some years, the fishery also concentrates in south-eastern Tasmanian waters where there are occasional seasons of high squid abundance.

Gould's squid are a common bycatch of demersal trawling in the SESSF. The most productive fishing grounds for the SSJF (western Victoria) are adjacent to deeper demersal trawling grounds where the trawl catch of Gould's squid is greatest.

The largest annual catch by Australian vessels from the SSJF was 2000 t in 1997, but catches since 2006 have been less than 1000 t. A peak in active jig vessels (42) occurred in 1996, but in most seasons since 2002, fewer than 20 vessels have fished. Before the development of a domestic squid jig fishery, there were foreign jig vessels licensed to fish off southern Australia from 1978 to 1987. A peak catch of about 8000 t was reported by Japanese vessels in the 1979–80 season under joint-venture arrangements with Australian companies.

The SSJF is managed using input controls, using an annual total allowable effort (TAE) limit under a formal management plan, unless additional management action is triggered under the harvest strategy. The absence of biomass estimates and the high interannual variability of squid populations would make the use of output controls particularly problematic for the SSJF.

No stock assessment has yet been conducted for Gould's squid in Australia. There has been some detailed research on its biology, confirming that it has a maximum life span of 12 months and great variability in recruitment and growth between seasons and locality (Jackson & McGrath-Steer 2003; Virtue et al. 2011).

Profitability in the SSJF has been low in three of the four seasons since 2008. Low prices, coinciding with low catch rates for jig vessels, depressed the value of the fishery to below $0.5 million in those years, recovering to a value of $1.7 million in 2011 (Woodhams et al. 2012).

The SSJF can be considered to be a data-poor fishery under the Commonwealth Fisheries Harvest Strategy Policy. Its high variability and low economic value is particularly relevant to this review. The policy provides limited guidance for these types of fisheries.

Harvest strategy attributes

Background

Although the harvest strategy (AFMA 2007a) is primarily for the SSJF, it also applies to the demersal trawl sectors of other Commonwealth fisheries within the distribution of Gould's squid. Currently, the SESSF CTS (CTS) is the main trawl fishery that catches Gould's squid with some catch coming from GABTS.

The short life span, a weak stock–recruitment relationship and high interannual variability in biomass make economic biomass targets, such as B_{MEY}, extremely difficult to estimate, They are also unlikely to be appropriate for this fishery. For species such as this, the optimal approach usually requires some form of real-time monitoring of catches with in-season adjustments based on appropriate measures of abundance, catch rate, and the species' availability or distribution. However, such monitoring and rapid response is data intensive, with associated costs.

Reference points and indicators

Target reference points

There are no target reference points implemented in the SSJF harvest strategy. The highly variable nature of the squid stock makes the development of target reference points a difficult proposition and, possibly, an ineffective tool for managing this fishery.

The harvest strategy currently uses a suite of catch-and-effort triggers to initiate fishery assessments and increased monitoring of the fishery, including biological data collection. The responses to triggers are intended to be in real-time or by within-season management (AFMA 2007a). However, the triggers have not been met since the harvest strategy for the fishery was implemented in 2008, so no in-season response has been triggered. These triggers are unlikely to be met if profitability levels remain low, because squid fishers tend to shift their effort towards other fisheries they have access to, such as state and Commonwealth scallop fisheries.

The catch triggers for this fishery have been set on a precautionary basis due to the lack of a quantitative stock assessment. The limit triggers are set at a level well below the historic peak annual catch taken by foreign jig vessels in 1979–80 and the intermediate triggers are in the vicinity of one-half that catch.

The recent low levels of fishing effort in the SSJF means that there is a low risk of overfishing this stock and, therefore, management and research resources have not yet been invested in determining if target reference points can be implemented.

Limit reference points

There are no limit reference points implemented in the SSJF harvest strategy, except by way of triggers. The catch limit trigger (see below) for the SSJF has been set based on domestic and foreign fishery catch so that it is considerably more than recent catch levels, but still less than the peak foreign vessel catch from the 1979–80 season of 8000 t.

Triggers

Intermediate triggers are set for when jig catch reaches 3000 t, combined jig and trawl catch reaches 4000 t, or fishing effort reaches a level of 30 standard jig vessels in any season.

The intermediate triggers require that depletion analyses be conducted for major fishing regions and the whole fishery. A rapid response is required to collect biological data to determine the cohort(s) being fished through size/age frequency data. These data should feed into the depletion analyses to enable catch estimation in terms of number of squid. If the assessment shows that depletion has not been significant for any region, then fishing can be allowed to proceed until a limit is reached. Alternatively, a TAC or season closure date can be determined for the whole fishery or fishery region (AFMA 2007a).

Limit triggers are set for when jig catch reaches 5000 t, trawl catch reaches 2000 t, or combined jig and trawl catch reaches 6000 t. For the jig fishery limit or combined jig/trawl limit, no further catch can be taken unless a depletion analysis provides evidence that a higher TAC is sustainable. If the 2000 t trawl limit is reached, jig fishing would not necessarily be impacted, but a stock assessment would be conducted to determine whether regulations, such as trip limits, would be needed for trawl operators.

The harvest strategy includes triggers to induce management intervention in the SSJF when fishing effort is high in a season of low general abundance of Gould's squid and centred on particular fishing grounds. If the number of active boats exceeds 45 in a season coinciding with low CPUE (< 20 per cent of long-term average), spatial closures are required to redirect fishing effort more widely in the fishery.

Harvest control rules

Given the lack of quantifiable biological and economic reference points for the SSJF, the harvest strategy does not include control rules related to such reference points. There are responses (decision rules) for the intermediate and limit triggers that focus on assessment, and increased biological data collection and fishery monitoring. Only the limit triggers would be considered to constitute control rules in as much as they require cessation of fishing until evidence is available for revised management. Management in the form of TACs (whole fishery or regional), season closure dates or trip limits (trawl fishery only) are likely responses.

The harvest strategy allows for identification of a 'boom season' with exceptional abundance of squid, and jig limit triggers may be overridden for that season to allow the SSJF to take advantage of the situation. The override may be rescinded and the season closed for the fishery or region if high effort is maintained following a large decline in CPUE.

The use of triggers for increased monitoring, assessment and management is consistent with the Commonwealth Fisheries Harvest Strategy Policy, where data-poor species can be subjected to control rules that do not manage catch or effort (DAFF 2007, section 7).

The practicality of responding to the triggers in terms of assessment, data collection and consultation within a fishing season remains untested, and this process is likely to be more complicated than expected.

The harvest strategy does not require determination of an RBC by the SquidRAG or agreed TACs unless a trigger has been reached and the ensuing assessment process determines that a TAC is appropriate due to evidence of depletion in any region of the fishery. Application of a TAC is most likely to be chosen if the limit trigger is reached, but could conceivably be applied to a region if depletion analyses following the intermediate trigger indicated that escapement of squid was reaching a critical range.

The catch of Gould's squid in state fisheries has historically been low with the exception of the Tasmanian Scalefish Fishery, where there has been high abundance of squid in some years (e.g. 480 t landed in 1999–2000 and 694 t landed in 2006–07). The harvest strategy recommends an annual assessment of catch-and-effort data that includes data from all fisheries, but there is no protocol for within-season sharing of catch-and-effort data for use in a depletion analysis and in determination of a Commonwealth TAC.

Management strategy evaluation and testing

The squid harvest strategy has not been subjected to management strategy evaluation or trials of the assessment process within a fishing season. As part of a review of historical CPUE trends, SquidRAG was provided with a preliminary depletion analysis for one year in the central region of the SSJF (Triantafillos unpub.). ABARES has also conducted post-fishing depletion analyses for the same region for 1995–2006 (Barnes et al. in prep.) Both studies highlight the amount of work required to produce suitable CPUE series and the need for real-time size, catch, and fishing effort reporting and associated data management procedures.

Although the depletion analyses conducted so far for the SSJF central zone did not show high levels of depletion, in some seasons, the escapement levels did approach what is considered a limit in the Falkland Islands squid fishery of 40 per cent escapement (Barnes et al. in prep). Although this escapement value may not be appropriate for the SSJF stock, these results were obtained for catches much less than the harvest strategy intermediate trigger of 3000 t. This highlights a possible need for a more conservative array of triggers for catch in the SSJF, perhaps including regional triggers (e.g. subdivision of the fishery into regions where intermediate triggers of 1500–2000 t operate as a precaution against localised depletion). Although localised depletion may not be a problem from a sustainability point of view in a widely dispersed, short-lived and productive stock, there may be ecological implications, such as disruption of predator feeding in some areas.

Harvest strategy application

Since the harvest strategy was introduced in 2008, the largest annual catch of Gould's squid has been 830 t in 2012 for the SSJF and 749 t for the trawl fisheries in 2011. Given that catch triggers are well above these levels, the harvest strategy has not yet had any influence on management of the fishery. Since 2008, the TAE-setting process has proceeded as specified in the management plan without the need to apply the 30-boat intermediate trigger decision rule. The current (2013) TAE of 550 standard jig machines would allow a fleet of 55 standard jig vessels. However, no more than 17 vessels have operated in any jig season since 2008.

The harvest strategy has not been modified since its introduction. The original document recommends that a review be undertaken to improve the decision rules and provide more detail on responses, particularly the nature of increased monitoring that should result when a trigger is breached. The need for a real-time monitoring strategy has been emphasised and the harvest strategy could be improved by a plan for implementation of real-time monitoring.

Fishery performance

The Gould's squid stock has been classified as 'not overfished' and 'not subject to overfishing' since the harvest strategy was introduced (Woodhams et al. 2012). Before that, the fishery was classified as 'uncertain' in terms of both biomass and fishing mortality status. Due to catches remaining below catch triggers, the harvest strategy has not directly contributed to this change in status, although it did provided impetus for development of depletion analyses for the fishery. The low level of recent fishing effort and catch in comparison with substantially higher historical catches means that the fishery must be considered sustainable at recent levels of fishing mortality. The results of preliminary depletion analyses have also provided evidence that the stock has not been overfished by the domestic fishery.

While the squid stock is not classified as 'overfished', the economic returns to the Australian community have probably not been maximised. The TAE has not constrained effort, and the generally high level of latent effort suggests that economic returns are low.

In conditions of unpredictable seasonal abundance of Gould's squid, high vessel running costs and price variability from a large global market for squid, estimation of an MEY target is difficult, and the SSJF harvest strategy is not capable of directing the fishery towards an optimised MEY target.

While a biomass target of B_{MEY} is not likely to be appropriate for the fishery, it is unclear how the fishery's harvest strategy complies with the economic objective of the Commonwealth Fisheries Harvest Strategy Policy of maximising NER. Management has not constrained effort in recent years, with latency averaging more than 80 per cent since the harvest strategy was introduced in 2008. However, the variable and unpredictable nature of the fishery means that if catch rates or economic conditions improve, it is possible that latent effort could be activated to generate increased economic returns from the fishery. The policy is limited to manipulation of fishing mortality to achieve its economic objective and is unable to provide guidance for fishing cost reduction, or improving post-harvest efficiency or market development. Given the characteristics of this fishery, the use of a trigger-based strategy is one of the few feasible and cost-effective methods of management.

Similar fisheries

Short-lived invertebrate species generally have similar issues to Gould's squid when application of a harvest strategy is considered (e.g. penaeid prawn species in the NPF).

Conclusions

Given the data-poor and low-value nature of the SSJF, the approach taken with the harvest strategy (catch-and-effort triggers that introduce increased monitoring and assessment) is appropriate. However, there are several areas where this harvest strategy lacks detail or needs to be updated:

- Addition of spatially structured triggers might be considered to identify regions where the risk of localised depletion should be investigated.
- More guidance for determining acceptable depletion levels would make the decision-making process clearer when catch reaches an intermediate catch trigger.
- Preparation of an agreed plan for implementation of real-time catch monitoring when the fishery approaches an intermediate harvest strategy trigger will enable effective application of decision rules. Arrangements for communication of catch and effort from Tasmania's Scalefish Fishery is desirable.
- A detailed specification of the how the depletion model will be run is not currently available. This work would expedite the application of the depletion analysis under circumstances where the Gould's squid fisheries (both jig and trawl) rapidly expand within a season. In the absence of within-season biological sampling for size and age composition, a preferred growth function should be specified by the RAG.

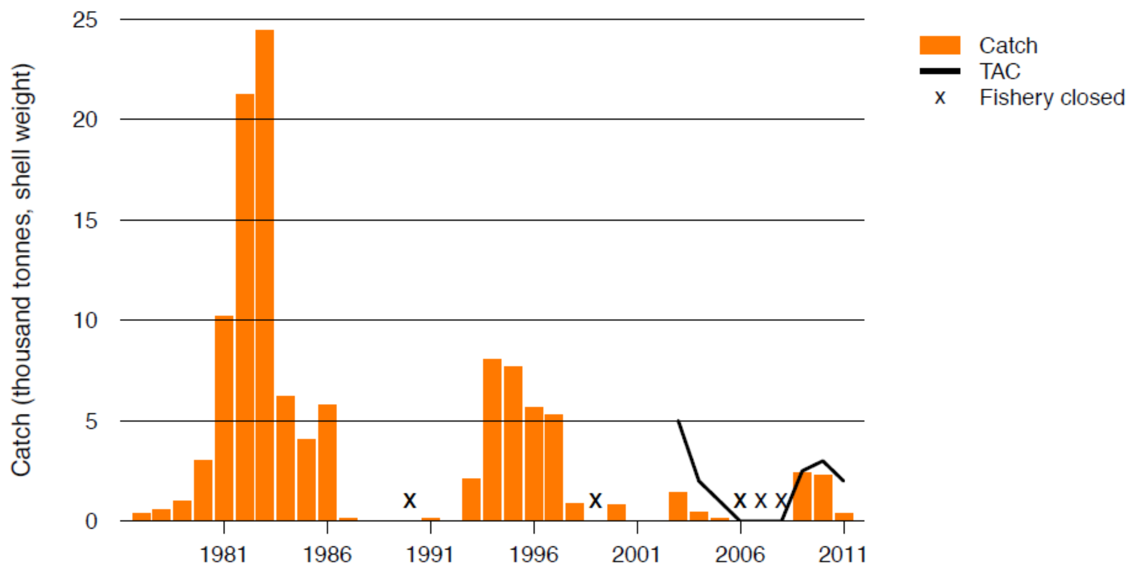
Bass Strait Central Zone Scallop Fishery

Fishery characteristics

The Bass Strait Central Zone Scallop Fishery (BSCZSF) covers waters in the Bass Strait between the Victorian and Tasmanian scallop fisheries (generally outside 20 nautical miles from the coastline). Operators target commercial scallop (*Pecten fumatus*) using scallop dredges to fish areas of dense aggregations (beds). In 2011, there were 12 active vessels in the fishery, down from 18 in 2010 and 26 in 2009.

Scallop populations are naturally highly variable as a result of sporadic and spatially patchy recruitment and high natural mortality. Some scallop populations were also substantially depleted by historical fishing, so that the potential for a fishery every year is now highly dependent on sporadic and variable recruitment. The scallop fishery is therefore characterised by 'boom and bust' periods, where new beds are found, and effort and catch rapidly increases until the bed is fished down (Figure 3). Scallop condition also fluctuates markedly within and across fishing seasons, which results in variable yield. Spatial management is used to try to manage these characteristics to ensure that scallop beds can be rotated or limited to prevent depletion in areas with poor recruitment. While the adults are resident, the population structure across the Victorian, Tasmanian and Commonwealth scallop fisheries is unclear, and initial results suggest that it may be spatially complex.

Figure 3 Catch and TAC of commercial scallop in the Bass Strait Central Zone Scallop Fishery, 1977-2011



TAC = total allowable catch

Note: Catches before establishment of the Bass Strait Central Zone Scallop Fishery in 1986 are likely to include some catch from outside the central zone

Source: Woodhams et al. (2012)

The Bass Strait scallop fisheries were very valuable in the early 1980s due to high prices and large volumes of landed catch (as high as $59 million in 2011–12 dollars for the whole southern scallop fishery [including Tasmanian and Victorian scallop fisheries]; BAE 1985). Since then, GVP for the fishery has declined considerably. Before the fishery's closure in 2006 (to allow rebuilding), the real GVP was as low as $0.5 million in 2004–05 and $0.2 million in 2005–06 (in 2010–11 dollars). Since the fishery reopened in 2009, higher GVPs of $1.2 million and $3.9 million were achieved in 2008–09 and 2009–10, respectively (noting that the 2008–09 estimate only includes the first month of the 2009 season). In 2010–11, the GVP fell to $2.9 million as a result of poor meat quality, stock die-offs and low beach prices.

The BSCZSF is managed spatially rather than using biomass-related controls. There is therefore a challenge in meeting the harvest strategy policy objectives of maintaining biomass between target and limit reference points.

Harvest strategy attributes

Background

The scallop harvest strategy is applied to commercial scallops (*Pecten fumatus*), but notes that doughboy scallops (*Chlamys (Mimachlamys) asperrimus*) may also be taken in the fishery. The harvest strategy uses a spatial management approach in which most of the fishing area remains closed, while specific areas are opened to fishing ('most areas closed–little open') depending on local abundance. Elements of the strategy include:

- identifying 'viable areas' and 'prospective viable areas' through preseason fishing surveys (viable areas are those where scallop density is high enough to enable commercial harvesting of the area and at least 80 per cent of scallops in the area will be at least 90 mm long or be at least three years old at the start of the season); prospective viable areas include those where these conditions are not met at the start of the season, but are likely to be met during the season.
- keeping at least 500 t of scallop in at least one viable or prospective viable areas closed to fishing, as identified through the surveys
- keeping at least 40 per cent of viable and prospective viable areas closed to fishing.

The harvest strategy notes that having a fishery in each year may not always be possible, and so this is not set as an objective. Although one of the stated objectives is to maximise the economic returns to the Australian community, the BSCZSF harvest strategy does not explicitly specify any MEY target, biomass based or otherwise.

Reference points and indicators

The 2012 BSCZSF harvest strategy does not specify biomass-based reference points due to the high natural variability in the stock's availability and recruitment. The harvest strategy notes that:

> The resource's naturally sporadic and fluctuating availability and intermittent recruitment make the concept of unfished biomass (B0) problematic… The aim of maintaining the fishery at a nominated target reference point is difficult to attain given the nature of the species. (AFMA 2012b)

The development of an appropriate economic target for the BSCZSF harvest strategy, consistent with the intent of the Commonwealth Fisheries Harvest Strategy Policy, is a key issue for this fishery. Although it might be inappropriate to base such a target on biomass, an explicit link to the objective of maximising NER to the Australian community should be established, if this can be done in a meaningful way. A harvest strategy may also need to consider how TAC settings affect the economics of operating in the fishery, and possible impacts on beach prices.

Due to the natural variability of scallops, no limit reference point is specified in the BSCZSF harvest strategy. However, the control rules specify that a viable or prospectively viable area containing at least 500 t must remain closed, and at least 40 per cent of viable and prospectively viable areas must remain closed. These rules act as proxy limit reference points for the fishery and are intended to be indirectly consistent with the MSY target reference point as defined in the original BSCZSF harvest strategy (AFMA 2007b).

Harvest control rules

The harvest strategy specifies proxy limit reference points for the fishery through the control rules (protection of 500 t biomass, 40 per cent of viable or prospectively viable beds to remain closed). These control rules do not directly align with the biology of commercial scallops in Bass Strait. Economics are not explicitly accounted for in the control rules, even though one of the policy's objectives is to '...maximise the economic returns to the Australian community...' (DAFF 2007). The harvest strategy's definition of 'viable areas' states that scallop density must be high enough to enable commercial harvesting to occur; however, it does not attempt to quantify this in terms of the number of operators or fishing days that the bed should be able to support.

The control rules provide quantifiable reference points (500 t biomass and 40 per cent of viable and prospectively viable beds to remain closed), which have proven straightforward to interpret. Gathering the data required to address these can be difficult though, as they require industry to survey areas, with no assurance that the costs of surveying will be offset by the catch they take. Additionally, there is often a delay between when surveys are conducted (often during the previous season, which ends in December) and the TAC for the season being set (often not until April, or even later).

There are no explicit control rules that target economic performance in the BSCZSF harvest strategy to date. This is primarily a result of the sensitivity of scallop price to domestic supply, and the fact that the control rules do not specify catch or biomass limits. However, even if such rules exist, sharing the same stock between multiple jurisdictions means that any control rules set by the BSCZSF are likely to be ineffective at improving economic performance, because catches in other jurisdictions can negatively affect the market price of scallops and the NER to the BSCZSF.

There is also no explicit recognition or evaluation of risk in the harvest strategy. Having two separate control rules that both need to be met to open the fishery means that the risk is somewhat diversified. However, the benefit of this is somewhat limited as the two control rules rely on the same data. As such, if one control rule results in an inappropriate management response because of input data, the other is likely to also result in inappropriate action.

The stock structure of scallops in Bass Strait unclear, with the possibility that the Commonwealth, Tasmanian and Victorian scallop fisheries target a common stock. This is not accounted for in the harvest strategy. Assessments and TACs do not take into account mortality from the state fisheries. The recreational catch is insignificant in the Commonwealth fishery.

The fishery has previously been classified as overfished (see ABARES 2012). Suggestions have been raised in the RAGs and MACs that other processes have had a large effect on preventing rebuilding of biomass. Alternative explanations include that scallops are naturally variable and are subject to 'die-off' events. While the reasons for this remain unclear, various hypotheses have been proposed, including the impacts of seismic surveying (e.g. Harrington et al. 2010), stressing scallops by fishing a bed lightly (as opposed to fishing the biomass right down; AFMA 2009b) and density-dependent effects (e.g. AFMA 2012b).

Management strategy evaluation and testing

An MSE was recently conducted on the Commonwealth, Tasmanian and Victorian scallop fisheries (Haddon 2011). It tested the Commonwealth harvest strategy that was in operation at the time (the harvest strategy was released in 2007 during a fishery closure and came into effect when the fishery reopened in 2009). A new harvest strategy was presented to ScallopRAG, ScallopMAC and industry on 14 December 2011 for use in the 2012 season. This revised harvest strategy is an interim strategy that will be further revised for the 2013 and subsequent seasons. While the harvest strategy has been revised since the MSE work was undertaken, the overarching principles of the harvest strategy released in 2007 (including protecting 500 t of biomass and 40 per cent of known beds) remain unchanged.

The MSE found that the harvest strategy would keep the fishery above the B_{LIM} proxy (a viable bed of at least 500 t) in 96 per cent of runs (thus, meeting the Commonwealth Fisheries Harvest Strategy Policy that indicates stocks should stay above B_{LIM} 90 per cent of the time). The results, however, rely on the assumptions used to model scallop abundance and recruitment in the MSE, including the assumption that biomass has no impact on the level of recruitment and the validity of 500 t as a proxy for B_{LIM}.

Due to the highly variable nature of scallops, the harvest strategy notes that the concept of a target reference point is problematic and therefore does not recommend one. The MSE used a target reference point of having a fishery each year—despite the harvest strategy noting that 'having a fishery in each year in the BSCZSF is not an objective of this Harvest Strategy...' (AFMA 2007b). The MSE found that the probability of having a Commonwealth fishery in each year varied from 0.25 to 0.66 and that, even with only token fishing pressure, natural variation in biomass was such that there would be years where the harvest strategy rules would prevent there being a fishery. There is debate, however, about whether scallops are naturally this variable or whether the current variability is in part due to a reduced biomass. Further work to confirm or refute this would be valuable.

Harvest strategy application

A harvest strategy is in place and has been implemented for the sole target species of the BSCZSF. The harvest strategy also sets a nominal TAC for a bycatch species (doughboy scallops) of 100 t. However, due to processing difficulties, there has been no interest in retaining doughboy scallops in recent years.

While the harvest strategy was released in 2007 (AFMA 2007b), it was not implemented until 2009 as the fishery was closed in the intervening years, which was the first year the fishery was active since release of the harvest strategy.

The harvest strategy was revised in 2012. The general principles of the harvest strategy have remained unchanged between the 2007 and 2012 harvest strategies. Modifications to the 2012 harvest strategy primarily focused on the operation of the fishery, through measures such as formally devolving some management responsibilities to an industry co-management committee, setting out the process for mid-season area changes, providing further guidance on how surveys should be run and the way scallop beds should be named. These changes were made to streamline within-season management, and to ensure consistency with surveys and the identification of beds.

Exceptional circumstances occurred at the start of the 2012 fishing season, where a die-off event resulted in scallop abundance declining in the area to be opened to fishing (AFMA 2012c). This resulted in an industry proposal to open the eastern half of the fishery with the exception of two beds in an attempt to facilitate widespread data collection as fishers would be able to search the eastern part of the fishery for new beds. This proposal was put into effect, meaning that management arrangements for the 2012 fishing season were outside the harvest strategy control rule of ‘only viable areas may be opened to fishing…’ (AFMA 2012f). This had the effect of changing the underlying management objective of ‘most areas closed–little open’ to ‘most areas open–little closed’ and resulted in less precautionary management of the fishery.

Since its implementation in 2009, the scallop fishery harvest strategy’s challenges have included:

- The data required for AFMA to set a TAC relies on fishers conducting surveys in one of three forms: exploratory surveys outside of known scallop beds; biomass or discard surveys to determine the status and size (biomass) of known beds; and preseason surveys to update the biomass or discard survey. There are large costs associated with these surveys. This is particularly the case for exploratory surveys, where the patchy distribution of scallops may result in fishers not catching enough scallops in new areas to cover the costs of surveying. Fishers are consequently reluctant to survey new areas so that surveys, and therefore the fishery, are concentrated around previously known beds with limited information available from outside these areas.

- The requirement that viable or prospectively viable beds containing at least 500 t must be keep closed is based partly on assuming that average annual catches from 1993 to 2004 (2643 t) equate to B0 and partly on the fishery recovering from one known bed with around 500 t biomass in Commonwealth waters. As the default proxy for BLIM is 20 per cent of B0, taking 20 per cent of 2643 t gives a BLIM proxy of 529 t. This assumes that, in each year between 1993 and 2004, every scallop in the fishery was taken. The 500 t threshold is therefore likely to be conservative (AFMA 2007b). If a slightly more realistic assumption is made that in each year 80 per cent of the total biomass in the fishery was taken, the BLIM proxy would be 661 t (calculated from data presented in AFMA 2007b). The reduction from 529 t to 500 t is based on the fishery having previously undergone recovery from a lower biomass (thought to be somewhere around 500 t of biomass within Commonwealth waters). The harvest strategy does concede that the process used to calculate the BLIM proxy is ’shaky’ and that ’such a BLIM is certainly not defensible on its own, but it sits as one of a suite of decision rules comprising the harvest strategy…‘ (AFMA 2007b).

- The requirement to keep at least 40 per cent of viable or prospectively viable areas closed to fishing becomes less precautionary as biomass, and therefore the number of beds, declines. For example, if ten beds are identified during surveys, at least four would be closed, but if two beds were identified, only one would be closed.

- There is no clear link between decision rules set in the current BSCZSF harvest strategy and the economic objectives of the Commonwealth Fisheries Harvest Strategy Policy. This partly reflects the fact that application of the policy has focused on biomass reference points, which may not be applicable to a fishery such as the BSCZSF. But in the absence of biomass reference points, the harvest strategy for the fishery has not been developed to include other approaches that meet the intent of the policy to achieve MEY. Moreover, exceptions to the decision rules in the harvest strategy are often not explicitly designed to result in an improvement in NER.

Fishery performance

The harvest strategy was developed in 2007 during a three-year fishery closure (2006–08). During this closure, the fishery was classified as ‘overfished’ but not subject to overfishing (Woodhams et al. 2012). The first year the harvest strategy came into effect was 2009 when the fishery reopened. In 2009 and in each year since then, the fishery has been classified as ‘uncertain’ if the stock is overfished, but ‘not subject to overfishing’ (ABARES 2012). The uncertain classification for overfished status has been partly based on the fact that there is being limited information available for the majority of the fishing ground, coupled with recent die-off events creating uncertainty around the health of previously identified beds, and the fishery more broadly. The 'not subject to overfishing' classification has been based largely on the harvest strategy requirement that 'only viable areas may be opened to fishing...' (AFMA 2012f).This has meant that the majority of the fishery remained closed to fishing and closed beds would be protected from fishing pressure.

Although the fishery's GVP improved considerably in the post-closure periods, real NER in the BSCZSF for 2009–10 and 2010–11 remained negative at –$1.1 million and –$1.0 million, respectively (George et al. 2012). When compared to previous negative NER for 1998–99 of –$1 million (Galeano et al. 2001), this suggests that profitability has not improved and that the MEY objective of the Commonwealth Fisheries Harvest Strategy Policy has not been met. Stock rebuilding and recent reported die-offs may also be influencing the economic performance of the fishery.

Similar fisheries

The state-managed Tasmanian and Victorian scallop fisheries have similar characteristics and implementation issues to the Commonwealth scallop fishery. The Tasmanian fishery uses a similar management approach to the Commonwealth fishery of 'most areas closed–little open'. The Victorian fishery protects juvenile beds when they are found, but allows fishing in the majority of the fishery, resulting in a 'most areas open–little closed' approach. It has been recognised that differing management strategies across the three fisheries is problematic. As such, rationalising management of the three fisheries has been raised in the past (e.g. (AFMA 2004) and again more recently (e.g. AFMA 2012d).

Conclusions

The fishery's harvest strategy appears to be robust to the variable nature of commercial scallops. However, the current design of the harvest strategy is not consistent with the Commonwealth Fisheries Harvest Strategy Policy's objective of achieving MEY. Alternatives to biomass-based MEY targets might need to be considered for episodic species like scallop, which need spatial management. The negative NER generated by the scallop fishery in recent years indicate that maximising returns should be a priority for the fishery.

Inclusion of results of recent (as yet, unpublished) work on scallop genetics to determine the stock structuring of commercial scallops across the Commonwealth, Victorian and Tasmanian scallop fisheries would likely improve the functioning of the three fisheries. Further work is need to verify whether protecting 500 t of scallops this provides sufficient precaution.

Eastern Tuna and Billfish Fishery

Fishery characteristics

The Eastern Tuna and Billfish Fishery (ETBF) extends from the tip of Cape York to the South Australia – Victoria border (141°E) and includes waters around Tasmania and Lord Howe Island. Most of the catch is taken with pelagic longline; however, a small quantity is taken using minor-line methods (trolling, hand lining and rod-and-reel fishing). The key commercial species of the longline sector are yellowfin tuna, bigeye tuna, albacore tuna, swordfish and striped marlin. A suite of non-target species, such as mahi mahi, wahoo and escolar, are retained and sold because they have market value and as such form an important byproduct component of the catch. The minor line sector also targets these and other species.

In recent years, the largest catches have been of yellowfin tuna (representing 35 per cent of the total catch of the five key target species during 2009–11) and swordfish (25 per cent). However, these species migrate between international waters and the 200 nautical mile exclusive economic zone (EEZ) of many countries, including Australia. The Australian catch of the target species is a small proportion of the total catch taken within the Convention Area of the Western and Central Pacific Fisheries Commission (WCPFC), the RFMO that manages stocks of tuna and tuna-like species. Between 2009 and 2011, the catch of yellowfin and bigeye tuna in the ETBF represented less than 0.5 per cent of the total WCPFC catch of these species, while the ETBF albacore catch represented 1.3 per cent of the total catch in the south Pacific. In contrast, the ETBF catches of swordfish and striped marlin represented around 12 per cent and 19 per cent, respectively, of the total catch of these species in the south Pacific region of the WCPFC Convention Area (and about 40 per cent of these stocks within the south-west Pacific). The ETBF therefore illustrates the difficulties associated with applying the Commonwealth Fisheries Harvest Strategy Policy to international stocks, fished by multiple fleets and countries.

The policy 'does not prescribe management arrangements' for stocks that are managed jointly with another jurisdiction or through an international body, because the policy recognises that this would be difficult (DAFF 2007). However, Australia's position at RFMOs is based on attempting to ensure compatibility with domestic obligations, and the policy is therefore advocated as an example of best practice for fisheries management. Further, the policy notes that 'it is Australian Government policy to support catch level decisions' taken by RFMOs (DAFF 2007). However, 'in the absence of agreement, Australia's domestic catch allocation decision would be consistent with the agreed whole of government position' (DAFF 2007).

Harvest strategy attributes

Background

Noting the guidance provided by the policy and the Ministerial Direction on applying harvest strategies in international fisheries (DAFF 2007), AFMA opted to develop a harvest strategy for the ETBF's five target species, applicable to fishing within the EEZ. The harvest strategy uses several empirical fishery indicators within a decision-tree framework. However, questions remain about the applicability and utility of a harvest strategy for some of the target species because of the relatively small catches taken by Australia compared to catches by other countries, and the potential connectivity of the ETBF with other regions of the Pacific.

Reference points and indicators

The harvest strategy is based on target reference points for CPUE and size-based indicators. These targets were derived by the Tropical Tuna Resource Assessment Group, based on the levels of these indicators during an identified reference period. Industry suggested that the years between 1997 and 2001 were a good and presumably profitable period in the fishery, and the mean annual CPUE for this period was set as the target CPUE (see below).

ABARES economic survey estimates suggest that the CPUE reference period was a period in which NER performance was probably at its best, although positive returns at the fishery level only occurred in the 1998–99, 1999–2000 and 2000–01 financial years (Perks & Vieira 2010). Although the fishery may have been profitable during this period, this does not mean that the level of CPUE that was achieved in that period should be pursued to achieve MEY. Current profitability depends not only on catch rates, but a range of other factors—in particular, the terms of trade (the output and input prices) faced by the fishery. The adopted reference period was associated with historically high tuna prices (due to a low Australian dollar) and low fuel prices. For example, the fishery's average unit prices in real terms were $12.68 per kg in 1999–2000, which is higher than the $6.05 per kg reported for 2009–10 (Skirtun et al. 2012). Fuel prices were also higher relative to what they were during the reference period. This demonstrates that targeting the reference period CPUE is likely to be inconsistent with maximising profits under currently prevailing prices.

Therefore, the use of a CPUE-based target also needs to incorporate the fishery's current terms of trade to meet the intent of the policy to maximise the fishery's NER. Under such an approach, the target reference CPUE would be updated subject to the prices (or price expectations) that are currently prevailing for the given species and, potentially, key inputs (e.g. fuel). For example, the target CPUE could be determined based on currently prevailing prices, together with an understanding of what level of revenue per unit effort (incorporating just output prices) or revenue per unit cost of effort target (incorporating output and input prices) is consistent with maximising profits. By explicitly incorporating such price information, CPUE targets would provide a better link to current fishery profitability.

The ETBF harvest strategy does not currently use limit reference points. These are being developed by the Tropical Tuna RAG to fully align with the policy.

In addition to CPUE, size-based indicators are used to adjust the recommended biological commercial catch (RBCC) in accordance with the control rule (see below).

Harvest control rules

The primary control rule in the harvest strategy for determining the RBCC is:

$$RBCC_{t+1} = TACC_t(1 + \beta . S_{CPUE})$$

where the RBCC is determined from the previous total allowable commercial catch (TACC) adjusted for using CPUE and a control parameter (β) (see Campbell 2012 for complete details).

The CPUE is calculated from commercial catch and effort only. It is considered to be a reliable index of abundance and so is used to index the total stock, even though additional sources of mortality, such as recreational catch, are not explicitly included. The control rule provides a relatively simple method of calculating the RBCC. However, additional information, primarily size-structure data and the CPUE of recruiting size classes to the fishery, is also used to assess the status of the stocks and refine the RBCC calculated from the above control rule using a decision tree (Figure 4).

Figure 4 Decision tree from the Eastern Tuna and Billfish Fishery harvest strategy

Level 1: Adjust RBCC based on status of CPUE-prime indicator

RBCC(t+1) = *TACC*(t)*[1+β.slope-to-target(*CPUE-prime*)]

Level 2: Assess status of rate of change in CPUE-prime

Rising | Stable | Falling

Level 3: Assess status of old fish relative to *SPR40* thresholds

A. If *CPUE-Old* above & *Proportion-Old* above C: If *CPUE-Old* below & *Proportion-Old* above

B. If *CPUE-Old* above & *Proportion-Old* below D: If *CPUE-Old* below & *Proportion-Old* below

Level 4: Assess status of recruits

A. Stock ↑or effort creep
Is *CPUE-Recruits* high?
Yes: No change No: Reduce RBCC
B. SPR ↓ (effort creep) and/or stock ↑
Is *CPUE-Recruits* high?
Yes: No change No: Reduce RBCC
C. Unusual transient dynamics
No change
D. SPR ↓(effort creep) or recruitment ↑
Is *CPUE-Recruits* high?
Yes: No change No: Reduce RBCC

Level 4: Assess status of recruits

A. All stable or lightly fished
No change
B. SPR↓ (effort creep)
Is *CPUE-Recruits* decreasing?
Yes: 2x reduce RBCC No: Reduce RBCC
C. Recruitment ↓or transition state
Is *CPUE-Recruits* decreasing?
Yes: Reduce RBCC No: No changes
D. SPR ↓(effort creep) or recruitment ↑
Is *CPUE-Recruits* decreasing?
Yes: 2x reduce RBCC No: Reduce RBCC

Level 4: Assess status of recruits

A. Failing recruitment?
Is *CPUE-Recruits* decreasing?
Yes: 2x reduce RBCC No: Reduce RBCC
B. Unusual transient dynamics
2x reduce RBCC
C. Failing recruitment?
Is *CPUE-Recruits* decreasing?
Yes: 2x reduce RBCC No: Reduce RBCC
D. General stock decline
Is *CPUE-Recruits* decreasing?
Yes: 3x reduce RBCC No: 2x reduce RBCC

Source: Campbell (2012)

There are several meta-rules associated with the ETBF harvest strategy, such as limiting the annual change in the TACC to no greater than 10 per cent. Further meta-rules may need to be developed in the future. For example, there are currently no provisions for rebuilding stocks because there are currently no limit reference points. When limit reference points have been developed, it may be necessary to develop meta-rules that apply to stocks that fall below these limits or for other exceptional circumstances.

Management strategy evaluation and testing

One formal MSE of the harvest strategy framework was undertaken before implementation in the ETBF (Kolody et al. 2010). Several alternative harvest strategies were evaluated for performance. This identified several issues, including that:

- the harvest strategy is not robust to uncertainty in population connectivity
- there was no evidence that the inclusion of size-based indices improved performance
- the performance of the harvest strategy was sensitive to several parameters (e.g. number of years used in the CPUE slope calculations) that did not behave in an 'intuitive' manner
- an alternative, model-based harvest strategy might have a more robust performance (although this had not been sufficiently demonstrated).

In addition, application of the harvest strategy to the five target species was evaluated with the following results:

- Swordfish: the ETBF could potentially impact the southwest Pacific stock and the harvest strategy had a reasonable capacity to achieve the objectives of the Commonwealth Fisheries Harvest Strategy Policy.
- Striped marlin: the evaluation was considered preliminary as the WCPFC stock assessment was out of date. However, the results suggest the ETBF may have a large impact on the stock and the CPUE level adopted may maintain the stock in a depleted state. It was suggested that striped marlin be reviewed when a new stock assessment was available.
- Bigeye tuna and yellowfin tuna: the evaluation found similar results for these species in that there was uncertainty in the connectivity between the ETBF and adjacent regions. If the populations of these species are highly connected and widely distributed, the ETBF has a minor impact and the harvest strategy will be ineffective.
- Albacore tuna: there was little confidence in the evaluation for this species and it was considered preliminary. The CPUE for the ETBF and the CPUE in the stock assessment conducted for WCPFC did not agree, suggesting that the ETBF has little impact on the larger stock.

A second MSE has been proposed using striped marlin as an example. This would include using updated stock assessments, which would likely improve confidence in the evaluations.

Harvest strategy application

The harvest strategy for the ETBF is currently not fully implemented and, for the 2012–13 fishing season, has only been used to determine the TACC for striped marlin and swordfish, following the introduction of quota in March 2011. The reason for the limited implementation relates to the uncertainty concerning the connectivity of the bigeye and yellowfin tuna targeted in the ETBF with the populations throughout the broader western and central Pacific Ocean, as well as the (potentially small) proportion of the total catch of these species taken by the ETBF. A similar implementation of the ETBF harvest strategy has also been recommended for the current determination of the 2013–14 TACCs. Harvest strategies have not yet been developed for other commercial or major byproduct species in this fishery.

Tagging and genetic evidence have shown that populations of striped marlin and swordfish occurring within the ETBF are likely to be localised within the south-west Pacific. Additionally, Australian catches of these species in the south-west Pacific are a significant proportion of total catches of these stocks (about 40 per cent during the past 5 years). Thus, it is logical and shown to be effective to implement the harvest strategy for these species, as it will have a direct impact on these local stocks.

The Tropical Tuna RAG recommended that the harvest strategy not be applied to albacore because the available evidence indicates that it is part of a much broader south Pacific stock (although the level of mixing remains unknown). In addition, the Australian catch is very small (about 1 per cent of the total catch in the WCPFC area). Thus, the RAG's view was that it is not appropriate to apply the harvest strategy to albacore, because any change to Australia's catch is unlikely to impact the status of the broader stock.

The harvest strategy has not been implemented for bigeye tuna and yellowfin tuna following divergent views in the Tropical Tuna RAG and its advice to the AFMA Commission. For these species, non-industry RAG members believed that the available tagging data were sufficient to conclude that the region fished by Australia has a low level of connectivity with the wider Pacific and can be managed as separate stocks. If this was the case, then the harvest strategy could apply and be expected to achieve the objectives of the policy. However, industry members of the RAG considered that there is a greater level of connectivity between the ETBF and adjacent areas for bigeye tuna and yellowfin tuna than the tagging data suggest. If this was the case, then implementing the harvest strategy for these species would have little impact on the broader stock and the harvest strategy could not be expected work effectively. The degree of connectivity is yet to be resolved.

The WCPFC has not set total catch levels and agreed national allocations for bigeye and yellowfin tuna. In the interim, AFMA has set TACs for bigeye tuna and yellowfin tuna based on historical catches.

Fishery performance

The status of stocks in the ETBF has remained largely unchanged since the 2007 release of the Commonwealth Fisheries Harvest Strategy Policy. Since the introduction of quotas for each of the five key target species on 1 March 2011, the harvest strategy has only been used once to recommend the 2012–13 TACC for striped marlin and swordfish, and so little change in stock status would be expected.

Based on the policy's default reference points, the WCPFC stock assessments indicate that most of the five target stocks are not overfished and not subject to overfishing, as reported in the 2011 *Fishery status reports* (Woodhams et al. 2012). The biomass status of striped marlin has been uncertain for many years due to the lack of an updated assessment. (An updated assessment was conducted in 2012 and will be considered in the 2012 *Fishery status reports*.) Bigeye tuna is classified as 'subject to overfishing' but not yet overfished. However, this is mostly attributed to overfishing by international purse seine and longline fleets, and needs to be resolved at the level of WCPFC. Given the relatively small Australian catch, implementing the ETBF harvest strategy would not prevent overfishing of the wider bigeye tuna stock.

Although NER have been negative since 2003–04, they have been improving since 2006–07, reaching –$4.5 million in 2009–10 (2010–11 dollars). This improvement can be attributed to the reduction in active vessel numbers and associated reduction in costs. These changes followed the voluntary exit of vessels from the fishery in response to market forces, as well as the 2006 structural adjustment package (Vieira et al. 2010), which bought 99 longline permits and 112 minor-line permits. A change in the production mix (i.e. species caught) towards more highly valued tuna species since 2006–07 has also had a positive impact on revenues and NER.

Similar fisheries

The Western Tuna and Billfish Fishery (WTBF) is similar to the ETBF, targeting the same species in the Indian Ocean. The WTBF currently does not have a harvest strategy implemented due to the very low levels of fishing effort (about 360 000 hooks deployed in 2011) and catch (263 t for the five target species combined in 2011). A WTBF harvest strategy is currently being designed and reviewed and, if effort in the fishery increases, will likely be implemented. A harvest strategy for the WTBF is likely to share many of the problems encountered in the ETBF because the stocks are generally considered to be shared with the wider Indian Ocean, and are fished by a range of fleets and countries. Establishing catch limits in the Australian fishery may not benefit the overall stocks.

Conclusions

The ETBF highlights the problems of applying a harvest strategy to fish resources that are potentially connected to large and widely distributed stocks that are fished by other fleets and countries. It shows that, for some local fish resources, it may not be effective to implement a domestic harvest strategy, as it will have little or no impact on the effective management of the larger stock. For example, the Tropical Tuna RAG has determined that, due to the strong connectivity with the broader Pacific stock, a harvest strategy for albacore will likely be ineffective and therefore it has not been implemented. Uncertainty about the degree of connectivity between the ETBF and the wider Pacific region has delayed the implementation of the harvest strategy for yellowfin and bigeye tuna. The harvest strategy was only implemented recently for striped marlin and swordfish, so its performance cannot yet be evaluated.

The Ministerial Direction indicates that the relevant international agreement will prevail in internationally managed fisheries to which Australia is a party, where that agreement includes an acceptable scientific process for setting sustainable catch levels. This is not currently the case in the WCPFC. The Commonwealth Fisheries Harvest Strategy Policy also indicates that, for fisheries issues that are not decided by an international management body or arrangement, DAFF and AFMA will consult on the management arrangements that will apply, and AFMA will implement those arrangements (DAFF 2007). In the case of bigeye and yellowfin tuna, after consulting with DAFF, AFMA determined what it considered to be appropriate catch levels based on past catch history. However, setting TACs in such circumstances and without a clear scientific evidence base remains a substantial challenge.

The policy indicates that in the absence of catch level decisions by RFMOs, Australia's domestic catch would be consistent with a whole-of-government position (DAFF 2007). The WCPFC has not set catch allocations for member countries, so it is presumed that a whole-of-government position on catch levels would need to be founded on the best available scientific evidence and so determining a position is faced with some of the same scientific uncertainties as the harvest strategy.

The ETBF also highlights how guidance is required on the circumstance under which a biomass-based MEY should be pursued for an internationally shared stock. This could be determined by the relative share of total international catch (i.e. some threshold level would be required) and potentially the value of the stock. Further guidance is required on rules, targets and objectives if domestic management has little influence on future stock biomass levels. These issues are also relevant to variable, environmentally dependent stocks such as the Commonwealth scallop fishery and the squid fishery.

As in other fisheries, fishery management must deal with risk and uncertainty in the ETBF. The Commonwealth Fisheries Harvest Strategy Policy encourages 'an evidence-based, precautionary approach to achieving long-term sustainability and profitability drawing on available information' (DAFF 2007). It is unlikely that the issue of the connectivity of stocks harvested in the ETBF will be fully resolved in the short to medium term. Nonetheless, it will remain a priority to resolve the question of applicability of the harvest strategy to yellowfin and bigeye tuna and, if necessary, to undertake further development and testing. The development of limit reference points will improve the usefulness of the harvest strategy. A new MSE assessment using an updated stock assessment for striped marlin would be useful to increase confidence in the performance of the harvest strategy for this species.

Discussion

Process for implementing the Commonwealth Fisheries Harvest Strategy Policy

Following the September 2007 release of the Commonwealth Fisheries Harvest Strategy Policy, AFMA directed RAGs and MACs to develop harvest strategies for fisheries under their responsibility, in accordance with the requirements of the policy. Support for the policy's implementation was provided by AFMA and CSIRO through key staff members attending MAC and RAG meetings to answer questions on the design of harvest strategies in accordance with the objectives of the new policy. Economists from the Australian National University (ANU) were also involved in providing advice on target reference points specified by the policy and in training AFMA staff in fisheries economics.

Funding for implementation was provided by the Science, Data and Compliance (SDC) Fund, which provided $6 million. AFMA received those funds as part of the Australian Government's Securing Our Fishing Future Initiative. This was combined with funding (both cash and in-kind) from CSIRO and AFMA core funding.

In addition to funding CSIRO's involvement in the development of harvest strategies, AFMA funded the attendance of RAG members at sessions on how to develop and implement harvest strategies. CSIRO conducted two specific projects on developing harvest strategies for small fisheries, in recognition of the capacity limitations that those fisheries faced in doing the work for themselves (Dowling et al. 2008).

The implementation of the policy was coordinated through an inter-agency steering committee involving AFMA, DAFF and the Australian Government Department of Sustainability, Environment, Water, Population and Communities. Following the policy's release, the steering committee convened a meeting to address the development of individual harvest strategies and to discuss other emerging issues. Individual harvest strategies were developed by RAGs and MACs, and AFMA provided feedback on whether the harvest strategies met the key requirements of the policy. Each harvest strategy was submitted to the AFMA Commission for approval.

The process of bringing all Commonwealth fisheries under the Commonwealth Fisheries Harvest Strategy Policy lasted about two years. Appendix C provides details of AFMA's reporting on the policy's implementation. AFMA (2013a) provides summaries of each fishery's harvest strategy, including the harvest strategies of several jointly managed and international fisheries.

For Commonwealth fisheries, AFMA has implemented harvest strategies for 72 fish stocks that are managed in 12 of the 13 active Commonwealth fisheries (Table 1). The Norfolk Island Offshore Demersal Finfish Fishery has not operated since 2003. Harvest strategies have been developed, but not implemented, for several species in the relatively small Coral Sea Fishery, which harvests numerous species. Table 4 lists key issues in implementing the policy along with major successes, which are drawn from the case studies and the summary tables.

Larger fisheries have tended to implement harvest strategies earlier than smaller fisheries (Table 1). This can be partly attributed to past investments by these large fisheries (e.g. the SESSF's harvest strategy framework predates the policy), extensive datasets, and their fishery management, research and economic capacity. For smaller and less valuable fisheries, the delay in policy implementation was partly due to the need to wait for the outcomes of a research project (Dowling 2011).

The fish stocks under harvest strategies include all quota-managed species and several other commercial species, including rebuilding stocks that were previously commercial species (e.g. eastern gemfish). The policy requires harvest strategies to be implemented for all key commercial species, which are defined as 'a species that is, or has been, specifically targeted and is, or has been, a significant component of the fishery' (DAFF 2007). Harvest strategies have also been implemented for several byproduct species (e.g. squid in the NPF). There are other species that are sometimes retained for sale but are not under harvest strategies (e.g. ocean jacket in the SESSF CTS).

Australia's domestic policy settings have been advocated at meetings of several RFMOs. International harvest strategies have been implemented by RFMOs for several stocks (e.g. southern bluefin tuna; Table 2). These international harvest strategies are consistent with many aspects of the Commonwealth Fisheries Harvest Strategy Policy. The CCAMLR harvest strategy and harvest strategies for the Heard Island and McDonald Islands Fishery predate the Commonwealth Fisheries Harvest Strategy Policy. Development of the CCSBT's management procedure commenced in 2001, but it was not adopted by the AFMA Commission until 2011. It has been used to set TACs for the 2011–12 fishing season. AFMA has developed and implemented harvest strategies for the domestic components of several international fisheries (e.g. the ETBF), which is considered a subcomponent of the international Western and Central Pacific Fishery.

Harvest strategy attributes

Reference points and indicators

The policy requires harvest strategies to maintain fish stocks, on average, at a target reference point equivalent to B_{MEY} and, at least 90 per cent of the time, above a limit reference point equal to or greater than $0.50B_{MSY}$. Bioeconomic modelling has been conducted in two fisheries to estimate species-specific B_{MEY}: tiger and endeavour prawn species in the NPF, and Bight redfish and deepwater flathead in the GABTS. This represents 4 of the 66 Commonwealth-managed stocks. Bioeconomic modelling has been conducted for tiger flathead in the SESSF CTS, but the RAG recommended a higher target reference point ($0.40B_0$) than the $0.36B_0$ estimated by the modelling, consistent with the policy's objectives. Bioeconomic modelling has not been conducted for any other Commonwealth fisheries. Therefore, most of the harvest strategies use the policy's default proxies of $1.20B_{MSY}$ (or $0.48B_0$) for the target and $0.50B_{MSY}$ (or $0.20B_0$) for the biomass limit reference points.

B_{MSY} is difficult to reliably estimate and its estimation through assessment models usually assumes that stocks are in equilibrium. In reality, B_{MSY} is seldom stable, but will vary as the stock's productivity (particularly recruitment), fishing patterns and selectivity change. Consequently, harvest strategies have more often used proxies based on ratios of current and unfished biomass (B_0), which are more accurately estimated than B_{MSY}. The *Orange Roughy Conservation Programme* (AFMA 2006) aims to maintain biomass on the Cascade Plateau at or above $0.60B_0$, which is more conservative than proxy reference points specified in the policy. Harvest strategies for the NPF (tiger prawn and endeavour prawn species) and the GABTS (Bight redfish and deepwater flathead) have a B_{MEY} target, but use limit reference points that are based on $0.50B_{MSY}$ or the $0.20B_0$ proxy. The proxy of $0.20B_0$ has been used as a hard limit. No harvest strategies have limit reference points that are less than $0.50B_{MSY}$ or the proxy, although harvest strategies for several Commonwealth fisheries do not specify a limit reference point.

Table 4 Summary of successes and issues identified in this review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy

Successes	Issues
Reference points and indicators	
Bioeconomic models have been used to estimate B_{MEY} for four stocks.	Most harvest strategies do not estimate B_{MEY}; they use the policy's proxies for target reference points, which are assumed to be accurate.
Fishery-wide MEY has been estimated for two fisheries.	For most fisheries, target reference point proxies are applied at a species or stock level, and they are not optimised across the entire fishery.
Most harvest strategies use the policy's proxies for reference points.	Harvest strategies for several low-value and data-poor fisheries have triggers instead of reference points because it is difficult to identify reference points that are consistent with the policy, the appropriate levels of triggers are largely unknown, and the assessments and management actions that are triggered may not be feasible within an appropriate timeframe.
Apparent changes in productivity have resulted in revised reference points for one species (jackass morwong).	For most species, reference points are fixed; they do not reflect the non-equilibrium nature of fish populations or environmentally induced changes in productivity.
Data and assessment	
Many stocks are assessed with quantitative models, which integrate a variety of data	The assessments of many stocks rely on CPUE reported by commercial vessels. They assume that CPUE is a reliable index of stock biomass and, in some cases, that the reference period represents B_{MEY} or B_0. These assumptions may not be valid for some stocks.
Harvest control rules	
Multiyear TACs have reduced assessment costs and provided industry with stability and certainty about short-term catch levels.	Some multiyear TACs do not take into account the increasing uncertainty in stock status with time since the last assessment, or have not been MSE tested.
Several harvest strategies have attempted to deal with the effects of spatial closures implemented for other reasons.	The policy provides little guidance on the treatment of the effects of spatial closures on existing harvest strategies and it has been difficult to identify reference points that are consistent with the policy for spatially structured species.
Management strategy evaluation and testing	
MSE and testing has demonstrated that harvest strategies are robust to uncertainty in valuable fisheries for which adequate data are available.	Lack of information has prevented testing of trigger-based harvest strategies and the harvest strategies of several small fisheries and data-poor stocks. Most of the testing has been generic, but MSE results can be significantly different among species within the same fishery and so there may also be a need to check harvest strategy performance at the species level.

Successes	**Issues**
Application	
Harvest strategies have been implemented for all quota species and key commercial species in all active Commonwealth fisheries.	Harvest strategies for small fisheries and data-poor fisheries are often not routinely run. They have not been implemented for several significant commercial species that are not under quota (e.g. ocean jacket). Several stocks and several species are managed as multispecies stocks.
Many fisheries have established routine processes for assessing stocks and running harvest strategies.	Delays or reductions in data acquisition, processing and assessment have contributed to uncertainty in stock status for some stocks.
Harvest strategies have attempted to take into account fishing mortality from all sources.	For several species and in the absence of catch-sharing arrangements, increasing state catches have been deducted from RBCs, and the TAC available to Commonwealth fishers has been reduced. Reliable estimates have not been available for significant sources of mortality, particularly recreational catches and discards, for several species.
Australia's domestic policy settings have been advocated at several RFMOs.	The approaches to fishery management vary among RFMO participants, and they may not be consistent with the Australian Government's policy.
Harvest strategies have been implemented for the domestic components of several international stocks.	Harvest strategies have not been used to set TACs for the domestic component of two ETBF stocks (yellowfin tuna and bigeye tuna) because of uncertainty about stock connectivity. For these stocks, TACs have been set based on historical catch levels.
Fishery performance	
Harvest strategies have prevented many stocks from becoming overfished.	The contribution of harvest strategies to stock status is difficult to separate from other factors, such as fishing effort reductions that result from structural adjustment. Several stocks have failed to rebuild because targeted fishing may have continued, fishing mortality from incidental catches may have hampered rebuilding, changes in the stock's productivity or ecosystem changes may have reduced productivity, rebuilding timeframes may have been too optimistic, or a through a combination of these factors.
The economic performance of many of the main Commonwealth fisheries has improved as a result of harvest strategies.	The economic performance of several fisheries is uncertain or cannot be evaluated due to a lack of the required economic data. The contribution of harvest strategies to improved economic performance is difficult to separate from other factors.

Several species, including scallops and royal red prawn, are largely sold on domestic markets where prices are highly sensitive to the volume of supply. Target reference points or proxies that ignore these price sensitivities are unlikely to maximise economic returns to the community. In several of these fisheries, industry or processors have therefore imposed their own limits on supply that are based on their processing capacity constraints, with heavy discounts on price paid to fishermen for fish landed outside these limits. Such limits are often below those that would be required under a B_{MEY} target. A further complication for scallops is that supply may be substituted from other states, again affecting prices obtained at domestic markets.

Catch curves, which require age-composition data to estimate fishing mortality rates, are used for several stocks in the SESSF CTS under Tier 3 assessments (the CTS case study describes the system of tiers that is used in the SESSF). The Tier 3 assessments estimate the fishing mortality rate (F) and compare it with the level of fishing mortality that will reduce biomass to the policy's default proxy of 48 per cent of the unfished level ($0.48B_0$). This rate of fishing mortality is referred to as F_{48}. The limit reference point (F_{20}) is the fishing mortality rate that will reduce the spawning biomass to the to the policy's default proxy of $0.20B_0$. Catch curves have been based on size composition data and growth curve for several species where representative age composition is not available (e.g. john dory before 2011).

CPUE-based assessments are applied where catch-at-age data are not available or catch-curve analyses are not appropriate (e.g. where the species is subject to dome-shaped selectivity). CPUE-based assessments use trends in CPUE to provide an indication of current biomass status. In the SESSF, Tier 4 assessments compare recent average CPUE to average CPUE during a historical reference period during which the stock was lightly fished and considered to correspond to B_{MEY} or B_0.

Harvest strategies that evaluate trends in CPUE are more common in Commonwealth fisheries than those based on direct estimates of biomass from surveys (6 stocks), catch curves that estimate fishing mortality rates (4 stocks) or integrated quantitative stock assessment models that estimate biomass and fishing mortality (23 stocks). Target reference points are directly estimated by quantitative assessments, and either estimated or based on biological information for catch-curve assessments.

CPUE is assumed to have a linear relationship to stock biomass. Target CPUE values for SESSF Tier 4 assessments are usually based on a historical reference period when catches and CPUE should be stable, and the stock is likely to have been fully exploited or represent unfished biomass. CPUE during the reference period is then assumed to correspond to the target B_{MEY}. The target reference point is the average CPUE during the reference period; the limit is 40 per cent of this target CPUE, which is approximately $0.20B_0$ or $0.50B_{MSY}$. For CPUE-based harvest strategies, recent average CPUE is used as the indicator of current biomass. Fishing mortality rates cannot be estimated from CPUE analyses without additional information.

The ETBF harvest strategies are based on size-based indicators (e.g. the proportion of 'old' fish in catches) combined with trends in CPUE. The CPUE reference period (1997–2001) was when the fishery was perceived to be profitable. However, this might not be consistent with the MEY intent of the harvest strategy because profitability during that period might have been affected by historically high tuna prices and low fuel prices.

For the WDTF and the NWSTF, CPUE during the reference period is assumed to represent B0 because it covers a period when little or no fishing occurred and the stock is assumed to have been at carrying capacity (B_0). For developing fisheries or for fisheries where activity is sporadic (e.g. the WDTF), where it is difficult to identify reference points that are consistent with the policy, a pragmatic approach has been adopted, that involves identifying a suite of key species and managing the fishery through separate catch triggers for each of those species (Dowling 2011).

Performance indicators specified in harvest strategies are designed to be directly comparable to reference points or their proxies. For some stocks, quantitative assessment models are available to estimate current biomass and current fishing mortality rates; assessments that are based on catch curves provide estimate current fishing mortality rates. Using MSE, Haddon (2013) shows that quantitative stock assessments can provide robust estimates of current biomass, fishing mortality rates and biomass depletion, resulting in effective harvest strategies. In comparison, there is lower precision in estimates of fishing mortality rates derived from catch curves.

The policy recognises the importance of ecological relationships among species, specifying that more conservative reference points might need to be considered for species that are important in the maintenance of food webs or communities ('keystone species'). For example, the Macquarie Island Toothfish Fishery, which adopted its harvest strategy from the international CCAMLR, takes into account the ecological role of harvested species.

Despite their higher productivity (and therefore relatively low B_{MSY}), exploitation rates of about 20–25 per cent of current biomass are generally considered appropriate for low trophic-level species because they are the key prey of larger fish and marine mammals; a larger proportion of the biomass of small pelagic species needs to be maintained to ensure ecosystem functioning (Smith et al. 2011, Pikitch et al. 2012). For the Small Pelagic Fishery, B_{MEY} is not considered to be an appropriate reference point because of the high interannual variability in the abundance of small pelagic fish species and their ecological importance as forage fish. The Small Pelagic Fishery's harvest strategy is based on direct estimates of stock biomass from daily egg production model (DEPM) surveys and limits exploitation rates to 20 per cent of the DEPM estimate of the current spawning biomass.

Reference points have not been defined for six Commonwealth fisheries. These are mostly low-value, data-poor or developing fisheries for which reference points are difficult to estimate, and which often have catch or effort triggers instead of target and limit reference points (see section on Small fisheries and data-poor stocks). The GABTS also uses trigger-based systems to activate data collection and assessments of species that are not under quota.

The BSCZSF ('scallop fishery') does not specify biomass-based reference points because of the natural variability in the stock's availability and recruitment. No limit reference point, in the usual sense of the word, is specified in the scallop fishery's harvest strategy. However, the control rules do specify that a viable or prospective area containing at least 500 t of scallop must remain closed, and at least 40 per cent of viable and prospectively viable areas must remain closed. The degree to which this approach meets the intent of the policy is unclear.

Harvest control rules

Recommended biological catches

The harvest strategies that have reference points include harvest control rules that specify management actions to control the intensity of fishing activity in response to current stock status. The form of control rules vary depending on management arrangements—for example, input controls (fishing effort limits) versus output controls (catch limits). The rules generate a RBC that is used as the basis for setting the next fishing season's TAC, in response to changes in performance indicators in relation to the target and limit reference points. For input-managed (effort-controlled) fisheries, recommendations take the form of a TAE. Harvest strategies are designed and tested to ensure that limiting total fishing mortality to the RBC has an acceptable probability of moving stock biomass towards the target reference point and avoiding limits. Quantitative stock assessment models are able to generate projections of future stock status and are used to predict an RBC for the coming year, as well as longer term RBCs. The models are often used to generate projections of predicted future biomass at alternative catch levels and under various alternative assumptions, to test the effect of alternative management actions or future conditions.

For those stocks with harvest strategies, TACs are usually been based on the RBCs that were generated by the assessments and harvest strategy control rules, and adjusted by meta-rules. Exceptions include situations where assessments have been rejected, where alternative assessment approaches have produced conflicting conclusions on stock status (e.g. redfish; AFMA 2012a) or where RBCs are considered unrealistic (e.g. john dory in 2011; AFMA 2011a). Harvest strategies have not included rules for these situations, with RAGs and MACs consequently recommending that TACs be rolled over from previous years.

The NPF is currently managed using input controls. In the tiger prawn subfishery, the level of fishing effort is optimised to achieve B_{MEY} from target species using a quantitative bioeconomic model. This TAE is managed spatially and temporally. The duration of the fishing season for banana prawn subfishery is directly influenced by tiger prawn catch rates and fishing effort data collected during the season through a process of in-season monitoring and adjustment.

Trigger-based harvest strategies do not specify biomass-based reference points or proxies. Instead, reaching a trigger (usually a level of catch or fishing effort) activates a process for developing a more reliable assessment and, in some cases, requiring the development and implementation of more rigorous harvest strategies (see, for example, the WDST case study). For some trigger-based harvest strategies for short-lived species, the development of a more reliable assessment and the implementation of management actions are unlikely to occur within the available timeframe (see, for example, the SSJF case study). Nevertheless, trigger-based harvest strategies often contain rules that can ultimately result in the setting of conservative limits or cessation of fishing (e.g. the WDSTF's harvest strategy). The key issue with these harvest strategies is that the trigger or conservative limit needs to be set at the correct level to prevent overfishing (Dowling 2011). However, the Commonwealth Fisheries Harvest Strategy Policy provides little guidance on determining appropriate trigger levels. For developing fisheries, the policy requires that triggers are demonstratively precautionary and it sets out generic steps for managing such fisheries.

By generating a zero RBC, harvest strategy control rules reflect the policy requirement that targeted fishing ceases for commercial species that are below their limit reference points. Issues associated with control rules for these overfished stocks are considered further in the 'Rebuilding overfished stocks' section of this report.

Total allowable catches

The Commonwealth Fisheries Harvest Strategy Policy requires that all sources of mortality are accounted for when determining TACs. For many harvest strategies, RBCs are translated into TACs through a set of rules that include deductions for expected mortalities due to discarding, research quota, catches in other Commonwealth fisheries, state commercial catches and recreational catches. The reliability of discarding estimates is highly dependent on the representativeness of observer coverage; it varies among fisheries and species, and over time.

For several species, state catches are deducted from RBCs and the TAC available to Commonwealth fishers has been steadily reduced as state catches have increased in the absence of catch-sharing arrangements. With school whiting, for example, state catches exceed Commonwealth catches, leaving Commonwealth fishers with a small portion of the total, yet most of the costs of data collection and assessment of this stock are recovered from Commonwealth fishers.

Recreational catches are significant for several Commonwealth species, such as jackass morwong. However, estimates of recreational catches are not always available from the states responsible for managing the recreational sector or they are considered to be unreliable, and so assessments and TAC calculations do not always include estimates of recreational catches (e.g. silver trevally). Several tuna fisheries involve significant recreational catches of species that are targeted by commercial fishers. The ETBF, for example, sets TACCs, which reflect that AFMA does not have direct control over recreational catches.

Uncertainty and risk

Fisheries management must deal with considerable uncertainty because marine ecosystems, fish populations and the fisheries that depend on them are highly complex and difficult to study. The existence of uncertainty does not mean that harvesting should not occur. However, it does require risks to be evaluated and uncertainty to be managed.

The intention of the Commonwealth Fisheries Harvest Strategy Policy is to maintain commercial fish stocks above the biomass limit reference point at least 90 per cent of the time, requiring that risk be consistent across different management (and assessment) approaches. Different assessment approaches have different levels of uncertainty. The level of uncertainty usually increases as the amount and quality of data and information decrease. Increased uncertainty associated with low-information assessments contributes to increased risk, requiring that this be addressed through the adoption of a higher level of precaution in management.

The Small Pelagic Fishery's harvest strategy recognises the increasing uncertainty in status with time since the last biomass estimate. In this harvest strategy, the maximum exploitation rate is reduced for each year after biomass was estimated, falling from 20 per cent to 7.5 per cent of biomass after five years.

The SESSF framework explicitly addresses this data-uncertainty–risk trade-off in assessments by requiring the application of discount factors at each of the lower information assessment tier levels—a 5 per cent discount is applied to RBCs derived from catch curve assessments (Tier 3) and a 15 per cent deduction or 'discount factor' is applied to RBCs derived from CPUE-based assessments (Tier 4). ShelfRAG originally recommended the discount values, noting that they were provisional pending further analysis of the levels that will provide comparable levels of risk across the tiers. Fay et al. (2013) recently concluded that the discount factors required to obtain equivalent risk across tiers varied among species. They also found that stock status and that uncertainties in the relationship between CPUE and biomass required additional precaution for managing data-poor stocks.

The SESSF framework acknowledges that discounts might not need to be applied in situations where other management measures are in place to address the uncertainty(e.g. closures or where there is evidence of recent stability of the stock at current fishing levels). As a result, the default discount factors have sometimes been waived where RAGs have accepted that significant spatial closures (even though implemented for other species or objectives) manage uncertainty in a way that is at least equivalent to that provided by a discount factor. However, concerns have been raised about the circularity in arguing that stability in recent CPUE justifies waiving the discount factor, when these assessments are based on CPUE, which was the reason for having a default discount factor in the first place. Fay et al. (2013) concluded that stability in CPUE did not warrant the waiving of discount factors, especially for data-poor stocks.

Multiyear TACs have been introduced for several species that have supported stable fisheries in recent years and stable biomass that is near the target. Multiyear TACs are intended to reduce assessment costs, and provide the fishing industry with stability and certainty about medium-term catch levels. Stokes (2010) proposed general criteria for selecting stocks that might be eligible for multiyear TACs. Multiyear TACs usually need to be set at a lower level than single-year TACs, to compensate for increasing uncertainty in stock status. For several stocks, multiyear TACs have been set at the level of the long-term RBC. They should also be tested using MSE or assessment model projections that assess the probability that proposed TAC levels will not result in overfishing. Multiyear TACs are not progressively discounted to take into account the increasing uncertainty in stock status with time since the last assessment, but multiyear TACs for high-information stocks are based on projections that demonstrate that the planned TACs will not result in increased risk of stock declines.

Nonetheless, it remains possible for stocks to change unexpectedly as a result of environmentally induced changes in productivity, unusually strong or weak year classes recruiting to the fishery or increased fishing mortality from other sources (e.g. state catches) , even though Commonwealth catches remain within the multiyear TAC. Therefore, multiyear TACs have often included breakout rules for responding to unexpected situations that were not envisaged or were not tested for, when the multiyear TAC was set. Breakout rules usually trigger a full assessment. For example, the CPUE of silver warehou, for which a multiyear TAC had been established, declined below the lower 95 per cent confidence interval of CPUE predicted by the Tier 1 stock assessment in 2011. This triggered a full update of the Tier 1 assessment. The updated assessment indicated a decline in stock biomass, although the small change limiting rule prevented a subsequent reduction in the silver warehou TAC (AFMA 2012e).

Management strategy evaluation and testing

The policy suggests that harvest strategies should be formally be tested with MSE, both at the generic level and at the species-specific level. Many, but not all, of the harvest strategies implemented in Commonwealth fisheries have been subjected to MSE or other forms of testing (Table 1). This has been undertaken as part of harvest strategy development or after implementation. Most of the MSEs have covered categories of species that are typical of particular life histories, data quality or fishery types. The testing by Wayte (2009), for example, demonstrated that the SESSF framework meets the intent of the policy by maintaining biomass at the target biomass and ensuring that it stays above the limit biomass at least 90 per cent of the time. A key issue is that the testing is only valid for the range of uncertainties that were investigated by each MSE.

MSE of the ETF (Kolody et al. 2010) indicated that the harvest strategy had an acceptable probability of achieving the policy's objectives for several stocks, including striped marlin. However, they concluded that uncertainty about connectivity with the wider western Pacific would be to undermine the effectiveness of harvest strategies for widely distributed and highly mobile species like bigeye tuna.

Testing has extended to several data-poor fisheries with trigger-based harvest strategies. Dowling (2011), for example, assessed catch trigger levels in the NWSTF, which are used to activate management responses scaled to prespecified catch levels. MSE of the BSCSF's harvest strategy showed that the highly variable and apparently random nature of recruitment of scallop to the fishery created problems in identifying a realistic target reference point,; and that current harvest control rules could result in there not being a Commonwealth fishery in some years of poor recruitment (Haddon 2011). For some species of trochus and sea cucumber, there is insufficient information to conduct MSEs (Plagányi et al. 2011a,b).

MSE of several harvest strategies was not completed until well after the harvest strategy was implemented. However, the generic approach taken to many MSEs informed the implementation of harvest strategies in other fisheries. MSE required a substantial investment in staff resources, partly because it has required the development of new software, including operating models, diagnostics and reporting routines. The software is now available for the testing and evaluation of other stocks in other fisheries. Haddon (2013) provides details of recent MSE in several Commonwealth fisheries and discusses the relevance of MSE to the implementation of the policy.

The policy suggests that harvest strategies should be reviewed every three to five years after harvest strategies are established. Many of the harvest strategies were updated during 2007–2012 in response to improved assessments, MSE and better knowledge about reference points. Details of those amendments are provided in the individual case studies. Many of the amendments have dealt with unexpected behaviour of control rules where the harvest strategy was found to have the potential to move the stock towards the limit rather than the target reference point under certain circumstances. Another common issue has been harvest control rules and assessments producing extremely large RBCs that RAGs have considered to be unrealistic or unachievable—for example, john dory and mirror dory in 2011.

Harvest strategy application

Stocks, species and multispecies stocks

The Commonwealth Fisheries Harvest Strategy Policy applies to key commercial species or stocks. The policy defines 'stocks' as fish populations or management units. In contrast, stock assessment scientists usually apply a biological definition of a stock—'a functionally discrete population that is largely distinct from other populations of the same species' (Woodhams et al. 2012). While productivity of different stocks of the same species might differ, within a single biological stock, biological parameters, histories and responses to fishing should be similar. However, fishery managers sometimes have to manage different fish populations (or even species) together as a single management unit because information on stock structure is lacking, or because the members of different populations or the different species are not distinguished in historical landings, in the data for assessment or in management arrangements. In the SESSF, for example, the harvest strategy framework is applied to 'other oreodories', which consist of several species that are managed through a single TAC. Similarly, more valuable species, such as jackass morwong, ling and blue warehou consist of multiple stocks that are managed under single TACs. For jackass morwong, the assessments and framework are applied separately to each biological stock, but a single TAC is derived for the combined management unit from the sum of those RBCs.

Several 'stocks' actually consist of multiple species. The species composition of several multispecies stocks (e.g. eastern deepwater sharks and other oredories) is often uncertain. The 'flathead' catch in the SESSF CTS is mostly tiger flathead (*Neoplatycephalus richardsoni*), but also includes several other flathead species. The assessment uses biological parameters derived from tiger flathead, but the RBC calculation is based on catches of all flathead species and the TAC applies to that species mix. This is justified by the relatively low proportion of other flathead species in the catch (AFMA 2013b). While this may be a practical and reasonable approach to managing some species groups, there is a need to regularly verify that other species do not comprise a significant proportion of the catch of multispecies stocks.

There has been a tendency, in output-managed (catch-limited) fisheries, to focus the implementation of harvest strategies on species that are under quota. Harvest strategies have been developed for some secondary species that are rarely targeted, but under quota, such as john dory in the SESSF CTS. Harvest strategies have generally not been developed for other, non-quota byproduct species, despite substantial catches of some of these species. For example, there are substantial landings of ocean jacket in the CTS from time to time and they are often discarded in large quantities. Western gemfish is under quota in the SESSF CTS, but catches of western gemfish in the GABTS are not under quota; they are currently managed through catch triggers rather than a harvest strategy.

Timeliness

There are often substantial time lags between data collection and setting TACs in Commonwealth fisheries. In the CTS, for example, fisheries data for 2010 are not available for analysis until mid-2011; assessments are completed and RBCs are recommended in late 2011; TACs for the 2012–13 fishing season, based on 2010 data, are then confirmed before the season commences in May 2012. For several Commonwealth species, quantitative models can be used to predict status in subsequent seasons, although the reliability of predictions depends on assumptions about the value of projection parameters in the intervening period, particularly recruitment. There have been instances where projections based on average recruitment have proven to be optimistic when stocks then undergo an extended period of poor recruitment, such as has happened to silver warehou in the SESSF during the past decade.

Information on stock abundance in the most recent fishing season is not usually available for assessments. The SESSF framework included a 'latest CPUE multiplier rule' to adjust TACs according to CPUE in the most recent year. The rule was designed to adjust the TAC by the ratio of recent CPUE and the average CPUE that was used in the original TAC calculation. MSE has shown that this rule does not reduce the likelihood of achieving the target biomass, but it does increase the variability in TACs (Wayte 2009). In 2013 the SESSFRAG proposed that this recent CPUE adjustment rule be removed. Rules are also applied in this and several other fisheries to stabilise TACs by limiting small and large changes in TACs between fishing seasons, and to allow limited overcatch or undercatch of the TAC to be carried over between fishing seasons.

Short-lived and highly variable species

The Commonwealth Fisheries Harvest Strategy Policy acknowledges the challenges with managing highly variable species, but recognises that stocks that fall below the limit reference point due to natural variability are still subject to the recovery requirements of the policy. Table 1 and the case studies highlight problems in implementing the policy for highly variable species, including scallops, squid and demersal crustaceans. These problems have been due to difficulties in identifying appropriate limit and target reference points (B_{MSY} or unfished biomass) and estimating current biomass for rapidly changing stocks. For scallops, the source of variation in recruitment is uncertain.

The success of the NPF in implementing the policy can be partly attributed to this fishery's investment in collecting data for stock assessment, researching species biology and drivers of interannual variability in biomass, particularly rainfall. Preseason fishery-independent surveys and within-season monitoring and management has been established in the banana prawn subfishery to deal with the high variability typical of such short-lived species.

Eastern school whiting illustrates another approach to managing highly variable species. Estimates of whiting biomass have varied considerably between successive assessments, largely as a result of this species late age of recruitment to the CTS (2–3 years) and variability in recruitment for this short-lived species (maximum age 7 years; Day 2012). Consequently, the RBCs have been based on projections of the performance in terms of abundance at different levels of fixed catch during an 18-year projection period. With a constant catch of 1700 t per year, the probability of the spawning stock biomass falling below the $0.20B_0$ limit reference point was less than 10 per cent (Day 2012). This approach is consistent with the policy, but its performance in maximising economic yields and preventing overfishing will depend on whether the model projections encapsulate the full range of uncertainty in population dynamics and the stock's responses to fishing.

Small fisheries and data-poor stocks

Data-poor fisheries or stocks are defined as those where information is insufficient to produce a defensible quantitative stock assessment (Haddon et al. 2013). Small fisheries include the Coral Sea Fishery and the NWSTF and the WDTF. The harvest strategies for large fisheries are often complex with substantial data requirements, and a high level of investment in the development and running of the harvest strategies. For example, the NPF has undertaken extensive assessment modelling, bioeconomic modelling and MSE. As mentioned previously, some of the smaller fisheries have harvest strategies that are trigger based and do not explicitly define target and limit reference points, and have not undertaken MSE or testing (e.g. the NWSTF and WDTF; Table 1). A risk-catch-cost trade-off between the fishery's value, and the costs of collecting data, developing, implementing and running harvest strategies has not been explicitly applied until recently.

There are several Commonwealth fisheries, particularly data-poor, developing or small fisheries, where the harvest strategy is not routinely used in fishery management (e.g. the WDTF, NWSTF and the squid fishery). Some fisheries may lack the capacity or financial capability to generate the data required to monitor indicators. Such harvest strategies often involve triggers that are consistent with the examples of triggers listed in the policy. For developing fisheries, the policy requires that triggers be demonstratively precautionary. However, it is difficult to demonstrate precaution in data-poor situations. Furthermore, the data required for assessments or management measures in response to a trigger being breached may not be routinely collected or such assessments may not feasible within a suitable timeframe, particularly for short-lived stocks. No stocks have deteriorated to an overfished or overfishing classification while under a trigger-based harvest strategy, although the biomass status of several stocks remain classified as 'uncertain' (e.g. bugs and ruby snapper in the WDTF).

Fishery-wide maximum economic yield

MEY is intended to apply at the fishery level rather than at the stock level. The Commonwealth Fisheries Harvest Strategy Policy acknowledges that, as a result of differences in the biology and economic characteristics of species in a multispecies fishery, optimising economic returns across the entire fishery might result in some target species and incidentally caught secondary species being reduced below B_{MSY}, due to harvest strategies being driven by the harvest strategy's targets for the main commercial species. It may be necessary to forgo some profits from one species to generate higher profits from other species to maximise profits across the entire fishery. While recognising these options, the policy requires the biomass of all species to be maintained above their limit reference points.

Most Commonwealth fisheries are multispecies fisheries, catching a variety of species of varying commercial importance, including byproduct species that are sometimes retained, and sometimes released or discarded. However, the tiger prawn subfishery of the NPF and the GABTS are the only Commonwealth fisheries that have attempted to optimise MEY across a small set of key commercial species. These have involved the development of bioeconomic models of differing complexity.

The challenges to optimising economic yield across multiple species include (Vieira & Pascoe 2013):

- uncertainty about the ability of skippers to target a specific mix of species actively
- difficulties in obtaining reliable data on the cost structures of a representative sample of the fishery's vessels or businesses
- a lack of reliable biological data and assessment models for secondary or byproduct species
- subcomponents of the fishery that target the same species may use different fishing methods and will have different cost structures, requiring trade-offs between sectors.

Research commenced in 2012 to develop alternative approaches to bioeconomic models for setting target reference points in multispecies fisheries (FRDC project 2011/200). In 2012, SESSFRAG identified quota species that were not known to be targeted or did not account for a significant proportion of the fishery's GVP. The RAGs subsequently reported RBCs for BMSY or $0.40B_0$ target reference points as well as for $0.48B_0$ (AFMA 2012a) for these secondary species, including redfish, john dory and offshore ocean perch. There has not yet been any MSE to evaluate the effect of using alternative targets for secondary species and whether these will be maintained above their limit reference points with the required 90 per cent probability (Haddon et al. 2013). A draft ABARES paper (Vieira et al. in prep.) on issues relating to the setting of target reference points for secondary species was recently considered by South East Management Advisory Committee when determining TACs for identified secondary species.

Rebuilding overfished stocks

The 2005 Ministerial Direction, which initiated the development of the Commonwealth Fisheries Harvest Strategy Policy, also directed AFMA to put an end to overfishing and to rebuild overfished stocks within reasonable timeframes. For overfished stocks, the policy requires the implementation of rebuilding strategies. These must support the research and management actions necessary to stop the decline of, and support the recovery of, the species and define targets for rebuilding with associated timeframes. Such stocks may also be eligible for listing under the *Environment Protection and Biodiversity Conservation Act 1999.* A listing under a high threat category (vulnerable, endangered or critically endangered) requires a formal recovery plan under the act; a listing as conservation dependent may also require a formal recovery plan. The policy specified 12-month transitional arrangements for stocks that were below their limit reference points at the beginning of 2008, with targeted fishing being reduced to zero during that year and targeting fishing ceasing after 1 January 2009.

Harvest strategies, apart from trigger-based harvest strategies, are designed to generate a zero RBC where the indicator is below the limit reference point. This reflects the policy's requirement that there be no targeted fishing on overfished stocks, as well as the need to reduce fishing mortality to a level that facilitates rebuilding within required timeframes. Where the RBC is zero, incidental catch allowances are usually set in the SESSF to cover acceptable levels of unavoidable catch that may occur when fishers are targeting other species. Those catches are sold by fishers and may be potentially valuable, encouraging fishers to continue fishing, or to sell or lease quota. Ideally, the effect of this unavoidable bycatch allowance should be tested, using MSE or stock assessment projections, to ensure that catches at that level will not jeopardise the stock rebuilding plan. However, data limitations or the absence of a quantitative stock assessment model have prevented this from being done for some species (e.g. blue warehou).

Seven Commonwealth-managed stocks, all of which were depleted below limits before the introduction of the policy, have remained classified as 'overfished' since the policy's introduction, including eastern gemfish, school shark, gulper sharks and orange roughy in all zones except the Cascade Plateau (Table 5). Blue warehou status was classified as 'uncertain' in

2007 and has been classified as 'overfished' since 2008 (Woodhams et al. 2012). The reasons why these stocks have not recovered to their limit reference points may include:

- total fishing mortality in recent years may have been too high to allow recovery
- assessment uncertainty (e.g. data availability may have decreased as a result of reduced fishing for the species, making it difficult to detect whether rebuilding is occurring)
- the low productivity of some stocks may mean that recovery will inevitably be slow, despite appropriate fishery management actions.

Reduced TACs or incidental catch allowances may result in fishers avoiding the species, which may affect the quantity of data and the reliability of indicators, such as CPUE. This adds to uncertainty in stock status and may create problems for monitoring the performance of the rebuilding plan.

In terms of fishing mortality reference points, several of the overfished stocks have also been classified as subject to overfishing, indicating that management measures have not sufficiently reduced fishing mortality to facilitate recovery. Overfishing of school shark has occurred since 2009, overfishing of eastern gemfish has occurred since 2010 and overfishing of gulper sharks has occurred since 2008. Overfishing of blue warehou occurred in 2009 and 2010, with its status being 'uncertain' in 2011 and in earlier years (Woodhams et al. 2012).

The orange roughy stocks have not been subject to overfishing since the Orange Roughy Conservation Programme was implemented in 2006, which effectively closed all of the orange roughy fishing areas (other than the Cascade Plateau) to fishing and reducing fishing mortality to almost zero. Despite these measures, the low productivity and long generation time of orange roughy are likely to result in slow recovery.

Most CPUE-based harvest strategies use catch-and-effort data reported by commercial fishers in logbooks. There are many factors that can reduce or bias the extent to which CPUE is a reliable index of stock biomass, particularly where structural adjustment or other operational changes have resulted in low fishing effort, active avoidance or substantial shifts of fishing effort to other areas. Variations in selectivity and fishing power as a result of sequential improvements in fishing technology and efficiency ('technological effort creep') will also affect the reliability of CPUE as an index of abundance. This has only been formally evaluated in the NPF (Dichmont et al. 2012). Difficulties with CPUE may also affect quantitative stock assessments because CPUE time-series are often the main index of abundance in those models. Recognising the problems relating to commercial CPUE for some species, the 2005 Ministerial Direction to AFMA (DAFF 2007) required the establishment a system of independent surveys for all major Commonwealth fisheries. Fisheries-independent surveys have been established in several fisheries, including the SESSF CTS and GABTS. Those surveys may eventually provide estimates that replace or augment commercial CPUE for many commercial species.

The essential requirement of a management approach for rebuilding overfished stocks is to reduce fishing mortality. This may involve limiting catch levels or fishing effort, including area or season closures and gear restrictions. In the SGSHS, fishing for the primary target species (gummy shark) in recent years has resulted in ongoing incidental mortality of overfished school shark. The Commonwealth Fisheries Harvest Strategy Policy provides little guidance on how mortality levels for overfished stocks should be set where constraining the catch of the overfished stock is likely to impact fishing for other species.

Table 5 Summary of rebuilding stocks (Commonwealth stocks that have been classified as overfished or uncertain if overfished during 2005-11)

Stock	Biological status, catches and plans									Reasons for 2011 classification	Assessment type	Assessment and management issues
	Indicator		2005	2006	2007	2008	2009	2010	2011			
Gemfish (east)	F	landings (t)	97	87	102	118	125	108	70	Total removals exceeded levels that would facilitate recovery	Quantitative stock assessment model, including projections	Reliability of survey CPUE as an abundance index; poor model fit to discards; recently poor recruitment, which is below model predictions
		other (t)	**78**	46	**129**	**115**	168	**181**	**122**			
		total (t)	**175**	133	**231**	**233**	293	**289**	**192**			
	allowance (t)		**100**	100	**104**	**100**	100	**100**	**100**			
	B						CD	CD	CD	Estimated biomass below $0.20B_0$		
Blue warehou (east)	F	landings (t)	33	17	15	48	25	20	13	Uncertain if reductions in fishing mortality will facilitate rebuilding	CPUE trends	Reliability of CPUE as an index of abundance; reliability of discard estimates
		other (t)	275	110	25	266	**17**	**23**	44			
		total (t)	308	127	40	314	**42**	**43**	57			
	allowance (t)		100	100	100	40	**40**	**40**	40			
	B									CPUE below limit reference point		
Gulper sharks (upper slope)	F	landings (t)	n.a.	n.a.	5	5	6	3	4	Incidental catches likely to be exceeding levels that would facilitate recovery	Depletion estimates from habitat mapping and carrying-capacity modelling	Stock structure; unreported discarding
		other (t)	n.a.	n.a.	n.a.	**n a**	**n a**	**≤1**	**≤1**			
		total (t)	n.a.	n.a.	≥5	**≥5**	**≥6**	**3**	**4**			
	allowance (t)		TL	TL	TL	**TL**	**TL**	**TL**	**TL**			
	B									Surveys indicate historical depletion exceeded 98 per cent for some species in several areas		

Stock	Biological status, catches and plans									Reasons for 2011 classification	Assessment type	Assessment and management issues
	Indicator		2005	2006	2007	2008	2009	2010	2011			
Orange roughy (east)	F	landings (t)	654	513	12	4	9	2	25	Very low catches and closure of most areas deeper than 700 m	Egg surveys and acoustic surveys	Assessment not updated since 2007 due to a lack of fishing and survey costs
		other (t)	100	100	0	0	0	0	0			
		total (t)	754	613	12	4	9	2	25			
	allowance (t)		738	700	70	25	25	25	25			
	B			CD	CD	CD	CD	CD	CD	Remains depleted from historical overfishing		
Orange roughy (south)	F	landings (t)	99	5	22	<1	17	16	17	Very low catches and closure of most areas deeper than 700 m	Egg surveys and acoustic surveys	Assessment not updated since 2000 due to a lack of fishing and survey costs
		other (t)	0	0	0	0	0	0	0			
		total (t)	99	5	22	<1	17	16	17			
	allowance (t)		100	10	25	25	35	35	35			
	B			CD	CD	CD	CD	CD	CD	Remains depleted from historical overfishing		
Orange roughy (west)	F	landings (t)	281	159	31	6	25	28	34	Very low catches and closure of most areas deeper than 700 m	Egg surveys and acoustic surveys	Assessment not updated since 2002 due to a lack of fishing and survey costs
		other (t)	0	0	0	0	0	0	0			
		total (t)	281	159	31	6	25	28	34			
	allowance (t)		487	250	60	50	60	60	60			
	B			CD	CD	CD	CD	CD	CD	Remains depleted from historical overfishing		
School shark	F	landings (t)	209	203	172	229	204	228	163	Incidental catch levels unlikely to be facilitating recovery	Quantitative stock assessment model, including projections	Historical underreporting of catches and trawl bycatch; reliability of current CPUE index; productivity may have been underestimated
		other (t)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.			
		total (t)	>209	>203	>206	>229	>204	>228	>163			
	allowance (t)		249	228	213	213	240	216	176			
	B						CD	CD	CD	Estimated pup production below 0.20P0		

CD = listed as conservation dependant; EW = no distinction between east and west stocks; n.a. = not available; TL = trip limit (a 150 kg trip limit in place for gulper sharks)

Notes: Status is classified for each calendar year, whereas allowances and catch estimates are usually for each fishing season. The 2011 column, for example, shows status for the 2012 calendar year, and allowances and catches for the 2011–12 fishing season.

Before 2008, the *Fishery status reports* classified orange roughy as a single stock in the SESSF Commonwealth Trawl Sector. Biological status was subsequently reported separately for the orange roughy eastern zone, southern zone and western zone. In this report, the status of Commonwealth Trawl Sector orange roughy is counted as if it was reported for three stocks throughout the period of interest so that the status of the Commonwealth Trawl Sector stock applies to each of the three stocks. The *Fishery status reports* have treated a fourth orange roughy stock (Cascade Plateau) as a separate stock throughout the period.

allowance: incidental catch allowance for overfished stocks or actual total allowable catch (TAC). Includes nominal east–west stock splits where appropriate

'other' removals may include estimated discards, state and recreational catches, but usually exclude research or survey catches.

Fishing mortality status (F)		**Biomass status (B)**
subject to overfishing	(red)	overfished
uncertain	(yellow)	uncertain
not subject to overfishing	(green)	not overfished

Sources: Status classifications and notes on assessments are from *Fishery status reports* (Woodhams et al. 2012). EPBC Act listing status from SEWPAC (2012). Catch and removals are from a variety of sources, including Woodhams et al. (2012), Haddon (2012), Upston & Klaer (2012) and AFMA logbook and landings data.

Annual *Fishery status reports* (Woodhams et al. 2012) have sometimes reported targeted fishing for overfished stocks, including school shark, eastern gemfish and, in the past, blue warehou and jackass morwong. Whereas unavoidable bycatch needs to be provided and accounted for in some way, the policy requires that the level of fishing mortality, including discards, allows rebuilding of the stock within a reasonable timeframe. However, the policy does not specify guidelines for actually setting incidental catch allowances and, in some cases, this allowance has been set above the levels estimated by assessments to allow recovery of the stock in accordance with the adopted rebuilding strategy. There may also be difficulties with obtaining accurate estimates of discards of species under incidental catch allowances. For example, it may be difficult to obtain representative observer coverage of rare or episodic catches of the species, or fishers may change fishing practices or discarding behaviour when observers are present.

AFMA and industry have worked to minimise the catch of several rebuilding stocks through a range of mechanisms in addition to the incidental catch allowance. Ultimately, however, an effective reduction of fishing mortality for these species is critical to ensure that overfishing does not continue. Additional guidance might be needed to further reduce fishing mortality on rebuilding stocks where assessments suggest that rebuilding is not occurring under current management arrangements, or that rebuilding is unlikely to occur within the specified timeframe.

Jointly managed and international fisheries

Jointly managed and international fisheries include those managed through a joint authority (with Australian states and the Northern Territory), straddling stocks (crossing the boundaries of EEZs) and fisheries managed through RFMOs. The Commonwealth Fisheries Harvest Strategy Policy applies to Commonwealth fisheries; other jurisdictions that are involved in managing the same stocks have different management objectives and policies. For example, the policy is unique in stipulating an explicit B_{MEY} *target. The harvest strategies of many* jurisdictions either do not have a target, or use the B_{MSY} target that is specified in the *United Nations Convention on the Law of the Sea* (UN 1982).

The policy recognises that it may be difficult to apply the policy to jointly managed stocks or to international stocks managed by RFMOs, and it does not prescribe management arrangements for these stocks (DAFF 2007). The policy notes that Australia should advocate principles and requirements of the policy at RFMOs and harvest strategies that are consistent with many aspects of the policy have been implemented by RFMOs for several other stocks (e.g. southern bluefin tuna).

Toothfish in the high seas of the Southern Ocean are managed under CCAMLR harvest strategies, which explicitly consider ecological links. CCAMLR's approach views the entire Southern Ocean as a matrix of interlocking ecological components with harvest strategies being designed to achieve conservative TACs. Such a conservative approach is generally not taken by other RFMOs, partly because the CCAMLR Convention is explicitly a conservation convention, and partly because it requires a great deal of data and analyses to understand the ecological linkages, develop the harvest strategies and calculate the TACs. Other RFMOs, such as the Indian Ocean Tuna Commission and the WCPFC have yet to implement harvest strategies and TACs for their target species.

Additional factors may need to be taken into account for internationally fished stocks, including connectivity of stocks, catch levels among the nations involved and the feasibility of implementing a harvest strategy for species that straddle EEZ boundaries. For example, it has been determined that there is a broad, Pacific Ocean stock of albacore that is fished by the

Commonwealth ETBF, but also by other countries in the wider WCPFC, who take a much greater proportion of the catch. Introduction of an ETBF harvest strategy for albacore therefore has little chance of achieving management objectives without cooperation of other countries. In contrast, scientific evidence indicates that swordfish and striped marlin have localised Australian stocks or substocks. It is therefore prudent to implement harvest strategies for the substocks that occur in Australian waters, to ensure that exploitation of these localised stocks meets policy objectives. The issue of connectivity has not yet been resolved for yellowfin and bigeye tuna in the ETBF, and harvest strategies have not been implemented for these species, either by the WCPFC or Australia.

Fishery performance

Biological status

Since the implementation of the *Fisheries Management Act 1991*, substantial effort has been invested in assessing and reporting on stock status for Commonwealth fisheries. This reporting has continued since the implementation of the Commonwealth Fisheries Harvest Strategy Policy (Woodhams et al. 2012). The classification of biological status aligns with policy limit reference points:

1) Biomass—whether stock biomass is below the limit reference point. In this case the stock is classified as 'overfished'.
2) Fishing mortality—whether current rates of fishing will result in stock biomass declining to below targets and limit reference points. In this situation the stock is classified as 'subject to overfishing'.

Woodhams et al. (2012) provide more details on these definitions of stock status.

The number of Commonwealth stocks classified as 'not overfished' increased from 21 in 2007 to 38 stocks in 2011 (Table 1). The number classified as 'overfished' declined from 8 to 7 stocks during this period. During 2007–2011, the number of stocks classified as 'uncertain' declined from 38 to 21. It is a coincidence that the statistics for uncertain and overfished stocks appear to be transposed; not all of the 38 stocks classified as 'uncertain' in 2007 were reclassified as 'not overfished' in 2011.

The reclassification of biomass status from 'uncertain' to 'not overfished' cannot be solely attributed to the implementation of the policy because it may be the product of several interrelated developments, as well as variation in stock productivity. Nonetheless, the policy has prompted and guided improved data collection, assessments and management responses, in addition to the decreased fishing effort resulting from structural adjustment. Harvest strategies may therefore have contributed directly to the reclassification of many of the previously uncertain stocks as 'not overfished'. Similarly, harvest strategies are likely to have helped to maintain many stocks as 'not overfished' during 2007–11 by preventing their biomass from falling below limit reference points.

A key objective of the policy, and a pivotal requirement of the Ministerial Direction to AFMA (DAFF 2007), is to stop overfishing. Similar to biomass status, the fishing mortality status of Commonwealth stocks has improved since the policy was introduced. The number of stocks classified as 'not subject to overfishing' increased from 37 in 2007 to 55 in 2011, and the number classified as 'uncertain' declined from 29 to 8 stocks in 2011 (Table 1). The number classified as 'subject to overfishing' increased from 1 stock (pink ling) in 2007 to 3 stocks (eastern gemfish, gulper sharks and school shark) in 2011.

Comparison of stock status since 2005, when the Ministerial Direction was made, highlights further improvements in biological status. In 2005, 9 stocks were classified as 'subject to overfishing' compared with 3 stocks in 2011; 13 stocks were classified as 'overfished' in 2005 compared to 7 in 2011.

The number of joint and international stocks classified as 'not overfished' and 'not subject to overfishing' increased between 2007 and 2011, and the number classified as 'uncertain' decreased (Table 2). The number classified as 'overfished' (four stocks) and 'subject to overfishing' (three stocks) did not change between 2007 and 2011. The status of these stocks might be the product of fishing activities by other nations in addition to activity within Commonwealth-managed fisheries.

Economic performance

The economic performance of the most valuable Commonwealth fisheries improved between 2007 and 2011 (Woodhams et al. 2012). Economic returns remained positive and improved in that period in the NPF, CTS and GHaT, which together account for about one-half of the GVP of Commonwealth-managed fisheries. These improvements have partly been associated with productivity growth—operators increasing catches in relation to costs and other inputs (Skirtun & Vieira 2012). This can be linked to the 2006 structural adjustment package. The vessel buy-back component of the package led to substantial reductions in vessel licences and the removal of some of the less efficient vessels in these fisheries. This is likely to have improved the average profitability of the operators that remained in the period following the structural adjustment. Productivity improvements can also be linked to increased trade of fishery entitlements (quota and effort entitlements) to more productive operators, where management settings (e.g. TACs) have been improved to be more consistent with MEY.

The economic performance of some Commonwealth-managed fisheries has been mixed during 2007–2011, with the economic performance of some fisheries not able to be ascertained from the available information. Economic returns in the Torres Strait Prawn Fishery, BSCZSF and the valuable ETBF remain low or negative. NER are also likely to be low for many other smaller Commonwealth fisheries where the data limitations make it difficult to assess economic performance.

It is difficult to distinguish the policy's effects on economic performance from the effects of other processes, such as government restructuring, fluctuating market demand for seafood, currency exchange rates, operating costs (e.g. fuel costs), effects of bycatch mitigation, and closures and other management measures. Many of the principles and management approaches embodied in the policy were in place in several fisheries before the policy was established, and had already been beneficial in increasing stock abundance and improving fishery performance. In these fisheries, recent improvements after the release of the policy are less substantial than if those fisheries had not been subject to active, target-driven management approaches before 2007.

Suggested performance measures

Implementation

Future evaluation of the implementation of the Commonwealth Fisheries Harvest Strategy Policy might involve the collation of statistics on the number of fish stocks and fisheries with harvest strategies, the number with limit and target reference points, and the number of harvest strategies that have been tested. A more detailed assessment of individual harvest strategies might consider the following questions, which are largely based on the characteristics reviewed in the current report.

Coverage

1) Which species or stocks does the harvest strategy cover?
   - Are there any key commercial species that are not under a harvest strategy?
   - Are there any multispecies stocks?
2) Does the harvest strategy apply throughout the stock's entire range?
   - Is the RBC adjusted for fishing mortality that occurs outside the fishery's control?

Reference points and indicators

1) Are the adopted proxies consistent with the policy?
   - What evidence is there that the harvest strategy's proxies are correct?
2) Are there any ambiguities in the indicators specified in the harvest strategy?
   - Do assessments take into account mortality resulting from all types of fishing?

Harvest control rules

1) To what extent are control rules linked directly to the biological and economic status of the fishery relative to reference points?
2) To what extent do control rules express objectives in the form of quantifiable reference points?
3) Will fishing mortality be reduced when the fishing mortality rate rises above FMSY?
   - Do TACs take into account removals by all types of fishing?
4) Will targeted fishing cease when biomass falls below the limit reference point?
5) Will targeted fishing cease when the fishing mortality rate rises above the fishing mortality limit reference point?
   - What is the probability of the harvest strategy maintaining fishing mortality rates below the limit?
6) For stocks below the biomass limit, is there a rebuilding strategy?

Management strategy evaluation and testing

1) What range of uncertainties has been tested?
   - How do those uncertainties relate to the full range of uncertainties for the stocks or species group concerned?
   - Have a broad range of stakeholders and independent experts been consulted?
   - Do fisheries on the same or similar species in other parts of the world provide any insights into uncertainties?
2) Will the harvest strategy achieve the target?
   - Are there estimates of the probability of the harvest strategy maintaining stock biomass at or around the target for the species?
3) Will the harvest strategy maintaining biomass above the limit reference point estimated?
4) Have meta-rules been tested and are they consistent with the policy?

Application

1) Has the harvest strategy been run?

2) Is the schedule of assessment and management advice timely?

3) Have control rules and RBCs been implemented?

4) Are any data, which are required for setting the RBC, missing or uncertain?

   – Do they reflect increasing uncertainty at higher tiers?

5) Has the use of meta-rules been consistent with the policy?

6) Are triggers regularly checked?

Achieving objectives

Assessing the policy's performance in meeting stated objectives is made difficult by the many factors that affect biological status and economic performance. The key performance indicators might include:

1) The number of stocks that are classified as 'overfished' and the number classified as 'not overfished'.

2) The number of stocks that are classified as 'subject to overfishing' and the number classified as 'not subject to overfishing'.

3) The number of stocks that are near their target reference point.

4) The fishery's NER.

These statistics are reported by annual *Fishery status reports* (Woodhams et al. 2012). However, there are a variety of factors, in addition to harvest strategies, that might influence these performance measures, and it is difficult to separate their effects. Additional factors that might influence the economic performance of fisheries include fluctuations in the demand for seafood, currency exchange rates, operating costs and management measures (e.g. state marine parks, Commonwealth marine reserves and closures). In combination with harvest strategies and other management measures, the stock's history, and the level and quality of research, assessment and data are likely to affect biological status.

Acronyms and abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
AFMA	Australian Fisheries Management Agency
B	stock biomass
B_0	unfished stock biomass
BSCZSF	Bass Strait Central Zone Scallop Fishery
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CPUE	catch-per-unit-effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation,
CTS	Commonwealth Trawl and Scalefish Hook sectors (Southern and Eastern Scalefish and Shark Fishery)
DAFF	Australian Government Department of Agriculture, Fisheries and Forestry
EEZ	200 nautical mile exclusive economic zone
ETBF	Eastern Tuna and Billfish Fishery
F	fishing mortality rate
GABTS	Great Australian Bight Trawl Sector
GHaT	Gillnet, Hook and Trap Sector
GVP	gross value of production
ITQ	individual transferable quota
HSF	Harvest Strategy Framework (Southern and Eastern Scalefish and Shark Fishery)
kg	kilogram
M	natural mortality rate
MAC	management advisory committee
MEY	maximum economic yield
MSE	management strategy evaluation
MSY	maximum sustainable yield
NER	net economic returns
NFP	Northern Prawn Fishery
NWSTF	North West Slope Trawl Fishery
RAG	resource assessment group
RBC	recommended biological catch
RFMO	regional fisheries management organisation

S or SB	spawning stock biomass
SESSF	Southern and Eastern Scalefish and Shark Fishery
SGSHS	Shark Gillnet and Shark Hook sectors
ShelfRAG	SESSF Resource Assessment Group
SPR	spawning potential ratio
SSJF	Southern Squid Jig Fishery
t	tonne
TAC	total allowable catch
TACC	total allowable commercial catch
TAE	total allowable effort
WCPFC	Western and Central Pacific Fishery Commission
WDTF	Western Deepwater Trawl Fishery

Appendix A Intellectual property

The information compiled by this project is published, widely disseminated and promoted. There is no need to protect intellectual property beyond the Australian Government's standard copyright that applies to the project's report and other outputs.

Appendix B Staff

Table B1 ABARES Fisheries and Quantitative Sciences Branch staff supported by the project

Name	Section
Scott Hansen	International Fisheries, Data and Assessments
James Larcombe	International Fisheries, Data and Assessments
Nic Marton	Marine Bioregional Planning
Andy Moore	Domestic Fisheries and Marine Environment
Heather Patterson	International Fisheries, Data and Assessments
Andrew Penney	Domestic Fisheries and Marine Environment
Phil Sahlqvist	International Fisheries, Data and Assessments
Maggie Skirtun	Fisheries Economics
Mary Stephan	Fisheries Economics
Simon Vieira	Fisheries Economics
Peter Ward	Domestic Fisheries and Marine Environment
James Woodhams	Domestic Fisheries and Marine Environment

Appendix C Reports on the harvest strategy policy's implementation

Reports to the Minister

The following reports to the Minister on how AFMA were implementing the 2005 Ministerial Direction.

<table>
<tr><td>May 2006</td><td>

- Letter from AFMA Chair, the Hon. Tony Rundle, about the six-monthly report against section 91 direction
- Progress reports from AFMA against section 91 direction
- First Six Monthly Report from the Hon. Tony Rundle

Summary

The letter and attachments outline the developments of harvest strategies, and provided deadlines for when harvest strategies would be implemented.</td></tr>
<tr><td>November 2006</td><td>

- Second six-monthly progress report from AFMA against the section 91 direction

Summary

Harvest strategies will be developed by 1 January 2007. Implementation of harvest strategies will take place in early 2007 for fisheries that have not already done so. AFMA will implement harvest strategies in the Southern and Eastern Scalefish and Shark Fishery by 1 January 2007. Other fisheries not subject to international fisheries agreements will have harvest strategies implemented, then will be further refined and fully implemented by January 2008.

- s91 Ministerial Direction to AFMA: First progress report and request for clarification

Summary

The Department supports the plan AFMA has proposed of implementing and tailoring harvest strategies from 1 January 2007 to January 2008.

The Department and AFMA is participating in a steering committee overseeing the development of guidelines by the CSIRO to assist implementation of the Harvest Strategy Policy.</td></tr>
<tr><td>May 2007</td><td>

- AFMA Second Progress Report against section 91 direction.

Summary

AFMA has implemented by January 1 2007 the total allowable catches and reference points according to the harvest strategies.</td></tr>
<tr><td></td><td></td></tr>
</table>

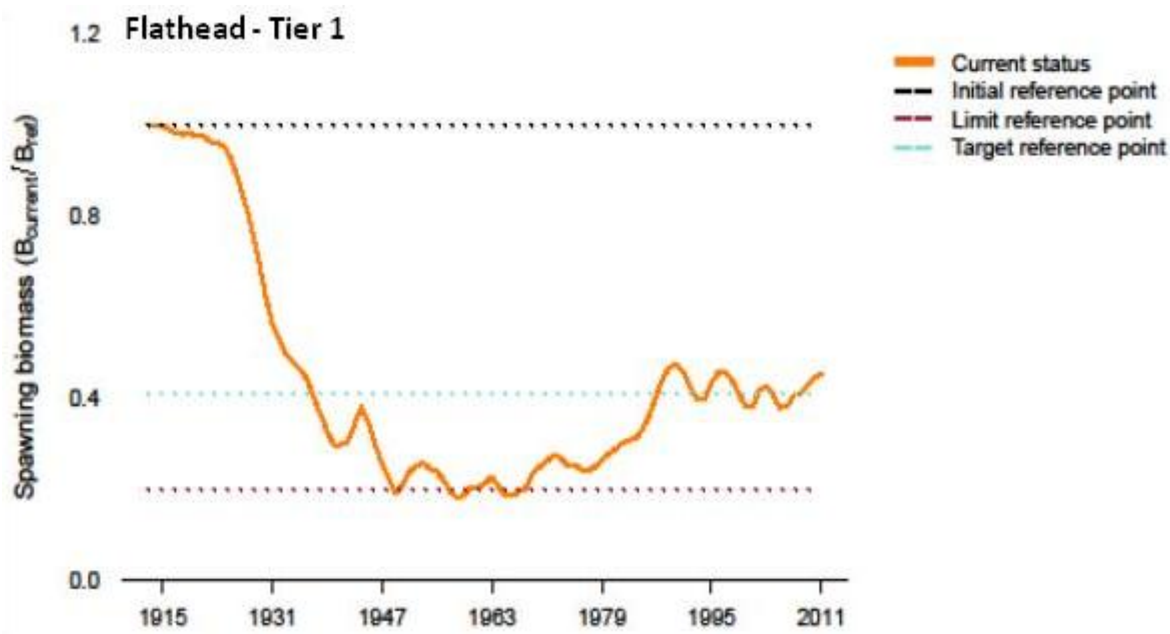
June 2008	• Letter from the Hon. Tony Rundle, AFMA Chair, about the section 91 Ministerial Direction to AFMA **Summary** AFMA has achieved the following: – developed the Commonwealth Harvest Strategy Policy – developed 13 harvest strategies across ten Commonwealth fisheries – implemented harvest strategies in most of these fisheries – established a Harvest Strategy Policy Advisory Committee to ensure harvest strategies are implemented in a way that is consistent with the Harvest Strategy Policy – set a zero total allowable catch for three years for the Bass Strait Scallop fishery, have established a system of fishery independent surveys, improved monitoring of fishing activity through the use of vessel monitoring systems and minimised the incentives for discarding.

Appendix D Examples of SESSF harvest control rules and assessments

Tier 1 assessments

Figure D1 shows spawning biomass estimates in relation to target and limit reference points for tiger flathead, a Tier 1 commercial species. Between 1930 and 1947, flathead biomass is estimated to have declined to what is now the limit reference point and remained near the limit until about 1965. Flathead biomass then rebuilt to the target reference point by about 1982 and has been maintained near the target since then, with the SESSF Harvest Strategy Framework (HSF) implemented in 2005. The RBC was estimated to be 3097 t for 2011 and a long-term RBC and the long-term RBC was 2623 t (Klaer 2010b).

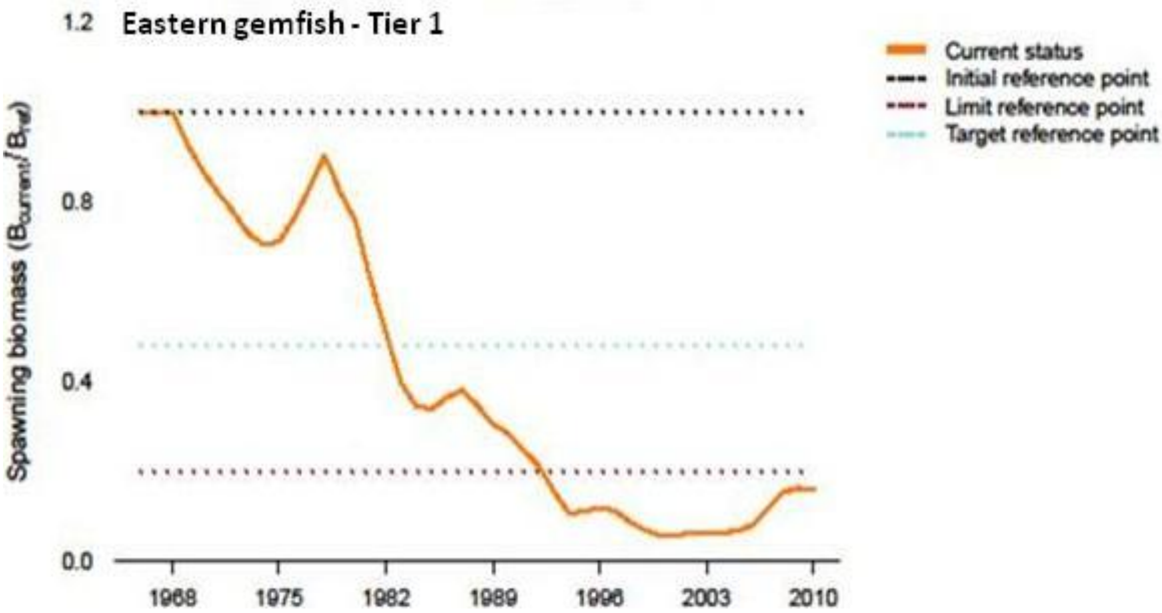
Figure D1 Historical trends in flathead biomass in relation to Tier 1 target and limit reference points



Source: Woodhams et al. (2012), based on Klaer (2011c)

In contrast to flathead, eastern gemfish biomass declined to below its Tier 1 limit reference point by the early 1990s and has subsequently remained below that level (Figure D2). The implementation of the HSF in 2005 has apparently not facilitated rebuilding of the eastern gemfish stock. The RBC has been zero since the early 1990s because eastern gemfish biomass is below that limit reference point (Woodhams et al. 2012). During this period, AFMA has set an incidental catch allowance of 100 t each year to cover the unavoidable bycatch of eastern gemfish that may occur when fishers are targeting other species.

Figure D2 Historical trends in eastern gemfish biomass against Tier 1 target and limit reference points



Source: Woodhams et al. (2012), based on Little & Rowling (2011)

Tier 3 assessment

Mirror dory is assessed as a Tier 3 species. Table D1 shows that mirror dory is not subject to overfishing because the current fishing mortality rate (F_{cur} = 0.030) was below the target reference point ($F_{spr}48$ = 0.147) and well below the limit reference point ($F_{spr}48$ = 0.355). Current fishing mortality is close to zero, resulting in a very large ratio of the target and current fishing mortality rates, and producing a large RBC. In this case, the M-based threshold was applied to limit the size of the multiplier and thereby limit the RBC to 2794 t for mirror dory. The Tier 3 five per cent discount factor was not applied to this RBC.

Table D1 Mirror dory Tier 3 reference points and estimates of mortality rates and RBC

$F_{spr}20$	$F_{spr}40$	$F_{spr}48$	Z_{cur}	F_{cur}	p	ymin	ymax	C_{cur}	F_{rbc}	Limit?	RBC
0.355	0.188	0.147	0.310	0.030	4.626	1993	2010	604	0.147	Yes	2,794

Notes: Klaer (2012a) provides a description of the Tier 3 assessment method, including definitions of the quantities presented in this table.

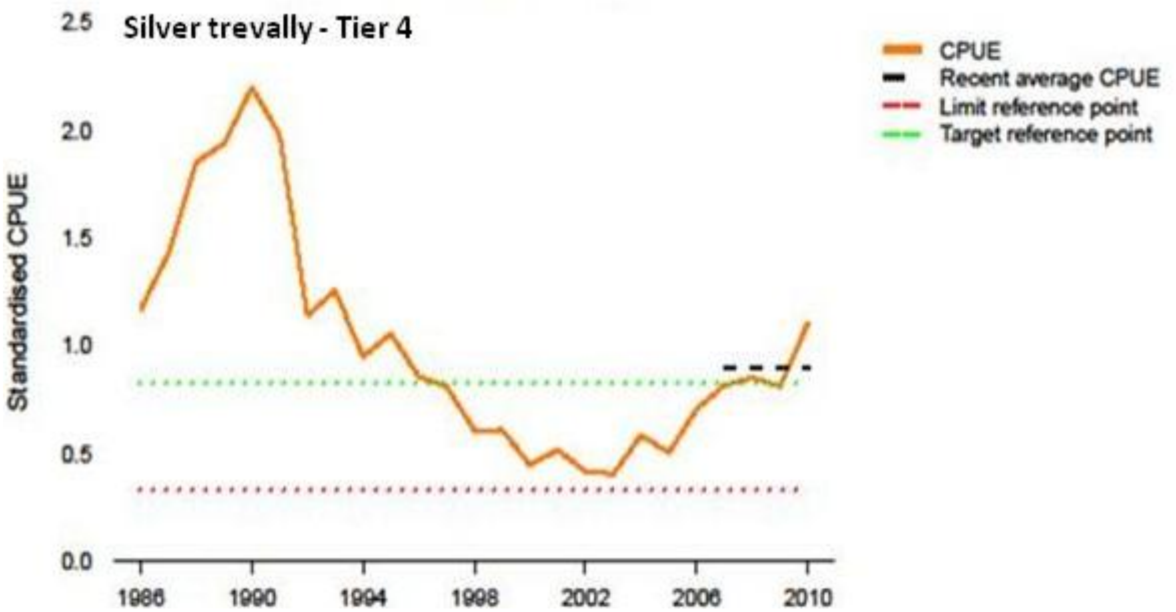
Source: AFMA (2013b) and Klaer (2012a)

A Tier 4 assessment was also conducted on mirror dory to provide information on biomass status. The time series of mirror dory CPUEs commences in 1986. Standardised CPUE declined to near the limit reference point in 2000. Following the implementation of the HSP, mirror dory CPUE returned to the target level in the late 2000s.

Tier 4 assessment

Figure D3 shows historical trends in silver trevally CPUE compared to its Tier 4 reference period, and target and limit reference points. Silver trevally declined to near the limit reference point in the early 2000s, then rebuilt to the target following the implementation of the HSP in 2005.

Figure D3 Historical trends in silver trevally CPUE in relation to Tier 4 target and limit reference points



Source: Woodhams et al. (2012), based on Haddon (2012)

The silver trevally Tier 4 does not include CPUE data from the area that is now closed to commercial fishing under the Batemans Marine Park. ShelfRAG waived the default Tier 4 discount factor of 15 per cent for the RBC on the basis that the marine park provides a refuge for spawning adults and juveniles across a significant portion of the species' distribution. However, the RBC calculation includes historical catches from that area. This implies that silver trevally in the marine park are fully available to fisheries outside this area.

References

AFMA 2004, *A review of the offshore constitutional settlement arrangements for Bass Strait scallops*, options paper 9 July 2004, Australian Fisheries Management Authority, Canberra. www.afma.gov.au/wp-content/uploads/2010/07/n20040709.pdf

—— 2006, *Orange Roughy Conservation Programme,* Australian Fisheries Management Authority, Canberra. www.afma.gov.au/wp-content/ uploads/2010/07/n20061207.pdf

—— 2007a, *Southern Squid Jig Fishery harvest strategy*, Australian Fisheries Management Authority, Canberra.

—— 2007b, *Harvest strategy for the Bass Strait Central Zone Scallop Fishery (BSCZSF)*, Australian Fisheries Management Authority, Canberra.

—— 2008, *Southern and Eastern Scalefish and Shark Fishery—Great Australian Bight Trawl Sector management arrangements booklet*, Australian Fisheries Management Authority, Canberra.

—— 2009a, *Harvest Strategy Framework for the Southern and Eastern Scalefish and Shark Fishery September 2009*, Australian Fishery Management Authority, Canberra. www.afma.gov.au/wp-content/uploads/2010/07/sessf_hsr_2009.pdf

—— 2009b, 15th meeting of ScallopRAG, Australian Fisheries Management Authority, Canberra.

—— 2011a, *Southern and Eastern Scalefish and Shark Fishery Shelf Resource Assessment Group (ShelfRAG)*, minutes 23–24 February 2011, Australian Fisheries Management Authority, Canberra.

—— 2011b, *Southern and Eastern Scalefish and Shark Fishery—Great Australian Bight Resource Assessment Group (GABRAG),* 27–28 October 2011, Australian Fisheries Management Authority, Adelaide.

—— 2011c, *Harvest strategy for the Western Deepwater Trawl Fishery and North West Slope Trawl Fishery 2011*, Australian Fisheries Management Authority, Canberra.

—— 2011d, *Status of tiger prawn stocks at the end of 2010 and estimated TACS for 2011 in the NPF,* report by CSIRO to the Northern Prawn Fishery Resource Assessment Group, Australian Fisheries Management Authority, Canberra.

—— 2012a, *Southern and Eastern Scalefish and Shark Fishery Shelf Resource Assessment Group (ShelfRAG)*, draft minutes 5–6 November 2012, Australian Fisheries Management Authority, Canberra.

—— 2012b, *19th Meeting of the Scallop Resource Assessment Group (ScallopRAG)*, draft minutes, Australian Fisheries Management Authority, Canberra.

—— 2012c, Letter to Statutory Fishing Right Holders 13 August 2012: Bass Strait Central Zone Scallop Fishery 2012 fishing season, Australian Fisheries Management Authority, Canberra.

—— 2012d, Letter to Statutory Fishing Right Holders 7 May 2012: Future management of the South-East Australia Commercial Scallop Fishery, Australian Fisheries Management Authority, Canberra.

—— 2012e, *Southern and Eastern Scalefish and Shark Fishery Slope Resource Assessment Group (SlopeRAG)*, draft minutes 7–9 November 2012, Australian Fisheries Management Authority, Canberra.

—— 2012f, *Harvest Strategy for the Bass Strait Central Zone Scallop Fishery*, Australian Fisheries Management Authority, Canberra.

—— 2013a, *Harvest strategies*, Australian Fisheries Management Authority, Canberra. www.afma.gov.au/managing-our-fisheries/harvest-strategies/

—— 2013b, *2012 stock assessment summaries for the Southern and Eastern Scalefish and Shark Fishery: summaries for species assessed by ShelfRAG*, Australian Fisheries Management Authority, Canberra.

BAE 1985, *Fish products: situation and outlook 1985*, Bureau of Agricultural Economics, Canberra.

Barnes, B, Ward, P & Boero, V in preparation, *Depletion analyses of Gould's squid in Bass Strait*, Australian Bureau of Agriculture and Resource Economics and Sciences report to the Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

Begg, GA, Chen, CCM, O'Neill, MF & Rose, DB 2006, *Stock assessment of the Torres Strait Spanish mackerel fishery*, CRC Reef Research Centre Technical Report No. 66, CRC Reef Research Centre, Townsville.

Campbell, R 2012, *Implementation of the ETBF harvest strategy and calculation of the recommended biological commercial catches for 2013/14*, working paper presented to the 5th meeting of the Tropical Tuna RAG, 4–5 September 2012, Canberra.

Candy, SG & Constable, AJ 2008, 'An integrated stock assessment for the Patagonian toothfish (*Dissostichus eleginoides*) for the Heard Island and McDonald Islands using CASAL', *CCAMLR Science*, vol. 15, pp. 1–34.

CCSBT 2011, Report of the Sixteenth Meeting of the Scientific Committee, 19–28 July 2011, Commission for the Conservation of Southern Bluefin Tuna, Bali, Indonesia.

Constable, AJ & de la Mare, WK 1996, 'A generalised model for evaluating yield and the long-term status of fish stocks under conditions of uncertainty', *CCAMLR Science*, vol. 3, pp. 31–54.

DAFF 2007, *Commonwealth Fisheries Harvest Strategy: policy and guidelines*, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

—— 2012a, *Terms of reference for the review of the Commonwealth Fisheries Harvest Strategy Policy*, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra. www.daff.gov.au/fisheries/domestic/harvest_strategy_policy/terms-of-ref

—— 2012b, *Commonwealth Fisheries Harvest Strategy Policy and Guidelines discussion paper*, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra. www.daff.gov.au/__data/assets/pdf_file/0006/2219856/hsp-review-v4.pdf

Day, JR, 2012, 'School whiting (*Sillago flindersi*): further exploration of fixed projected catches, potential indicators and alternative harvest strategy analyses', in GN Tuck (ed.), Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2012, part 1, AFMA & CSIRO Marine and Atmospheric Research, Hobart.

de la Mare, WK, Williams, R & Constable AJ 1998, 'An assessment of mackerel icefish (*Champsocephalus gunnari*) off Heard Island', *CCAMLR Science*, vol. 5, pp. 70–101.

Dichmont, CM, Deng, A, Punt, AE, Ellis, N, Venables, WN, Kompas, T, Ye, Y, Zhou, S & Bishop, J 2008, 'Beyond biological performance measures in management strategy evaluation: bringing in economics and the effects of trawling on the benthos', *Fisheries Research*, vol. 94, pp. 238–250.

Dichmont, CM, Deng, A, Punt, A, Venables, W & Haddon, M 2006. 'Management strategies for short lived species: the case of Australia's Northern Prawn Fishery 2. Choosing appropriate management strategies using input controls', *Fisheries Research,* vol. 82, pp. 221–234.

Dichmont, C, Jarrett, A, Hill, F & Brown, M 2012, *Harvest strategy for the Northern Prawn Fishery under input controls*, Australian Fisheries Management Authority, Canberra.

Dichmont, CM, Pascoe, S, Kompas, T, Punt, AE & Deng, R 2010, 'On implementing maximum economic yield in commercial fisheries', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 107, no. 1, pp. 16–21.

Dowling, N 2011a, 'The Northwest Slope Trawl Fishery', in Haddon, M (ed.) 2012, *Reducing uncertainty in stock status: harvest strategy testing, evaluation, and development. General discussion and summary*, CSIRO Marine and Atmospheric Research, Hobart.

Dowling, N 2011b, *Management strategy evaluation testing of the management strategies used with North West Slope Trawl Fisheries*, CSIRO, Marine and Atmospheric Research, Hobart.

Dowling, N, Smith, D, Knuckey, I et al. 2008, Developing harvest strategies for low-value and data-poor fisheries: case studies from three Australian fisheries, Fisheries Research, vol. 94, pp. 380–390.

Fay, G & Tuck, GN (eds) 2011, Development of a multi-gear spatially explicit assessment and management strategy evaluation for the Macquarie Island Patagonian toothfish fishery, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Wealth from Oceans Flagship, Canberra. http://web-test.afma.gov.au/wp-content/uploads/2010/06/rr2008_0873_toothfish2011.pdf

Fay, G, Little, LR, Tuck, GN, Haddon, M & Klaer, NL 2013, *Maintaining risk equivalency among fishery harvest control rules in the SESSF*, document prepared for SESSF RAG, February 2013, CSIRO Wealth from Oceans National Research Flagship, Hobart.

Galeano, D Johnson, C, Levantis, C & Sharfron, W 2001, *Australian fisheries surveys report 2000*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

George, D, Vieira, S & New, R 2012, *Australian fisheries surveys report 2011, results for selected fisheries 2008–09 to 2010–2011*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. http://adl.brs.gov.au/data/warehouse/AustFishSurveys/AustFishSurveys2011_v1.0.0.pdf

Giannini, F, Hobsbawn, PI, Begg, GA & Chambers, M 2010, *Management strategy evaluation (MSE) of the harvest strategy for the Small Pelagic Fishery*, Bureau of Rural Sciences, Canberra.

Haddon, M 2011, *Management strategy evaluation testing of the management strategies used with south-eastern scallop fisheries*, CSIRO, Hobart.

—— M 2012, *Tier 4 analyses in the SESSF data from 1986–2011*, November 2012, draft pre-2nd RAG Meeting, CSIRO Wealth from Oceans National Research Flagship, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart.

—— Haddon, M 2013, *Reducing uncertainty in stock status: harvest strategy testing, evaluation, and development, general discussion and summary*, report prepared for the Australian Government Department of Agriculture, Fisheries and Forestry, Wealth from Oceans Flagship, CSIRO, Hobart.

Haddon, M, Klaer, N, Smith, DC, Dichmont, CD & Smith, ADM 2013, *Technical reviews for the Commonwealth Harvest Strategy Policy,* FRDC 2012/225, CSIRO, Hobart.

Harrington, JJ, McAllister, J & Semmens, JM 2010, *Assessing the short-term impact of seismic surveys on adult commercial scallops (*Pecten fumatus*) in Bass Strait*, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Hobart.

Jackson, GD & McGrath-Steer, BL 2003, *Arrow squid in southern Australian waters—supplying management needs through biological investigations*, final report to the Fisheries Research and Development Corporation, project 1999/112, Institute of Antarctic and Southern Ocean Studies, University of Tasmania, Hobart.

Klaer 2009, 'Bight redfish (*Centroberyx gerrardi*) stock assessment based on data up to 2008/09', in Tuck, GN (ed.) 2010, *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2012, part 1*, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart, pp. 330–340.

—— 2010a, 'Deepwater flathead (*Neoplatycephalus conatus*) stock assessment based on data up to 2009/10', in Tuck, GN (ed.), *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2011, part 2*, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart.

—— N 2010b, *Tiger flathead (*Neoplatycephalus richardsoni*) stock assessment based on data up to2009*, report to ShelfRAG, Wealth from Oceans Flagship, CSIRO, Hobart.

—— N 2011a, 'Species associations and companion TACs in the SESSF: 2010 update', in Tuck, GN (ed.), *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2010*, part 2, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart, pp. 219–225.

—— N 2011b, 'Bight redfish (*Centroberyx gerrardi*) stock assessment based on data up to 2010/11', in Tuck, GN (ed.) 2012, *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2012*, part 1, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart, pp. 330–340.

—— N 2011c, *Tiger flathead (*Neoplatycephalus richardsoni*) stock assessment based on data up to 2009*, report to ShelfRAG, Australian Fisheries Management Authority, Canberra.

—— N 2012a, *Yield, total mortality values and Tier 3 estimates for selected shelf and slope species in the SESSF 2012*, draft, CSIRO Wealth from Oceans National Research Flagship, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart.

—— N 2012b, 'Deepwater flathead (*Neoplatycephalus conatus*) stock assessment based on data up to 2011/12', in Tuck, GN (ed.), *Stock assessment for the Southern and Eastern Scalefish and*

Shark Fishery 2013, part 2, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart.

—— N 2012c, 'Notes on blue warehou targeting 2010', in Tuck, GN (ed.), *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2011, part 2*, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart.

Klaer, N & Wayte, S 2012, *Demersal MSE for trawl fish in the Southern and Eastern Scalefish and Shark Fishery and other like species*, report prepared for the Australian Government Department of Agriculture, Fisheries and Forestry, Wealth from Oceans Flagship, CSIRO, Hobart.

Kolody, DS, Preece, AL, Davies, CR, Hartog, JR & Dowling, NA 2010, *Integrated evaluation of management strategies for tropical multi-species longline fisheries*, final report for the Fisheries Research and Development Corporation, FRDC project 2007/017, Canberra.

Kompas, T, Che, N, Chu, L & Klaer, N 2012, *Transition to MEY goals for the Great Australian Bight Trawl Fishery*, report to the FRDC, Australian Centre for Biosecurity and Environmental Economics, Crawford School of Public Policy, Australian National University, Canberra.

Little, R & Rowling, K 2011, '2010 update of the eastern gemfish (*Rexea solandri*) stock assessment, in Tuck, GN (ed.), *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2010, part 1*, Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart.

Little, R, Tuck, GN, Haddon, M, Day, J, Klaer, N, Smith, ADM, Thomson, R & Wayte, S 2009, 'Developing CPUE targets for the Tier 4 harvest strategy of the SESSF', in Tuck, GN (ed.), *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2008*, *part 2*, Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart, pp. 233–254.

Little, LR, Wayte, S, Tuck, GN et al. 2011, 'Development and evaluation of a cpue-based harvest control rule for the southeastern scalefish and shark fishery of Australia', *ICES Journal of Marine Science*, vol. 68, no. 8, pp. 1699–1705.

McIlgorm, A 2012, *Literature study and review of international best practice, fisheries harvest strategy policy approaches*, report to the Australian Government Department of Agriculture Fisheries and Forestry, Canberra.

Milton, D, Fry, GC, Kuhnert, P, Tonks, M, Zhou, S & Zhu, M 2010, *Assessing data poor resources: developing a management strategy for byproduct species in the Northern Prawn Fishery*, final report for the Fisheries Research and Development Corporation project 2006/008, CSIRO Marine and Atmospheric Research, and Fisheries Research and Development Corporation, Canberra.

Moore, AS, Gerner, M & Patterson, HM 2007a, *Western Deepwater Trawl Fishery data summary 2006*, Australian Fisheries Management Authority, Canberra.

Moore, AS, Gerner, M & Patterson, HM 2007b, *North West Slope Trawl Fishery data summary 2006*, Australian Fisheries Management Authority, Canberra.

Pascoe, S, Coglan, L, Punt, AE & Dichmont, CM 2012, 'Impact of vessel capacity reduction programmes on efficiency in fisheries: the case of Australia's multispecies Northern Prawn Fishery', *Journal of Agricultural Economics*, vol. 63, no. 2, pp. 425–443.

Penney, AJ, Ward, P & Vieira, S 2013, *Technical reviews for the Commonwealth Harvest Strategy Policy: technical overview*, Fisheries Research and Development Corporation project 2012/225, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Perks, C & Vieira, S 2010, *Australian fisheries surveys report 2010—results for selected fisheries, 2007–08 and 2008–09, preliminary estimates for 2009–10,* Australian Bureau of Agricultural and Resource Economics and Sciences report prepared for the Fisheries Resources Research Fund, Canberra.

Pikitch, E, Boersma, PD, Boyd, IL et al. 2012, *Little fish, big impact: managing a crucial link in ocean food webs*, Lenfest Ocean Program, Washington DC.

Plagányi, É, Skewes, T, Dowling, N & Haddon, M 2011a, *Evaluating management strategies for data-poor sea cucumber species in the Torres Strait*, CSIRO Marine and Atmospheric Research, Hobart.

Plagányi, É, Skewes, T, Dowling, N, Haddon, M, Woodhams, J, Larcombe, J & Chambers, M 2011b, *Evaluating management strategies for data-poor sea cucumber species in the Coral Sea Fishery*, CSIRO Marine and Atmospheric Research, Hobart.

Punt, AE & Smith, ADM 1999, 'Harvest strategy evaluation for the eastern stock of gemfish (*Rexea solandri*)', *ICES Journal of Marine Science*, vol. 56, pp. 860–875.

Punt, AE & Thompson, R 2011, 'Gummy shark (*Mustelus antarcticus*) assessment based on data up to 2009', in Tuck, GN (ed.), *Stock assessment for the Southern and Eastern Scalefish and Shark Fishery: 2010, part 1,* Australian Fisheries Management Authority & CSIRO Marine and Atmospheric Research, Hobart, pp. 294–328.

SEWPaC 2012, *EPBC Act list of threatened fauna*, Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra. www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl

Skirtun, M & Vieira, S 2012, *Understanding the drivers of profitability in Commonwealth fisheries*, Australian Bureau of Agricultural and Resource Economics and Sciences technical report 12.4, Canberra.

Skirtun, M, Sahlqvist, P, Curtotti, R & Hobsbawn, P 2012, *Australian fisheries statistics 2011*, Canberra.

Smith, ADM 2009, 'Proposed revisions to the SESSF Harvest Strategy Framework for 2007—a discussion paper', in Wayte, SE (ed.), Evaluation of new harvest strategies for SESSF species, report 2006/815, CSIRO Marine and Atmospheric Research, Hobart and Australian Fisheries Management Authority, Canberra.

Smith, ADM, Brown, CJ, Bulman, CM, Fulton, EA, Johnson, P, Kaplan, IC, Lozano-Montes, H, Mackinson, S, Marzloff, M, Shannon, LJ, Shin, Y-J & Tam, J 2011, 'Impacts of fishing low–trophic level species on marine ecosystems', *Science*, vol. 333, no. 6046, pp. 1147–1150.

Smith, ADM, Smith, DC, Tuck, GN, Klaer, N, Punt, AE, Knuckey, I, Prince, J, Morison, A, Kloser, R, Haddon, M, Wayte, S, Day, J, Fay, G, Pribac, F, Fuller, M, Taylor, B & Little, LR 2008, 'Experience in implementing harvest strategies in Australia's south-eastern fisheries', *Fisheries Research,* vol. 94, pp. 373–379.

Stokes, K 2010, *Criteria to implement and manage multi-year TACs in the SESSF*, 24 June 2010 (rev. 12 August 2010) report to the Australian Fisheries Management Authority, Canberra.

Thomson, RB & Punt, AE 2009, *SharkRAG 2009: 2009 Stock Assessment Report for School Shark (*Galeorhinus galeus*),* prepared by the Shark Resource Assessment Group (SharkRAG).

Triantafillos, L n.d., 'Use of depletion analysis in the Southern Squid Jig Fishery of Australia', unpublished report to the Australian Fisheries Management Authority, Canberra.

UN 1982. United Nations Convention on the Law of the Sea, United Nations, Conference 62/122, New York.

Upston, J & Klaer, N 2012, *Integrated scientific monitoring program for the Southern and Eastern Scalefish and Shark Fishery—discard estimation 2011*, CSIRO Marine and Atmospheric Research, Australian Fisheries Management Authority.

Vieira, S & Pascoe, S 2013, *Technical reviews for the Commonwealth Harvest Strategy Policy: economic issues*, FRDC 2012/225, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, and CSIRO Wealth from Oceans National Research Flagship, Brisbane.

Vieira, S, Hormis, M, Penney, AJ & Woodhams, J in prep., *Setting target reference points for secondary species in the SESSF*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Vieira, S, Perks, C, Mazur, K, Curtotti, R & Li, M 2010, *Impact of the structural adjustment package on the profitability of Commonwealth fisheries,* Australian Bureau of Agricultural and Resource Economics and Sciences research report 10.01, Canberra.

Virtue, P, Green, C, Pethybridge, H , Moltschaniwskyj, N, Wotherspoon, S & Jackson, G 2011, *Arrow squid: stock variability, fishing techniques, trophic linkages—facing the challenges*, final report to the Fisheries Research and Development Corporation, project 2006/12, Institute for Marine and Antarctic Studies, Hobart.

Wayte, SE (ed.) 2009, *Evaluation of new harvest strategies for SESSF species,* report 2006/815, CSIRO Marine and Atmospheric Research, Hobart, & Australian Fisheries Management Authority, Canberra.

Wayte, SE & Klaer, NL 2011, 'An effective harvest strategy using improved catch-curves', *Fisheries Research*, vol. 106, pp. 310–320.

Welsford, DC 2012, *A preliminary assessment of mackerel icefish (*Champsocephalus gunnari*) in Division 58.5.2, based on recent survey results*, WG-FSA-12/26, report to the Convention on the Conservation of Antarctic Marine Living Resources Working Group on Fish Stock Assessment, Hobart.

Woodhams, J, Stobutzki, I & Vieira, S (eds) 2012, *Fishery status reports 2011: status of fish stocks and fisheries managed by the Australian Government*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Zhou, S, Pascoe, S, Dowling, N, Haddon, M, Klaer, N, Larcombe, J, Smith, ADM, Thebaud, O & Vieira, S 2012, *Quantitatively defining biological and economic reference points in data poor and data limited fisheries*, final report on Fisheries Research and Development Corporation project 2010/044, CSIRO Marine and Atmospheric Research, Canberra.

18 Appendix 6: Technical Overview

Penney, A., Ward, P. and S. Vieira (2013) *Technical reviews for the Commonwealth Harvest Strategy Policy: Technical Overview*. FRDC 2012/225. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2013.

Appendix B

Australian Government

Department of Agriculture, Fisheries and Forestry

ABARES

Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: technical overview

Andrew Penney, Peter Ward & Simon Vieira

Research by the Australian Bureau of Agricultural and Resource Economics and Sciences

May 2013

FRDC

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

FRDC project no. 2012/225

Cataloguing data
Penney, AJ, Ward, P & Vieira, S 2013, Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy 2007: technical overview, ABARES, Report to client prepared for the Fisheries Research and Development Corporation), Canberra, May.

ISBN 978-1-74323-134-0

Internet
Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy 2007: technical overview is available at: daff.gov.au/abares/publications.

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)
Postal address GPO Box 1563 Canberra ACT 2601
Switchboard +61 2 6272 2010|
Facsimile +61 2 6272 2001
Email info.abares@daff.gov.au
Web daff.gov.au/abares

Acknowledgements
This project was funded by the Fisheries Research and Development Corporation. This report has benefitted from review and constructive criticism of previous drafts by T. Karlov (DAFF), I. Stobutzki, J. Larcombe (ABARES), N. Rayns (AFMA) and members of the Harvest Strategy Policy Review Steering and Advisory Committees.

Contents

Tables

Figures

Project details

FRDC project number:	**2012/225**
Project title:	A technical review of formal fisheries harvest strategies
Principal investigators:	Andrew Penney, Peter Ward, Simon Vieira
Affiliation:	Australian Bureau of Agricultural and Resource Economics and Sciences, Department of Agriculture, Fisheries and Forestry
Address:	18 Marcus Clarke Street GPO Box 1563, Canberra ACT 2601 Australia
Telephone:	Ph. 02 6272 4163, Fax 02 6272 2104

Objectives

The original objectives of FRDC project 2012/225, as agreed in June 2012, were as follows:

1) Provide a technical review of recent research on fisheries harvest strategies (both in Australia and overseas) so as to identify information, methods or strategies that may help to address key issues identified by the review of the Commonwealth Fisheries Harvest Strategy: policy and guidelines (Commonwealth Fisheries Harvest Strategy Policy, or the policy) (DAFF 2007).

2) Identify further research required to update the harvest strategies used for Australian fisheries.

3) Provide technical advice on how the policy (including the guidelines) might be revised in the light of the review conducted in this project and, where relevant, suggest associated technical refinements of the policy's wording.

4) Identify alternative indicators of economic performance.

Further components were added to this project on 30 October 2012, adding objectives that would:

5) Provide a detailed review of the implementation of the policy, including the identification of potential performance measures.

6) Draft a technical overview paper for consideration by stakeholders and Australian Government agencies as part of the review of the policy.

This overview report addresses objective six, and summarises key conclusions and advice on potential improvements to technical aspects of the Commonwealth Fisheries Harvest Strategy Policy from the reports prepared under the preceding objectives, to provide a summary and interface between the technical detail in those reports, and a discussion of potential improvements to the policy and implementation guidelines.

Outcomes achieved to date

An advisory committee was established to guide the Commonwealth Fisheries Harvest Strategy Policy review, consisting of Australian Government agencies (Department of Agriculture, Fisheries and Forestry [DAFF], Australian Fisheries Management Authority [AFMA], Department of Sustainability, Environment, Water, Population and Communities [SEWPaC], Fisheries Research and Development Corporation, Commonwealth Scientific and Industrial Research Organisation and Australian Bureau of Agricultural and Resource Economics and Sciences [ABARES]), the fishing industry (Commonwealth Fisheries Association [CFA], Great Australian Bight Industry Association and Australian Southern Bluefin Tuna Industry Association), recreational anglers (Amateur Fishermen's Association of the Northern Territory) and nongovernment organisations (Worldwide Fund for Nature, Australian Marine Conservation Society). ABARES and DAFF presented an issues paper at the advisory committee's first meeting (May 2012).

The proposal for this project was developed in consultation with DAFF and CFA after identification of technical issues with the Commonwealth Fisheries Harvest Strategy Policy in an issues paper drafted by ABARES and DAFF, and confirmed by the advisory committee. The steering committee (DAFF, AFMA, SEWPaC) received regular updates on project progress. Draft review papers were provided to the advisory committee before presenting key results of the technical reviews to an advisory committee meeting on 5 February 2013.

The commissioned contributory technical review reports to the Harvest Strategy Policy Review were completed by December 2012. Key issues arising from these reports were identified and discussed with DAFF staff responsible for the policy review itself, to identify issues for inclusion in this Technical Overview. Drafts of the various technical review reports, including this overview, were provided to the Harvest Strategy Review Steering Committee in January 2013, and discussed at a meeting of the Advisory Committee in February 2013.

All key issues identified in the technical review reports were summarised in this overview and communicated to the DAFF team responsible for preparing the Harvest Strategy Policy Review report, to ensure that the review process remained informed of all emerging technical issues and potential improvements. This Technical Overview was finalised in May 2013.

Non-technical summary

The main conclusions and issues of direct relevance to revision of the *Commonwealth Fisheries Harvest Strategy: policy and guidelines* (Commonwealth Fisheries Harvest Strategy Policy, or the policy) (DAFF 2007), as identified in the various technical review reports written to inform the review, group themselves into a number of key categories. The key issues raised under each of these categories are summarised below. Under each category, a statement on the current situation is followed by identification of aspects of the policy or guidelines that might benefit from improvement at the moment, as well as aspects that likely require further work before options for improvement can be identified (in *italics*).

As a direct result of the fact that these issues have been identified in technical reports, most of the potential improvements identified relate to the implementation guidelines, and not to the wording of the policy itself. However, some of the suggested improvement in the guidelines may require some supporting or enabling text in the policy.

Before identifying the potential improvements, it must first be emphasised that the various contributory technical reports reviewed all noted that the policy provides comprehensive and effective guidance on design and implementation of harvest strategies to ensure that optimal benefits are derived from harvesting of Commonwealth marine resources. Most aspects of the policy and guidelines are considered to meet or exceed world's best practice. Harvest strategies developed under this policy have been implemented for all of the important Commonwealth fish stocks, and management actions implemented under these harvest strategies have contributed to improvements in stock status and economic yields for most of these stocks. Many of the potential improvements identified result from experience accumulated in developing and implementing the existing harvest strategies, and from improvements in stock assessment and management strategy methodology.

The key issues and potential improvements identified in the reviewed technical review reports and papers group themselves logically into a number of categories. The key conclusions for each of these categories are summarised below. Under each category, the recommendations or options for improvement, which are embedded in the main text of this summary report, are individually bulleted out for emphasis. In addition, options for future work to support further improvement under each category are bulleted out *in italics*.

Harvest Strategy Technical Reviews

Reference points and proxies

Current typical target and limit reference points (such as B_{MEY}, B_{MSY}, B_{LIM}; see the glossary for definitions of these terms) and their proxies ($0.48B_0$, $0.40B_0$, $0.20B_0$) meet international best practice. Use of B_{MEY} ($0.48B_0$) as a target exceeds international best practice. The use of F_{MSY} as the default effort limit reference point, and to define overfishing, is also international best practice.

- More explicit account should be taken of recent work suggesting that best practice targets for different species groups vary, depending on biology and productivity:
    - Targets for important forage fish, such as small pelagic species, should be above B_{MSY} and B_{MEY} at around $0.75B_0$ to ensure that stocks remain large enough to fulfil their ecotrophic function (Smith et al. 2011; Pikitch et al. 2012).

- Actual maximum sustainable yield (MSY) estimates for a range of teleost species groups range from $0.26B_0$ to $0.46B_0$ (Thorston 2012). For chondrichthyans, Brooks et al. (2010) obtained similar values of $0.21B_0$ to $0.47B_0$, with most sharks lying towards the upper end of that range.
- Although estimated B_{MSY}/B_0 ratios are similar for bony fishes and sharks, Zhou et al. (2012) found that the ratio of F/M differs substantially between teleosts and chondrichthyans, with $F_{MSY} = 0.87M$ for teleosts and $F_{MSY} = 0.41M$ for chondrichthyans due to lower productivity of the latter.

- Proxy B_{MSY} in the range of $0.35B_0$ – $0.40B_0$ minimises the potential loss in yield for teleost species compared to the yield that would arise if B_{MSY} was known exactly (Punt et al. in press). This is consistent with the current policy proxy of $0.40B_0$ for B_{MSY}.
- The proxy B_{MSY} for some shark species may need to be closer to $0.50B_0$.
- Given the differences in B_{MSY} ratios for different species groups, the principle of setting $B_{LIM} = 0.50B_{MSY}$ should be retained to cater for those species where $B_{MSY} > 0.40B_0$, to ensure that limits designed to prevent unacceptable biological risk also take into account factors that dictate a higher B_{MSY} proxies (and therefore higher limits based on ½ B_{MSY}).
- *Due to higher uncertainty in cost data, the proxy for B_{MEY} to minimise the potential loss in profit is estimated to lie in the range $0.50B_0$ – $0.60B_0$ (Punt et al. in press). This is higher than the current proxy of $0.48B_0$ for B_{MEY} as a result of higher uncertainty around cost data. Proxy values for B_{MEY} may more appropriately be $1.3B_{MSY}$ – $1.4B_{MSY}$, rather than the current recommended $1.2B_{MSY}$. Economically optimal effort levels are most likely to fall between 55 per cent and 65 per cent of MSY effort levels (Zhou et al. 2013).*
- *Harvest strategies may need to be revised and MSE retested for some species or fisheries if higher B_{MEY} targets are indicated, to ensure a high probability that harvest strategies and control rules will manage fisheries towards these objectives.*

Alternative maximum economic yield targets

Maximum economic yield (MEY) targets have been estimated for the Northern Prawn and Great Australia Bight fisheries. For all others, the proxy (1.2BMSY or 0.48B0) is used. One of the main problems is estimating BMEY for other species has been the difficulty in getting the necessary representative cost data to enable bioeconomic modelling.

- Where alternative targets (B_{MSY} or lower) are established for secondary species in multispecies fisheries, these should be MSE tested to ensure that risks remain acceptable.
- *Better guidance is required on economic objectives (what MEY means) and how they can be best achieved for different fisheries, such as highly variable fisheries and those where market process can be controlled by adjusting catch volumes.*
- *Further practical guidance is required on the circumstances under which an MEY target should be quantitatively estimated, rather than using a proxy value, how this should be estimated for different fishery types and the key principles for successful implementation.*
- *A more practical approach is required to using existing economic data and incorporating economic parameters into current stock assessments to estimate B_{MEY}, as opposed to developing separate bioeconomic assessments.*
- *There should be further exploration of alternative indicators and reference points for MEY, including those based on optimal fishing capacity and catch rates, and more appropriate proxies for different fisheries and gear types.*

Target ranges and dynamic targets

With the exception of the Northern Prawn Fishery, targets and limits are generally set as single fixed (static) values, either estimated from assessments or using default proxy values, assuming that the stock will achieve some long-term equilibrium. However, even in a perfectly managed fishery, stocks will fluctuate naturally around the target due to inter-annual variability in environmental conditions, spawning success and recruitment.

- Target ranges can cater for this natural variability by defining the target as a range between two plausible values, or using the uncertainty around estimates of MSY or MEY as a target range. Target ranges can be implemented within harvest strategies by adopting decision rules that incorporate a total allowable catch (TAC) plateau over the target range (Haddon et al. 2013).

- Where target ranges are set, these should be tested to ensure that there is still a less than 10 per cent probability of stocks declining below the limit if managed at the lower end of the target range.

- Limits should remain as single specified values (whether static or dynamic), as the required probability of not breaching these (> 90 per cent) already constitutes a range.

- *In addition to natural interannual variability, highly variable stocks can show interdecadal cycles in recruitment and productivity in response to environmental cycles (e.g. El Niño), or long-term climatic trends or regime shifts. Fixed target levels or ranges are inappropriate for such species; targets for such species are more appropriately specified as a ratio of the stock status if no fishing had occurred, referred to as $B_{Unfished}$ (e.g. $0.40B_{Unfished}$), where this can be estimated.*

- *Where variability in species productivity indicates the need for a dynamic target as a result of trends in productivity, a similarly dynamic limit (e.g. set at half the target) would also be indicated.*

Tiered harvest strategies

There is a wide range in data availability for different fish stocks, from low information for discarded bycatch species to high information for main commercial target species. Tiered assessment approaches and harvest strategies have been developed to deal with this range in data availability and applied to stocks in the Southern and Eastern Scalefish and Shark Fishery (SESSF). These tiers have recently been expanded to cater for lower information stocks, such as where only catch data are available (Dichmont et al. 2013).

- Discount factors (5–15 per cent) applied to recommended biological catches derived from various assessment tiers, to compensate for increased uncertainty as a result of lower information, are not always consistently applied. These discounts should be MSE tested to ensure that they achieve comparable risk across the tiers.

- Below these analytical approaches, ecological risk assessments (ERAs) can be used for low information species to determine whether particular species are vulnerable to the effects of fishing. ERA approaches would be appropriate for minor byproduct species that do not contribute substantially to catches or revenue.

- The full range of potential assessment methods should be integrated into a comprehensive hierarchical guide to assessment methods, data requirements, potential indicators and feasible harvest strategies at each tier in the hierarchy, covering the full range from Level 1 ERA to Tier 1 stock assessment.

- *Additional byproduct species brought into a revised harvest strategy policy would need to be evaluated to determine whether they are at low biological risk (analogous to being above Blim) from current fishing levels, using existing or updated Level 1 or 2 ERAs.*
- *ERAs may need to be reviewed to ensure that determination of 'low risk' under an ERA is analogous to there being a low probability of these species declining below BLIM levels under current fishing.*
- *Additional work is required to develop and test harvest strategies that could be applied effectively to the additional lower information assessment tiers (Tiers 5–7) developed by Dichmont et al. (2013).*
- *Development and MSE testing of harvest strategies designed to manage stocks towards targets and away from limits at each tier level should mean that additional discount factors are not required. If harvest strategies have not been tested to ensure low risk of breaching limits, and if discount factors are to be applied, then these discount factors should be extended to the new Tiers 5–7, and should themselves be MSE tested.*

Data requirements and risk-catch-cost trade-off

Data requirements for the various ERA and analytical assessment tiers are well understood (Dichmont et al. 2013). However, managing data-poor fisheries towards maximum economic yield (B_{MEY}) or proxy ($0.48B_0$) is less well understood, and will be difficult without increased data collection.

- There are increasing costs associated with moving to more certain, lower risk assessments. Selection of assessment tiers and data collection requirements should be guided by the trade-off between risk, catch and cost.
- *More work is required to develop B_{MEY} proxies for use with such data-poor fisheries.*

Multiyear total allowable catches

Multiyear TACs have been established for a number of species in the SESSF to reduce the annual assessment cost. Multiyear TACs provide greater certainty regarding the levels of future TACs and can provide greater catch stability during the multiyear TAC. In general, multiyear TACs require a discount of some level of catch below optimised annual TACs to balance the greater risk associated with less frequent review and adjustment.

When multiyear TACs are established, 'breakout' rules are usually adopted to detect extraordinary conditions not tested for when the multiyear TACs were initially determined (such as an unexpectedly large increase or decrease in catch-per-unit effort [CPUE]), and therefore require stock status and the multiyear TAC to be reviewed. Collection of the data required to calculate the breakout rule has to continue to allow these breakout rules to be evaluated every year.

- Additional guidance is required on when and how best to set multiyear TACs.
- For stocks with quantitative stock assessments and for which projections can be generated, projections at various catch levels and during various periods of time should be used to determine the level of multiyear TAC appropriate during various time periods (i.e. what level of catch is 'safe' over 2, 3 or 5 years).
- *For lower information stocks for which projections cannot be run, MSE testing should be used to determine the appropriate discount rates to use when setting multiyear TACs during different periods.*

Rebuilding strategies

The Commonwealth Fisheries Harvest Strategy Policy requires that active rebuilding strategies be implemented for all stocks that decline below B_{LIM}, to rebuild these towards B_{TARG}. Targeted fishing must cease below B_{LIM}. Stocks managed under rebuilding strategies have not shown the expected rebuilding within the planned or assumed timeframe. Some depleted species (e.g. eastern gemfish) would not recover in the 10 years plus one generation time stipulated in the policy. Reductions in productivity have been proposed (jackass morwong, Wayte 2012) and suggested (eastern gemfish, Morison et al. 2013) as the reason why these stocks have not recovered as predicted.

- There is some uncertainty regarding whether recovery timeframes stipulated in the policy apply to recovery to above B_{LIM}, or recovery to B_{TARG}, and whether targeted fishing can occur on conservation-dependent species even if they are above B_{LIM}. This should be clarified.
- Recovery timeframes stipulated in the policy (minimum of 10 years plus one generation, or three generation times) may not account for differences in productivity, variability in recruitment, and the possible relationship between spawning biomass and recruitment. A biologically appropriate definition of recovery time is required that can account for differences in productivity.
- The United States (US) and New Zealand (NZ) require rebuilding in relation to T_{min}, the minimum time to recovery under zero fishing: USA = T_{min} plus one generation; NZ = $2 \times T_{min}$. This sort of approach is able to deal with a wide range in species productivity and recovery rates, and provides better estimates to what might be considered to be a 'biologically appropriate' recovery time.
- Persuasive evidence of a change in productivity resulting from some external environmental factor is required before an environmental change can be adopted as the justification for changing the productivity parameters, targets and limits for a species under a rebuilding plan.
- Reduced recruitment as a result of spawning depensation in a depleted stock does not necessarily alter the long-term productivity of the stock, and so should not justify a change in targets. However, recruitment depensation can result in low productivity in the short-term, requiring substantial reductions in fishing mortality.
- *McIlgorm (2012) notes that the formally legislated recovery plans used in the United States appear to have one of the best records of stock recovery.*

Reduction of discards

International best practice aims to achieve zero discards by either prohibiting discards, or by implementing a system whereby fishers are required to land all catches, to deduct these from quotas or to pay 'deemed values' for catches above their quota allocations. One of the factors that has reduced the ability to monitor rebuilding of depleted stocks is poor estimates of discards for stocks subject to rebuilding plans. Reduced information on discard rates can mask recovery that may be occurring.

- Rebuilding plans for depleted stocks should include requirements to ensure adequate monitoring and data collection, to be able to obtain accurate estimates of discards, and to track increases in abundance or availability.

Spatial management

The Commonwealth Fisheries Harvest Strategy Policy recognises that spatial management may be used in various ways, including rotational closures to protect spawning seasons or nursery areas, rotational harvesting, separate TACs by area or protection of key habitat areas. These are all valid and useful management options that are particularly applicable to protection of nonmobile (e.g. shellfish, sea cucumbers), highly resident or seasonally aggregating species.

- Additional guidance is required on evaluating the extent to which a stock is considered to have been protected—and fishing mortality rates decreased—by closures, or how management of the remaining stock in open areas should be revised to account for the effects of closures.
- *Work is under way (FRDC project 2011/032: Incorporating the effects of marine spatial closures in risk assessments and fisheries stock assessments) to evaluate the extent to which fishing mortality on a range of stocks has been decreased by the establishment of an increasing number of marine protected areas (MPAs) or large-scale, permanent closures for protection of other species.*
- *Assessment approaches and harvest strategies may need to be revised for some species to account for the protective effect of these spatial closures. This will require some understanding of the rate of movement between closed and open areas, as well as agreement on objectives for how the remaining stock in open areas is to be exploited.*

Review of International Best Practice

Ecosystem-based fisheries management

The harvest strategy policy was not intended to meet Australia's international undertakings to implement an ecosystem approach to fisheries under the United Nations Convention on Biodiversity (UN 1992) or the Food and Agriculture Organization Code of Conduct for Responsible Fisheries (FAO 1995) and associated guidelines.

Nonetheless, McIlgorm (2012) did make some observations on ecosystem based fisheries management in his review of international best practices, noting that there are several recent international ecosystem and environmental monitoring and management trends that have surpassed the Commonwealth Fisheries Harvest Strategy Policy. In this regard, McIlgorm (2012) concluded that:

- Australia has a multiagency approach to environmental management, probably requiring some additional broader or overarching policy to address requirements for ecosystem-based fisheries management.

Implementation review

In addition to the technical reviews of various aspects of the policy and guidelines conducted by Haddon et al (2013) and Vieira & Pascoe (2013), the separate *A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy* (Ward et al. 2013) summarises experiences, successes and difficulties with development and implementation of harvest strategies for Commonwealth fisheries since adoption of the Commonwealth Harvest Strategy Policy.

This review identifies many of the same technical issues relating to harvest strategies that are identified in the Haddon et al. (2013) technical review of the policy, as well as some additional issues relating specifically to implementation. The recommended improvements listed below, arising from the implementation review, therefore duplicate some of those arising from the other technical reviews.

Reference points and indicators

Most harvest strategies do not use estimated B_{MEY} targets; instead they use the Commonwealth Fisheries Harvest Strategy Policy's proxies for target reference points. For most stocks, reference points are fixed and do not reflect the non-equilibrium nature of variable fish populations. It has been difficult to identify meaningful reference points for spatially structured species.

Harvest strategies for several low-value and data-poor fisheries have catch or CPUE triggers instead of reference points because it has been difficult to identify meaningful biomass-related reference points. For many of these, the most appropriate levels of these triggers are unknown, and the assessments and management actions that are triggered may not be feasible within an appropriate timeframe.

Targets required to optimise fishery-wide MEY have not been estimated for most Commonwealth fisheries.

- The reliance on proxies for targets and limits for most stocks emphasises the importance of ensuring that these proxies reflect appropriately the different biology and productivity of various species groups.
- Where catch or CPUE triggers for low-information stocks are designed to trigger immediate additional assessment work (e.g. to support in-season adjustment or some other immediate management action), data collections programs need to be in place to ensure that the data required for such additional assessments are available.
- *The implementation review also noted the need for further work on appropriate MEY proxies for various species groups and fisheries.*

Spatial management

The use of marine reserves and other spatio-temporal closures as fishery management tools, and the evaluation of the effect of such closures, has differed across fisheries.

- Harvest strategy implementation could be improved with additional guidance on evaluating the effects of closures on protection of stocks in closed areas and effective management of remaining stocks in open areas.
- *Assessment approaches and harvest strategies may need to be revised for some species to account for the effects of spatial closures.*

Management strategy evaluation and testing

Most harvest strategies have been tested using management strategy evaluation (MSE) to ensure that there is low risk (i.e. < 10 per cent) of breaching limits. For low-information species, some of this MSE testing has been generic, rather than species specific, evaluating the performance of a particular harvest strategy approach across a group of species in a fishery.

Insufficient information has precluded testing of the harvest strategies of some small fisheries and data-poor fisheries. MSE testing has also not been conducted to evaluate the effectiveness of proposed discount factors applied when moving from Tier 1 to higher tier (Tier 3 and 4) assessments, to evaluate the increase in risk that might be associated with moving to alternative targets below B_{MEY} for secondary species, or to evaluate multiyear TACs where these have not been developed using projections from a Tier 1 assessment.

- *Additional MSE testing should be used to evaluate the effectiveness of discount factors and multiyear TAC catch levels for low-information stocks.*

Application of harvest strategies

Harvest strategies for small fisheries and data-poor fisheries are often rudimentary or are not run routinely. Several stocks or species are assessed and managed as 'multispecies stocks'. Harvest strategies have not been implemented for a few significant commercial species in some fisheries, such as ocean jacket in the SESSF.

For several species, reliable estimates have not been available for significant sources of mortality, such as recreational catches and discards. Delays in data acquisition, processing and assessment have contributed to uncertainty in stock status.

It is unclear whether harvest strategies are required for the domestic component of three Eastern Tuna and Billfish Fishery stocks because of uncertainty over stock connectivity between the 200-nautical mile exclusive economic zone and high seas, and uncertainty about the effects of high-seas fishing on stock abundance in the Australian zone.

- Inclusion of additional low-information species under a revised Commonwealth Fisheries Harvest Strategy Policy will require consideration of whether a harvest strategy is required and what form this should take—depending on information availability and the risk-catch-cost trade-off. Harvest strategies could be unnecessary and unfeasible for low-information, low-risk (as determined using ERA), minor byproduct species.
- Where harvest strategies are agreed to and adopted, guaranteed monitoring and data collection programs need to be implemented to ensure that the data required to apply those harvest strategies will be available.
- *Additional harvest strategies may be required for important secondary species not currently under harvest strategies (e.g. ocean jacket) or minor species evaluated by ERA to be at medium or high risk from current fishing activities.*

Rebuilding strategies

A number of stocks depleted to below limits before the introduction of the Commonwealth Fisheries Harvest Strategy Policy and placed under rebuilding plans have so far failed to rebuild to above limits reference levels. A number of factors may have contributed to the failure of these stocks to rebuild, including rebuilding timeframes may have been too optimistic, some level of targeted fishing may have continued and fishing mortality may have been high enough to prevent rebuilding, or changes in the stock's productivity or ecosystem changes may have inhibited rebuilding.

- Harvest strategies for stocks under rebuilding plans currently state that recommended biological catches are zero, but provide no guidance on setting of incidental catch levels. More guidance is required in the policy on harvest strategy requirements that will ensure rebuilding of stocks placed under rebuilding plans.
- *Alternative approaches should be explored, and consideration given, to how to best define biologically appropriate rebuilding timeframes that are able to deal with differing species productivity and recovery rates.*

- *Persuasive evidence of a change in productivity is required before an environmental productivity shift can be adopted as the justification for changing the productivity parameters, targets and limits for a species under a rebuilding plan.*

Background

The development and implementation of harvest strategies is a crucial step towards improving fishery management in Australia (Smith et al. 2008) and internationally (Cadrin et al. 2004; Cadrin & Pastoors 2008). The *Commonwealth Fisheries Harvest Strategy: policy and guidelines* (Commonwealth Fisheries Harvest Strategy Policy, or the policy) is widely acknowledged as a key driver of improvements in the performance of Commonwealth fisheries since its introduction in 2007 (DAFF 2007). The policy has cultivated a transparent, evidence and risk-based approach to developing harvest strategies that incorporate target and limit reference points and performance measures for assessing a wide range of species, along with decision rules for generating advice for managing key commercial species in Commonwealth fisheries. Many aspects of the policy are considered to be examples of world's best practice for managing fisheries (McIlgorm 2012).

A review of the policy was conducted between July 2012 and May 2013, with the review's report submitted to ministers in May 2013. As part of the review, the Australian Bureau of Agricultural and Resource Economics and Sciencs (ABARES) and the Australian Department of Agriculture, Fisheries and Forestry (DAFF) consulted various Commonwealth agencies, scientists, economists and stakeholders on their views on the policy and identified areas where it might be improved. The review's advisory committee (representing a wide range of stakeholders) provided input, and wider opinion was sought through public consultation. This project was designed to link past and current research with the review, and provide technical advice on areas of potential improvement in either the policy itself or in the implementation guidelines.

Need

Since the Commonwealth Fisheries Harvest Strategy Policy was introduced in 2007 (DAFF 2007) there has been a great deal published nationally and internationally concerning the development and application of harvest strategies. Therefore, this policy needed to be reviewed for new technical content, especially with respect to new and developing methodologies for stock assessments and risk evaluation, and how the new work relates to issues of concern identified with the current policy.

The Commonwealth Fisheries Harvest Strategy Policy is generally regarded as having been largely successful in achieving the stated objectives. However, initial stages of the policy review have identified aspects of the policy, guidelines and implementation that might be improved to better meet the policy's objectives. Areas of potential improvement identified include:

- consideration of appropriate limit reference points based on trophic role or the biological characteristics of different groups of species (e.g. teleosts v. chondrichthyans)
- incorporation of spatial management
- approaches to setting total allowable catches (TACs) in multispecies fisheries
- data-poor stocks (including byproduct)
- rebuilding strategies
- indicators of economic performance.

This project reviewed the latest publications relevant to those priority areas, along with research work in progress, to provide the policy's advisory committee with technical advice on potential improvements to these aspects of the existing policy. Evaluation of current research and developing technologies can provide a basis for a revised policy to incorporate greater flexibility in responding to shifts in stocks and ecosystems in response to environmental drivers, such as climate change. This work should ultimately contribute to continued improvements in the economic performance and sustainability of Commonwealth fisheries, and will have relevance to shared fisheries, fisheries in other jurisdictions and internationally.

Methods

This technical overview was conducted by reviewing all of the technical review reports commissioned under Fisheries Research and Development Corporation (FRDC) Project 2012/225 to inform the review of the Commonwealth Fisheries Harvest Strategy Policy, as well as additional technical review reports not commissioned for the review, but nonetheless relevant to particular aspects thereof. A number of directly relevant peer-reviewed scientific journal publications on key aspects of harvest strategy design and implementation were also reviewed.

Conclusions from these reports on technical challenges with interpretation or implementation of objectives and requirements of the policy were distilled from these reports. Common themes were identified and grouped into categories. Potential improvements were then identified under each category relating to improving some of the enabling wording of the policy itself, or providing clearer or additional guidance in the implementation guidelines.

Technical reports reviewed

The following technical reports were reviewed in preparation of this technical overview:

- ***Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy*** (Haddon et al. 2013). This is the main product of FRDC project 2012/225, addressing the first three objectives. The report focuses on technical details of existing harvest strategies under separate chapters on reference points appropriate to life-history characteristics, buffered targets or meta-rules, data-poor fisheries and tiered harvest strategies, TAC setting and multiyear TACs, rebuilding strategies and bycatch-only TACs, and spatial management. Information is provided under each of these chapters on how the requirements of the Commonwealth Fisheries Harvest Strategy Policy have been interpreted technically in the harvest strategies developed for Commonwealth fisheries. Where difficulties have been experienced with harvest strategy development or implementation, technical reasons for this are analysed and advice is provided on how these may be addressed.

- ***Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy: economic issues*** (Vieira & Pascoe 2013). This report addressed economic aspects relevant to the first three objectives of the project, as well as its fourth objective. The harvest strategy policy requires that Commonwealth fisheries be managed to maximise the net economic returns to the Australian community. Estimating maximum economic yield (MEY) requires a bioeconomic model that has high biological, fishery and economic data requirements. Data limitations have prevented bioeconomic models from being developed for most fisheries, so that proxy values for B_{MEY} have to be used. The report considers circumstances under which the current interpretation of MEY, and the actual targets used for different stocks, could be modified to better achieve the economic objective and intent of the Commonwealth Fisheries Harvest Strategy Policy.

- ***A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy*** (Ward et al. 2013). This report addresses the fifth objective to this project. An overview table of the implementation of policy-compliant harvest strategies across all Commonwealth fisheries is provided. A number of fisheries exhibiting particular characteristics that affect the implementation of harvest strategies for those fisheries are then used as case studies to identify circumstances under which harvest strategy policy implementation has worked well, and to explain why implementation has encountered difficulties under other circumstances.

- ***Literature study and review of international best practice in fisheries harvest strategy policy approaches*** (McIlgorm 2012). This report was commissioned by DAFF to inform the Commonwealth Fisheries Harvest Strategy Policy review regarding recent international developments and best practices relating to fisheries harvest strategies. The report identifies aspects of harvest strategy best practice in international agreements and guidelines, and in harvest strategy approaches developed by the United States, New Zealand, Iceland and Norway. Aspects of the policy are contrasted with these to evaluate the extent to which the Australian policy meets or exceeds international best practice.

- ***Risk-based approaches, reference points and decisions rules for managing fisheries bycatch and byproduct species*** (Kirby et al. 2013). This report was commissioned under FRDC project 2011/251 to inform the review of the *Commonwealth policy on fisheries bycatch* (DAFF 2000). An objective, to evaluate the application of risk-based approaches to byproduct (secondary commercial) species, was added to the project, which makes aspects of this report relevant to the Commonwealth Fisheries Harvest Strategy Policy review. This report recognises that a broad hierarchy of assessment approaches are potentially applicable to any species subject to fishing mortality, depending on data availability. These approaches range from qualitative ecological risk assessment (ERA) approaches, through quantitative ERAs, low to moderate analytical assessments, to high-information stock assessments. Each approach has specific data requirements and the preferred approach is driven by a risk-catch-cost trade-off.

A number of other reports or recent scientific publications considered to be directly relevant to an overview of issues raised in the above reports were also reviewed:

- ***Reducing uncertainty in stock status: harvest strategy testing, evaluation, and development. General discussion and summary*** (Haddon 2012). The Reducing Uncertainty in Stock Status (RUSS) project was a substantial research project initiated in 2009 in collaboration between Commonwealth Scientific and Industrial Research Organisation and the Bureau of Rural Sciences (now ABARES); the objective was to reduce the number of fisheries classified as 'uncertain' in the annual ABARES fishery status reports. The project consisted of two streams. Stream 1 examined a range of data-poor assessment methods to determine whether some low-information uncertain status stocks could be assessed using these methods. Stream 2 used management strategy evaluation (MSE) to test the harvest strategies implemented in an array of different fisheries. This document summarises the outcomes of the second stream; in particular, the results of the MSE analyses conducted.

- ***'Impacts of fishing low trophic level species'*** (Smith et al. 2011). This paper uses a range of ecosystem models to explore the effects of fishing low trophic–level species (such as small, pelagic, shoaling species) in five marine ecosystems. Results show that that fishing these species at maximum sustainable yield (MSY) levels can have large impacts on other parts of the ecosystem. Halving exploitation rates would result in lower impacts on marine ecosystems while achieving 80 per cent of MSY.

- ***'On the use of BMSY and BMEY as reference points: selecting proxy target biomass levels to achieve pretty good yield and pretty good profit'*** (Punt et al. in press). There are difficulties in estimating actual B_{MSY} and B_{MEY} target reference points. This paper explores proxies for each of these targets, expressed as depletion levels relative to carrying capacity, which are more easily estimated than actual levels. Integration across a range of uncertainties about stock dynamics and the costs of fishing suggests that a proxy for B_{MSY} in the range of 35–40 per cent of carrying capacity (B_0) minimises the potential loss in yield compared to what would arise if B_{MSY} was known exactly. A proxy for B_{MEY} of 50–60 per cent of carrying capacity minimises the corresponding potential loss in profit.

- ***Setting target reference points for secondary species in the SESSF*** (Vieira et al. in prep). This report to the Australian Fisheries Management Authority (AFMA) provides an overview of the theoretical justification for use of alternative target reference points below B_{MEY} for secondary species in the Southern and Eastern Scalefish and Shark Fishery (SESSF), to optimise multispecies MEY across this fishery. Criteria for identifying nontargeted, low–economic return species are identified and used to select candidate secondary species in the SESSF. Potential increases in economic returns from reducing targets for these secondary species to B_{MSY} are evaluated.

Technical overview

There have been many achievements in implementing harvest strategies under the Commonwealth Fisheries Harvest Strategy Policy (Ward et al. 2013), and many aspects of the technical guidelines and approaches taken have resulted in effective harvest strategies (Haddon et al. 2013). Many aspects of the policy and resulting harvest strategies also meet or exceed international best practice (McIlgorm 2012). This overview focuses on difficulties experienced with development and implementation of harvest strategies under the policy, and summarises advice from the reviewed technical reports on how these might be addressed through improvements to the policy or guidelines.

The issues of concern identified in the various technical reports group themselves into a number of clear themes. Key issues under each of these themes are summarised below, together with any advice provided in the technical reports on how technical difficulties might be addressed and improvements made, either by improving the enabling provisions of the policy or the guidance provided in the implementation guidelines.

Reference points and proxies

Target and limit reference points are essential components of any effective management strategy. Without them, there is no consistent and objective basis for evaluating stock status or trends in performance indicators against management targets. McIlgorm (2012) notes that international best practice adopted BMSY as the biomass objective following the adoption of the United Nations Convention on the Law of the Sea (UNCLOS) in 1982 (UN 1982). There is increasing evidence that targets should be set above B_{MSY} for various reasons (Sainsbury 2008), but Australia is unique in explicitly setting targets at B_{MEY} and in adopting a proxy of $1.2B_{MSY}$ (or $0.48B_0$) for this target.

Following the adoption of the United Nations (UN) Fish Stocks Implementation Agreement (UNFSIA) (UN 1995), limit reference points (B_{LIM}) have been adopted by most countries to prevent stocks from being fished down to levels below which reproductive capacity becomes impaired. The most common proxy for B_{LIM} is ½ B_{MSY}, or $0.2B_0$. Most jurisdictions, including Australia, have adopted B_{LIM} as the point below which stocks are considered to be overfished. The policy prescribes ½ B_{MSY} or $0.2B_0$ as proxies for this limit. The policy additionally requires a 90 per cent probability of not being below B_{LIM}, which is a higher standard than other nations examined, depending on how B_{LIM} is defined. For example, the New Zealand Harvest Strategy Standard (Ministry of Fisheries 2008) defines a 'soft limit' of $0.2B_0$, and considers this to have been breached when there is a 50 per cent probability that biomass is below this level.

F_{MSY} is widely accepted internationally as the limit above which overfishing is considered to be occurring, and fishing mortality should be reduced (Mace 2001). Australia applies this definition of overfishing, with F_{MSY} being used as the default proxy for the overfishing limit, F_{LIM}.

Alternative target reference points

The policy approach to, and recommended proxies for, target and limit reference points therefore meet and, in the case of biomass targets exceeds, international best practice. However, B_{MSY} and B_{MEY} are difficult to estimate accurately for most stocks (Punt et al. in press) and are often not estimable for low-information stocks. As a result, proxies for targets and limits are used for most stocks in Australian fisheries. While the harvest strategy policy default proxy values comply with historical best practice, there is an increasing amount of recent research questioning these default proxy values and, particularly, whether one fixed proxy value is appropriate for species with widely differing biological characteristics and productivity.

As a result of increased focus on ecosystem approaches to fisheries, there has been a recent focus on appropriate target and limit reference points for important low trophic–level forage species. Several recent studies (Smith et al. 2011; Pikitch et al. 2012) have used ecosystem models to examine the effects on predators and other parts of the marine ecosystem of fishing these forage species. There is an emerging consensus that exploitation rates for these important food species should be set more conservatively than conventional single species MSY. Smith et al. (2011) conclude that considerable reductions in ecosystem impact can be achieved by moving from exploitation at MSY levels (typically close to 60 per cent depletion levels) to a target of 75 per cent of unexploited biomass (25 per cent depletion) for these species.

Pikitch et al. (2012) go further to recommend a tiered approach relating to data availability for low trophic–level species: high data—no more than $0.75F_{MSY}$ and no less than $0.30B_0$ to be left in the ocean; intermediate data—no more than $0.50F_{MSY}$ and B_{LIM} at least $0.40B_0$; and data poor—B_{LIM} no less than $0.80B_0$. As a result, the Marine Stewardship Council now identifies criteria for identifying 'key' low trophic–level species and requires that default target biomass reference points be set at $0.75B_0$, corresponding to exploitation rates of about $0.5F_{MSY}$. The harvest strategy framework adopted for the Small Pelagic Fishery (SPF) is compatible with these guidelines, limiting harvest levels to a maximum of $0.20B_0$ if a recent stock assessment is available and reducing this harvest level down to a maximum of $0.075B_0$ as time elapses since the last assessment.

In recent studies, Thorston et al. (2012) found average B_{MSY}/B_0 values for Pleuronectiformes (flatfish) of 39.5 per cent, Gadiformes (grenadiers, cods, hakes) of 43.9 per cent, Perciformes (perch-like fish—morwong, whiting, tunas, swordfish) of 35.3 per cent, Clupeiformes (herring and anchovy) of 26.1 per cent, Scorpaeniformes (gurnards, flathead, rockfish, ocean perch) of 46.3 per cent and other species of 40.5 per cent. While $0.40B_0$ does still seem to be a useful compromise as a proxy for B_{MSY}, default targets for some species groups should be higher or lower than this. For fishing mortality targets or limits, Zhou et al. (2012), based on analysis of 245 fish species worldwide, found $F_{MSY} = 0.87M$ for teleosts and $F_{MSY} = 0.41M$ for chondrichthyans. As an example of adapting targets to this range in productivity, New Zealand has adopted an approach to setting alternative targets using productivity categories, defined by the Food and Agriculture Organization (FAO) (2001) and Musick (1999), to define biomass targets ranging from $0.25B_0$ for high-productivity species to $> 0.45B_0$ for low-productivity species (Haddon et al. 2012).

Particular difficulties arise in trying to estimate target reference points for low-information stocks, for which estimates of MSY are highly uncertain. Tested and robust proxies, appropriate for the species group concerned, are better than attempting to use highly uncertain estimates of MSY. Integrating a range of uncertainties about stock dynamics and costs of fishing, Punt et al. (in press) demonstrate that a proxy for B_{MSY} in the range of 35–40 per cent of carrying capacity minimises the potential loss in yield compared to the yield that would arise if B_{MSY} was known exactly. This corresponds well with the Commonwealth Fisheries Harvest Strategy Policy default B_{MSY} proxy value of $0.4B_0$. However, because cost information for these fisheries is particularly uncertain, the corresponding proxy for B_{MEY} to minimise the potential loss in profit lies in the range of 50–60 per cent of carrying capacity. For the two fisheries analysed, target biomass of $0.45–0.63B_0$ for blue grenadier and $0.43–0.58B_0$ for tiger flathead achieve at least 90 per cent of the potential profit, integrated over uncertainties in the input parameters.

Zhou et al. (2013) note that proxy values for B_{MEY} may more appropriately be $1.3–1.4B_{MSY}$, rather than the currently recommended $1.2B_{MSY}$, and that optimal effort levels are most likely to fall between 55 per cent and 65 per cent of MSY effort levels. They point out that both economic and biological information is an important determinant of optimal biomass ratios, and that optimal B_{MEY}/B_{MSY} ratios range from 0.5 for species with slow growth, high catchability and contributing a small share of total revenue, to 1.7 for species with higher revenue shares, moderate growth rates and low catchability. The Commonwealth Fisheries Harvest Strategy Policy may need to be more explicit about ensuring that targets and limits are appropriate for different species and fisheries, and be more flexible in allowing a range of proxy values to be used. The guidelines will need to provide more advice on how this is to be done, and harvest strategies for some stocks may need to be revised to reflect revised MSY and MEY proxy levels.

Alternative limit reference points

The selection of $0.20B_0$ as the default limit reference point in the Commonwealth Fisheries Harvest Strategy Policy reflects earlier literature (Haddon et al. 2012). As an indicator of potential recruitment overfishing, Restrepo et al. (1998) recommend $½B_{MSY}$ as an appropriate limit, but consider $0.20B_0$ to be an acceptable proxy for that figure. However, for productive species with estimates of $B_{MSY} < 0.20B_0$, $0.50B_{MSY}$ would be $< 0.20B_0$. Given the uncertainty inherent in estimation of stock productivity, a precautionary approach would require good evidence that $0.50B_{MSY}$ is indeed below $B_{20\%}$. Even then, it is appropriate to retain $0.20B_0$ as the lowest proxy value for B_{LIM}.

The policy requires that there be a < 10 per cent probability that stocks will decline below established limit reference points. However, for many stocks, particularly those with low information, it is not possible to determine the confidence intervals around current stock status estimates with the precision required to ascertain whether stocks have a < 10 per cent probability of being below B_{LIM}. In recognition of the uncertainty around estimating B_{LIM} reference points and stock status against these, the International Council for the Exploration of the Sea (ICES) proposed the use of 'precautionary approach' reference points, B_{pa} and F_{pa}, set at some level above conventional B_{LIM} reference levels (1997). This approach to dealing with uncertainty in evaluation of stock status against limit reference points has been taken up in the FAO Stock assessment manual (Cadima 2003), which provides a method for calculating B_{pa} and F_{pa} reference points based on the work by ICES (1997):

$$F_{pa} = F_{LIM}.e^{-1.645.\sigma} \quad \text{and} \quad B_{pa} = B_{LIM}.e^{+1.645.\sigma}$$

The constant σ is a measure of the uncertainty in the estimation of the fishing mortality level F. The values obtained in several fisheries indicate that values of σ are 0.2–0.3 (ICES 1997), so that estimates of F_{pa} lie in the range $0.47–0.61F_{LIM}$ and estimates of B_{pa} lie in the range $1.39–1.64B_{LIM}$. For a B_{MSY} proxy of $0.40B_0$, recommended B_{pa} reference points calculated using the above formula would lie in the range 0.29–0.33 B_0, about halfway between the current proxies for B_{MSY} and B_{LIM}. Where there is high uncertainty around determining stock status in relation to a $0.20B_0$ limit, or concerns that this may not be an appropriate proxy for low-productivity species, use of B_{pa} reference points can constitute an explicit precautionary approach to dealing with this uncertainty.

Alternative maximum economic yield targets

Due to limitations in available economic data, or difficulties in collecting adequate economic data to support bio-economic modelling, bio-economic models have only been used to develop fishery-specific estimates of maximum economic yield (MEY)-related reference points, expressed in terms of biomass or fishing effort, for the Northern Prawn and Great Australian

Bight fisheries. Vieira and Pascoe (2012) have identified a number of opportunities or options for estimating alternative MEY-related targets, or alternative proxies for MEY targets, for lower information fisheries for which bioeconomic modelling has proved difficult.

The relevance of using an optimal fishing capacity approach to achieving the objectives of the policy, and potential decision rules around fishing capacity, should be explored. This could allow for improved performance against the economic intent of the policy for variable fisheries, international fisheries (fisheries where biomass targets are less relevant) and multispecies fisheries. Application of the approaches used by Zhou et al. (2013) for data-poor fisheries may be an option for improving performance against economic targets. However, further development of the approach is required to improve its reliability.

Options for incorporating readily available economic information into stock assessments, rather than conducting separate economic analyses, to provide better information for management to MEY targets should be explored. These options include applying an assumed price to TAC outputs and assumed cost parameter to fishing effort. Vieira and Pascoe (2013) recommend that such options should be explored to build on current Tier 3 (catch-curve) and Tier 4 (catch-per-unit-effort [CPUE]) assessments for data-poor fisheries to incorporate economic factors, such done by Defeo and Seijo (1999). They also recommend incorporating economic aspects into management strategy evaluation (MSE) testing of MEY-related targets.

A FRDC project (FRDC 2011/200) is under way to look at proxy measures for MEY in multispecies fisheries, particularly for secondary species. Preliminary results from this project should be available in mid-2013 and should allow more appropriate proxies to be determined for multispecies fisheries. Ensuring communication of these results to resource assessment groups (RAGs) should assist with setting of multispecies targets. Vieira et al (in prep) note that, where alternative targets (such as B_{MSY} or lower) are adopted for secondary species, these should be MSE tested to ensure that they do not result in unacceptable risks of breaching BLIM reference points.

The implementation guidelines could benefit from additional guidance on the following aspects relating to alternative MEY targets for different fisheries:

- Provision of practical guidance on the circumstances under which an MEY target should be estimated, how it should be estimated for different fishery types and key principles of successful implementation, would help guide RAG recommendations on these aspects.
- Better guidance on what MEY means, and how economic objectives change, for different fishery types when trying to maximise net economic returns for variable fisheries or those with market power.
- Further guidance on what constitutes meeting the MEY objective for data-poor stocks and the appropriate level of research investment for such stocks.

While some recent work has been conducted on aspects of alternative MEY targets for low-information fisheries (Vieira & Pascoe 2012), additional work will be required to inform the drafting of guidance on the above aspects.

Target ranges and dynamic targets

Where explicit targets have been expressed in harvest strategies developed under the Commonwealth Fisheries Harvest Strategy Policy, they are expressed as single values, usually as proportions of a theoretical equilibrium 'unfished' biomass (e.g. $0.48B_0$), as B_{MSY} (the proxy for which is also a proportion of B_0), or some proportion of an average fishing mortality or CPUE over a chosen historical reference period during which the stock was considered to have been lightly fished and stable. In reality, fish stocks are not expected to achieve a stable equilibrium, and natural variation in stock productivity and biomass will result from changing environmental conditions and recruitment variability from year to year. Even in well-managed fisheries, stocks will therefore fluctuate naturally around the target and, for species with substantial interannual variability in recruitment, this fluctuation can be substantial.

In addition to (and, partially, as a result of) this variability in recruitment, there is uncertainty around the determination of target values such as B_{MSY}, as well as around estimates of the ratio of current status to B_0. All of these estimates are therefore not single, precise values, but are more correctly expressed as probability ranges around a median best estimate. This also represents international best practice on how to report stock status (McIlgorm 2012). The combination of natural stock fluctuations around targets and uncertainty in estimates of targets and current status mean that expressing targets as single numbers can result in unrealistic determinations that stocks are sequentially above and below targets, when they are actually within the uncertainty around the target or within natural stock variability ranges.

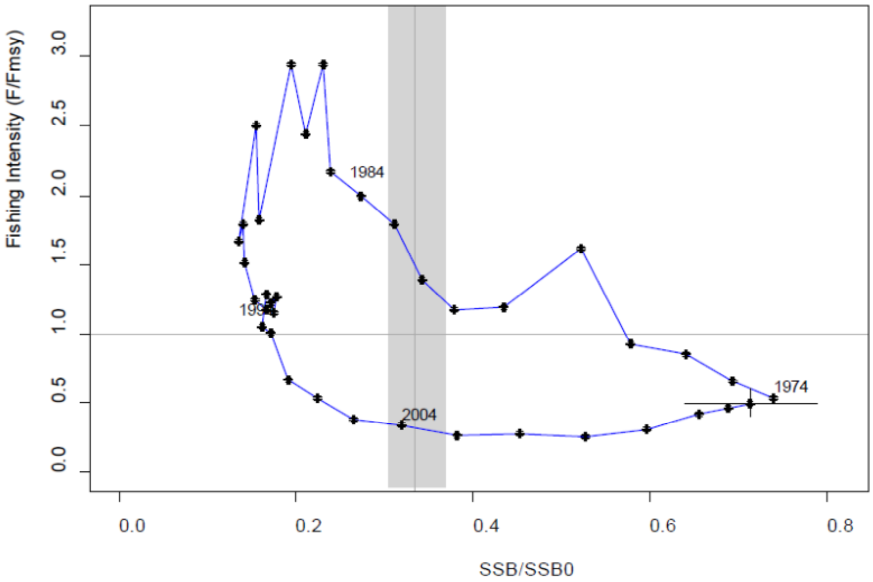
There are various ways of dealing with uncertainty around equilibrium estimates of targets, or with natural variability in these targets, in management strategies. Haddon et al. (2013) describe approaches whereby this can be dealt with by including a plateau in decision rules, providing a buffer region above which changes in stock status do not result in changes in TACs. For example, a decision rule designed around a target of $0.48B_0$ could include a plateau down to $0.40B_0$, with TACs being kept constant (and fishing mortality allowed to increase) until the stock reaches $0.40B_0$, after which TAC changes would be recommended. Plateau decision rules are used for a number of New Zealand rock lobster (*Jasus edwardsii*) fisheries (see decision rules for the CRA 4, CRA5, CRA7 and CRA8 stocks in Ministry for Primary Industries 2012b), and are generally designed to maintain stocks well above B_{MSY} levels.

A simpler approach to addressing natural variability, and uncertainty in stock status around targets, is to express targets as target ranges, rather than single numbers. There are various ways of doing this. One approach is to set the target range to include some proportion of the uncertainty around estimates of B_{MSY} or B_{MEY}. Estimates of these theoretical equilibrium values are typically uncertain and this uncertainty can be used to set a target range (e.g. the 90 per cent or 75 per cent confidence interval around the estimate), expressing this as the resulting target range in $\%B_0$. This uncertainty range would be expected to be narrower for stocks with reliable assessments and stable productivity (such as longer lived species with steady recruitment) and wider for highly variable species (with highly variable recruitment). Uncertainty-based target ranges can therefore potentially deal appropriately with species with different biological characteristics. Figure 1 shows an example uncertainty range (90 per cent confidence interval) around B_{MSY} for the New Zealand CRA 8 rock lobster stock (Ministry for Primary Industries 2012b).

Another approach is to set target ranges based on a range of estimates of B_{MSY} or B_{MEY} from stock assessments, or to choose a target range to achieve specific management objectives. A range of estimates for these targets could result, for example, from alternative assessment model runs using different values of the key input parameters (such as natural mortality or stock recruit steepness) or from different weighting of alternative biomass abundance indices (such as CPUE and fisheries independent surveys). Managers can choose to set target ranges to ensure the maintenance of a large stock size, such as the target range set by fishery managers for the New

Zealand eastern hoki (blue grenadier, *Macruronus novaezelandiae*) stock at 0.35–0.50B_0, well above the estimated B_{MSY} for this stock of 0.25B0 (Figure 2).

Figure 1 Historical trajectory of spawning biomass and fishing intensity for the New Zealand CRA 8 rock lobster stock from 1974 to 2011.

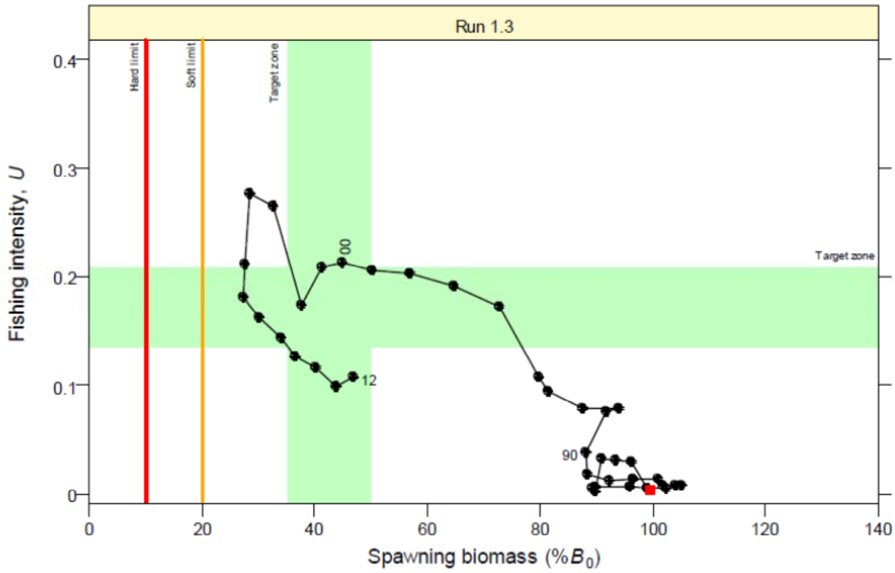


Note: This figure shows an example of a target range based on uncertainty around the estimate of B_{MSY}. The x-axis is spawning stock biomass (SSB) in each year as a proportion of the unfished spawning stock, SSB0. The y-axis is fishing intensity in each year as a proportion of the fishing intensity (F_{MSY}) that would have given maximum sustainable yield (MSY) under the fishing patterns in that year. The vertical shaded area shows the median (line) and 90% confidence interval around SSB_{MSY}.

Data source: Ministry for Primary Industries (2012b)

Targets specified as ranges can still be inadequate to deal with stocks that exhibit highly variable productivity (e.g. extended periods of alternating high and low recruitment), longer term trends in productivity over time (climate-related increases or decreases) or productivity shifts in response to environmental change. For such species, the unfished biomass itself can vary substantially over time, either cyclically in response to variable recruitment driven by environmental cycles, or following a trend in response to climatically or oceanographically driven regime shifts. Within the Southern and Eastern Scalefish and Shark Fishery (SESSF), there is already an example of a relatively depleted species that was near the limit reference point (jackass morwong, *Nemadactylus macropterus*) and exhibited a 20-year series of estimated below-average recruitment (as estimated by the stock assessment), preventing recovery to the original target. This was eventually characterised as a change in the species productivity, or an alteration in prevailing environmental conditions that affected productivity and has lasted for decades (Wayte 2012). The original target for this species is no longer attainable under these conditions and would need to be reduced to reflect the reduced B_0 capability of this stock.

Figure 2 Historical trajectory of fishing intensity (U) and spawning biomass (%B_0), for the New Zealand eastern hoki stock from 1972 to 2012.



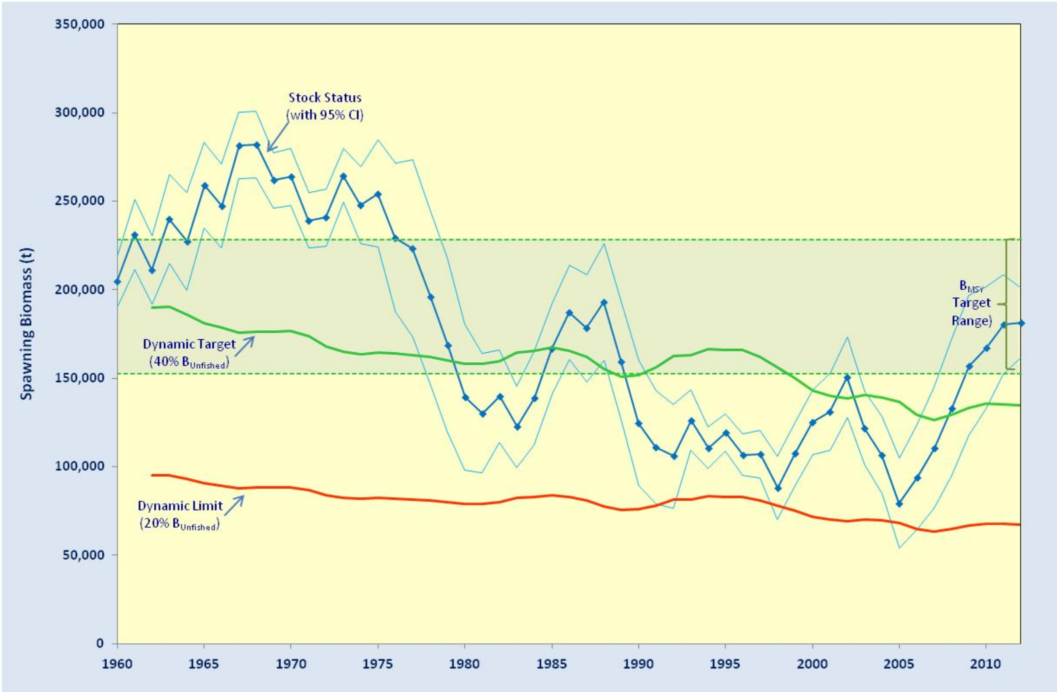
Note: This figure shows an example of explicitly set management target ranges around biomass and fishing mortality. The vertical line at $0.20B_0$ is the soft limit and the shaded areas represent the management target ranges in biomass (0.35–$0.50B_0$) and fishing intensity

Data source: Ministry for Primary Industries (2012b)

Under such circumstances, the concept of a stable, average, equilibrium MSY or limit reference point is inappropriate and it is better to express stock status in relation to dynamic reference points, such as $B_{Current}/B_{Unfished}$. Provided $B_{Unfished}$ can be estimated, this type of dynamic biomass reference point automatically compensates for recruitment variability, trends in productivity and environmentally induced recruitment regime shifts. Dynamic biomass target and limit reference points are used, for example, by international regional fisheries management organisations for variable pelagic species such as tunas and jack mackerel (SPRFMO 2012). The Northern Prawn Fishery currently uses a dynamic F-based reference point.

Figure 3 illustrates these alternative options around reporting stock status incorporating assessment uncertainty—in relation to a target range, or to dynamic targets and limits. This hypothetical example shows a stock that is interannually variable, but is also exhibiting a long-term decline in productivity (and therefore in attainable targets), which is contributing to a decline in biomass of the species.

Figure 3 Illustration of alternative approaches to setting target ranges or dynamic targets to account for natural variability and uncertainty in targets and current stock status



Note: Uncertainty around estimates of stock status (expressed as 95% confidence intervals); uncertainty or an explicit range around a B_{MSY} target; and a dynamic target and limit, expressed as $\%B_0$, changing over time as a result of changes in stock productivity.

In setting target ranges, management decision rules should be designed to manage towards the centre of the target range. Nonetheless, it would be necessary to ensure that the lower end of such ranges still represents an appropriate target, with a < 10 per cent probability of breaching limits. In terms of future research, if it was decided to pursue buffered decision rules, target ranges or dynamic targets, results would need to be MSE tested to determine whether such a harvest strategy increases or decreases the risk of breaching limit reference points.

Data-poor fisheries and tiered harvest strategies

Haddon et al. (2013) note that data-poor stocks lack sufficient biological and/or fisheries information to:

- estimate the exploitation status of the targeted stocks
- determine meaningful reference points
- produce a defensible stock assessment
- evaluate stock status against reference points.

Nonetheless, the Commonwealth Fisheries Harvest Strategy Policy requires approaches that ensure a consistent degree of risk across all fisheries. This creates particular challenges for data-poor fisheries. In this regard, the harvest strategy policy states that:

> *A tiered approach to control rules is encouraged in order to cater for different levels of certainty (or knowledge) about a stock … Such an approach provides for an increased level of precaution in association with increasing levels of uncertainty about stock status, such that the level of risk is approximately constant across the tiers*. (DAFF 2007)

This has resulted in the development of a tiered system of analytical assessment methods and associated control rules, pioneered in the SESSF (Smith et al. 2008; Little et al. 2011). An extended tiered approach (Dichmont et al. 2013) specifies a broad range of assessment approaches from integrated stock assessments (Tier 1), where substantial data are available, to approaches where data are limited to catch-at-size and catch rates (Tiers 3 and 4), to approaches where only catch data are available (Tiers 5–7) (Dichmont et al. 2013; Dowling et al. 2013). Catch triggers can also be used for data-poor species to trigger increased data collection, should catches increase above a certain level, to provide for higher information assessments in an adaptive management approach. Where such triggers are intended to trigger an immediate re-assessment (e.g. to support in-season adjustment or some other immediate management response), data collection programs need to be in place to ensure that the data required for such re-assessment are available.

Haddon et al. (2013) cite numerous international reviews that have been conducted on alternative indicators and assessment methods for data-poor species. Many of these have proposed hierarchical approaches to selection of assessment methods, depending on data availability. Scandol (2003, 2005) investigated a wide range of potential indicators including total catch, catch rate, length distribution, age distribution, catch, CPUE, mean age, mean length, recruitment fraction, total mortality and fishery-independent surveys. Biomass surveys were found to provide best results, followed by mean age and length, and recruitment fractions. Time series of CPUE and catch had the worst performance but were still acceptable.

In developing scientific guidance for evaluation of bycatch and discards in Canadian commercial fisheries, Fisheries and Oceans Canada developed a hierarchical guide to selection of the most appropriate of these many analytical assessment approaches, depending on data availability (DFO 2012). The Canadian approach is similar in concept to the extended tiered approach proposed by Dowling et al. (2013) and Dichmont et al. (2013).

Below this broad range of analytical assessment methods, ecological risk assessment for the effects of fishing (ERAEF; Hobday et al. 2011) can be used for species with very low levels of information, to determine whether particular species are highly vulnerable to fishing. If numerous data-poor species become included under the revised Commonwealth Fisheries Harvest Strategy Policy as a result of being identified as minor byproduct species, there will be a need to use ecological risk assessment (ERA) results to determine which of these minor species are at low risk of being overfished at current fishing levels. Species assessed as being at high risk, or species for which catches increase above predetermined catch trigger levels to become significant contributors to commercial catches, would either need to move to being assessed using an appropriate analytical method under one of the assessment tiers, or managed under a precautionary approach to reduce risk. There is, therefore, a need to integrate ERAEF and the various analytical assessment tiers into a comprehensive, hierarchical guide to assessment methods, data requirements, potential indicators and harvest strategies at each tier, covering the full range from Level 1 ERA to Tier 1 stock assessment.

To date, most developmental work in this regard has focused on comparing data-poor assessment methods, rather than comparing the effectiveness of data-poor harvest control rules. Further work is therefore required to develop appropriate harvest strategy approaches for application to species under the lower information tiers (Tiers 5–7) proposed by Dowling et al. (2013) and Dichmont et al. (2013). Haddon et al. (2013) emphasise that there remains a real need to provide guidance on formulating control rules that link empirical indicators with suitable management responses for low-information stocks.

MSE testing across a range of the current tiered assessment methods and fisheries (Haddon 2011; Little et al. 2011; Klaer et al. 2012) shows that most of these approaches can potentially meet the objectives of the Commonwealth Fisheries Harvest Strategy Policy, provided certain conditions are met under each method. Where MSE testing indicates that a given information strategy and control-rule combination will meet objectives, the approach can be used as is. Where MSE is inconclusive, increasing precaution should be applied to lower information tiers (Haddon et al. 2013). In particular, candidate harvest strategies developed for the newly proposed lower information tiers (Tiers 5–7) need to be MSE tested to ensure that the risks of breaching limits remain acceptable under these low-information harvest strategies.

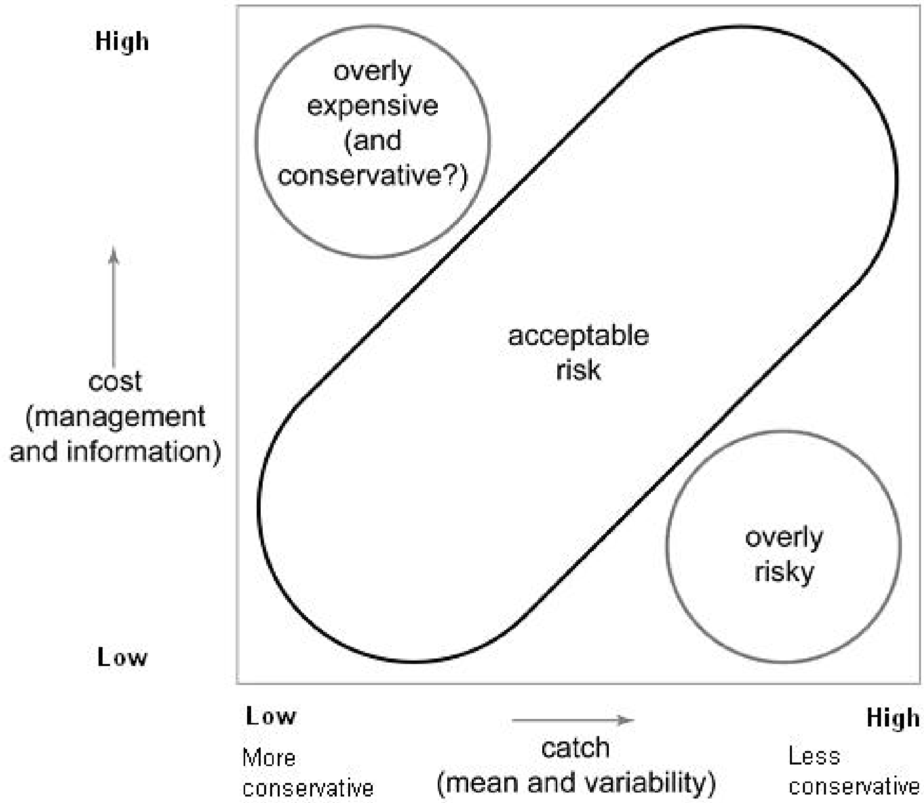
Data requirements and the risk-catch-cost trade-off

Each assessment method under the tiered assessment approach described above has certain minimum data requirements, described in Dichmont et al. (2013, tables 2 and 3). There are certain types of data that all fisheries should collect on a routine basis, such as fishing dates and positions, fishing effort and catch weight for all retained species. This would usually be supplemented with representative length and age data for the primary commercial species. Haddon et al. (2013) note that additional minimum data standards could then apply to some fisheries depending on their scale and likely level of ecological impact, to allow the impacts of fishing on secondary stocks, minor byproduct species and the ecosystem to be evaluated. Determination of which fisheries these additional requirements would apply to could be based on the value of the fishery, the volume of landings in the fishery and/or the overall ecological footprint of the fishery. This could be determined using risk assessments or on a case-by-case basis using the steps described in Dichmont et al. (2013). How this is dealt with should form part of the guidance provided on implementation of a broadened tiered approach to stock assessment and harvest strategy development.

The minimum data requirements for each assessment tier have direct costs for data collection, storage and analysis. Each assessment tier also has a particular level of uncertainty, with higher information assessments providing higher certainty and lower risk compared to low-information assessments. There is, therefore, a direct risk-cost-catch trade-off associated with a decision to assess and manage a particular stock at a particular assessment tier level. Higher information tiers are more expensive, but have lower risk and so permit higher fishing intensity and potentially higher catches (Figure 4). An FRDC-funded project (2012/202) on ‘Operationalising the risk cost catch trade-off’, which began in July 2012 at the Commonwealth Scientific and Industrial Research Organisation and is due to finish in June 2014, will provide advice on practical application of this risk-cost-catch trade-off when selecting assessment tiers for particular stocks.

Whether assessments are conducted using ERA or analytical assessment tiers, there are potentially two options for a management response to indications of high risk: 1) move to a more data rich and certain method, and test if this risk still remains; or 2) mitigate this risk through precautionary management action. Haddon et al. (2013) note that development work to date has tended to focus on data-rich approaches, with less guidance provided on appropriate risk mitigation under data-poor circumstances. However, the assumption that moving to a more data-rich approach is a better way of addressing risk assumes that the necessary resources will be provided for additional data collection and analysis. This is not affordable for all stocks and so a funding model is required that provides optimal balance between the option to demonstrate that low-information harvest strategies are effective (through MSE testing) and the option to collect additional data to support more complex assessments.

Figure 4 Schematic of unacceptable catch-cost combinations and the spectrum of acceptable risk combinations extending from high catch-high cost to low catch-low cost



Data source: Sainsbury (2005)

Application of discount factors

As a direct result of the increasing uncertainty associated with lower information assessment tiers, there is associated increased risk for these assessments. To meet the objectives of the Commonwealth Fisheries Harvest Strategy Policy across all of the tiers consistently, some process is required to ensure that risk remains comparable across the tiers. This has been addressed in the SESSF by applying discount factors to the total allowable catches (TACs) for stocks assessed using lower information assessments. A 5 per cent discount is applied to the TACs derived from catch curve (Tier 3) methods and a 15 per cent discount is applied to the TACs from CPUE trend (Tier 4) methods. However, these discount factors were essentially arbitrarily chosen and it is likely that the appropriate discount factors should differ for different species. These discounts are also not applied consistently, and may be waived if, in the opinion of the SESSF RAGs, other factors (such as spatial closures) are reducing risk to the extent that discounts are no longer necessary. More importantly, the effectiveness of these discounts in reducing risk to comparable levels has not been MSE tested.

The principle of not applying discounts where other factors have reduced the risk adequately is sound, but further guidance is required on what might constitute adequate grounds for waiving the agreed discounts. The more appropriate approach would be to develop appropriate harvest strategies for each assessment tier level that directly compensates for the increased uncertainty in lower information assessments. Additional discount factors should then not be necessary. If discounts are to be used, then the effect of these discount factors in reducing risk should be tested and demonstrated using MSE approaches, to show that management objectives will be achieved and that the risk of breaching limits remains comparable across the tiers.

Multiyear total allowable catches

The initial approach taken to setting TACs after adoption of the Commonwealth Fisheries Harvest Strategy Policy was to set TACs for each species on an annual basis. This created the requirement that each species under a TAC be re-assessed annually. Since then, budget and time constraints have increasingly resulted in the need to prioritise and stagger stock assessments, and not to conduct these annually for all species. This, in turn, means that revised advice on recommended biological catches will not be available every year. Under such circumstances, fishery managers need to decide whether to simply retain TACs at their existing levels, or to apply some level of TAC decrease to compensate for the increased uncertainty in stock status as time elapses since the last assessment.

The latter option is explicitly applied, for example, in the harvest strategy for the Small Pelagic Fishery (SPF), under which the SPF version of a Tier 1 approach requires a biomass estimate from daily egg production method (DEPM) surveys, plus age and length frequency data. Harvest strategy rules limit harvest to a maximum catch of 20 per cent of the best Tier 1 biomass estimate, with provision for a discount of 2.5 per cent in this maximum for each year after a DEPM assessment is not undertaken. After 5 years without a DEPM survey, the stock reverts to a Tier 2, with a maximum catch of 7.5 per cent of the best biomass estimate.

Provided that risk is not increased as a result, there are benefits to setting multiyear TACs. Doing away with the need to conduct annual assessments results in cost savings and allows available time and resources to be dedicated to assessments of fewer stocks on a rotational basis. Whether resulting TACs are fixed or determined for a number of years ahead, multiyear TACs result in greater certainty and stability for the industry. In general, multiyear TACs require a discount of some level of catch to balance the greater risk associated with less frequent review and adjustment.

The effect of setting of multiyear TACs has not been subject to formal MSE and no decisions have yet been made about how best to set multiyear TACs. Haddon et al. (2013) note that this is offset to some extent by the adoption of break-out rules to trigger a re-assessment if some indicator of stock status goes outside expected 'safe' ranges of some monitored performance indicator. However, the effectiveness of these breakout rules in triggering a response that prevents increased risk have also not been MSE tested, and rules are currently set rather arbitrarily on a case-by-case basis. The exploration of the risk-cost-catch trade-off currently under way in a FRDC project should evaluate the different options for setting multiyear TACs and should provide insights on whether multiyear TACs should always be reduced below single year TACs to reduce the risk of overfishing.

Rebuilding strategies

Stocks that have declined to below the B_{LIM} limit reference point (more correctly, that can be shown to have a > 10 per cent probability of having declined to below B_{LIM}), need to placed under a rebuilding strategy to rebuild the stock towards B_{TARG}. Targeted commercial fishing of such stocks should cease until they have recovered to above B_{LIM}. Although this is not explicitly stated, this should be interpreted as requiring that targeted fishing not be permitted until there is a 90 per cent probability that stocks have recovered to above B_{LIM}. Rebuilding strategies have been implemented for four species that were depleted before implementation of the harvest strategy policy: orange roughy, eastern gemfish, school shark and blue warehou. The latter three of these species have so far not shown clear evidence of rebuilding.

In terms of timeframes for rebuilding, the policy states that 'typically recovery times are defined as the minimum of 1) the mean generation time plus ten years, or 2) three times the mean generation time' (DAFF 2007). Haddon et al. (2013) note that there has been some debate about the scientific basis for these timeframes, and whether this statement pertains to the timeframe for moving the stock to above B_{LIM} or to B_{TARG}. Attempting to meet these recovery timeframes has been problematic for these three stocks.

Depleted species may be subject to general productivity declines. The failure of the northern cod fishery to recover is currently considered to have been exacerbated by a decline in the productivity of the stock, such that recovery, if it ever happens, is not presently predictable. Haddon et al. (2013) note that some low-productivity species, particularly if they are fished as a group of mixed species (such as gulper sharks), may be reduced to such low levels that the probability of them recovering is impacted by random environmental events that result in poor recruitment, even at low F levels. Recent work has shown that depleted stocks may suffer a substantial loss of resilience, with recovery being far slower than predicted from assessments of productivity of the nondepleted stock (Neubauer et al. 2013)

Feasible recovery timeframes to any particular recovery target are therefore dependent on species productivity. Different species will have different feasible recovery timeframes, establishing the need to base these on estimates of life span, and preferably on estimates of T_{min}—the minimum time to recovery under zero fishing mortality. If species productivity changes, then recovery potential will also change and so, provided these productivity changes can be detected, this approach would automatically compensate for productivity shifts, such as is considered to have happened for jackass morwong. If overfishing of a stock to below B_{LIM} does result in reduced productivity (as a result of spawning depensation), then estimates of T_{min} and recovery timeframes will change. This provides further support for the use of dynamic targets which, together with T_{min}-related recovery schedules, will result in recovery timeframes being able to be adjusted to compensate for detected changes in productivity.

Haddon et al. (2013) note that different countries have different rebuilding requirements and timeframes. The New Zealand approach is designed to adjust rebuilding timeframes in direct response to the biological productivity of different species, basing recovery on T_{min}, the minimum possible time to recovery under zero fishing mortality. The New Zealand Harvest Strategy Standard states:

> Where the probability that a stock is at or below the soft limit [$0.2B_0$] is greater than 50 per cent, the stock should be rebuilt to the target [$0.4B_0$] within a time period between T_{min} and $2 \times T_{min}$ (where T_{min} is the theoretical number of years required to rebuild a stock to the target with zero fishing mortality). (Ministry of Fisheries 2008)

The United States has a similar T_{MIN}-related approach:

> The maximum rebuilding period, T_{max}, should be 10 years, unless T_{min} (the expected time to rebuilding under zero fishing mortality) is greater than 10 years, when T_{max} should be equal to T_{min} plus one mean generation time. (Restrepo et al. 1998)

Australia's approach of ten years plus the mean generation does not account for variable recruitment and the possible relationship between spawning biomass and recruitment, whereby low biomass can result in reduced recruitment (Myers & Barrowman 1996). There are some depleted species in Australia (such as Eastern gemfish) that, given the previous variation inferred from the Tier 1 assessment, would not be expected to recover in a maximum of 10 years plus the mean generation time. The New Zealand approach therefore appears to be more appropriate, allowing for longer recovery timeframes that are biologically feasible, while allowing for some level of fishing mortality while the stock rebuilds.

The Commonwealth Fisheries Harvest Strategy Policy also does not explicitly require that harvest strategies impose a zero catch limit on stocks below B_{LIM}. Some of these species (notably school shark) are unavoidably caught as bycatch in multispecies fisheries. Incidental catch allowances are usually still provided for species under rebuilding strategies, set at the estimated level of 'unavoidable bycatch', in recent years including discards. These incidental bycatches would certainly be expected to delay recovery and may in fact exceed the annual sustainable yield levels of a depleted resource, potentially preventing recovery. Haddon et al. (2013) note that recent assessments and projections suggest that the total fishing mortality for eastern gemfish, school shark and blue warehou has not been reduced sufficiently to allow rebuilding within the specified timeframes.

Haddon et al. (2013) consider that there may be some lack of clarity in the policy about rebuilding targets, and whether an overfished stock must be rebuilt to B_{MSY} before targeted fishing can recommence. However, it appears to be clear in the policy that targeted fishing may restart once a stock has been rebuilt to above B_{LIM}, provided this is conducted under a harvest strategy that continues to rebuild the stock towards B_{TARG}. The policy is clear about the targets for rebuilding, stating that 'for a stock below B_{LIM}, a stock rebuilding strategy will be developed to rebuild the stock to B_{TARG}. Once such a stock is above B_{LIM} it may be appropriate for targeted fishing to re-commence in-line with the stock rebuilding strategy and harvest strategy' (DAFF 2007).

There may be a question as to whether targeted fishing can occur on conservation-dependent species when they have been rebuilt to above B_{LIM}. This may require clarification from those administering the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth). Haddon et al. (2013) also ask whether there is a requirement to rebuild secondary species to a B_{MEY} target. The policy would also seem to be clear on this aspect. B_{LIM} limits would still apply to secondary species and initial rebuilding would have to be to above B_{LIM}. After that, if a secondary species is being managed to an alternative target below B_{MEY}, then rebuilding should continue under a harvest strategy towards that alternative target.

In a review of internal best practices, McIlgorm (2012) notes that the United States, which has formal legislated species recovery plans, appears to have one of the best records of stock recovery (Wakeford et al. 2009).

Reduction of discards

International best practice aims to achieve zero fishery discards by either legislating for this, or by implementing a system whereby fishers are required to land all quota species and to deduct these catches off quota, or to pay a predetermined 'deemed value' (such as is applied in New Zealand) for catches in excess of the TAC (McIlgorm 2012). One of the complicating factors that has reduced the ability to monitor rebuilding of depleted stocks is poor estimates of discards for stocks subject to rebuilding plans, and for which targeted fishing has been prevented. Reduced information on discard rates can mask any recovery that may be occurring.

An unintended problem that arises from implementation of rebuilding strategies and preventing targeted fishing is that, under cost recovery, it becomes difficult to fund research on fisheries for which directed commercial activity has ceased. It is not clear how the necessary additional work to demonstrate that recovery is occurring should be funded. McIlgorm (2012) concludes that the Commonwealth Fisheries Harvest Strategy Policy could benefit from revisions to make stock rebuilding plans more effective, including consideration of active measures to reduce discards.

Spatial management

Haddon et al. (2013) note that spatial management can be incorporated into fisheries management approaches in various ways. Spatial management can form the main harvest strategy framework (such as in a system of rotational closures), be used to augment a harvest strategy framework or be invoked under a control rule. For some resident or slowly dispersing species, a system of spatial or temporal fishery closures can be more robust to uncertainty than control of catch, since only a component of the stock is exposed to the fishery. Spatial management may therefore be a cost-effective approach in the absence of other information required to inform other management measures.

Closed areas may be used to augment a harvest strategy in the face of uncertainty (Dowling et al. 2008a,b) or when a fishery interacts with highly vulnerable species that occur in limited identifiable areas. Closures can be permanent or implemented under a control rule in response to trigger levels being reached for vulnerable species interactions. Alternatively, similar protection under uncertainty could be achieved using 'move on' provisions, again triggered by predefined trigger catch levels. Rotational spatial management can form part of harvest strategies, using control rules to determine which areas to open or close to fishing during a given period, thereby maintaining a level of stock protection in each area and avoiding the breaching of biomass limit reference points.

Haddon et al. (2013) note that differences in fish density within and outside marine protected areas (MPAs) could be used to evaluate the relative status of stocks or portions of stocks outside MPAs. Such approaches are potentially applicable to fisheries targeting near-shore rocky reef species that exhibit spatial variation, limiting traditional stock assessment approaches. For example, McGilliard et al. (2011) used the ratio of the density of fish inside and outside an MPA in a control rule to recommend the fishing effort level for the next year. Such approaches should be MSE tested to evaluate the performance of the density ratio under different productivity and fish-movement scenarios, to optimise long-term cumulative catch.

Barnes and Sidhu (submitted), using a variety of modelling approaches, conclude that the main benefits of closures for fisheries are reliable (rather than increased) yields and an effective safeguard against uncertainty. While total yield is likely to be similar to the yield without closed areas, there are advantages in regular replenishment and faster recovery. Closed areas can generate improved longer term yield when stocks are severely depleted, providing benefits in terms of conservation and improved yield. These results support the earlier conclusions by Lauck et al. (1998), who stated that closed areas may be the simplest means of implementing the precautionary principle and achieving sustainability, particularly where there is uncertainty regarding stock status.

In all the above cases, further guidance is needed in the Commonwealth Fisheries Harvest Strategy Policy on evaluating the effects of closures in protecting resources inside the closed areas, and on how management of stocks outside the closed areas may need to be revised to take account of the effects of closures.

Ecosystem-based fisheries management

The current Harvest Strategy Policy was not intended to meet Australia's international undertakings to implement an ecosystem approach to fisheries under the Convention for Biodiversity (UN 1992) or the FAO Code of Conduct for Responsible Fisheries (FAO 1995) and associated guidelines, and so the scope of the policy does not extend to ecosystem-based fisheries management (EBFM). However, in his review of international best practices relating to harvest strategy policies, McIlgorm (2012) does make some observations and recommendations regarding ecosystem approaches to fisheries management, and so these are summarised here.

McIlgorm (2012) notes that there are several recent international ecosystem and environmental monitoring and management trends that have surpassed the Commonwealth Fisheries Harvest Strategy Policy. For example, the European Union (EU) has explicitly included biodiversity and trophic measures under a broader marine agency environmental approach of the Marine Strategy Framework Directive. It appears that the EU intends to address impacts on nontarget species, bycatch, discards, stock structure and environmental impacts on trophic relationships more fully during the next decade.

These international trends suggest there will be a greater emphasis on the marine ecosystem, biodiversity and trophic functioning in the future. (McIlgorm 2012) notes that, within Australian fisheries, there is a multiagency approach to environmental issues and this requires a wider whole-of-government policy incorporating broader ecosystem objectives to address EBFM. Further progress on wider environmental and ecosystem management will require clarification of the role of the policy in an Australian whole-of-government approach to the ecosystem attitude to fisheries.

Issues identified by the implementation review

The supporting technical review report, *A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy* (Ward et al. 2013), identifies key issues and problems that have arisen during efforts to develop and implement harvest strategies since the adoption of the policy. These are summarised in Table 1, extracted from that report.

Table 1 Key issues and problems since the adoption of the Commonwealth Fisheries Harvest Strategy Policy

Successes	**Issues**
Reference points and indicators	
Bioeconomic models have been used to estimate B_{MEY} for six stocks.	Most harvest strategies use the policy's proxies for target reference points.
Fishery-wide MEY has been estimated for two fisheries.	Fishery-wide MEY has not been estimated for most Commonwealth fisheries.
Most harvest strategies use the Commonwealth Fisheries Harvest Strategy Policy's proxies for reference points.	The default proxies may not be appropriate for all species, particularly not for low-productivity species and important forage fish. Several harvest strategies do not have target and/or limit reference points. Harvest strategies for several low-value and data-poor fisheries have triggers instead of reference points because it has been difficult to identify meaningful reference points. The correct levels of triggers are largely unknown and have not been MSE tested. The assessments and management actions that are triggered may not be feasible within an appropriate timeframe.
Apparent changes in productivity have resulted in revised reference points for one species (jackass morwong).	For most species, reference points are fixed; they do not reflect the non-equilibrium nature of fish populations or environmentally induced changes in productivity.
Data and assessment	

Successes	**Issues**
Many stocks are assessed with quantitative models, which integrate a variety of data.	Many assessments rely on CPUE reported by commercial vessels. They assume that CPUE is a reliable index of stock biomass They assume that the reference period represents BMEY. These assumptions may not be valid for some stocks.
Control rules and TACs	
Multiyear TACs have reduced assessment costs and provided industry with stability and certainty about short-term catch levels.	Some multiyear TACs do not take into account the increasing uncertainty in stock status with time since the last assessment, or have not been MSE tested.
Several harvest strategies have attempted to deal with the effects of spatial closures implemented for other reasons.	The policy provides little guidance on the treatment of the effects of marine reserves and other closures on existing harvest strategies. It has been difficult to identify meaningful reference points for spatially structured species.
Management strategy evaluation and testing	
MSE testing has demonstrated that harvest strategies are robust to uncertainty in valuable fisheries for which adequate data exist to allow stock assessments.	Insufficient information has precluded testing of the harvest strategies of several small fisheries and data-poor stocks. Most of the testing has been generic rather than species specific.
Application	
Harvest strategies have been implemented for all quota species and key commercial species in all active Commonwealth fisheries.	Harvest strategies for small fisheries and data-poor fisheries are often rudimentary or are not routinely run. Harvest strategies have not been implemented for a few significant commercial species that are currently considered to be byproduct species (e.g. ocean jacket). Several stocks and several species are assessed and managed as multistock 'baskets'.
Many fisheries have established routine processes for assessing stocks and running harvest strategies.	Delays or reductions in data acquisition, processing and assessment have contributed to uncertainty in stock status for some stocks.
Harvest strategies have attempted to take into account fishing mortality from all sources.	For several species, and in the absence of catch-sharing arrangements, increasing state catches have been deducted from recommended biological catches, and the TAC available to Commonwealth fisheries has been reduced.
	For several species, reliable estimates have not been available for significant sources of mortality, particularly recreational catches and discards.
Australia's domestic policy settings have been advocated at several RFMOs.	There may be politically driven delays within regional fisheries management organisations to adopt approaches to fishery management that are consistent with the Commonwealth Fisheries Harvest Strategy Policy.
Harvest strategies have been implemented for the domestic components of several international stocks.	Harvest strategies have not been used to set TACs for the domestic component of two Eastern Tuna and Billfish Fishery stocks (yellowfin tuna and bigeye tuna) because of uncertainty about stock connectivity. For these stocks, TACs have been set based on historical catch levels.
Fishery performance	

Successes	Issues
Harvest strategies have prevented many stocks from becoming overfished.	The contribution of harvest strategies to stock status is difficult to separate from other factors, such as effort reductions as a result of structural adjustment. Several stocks have failed to rebuild because: targeted fishing may have continued fishing mortality from incidental catches may have hampered rebuilding changes in the stock's productivity or ecosystem changes may have reduced productivity rebuilding timeframes may have been too optimistic.
The economic performance of many of the main Commonwealth fisheries has improved as a result of harvest strategies.	The economic performance of several fisheries is uncertain or cannot be evaluated due to a lack of the required economic data.
	The contribution of harvest strategies to improved economic performance is difficult to separate from other factors.

Note: CPUE = catch-per-unit effort; MEY = maximum economic yield; MSE = management strategy evaluation; MSY = maximum sustainable yield; TAC = total allowable catch

Source: Ward et al. (2013)

Future research

There are already a number of FRDC-funded research projects under way that are expected to provide results and conclusions that will be useful to the Commonwealth Fisheries Harvest Strategy Policy review. Several of these projects have started only recently, but they are likely to generate outputs of relevance to future improvement of the policy and guidelines:

- ***The risk-cost-catch trade-off***. FRDC project 2012/202, 'Operationalising the risk-cost-catch trade-off'.
- ***The influence of closures on the harvest strategy policy***. FRDC project 2011/032, 'Incorporating the effects of marine spatial closures in risk assessments and fisheries stock assessments'.
- ***The management of byproduct species***. FRDC project 2011/028, 'Development of robust methods to estimate acceptable levels of incidental catches of different commercial and byproduct species'.
- ***Proxy measures for MEY in multispecies fisheries***. FRDC project 2011/200, *'Setting economic target reference points for multiple species in mixed fisheries*'.

Additional useful work identified as a result of this review includes:

- ***Multiyear TACs***. While some criteria have been drafted for selecting those species deemed suitable for multiyear TACs, these have yet to be tested formally using MSE.
- ***Alternative data-poor harvest strategies***. For the major mixed fisheries, it would be valuable to conduct research to devise or recommend further data-poor stock assessment methods and harvest strategies to improve the management of such fisheries.

Acronyms and abbreviations

ABARES	**Australian Bureau of Agricultural and Resource Economics and Sciences**
B	stock biomass
B_0	unfished stock biomass
B_{LIM}	minimum stock biomass limit reference point, below which reproduction is likely to be impaired and the stock is considered to be overfished
B_{MEY}	stock biomass producing maximum economic yield
B_{MSY}	stock biomass producing maximum sustainable yield
CPUE	catch-per-unit effort
DAFF	Australian Government Department of Agriculture, Fisheries and Forestry
ERA	ecological risk assessment
F	fishing mortality rate
M	natural mortality rate
MEY	maximum economic yield
MSE	management strategy evaluation
MSY	maximum sustainable yield
RBC	recommended biological catch
SESSF	Southern and Eastern Scalefish and Shark Fishery
TAC	total allowable catch

References

Barnes, B & Sidhu, H (submitted), 'The impact of marine closed areas on fishing yield under a variety of management strategies and stock depletion levels', *Ecological Modelling*.

Brooks, EN, Powers, J & Corte´s, E 2010, 'Analytical reference points for age-structured models: application to data-poor fisheries', *ICES Journal of Marine Science*, vol. 67, pp. 165–175.

Cadima, LE 2003, 'Biological reference points and regulation measures', in Fish stock assessment manual, *FAO Fisheries Technical Paper*, vol. 393, pp. 53–66.

Cadrin, SX, Boutillier, JA & Idoine, JS 2004, 'A hierarchical approach to determining reference points for Pandalid shrimp', *Canadian Journal of Fisheries and Aquatic Sciences,* vol. 61, no. 8, pp. 1373–1391.

Cadrin, SX & Pastoors, MA 2008, 'Precautionary harvest policies and the uncertainty paradox', *Fisheries Research*, vol. 94, no. 3, pp. 367–372.

DAFF 2000, Commonwealth Policy on Fisheries Bycatch, Department of Agriculture Fisheries and Forestry, Canberra. www.daff.gov.au/__data/assets/pdf_file/0016/5812/bycatch.pdf

—— 2007, Commonwealth Fisheries Harvest Strategy: policy and guidelines, Australian Government Department of Agriculture Fisheries and Forestry, Canberra. www.daff.gov.au/fisheries/domestic/harvest_strategy_policy

—— 2012, Report of the stakeholder workshop on the review of the Commonwealth Policy on Fisheries Bycatch, Department of Agriculture, Fisheries and Forestry, Canberra.

Defeo, O & Seijo, CJ 1999, 'Yield-mortality models: a precautionary bioeconomic approach', Fisheries Research, vol. 40, no. 1, pp. 7–16.

DFO 2012, 'Guidance related to bycatch and discards in Canadian commercial fisheries,' Canadian Science Advisory Secretariat Science Advisory Report, 2012/022.

Dichmont, CM, Dowling, NA, Smith, ADM, Power, D, Smith DC & Galeano, D 2013, Designing information requirements for the management of Commonwealth fisheries, CSIRO, Brisbane.

Dowling, NA, Smith, DC, Knuckey, I, Smith, ADM, Domaschenz, P, Patterson, HM & Whitelaw, W 2008a, 'Developing harvest strategies for low-value and data-poor fisheries: case studies from three Australian fisheries', Fisheries Research, vol. 94, pp. 380–390.

Dowling, NA, Smith, DC & Smith, ADM 2008b, Finalisation of harvest strategies for AFMA's small fisheries, final report for Project 2007/834 to the Australian Fisheries Management Authority, Canberra.

Dowling, NA, Dichmont, CM, Venables, W, Smith, ADM, Smith, DC, Power, D & Galeano, D 2013, 'From low- to high-value fisheries: is it possible to quantify the trade-off between management cost, risk and catch?' *Marine Policy*, vol. 40, pp. 41–52.

FAO 1995, Code of Conduct for Responsible Fisheries, Food and Agriculture Organization of the United Nations, Rome.

FAO 2001, BAYES-SA: Bayesian stock assessment methods in fisheries management—user manual, Computerized Information Series, Food and Agriculture Organization of the United Nations, Rome. www.fao.org/docrep/005/Y1958E/y1958e00.htm

Haddon, M 2011, Management strategy evaluation testing of the management strategies used with south-eastern scallop fisheries, report prepared for the Australian Government Department of Agriculture, Fisheries and Forestry as part of the Reducing Uncertainty in Stock Status project, CSIRO Wealth from Oceans Flagship, Hobart.

Haddon, M 2012, Reducing uncertainty in stock status: harvest strategy testing, evaluation, and development. General discussion and summary, CSIRO report as part of the Reducing Uncertainty in Stock Status (RUSS) project, CSIRO.

Haddon, M, Klaer, N, Smith, DC, Dichmont, CD & Smith, ADM 2013, Technical reviews for the Commonwealth Fisheries Harvest Strategy Policy, CSIRO, Hobart.

Hobday, AJ, Smith, ADM, Stobutzki, IC, Bulman, C, Daley, R, Dambacher, JM, Deng, RA, Dowdney, J, Fuller, M, Furlani, D, Griffiths, SP, Johnson, D, Kenyon, R, Knuckey, IA, Ling, SD, Pitcher, R, Sainsbury, KJ, Sporcic, M, Smith, T, Turnbull, C, Walker, TI, Wayte, SE, Webb, H, Williams, A, Wise, BS & Zhou, S 2011, 'Ecological risk assessment for the effects of fishing', Fisheries Research, vol. 108, pp. 372–384.

ICES 1997, Report of the Comprehensive Fishery Evaluation Working Group, Copenhagen, 25 June – 4 July 1997, International Council for the Exploration of the Sea CM 1997/ASSESS, p. 15.

Kirby, D, Penney, AJ & Cheshire, K 2013, Risk-based approaches, reference points and decisions rules for managing fisheries bycatch and byproduct species, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Klaer, NL, Wayte, SE & Fay, G 2012, 'An evaluation of the performance of a harvest strategy that uses an average-length-based assessment method', Fisheries Research, vol. 134–136, pp. 42–51.

Lauck, T, Clark, C, Mangel, M & Munro, GR 1998, 'Implementing the precautionary principle in fisheries management through marine reserves', Ecological Applications, vol. 8, pp. S72–S78.

Little, LR, Wayte, SE, Tuck, GN, Smith, ADM, Klaer, N, Haddon, M, Punt, AE, Thomson, R, Day, J & Fuller, M 2011, 'Development and evaluation of a cpue-based harvest control rule for the southern and eastern scalefish and shark fishery of Australia', ICES Journal of Marine Science, vol. 68, pp. 1699–1705.

Mace, PM 2001, 'A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management', Fish and Fisheries, vol. 2, pp. 2–32.

McGilliard, CR, Hilborn, R, MacCall, A, Punt, AE & Field, JC 2011, 'Can information from marine protected areas be used to inform control-rule-based management of small-scale, data-poor stocks?,' ICES Journal of Marine Science, vol. 68, no. 1, pp. 201–211.

McIlgorm, A 2012, Literature study and review of international best practice in fisheries harvest strategy policy approaches, Australian National Centre for Ocean Resources and Security, University of Wollongong.

Ministry for Primary Industries 2012a, Stock assessments and yield estimates. Part 1: Introductory sections to jack mackerel, report from the Fisheries Assessment Plenary May 2012, Government of New Zealand, Auckland.

Ministry for Primary Industries 2012b, Stock assessments and yield estimates, Fisheries Assessment Plenary November 2012, Government of New Zealand, Auckland.

Ministry of Fisheries 2008, Harvest Strategy Standard for New Zealand fisheries, Government of New Zealand, Auckland.

Morison, AK, Knuckey, IA, Simpfendorfer, CA & Buckworth, RC 2013, South East Scalefish and Shark Fishery: draft 2012 stock assessment summaries for species assessed by GABRAG, ShelfRAG and Slope/DeepRAG, report for the Australian Fisheries Management Authority, Canberra.

Musick, JA 1999, 'Criteria to define extinction risk in marine fishes', *Fisheries*, vol. 24, pp. 6–14.

Myers, RA & Barrowman, N 1996,' Is fish recruitment related to spawner abundance?,' Fisheries Bulletin, vol. 94, pp. 707–724

Neubauer, P, Jensen, OP, Hutchings, JA & Baum, JK 2013, 'Resilience and recovery of overexploited marine populations', Science, vol. 340, pp. 347–349.

Pikitch, E, Boersma, PD, Boyd, IL, Conover, DO, Cury, P, Essington, T, Heppell, SS, Houde, ED, Mangel, M, Pauly, D, Plagányi, É, Sainsbury, K & Steneck, RS 2012, Little fish, big impact: managing a crucial link in ocean food webs, Lenfest Ocean Program, Washington, DC.

Punt, AE, Smith, ADM, Smith, DC, Tuck, GN & Klaer, NL in press, 'On the use of BMSY and BMEY as reference points: selecting proxy target biomass levels to achieve pretty good yield and pretty good profit', *Fish and Fisheries*.

Restrepo, V R, Thompson, GG, Mace, PM, Gabriel, WL Low, LL, Mac-Call, AD, Methot, RD, Powers, JE, Taylor, BL, Wade, PR & Witzig JF 1998, Technical guidance on the use of precautionary approaches to implementing national standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act, *NOAA Technical Memorandum* NMFS-F/SPO-31, US Department of Commerce, Washington, DC.

Sainsbury, K 2005, Cost-effective management of uncertainty in fisheries, ABARES 2005 Outlook Conference paper, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Sainsbury, K 2008, Best practice reference points for Australian fisheries, report R2001/0999 to the Australian Fisheries Management Authority & the Department of the Environment and Heritage, AFMA, Canberra. www.afma.gov.au/wp-content/uploads/2010/06/R2001-0999.pdf

Scandol, JP 2003, 'Use of cumulative sum (CUSUM) control charts of landed catch in the management of fisheries', Fisheries Research, vol. 64, pp. 19–36.

Scandol, JP 2005, 'Use of quality control methods to monitor the status of fish stocks', *Fisheries Assessment and Management in Data-Limited Situations,* vol. 1, pp. 213–233.

Smith, ADM, Brown, CJ, Bulman, CM, Fulton, EA, Johnson, P, Kaplan, IC, Lozano-Montes, H, Mackinson, S, Marzloff, M, Shannon, LJ, Shin, Y-J & Tam, J 2011, 'Impacts of fishing low trophic level species', Science, vol. 333, no. 6046, pp. 1147–1150.

Smith, ADM, Smith, DC, Tuck, GN, Klaer, N, Punt, AE, Knuckey, I, Prince, J, Morison, A, Kloser, R, Haddon, M, Wayte, S, Day, J, Fay, G, Pribac, F, Fuller, M, Taylor, B & Little, LR 2008, 'Experience in implementing harvest strategies in Australia's south-eastern fisheries', *Fisheries Research*, vol. 94, no. 3, pp. 373–379.SPRFMO 2012, Report of the Jack Mackerel Sub-Group, in Report of the 11th Science Working Group meeting, Lima, Peru, 15–19 October 2012, South Pacific Regional Fisheries Management Organisation, Wellington New Zealand.

Thorston, JT, Cope, JM, Branch, TA & Jensen, OP 2012, 'Spawning biomass reference points for exploited marine fishes, incorporating taxonomic and body size information', *Canadian Journal of Fisheries and Aquatic Sciences,* vol. 9, pp. 1556–1568.

UN 1982, United Nations Convention on the Law of the Sea, United Nations, New York. www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm

—— 1992, Convention on Biological Diversity, United Nations, New York. www.cbd.int/convention/text/

—— 1995, The United Nations Agreement for the implementation of the provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks, United Nations, New York.
www.un.org/Depts/los/convention_agreements/convention_overview_fish_stocks.htm

Vieira, S & Pascoe, S 2013, Technical reviews for the Commonwealth Harvest Strategy Policy: economic issues, Australian Bureau of Agricultural and Resource Economics and Sciences & CSIRO, Canberra.

Vieira, S, Hormis, M, Penney, AJ & Woodhams, J in preparation, Setting target reference points for secondary species in the SESSF, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Wakeford, RC, Agnew, DJ & Mees, CC 2009, 'Review of institutional arrangements and evaluation of factors associated with successful stock recovery plans', Reviews in Fisheries Science, vol. 17, no. 2, pp. 190–222

Ward, P, Marton, N, Moore, A, Patterson, H, Penney, A, Sahlqvist, P, Skirtun, M, Stephan, M, Vieira, S & Woodhams, J 2013, A technical review of the implementation of the Commonwealth Fisheries Harvest Strategy Policy, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Wayte, SE 2012, 'Management implications of including a climate-induced recruitment shift in the stock assessment for the jackass morwong (*Nemadactylus macropterus*) in south-eastern Australia', Fisheries Research, vol. 142, pp. 47–55.

Zhou, S, Pascoe, S, Dowling, N, Haddon, M, Klaer, N, Larcombe, J, Smith, ADM, Thebaud, O & Vieira, S 2013, Quantitatively defining biological and economic reference points in data poor and data limited fisheries, final draft report on FRDC project 2010/044, Fisheries Research and Development Corporation, Canberra.

Zhou, S, Yin, S, Thorson, JT, Smith ADM & Fuller, M 2012, 'Linking fishing mortality reference points to life history traits: an empirical study', Canadian Journal of Fisheries and Aquatic Sciences, vol. 69, pp. 1292–1301.

Appendix A. Intellectual Property

The information compiled by this project is published, widely disseminated and promoted. There is no need to protect intellectual property beyond the Australian Government's standard copyright that applies to the project's report and other outputs.

Appendix B. Staff

Name	Organisation
Andrew Penney	ABARES
David Ward	ABARES
Simon Vieira	ABARES

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

YOUR CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

FOR FURTHER INFORMATION

Wealth from Oceans
Malcolm Haddon
t +61 3 6232 5097
e Malcolm.Haddon@csiro.au
w www.csiro.au/

Distribution list for FRDC Final Report

Title: Technical Reviews of Formal Harvest Strategies
FRDC Report No: 2012-225-DLD

The Librarian,
CSIRO Division of Marine Research
GPO Box 1538
Hobart
Tasmania 7001

The National Library of Australia,
Legal Deposit Unit,
Canberra
ACT 2600

Legal Deposit Officer
State Library of Tasmania
91 Murray Street
Hobart
Tas 7000

The Librarian,
WA Fisheries and Marine Research Laboratories,
39 Northside Drive,
Hillarys,
PO Box 20,
North Beach
Western Australia 6920,
Australia

The Librarian,
SARDI, South Australia Aquatic Sciences Centre,
P.O. Box 120
Henley Beach,
South Australia 5022

The Librarian,
AIMS, Australian Institute of Marine Science,
PMB 3,
Townsville MC,
Townsville,
Queensland 4810
Australia

Groups or individuals specified as beneficiaries in the application and other interested parties.

COM FRAB John Glaister via Yvonne Zunic,

AFMA,
P.O. Box 7051,
Canberra MC,
Canberra,
ACT 2610.

NSW FRAB
Peter Dundas-Smith via Rhonda Farlow,
51-55 River Street,
Maclean,
NSW, 2463

NT FRAB
Ian Curnow via Dick Slack-Smith,
Fisheries Group,
GPO Box 3000,
Darwin,
NT 0801

QLD FRAB
James Fogarty via Tom Roberts,
DAFF (Queensland),
GPO Box 46,
Brisbane,
QLD 4001

SA FRAB
Catherine Cooper via Kylie Leppa,
Executive Officer
SA Research Advisory Committee,
14th Floor, 25 Grenfell Street,
Adelaide,
SA 5000

TAS FRAB
Ian Cartwright via Gail Richardson,
IMAS,
Taroona,
Private Bag 49,
Hobart,
Tas 7001

VIC FRAB
Peter Rankin via Ashley Oliver,
Seafood Industry Victoria,
Office 14, Melbourne Seafood Centre,
133 Kensington Road,
West Melbourne,
VIC 3003

WA FRAB
Guy Leyland via Neil MacGuffie,
Western Australian Fishing Industry Council,
P.O. Box 55,
Mount Hawthorn,
WA 6915

Dr Ilona Stobutzki
Fisheries & Quantitative Sciences Branch
ABARES
GPO Box 1563
Canberra
ACT 2601

Dr Cathy Dichmont
CSIRO Division of Marine and Atmospheric Research
Ecosciences Precinct,
GPO Box 2583,
Brisbane,
QLD 4001

Dr Sandy Morison
28 Wallaby Way
Horseshoe Bay,
Qld 4819