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Experience in implementing harvest strategies in Australia's south-eastern fisheries

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ABSTRACT

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a complex multi-species fishery, with 34 stock units under quota management, for which a harvest strategy framework was developed in 2005. The framework involves the application of a set of tier-based harvest control rules (HCR) designed to provide a precautionary approach to management. The harvest strategy framework has been applied from 2005 to 2007, resulting in substantial reductions in quotas across the fishery. The experience in implementing the framework, both positive and negative, is described, and general lessons are drawn. Key lessons include the importance of formally testing such strategies using management strategy evaluation, the impact of external management drivers on implementation of the approach, the need to define strategies for setting "bycatch quotas" in multi-species fisheries, and the need for flexibility and pragmatism in the early stages of implementing such an approach.

1. Introduction

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a multi-species multi-gear fishery managed by the Australian Fisheries Management Authority, AFMA (Smith and Smith, 2001). The SESSF was established under a single management plan in 2003, 18 years after various sectors of the fishery came under federal jurisdiction in 1985. As described more fully in Smith and Smith (2001), the fishery extends from sub-tropical south-east Queensland south to Tasmania and then westward to south-west Western Australia, spanning 20 degrees of latitude and 40 degrees of longitude. The fishery extends from the coast to depths in excess of 1200 m, and mainly targets demersal teleost and chondrichthyan species. Fishing methods include demersal and mid-water trawl, Danish seine, gillnet, demersal line, and trap. Apart from the quota management system, there is now a complex set of spatial management arrangements in the fishery, as well as restrictions on gear, and input controls limiting overall levels of effort (by sector). The Total Allowable Catches (TACs) for the 34 stock units in the quota management system are allocated as individual transferable quotas, and permits to fish are allocated as statutory fishing rights.

AFMA adopts a partnership approach to fishery management (Smith et al., 1999, 2001), involving stakeholders (including fishers, environmental non-government organizations, scientists and managers) in all aspects of management. This partnership approach extends to the Resource Assessment Groups (RAGs), which are the forum for review and reporting of stock assessments for all quota species. Given the size and complexity of the SESSF, there are five separate RAGs differentiated by depth (shelf, slope, deepwater), region (Great Australian Bight) and taxonomic grouping (sharks), with overall coordination provided by the SESSF RAG. The RAGs are now tasked with the calculation of the recommended biological catch (RBC) levels for each quota species, based on application of the harvest control rules (HCR) described in this paper.

Despite the introduction of a quota management system for 16 species in 1992, a number of those species remained overfished in 2005 (by which time 34 species or stock units were included in the quota management system). The Australian Bureau of Rural

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Sciences provides an annual audit of the status of stocks in Commonwealth (federally managed) fisheries. Of the 24 species listed as overfished or subject to overfishing in its 2005 report, 12 were species managed as part of the SESSF (McLoughlin, 2006).

In September 2007, the Australian federal government introduced its Harvest Strategy Policy for Commonwealth fisheries, with an implementation date of January 2008. Plans for the Policy were first announced in November 2005, as part of a government strategy for fisheries entitled "Securing our Fishing Future". Shortly prior to that announcement, the federal Minister for Fisheries had provided a Ministerial Direction to the AFMA instructing them to take immediate steps to cease overfishing and recover overfished stocks.

A comprehensive harvest strategy framework was introduced into the SESSF in 2005 (Smith et al., 2007), prior to the Ministerial Direction and to development of the Commonwealth Harvest Strategy Policy, and has been applied each year from 2005 to 2007. The framework adopts a tier-based system of assessments and associated harvest control rules that apply to all 34 units in the quota management system. This paper first outlines the harvest strategies used in the past in the SESSF, then describes the framework that was adopted in 2005, how and why it has been modified since, and the general experience in applying such a framework in the SESSF. The paper concludes by drawing general lessons about the design and application of a harvest strategy framework in a complex multi-species fishery.

2. Past harvest strategies in the SESSF

A harvest strategy is the process of setting harvest limits for a fished species and is generally considered to comprise three elements: (a) a monitoring strategy, (b) a method for assessing stock status, and (c) a decision process. All quota-managed fisheries require some form of harvest strategy to set TACs, but strategies differ in their degree of formalism, and rigour of application. A formal harvest strategy involves the application of an explicit "harvest control rule" applied to information about the current status of the resource, while a "management procedure" involves complete specification of all three elements in the harvest strategy as well as a simulation evaluation to assess the extent to which it is capable of achieving management goals. No management procedures have been adopted in Australian fisheries to date.

Prior to 2005, the harvest strategy applied in the SESSF can best be described as informal, in that while it included a fairly comprehensive monitoring and assessment process, it lacked any formal HCRs. However over the years there had been a number of attempts to introduce more formal HCRs within the fishery, and several studies designed to test prospective harvest strategies for individual species using management strategy evaluation (MSE) methods have been undertaken (Punt et al., 2001). MSE analyses were undertaken for orange roughy *Hoplostethus atlanticus* (Smith, 1993), eastern gemfish *Rexea solandrii* (Punt and Smith, 1999), school shark *Galeorhinus galeus* (Punt et al., 2005), and for a suite of shelf and slope species (Punt et al., 2002a,b,c). Although there were several attempts to introduce formal harvest strategies into the SESSF prior to 2005 (e.g. Smith and Smith, 2002), none of these were successful. The process for setting TACs remained one of occasional precaution mixed with expediency, with mixed results across species, as documented by the Australian Bureau of Rural Sciences. The lack of formal harvest control rules in this process contributed to the unacceptably high proportion of stocks that were classified as overfished or subject to overfishing. Bax et al. (2005) provide a detailed analysis of the management of orange roughy stocks in the SESSF, applying the term "delusional optimism" to the process.

3. The harvest strategy framework in the SESSF

The imperative that finally resulted in the formal adoption of harvest strategies in the SESSF arose out of the application of environmental legislation to federally managed fisheries. The Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 requires that fisheries be assessed strategically every 3–5 years against a set of sustainability criteria that broadly embrace an ecosystem approach to fisheries management. The EPBC Act has broad-ranging powers, and can, for example, prohibit the export of products from a fishery that fails its strategic assessment. The process to date has not resulted in outright failure of any fisheries, but has resulted in the federal environmental department that administers the EPBC Act (currently the Department of Environment and Water Resources) setting a number of conditions on continued operation of the fisheries that have been assessed (all federally managed fisheries and any state-managed fisheries that export product). The SESSF was given conditional certification in 2003, with one of the 18 conditions of continued operation that it introduce formal harvest strategies for key target species by 2006. It was this condition that resulted in the development and adoption of a SESSF harvest strategy framework in 2005 (with first application to the setting of TACs for the 2006 fishing year).

Despite the EPBC condition having been set in 2003, development of a harvest strategy framework did not commence until well into 2005. The initial framework was developed by the chair of the SESSF RAG and by a former RAG chair (Smith and Smith, 2005), with significant input from the senior AFMA manager in the SESSF. The framework was discussed in turn by the five individual RAGs, slightly modified, and provided for comment to the three management advisory committees (MACs) in the SESSF, and for final endorsement by the AFMA Board. The process from initial development to endorsement was completed in 3 months. The research team conducting the assessments then had 2 months to implement the framework, which involved applying the HCRs based on the results of the assessments, but also substantially modifying and extending a number of the assessments to enable this to happen.

The short time frame for development did not allow the harvest strategy framework to be tested for performance and robustness (for example using MSE methods) prior to adoption. However the framework that was finally selected was informed by prior experience from the MSE analyses already undertaken in this and other fisheries, together with considerable experience in both the assessment of the SESSF quota species and the application of harvest strategy frameworks elsewhere. Given the large number of species and stocks in the quota management system, and the fact that less than half of these had been assessed previously using a quantitative stock assessment, a single HCR could not be applied to all species. Instead, the fishery adopted the idea of a "tiered" approach from similar fisheries in the USA (Goodman et al., 2002) while extending that approach somewhat as described further below.

In developing the harvest strategy framework for the SESSF, a series of design criteria were adopted to build in a precautionary approach (Smith and Smith, 2005):

1. The harvest strategy will specify both a maximum fishing mortality rate which defines overfishing, and a target fishing mortality rate that defines optimum utilization. These will be defined operationally in terms of a limit and target reference points for fishing mortality (F_{LIM} and F_{TARG}, respectively).
2. The harvest strategy will involve decreases in fishing mortality rates at low stock sizes.
3. The harvest strategy will set a minimum biomass level, B_{LIM}, below which targeted fishing for a stock would cease.

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4. The target fishing mortality, F_{TARG}, will decrease as uncertainty about stock status increases.
5. The harvest strategy framework will be implemented through a set of Tier rules. Each species will be assigned to one of four Tier levels depending on the amount and type of information available to assess stock status, where Tier 1 represents the highest quality of information available (e.g. a current robust quantitative stock assessment). Consistent with design criterion 4, target fishing mortality rates will decrease as Tier levels increase.

The four Tier rules are designed to apply to three types of assessments. Tiers 1 and 2 are used for stocks for which there is a quantitative stock assessment that provides estimates of current absolute and relative biomass (Tier 1 if the assessment is regarded as "robust", Tier 2 for a less certain or preliminary assessment). Tier 3 is based on estimates of current fishing mortality derived from catch curves (requiring age and/or length frequency data, but not catch rates or abundance estimates). Tier 4 is based on recent trends in (commercial) catch rates. The RAG selects the most appropriate Tier level for a species or stock based on data availability and its expert judgement, and a recommended biological catch is calculated based on application of the HCR for that Tier to the current "assessment". The details of the HCRs developed in 2005 are provided in Appendix A.

The 2005 harvest strategy framework specified a target and limit biomass reference point, as well as a target fishing mortality rate for each stock. For Tier 1 stocks, the target is B_{40} (40% of unfished biomass B_0 – the proxy for B_{MSY}). The limit biomass reference point is B_{20} (half of the proxy for B_{MSY}). The target fishing mortality rate is set at F_{40} (the fishing mortality rate at which the stock will equilibrate at B_{40} in the absence of process and implementation error. Note that F_{40} differs from a similar quantity evaluated on the basis of spawning biomass per recruit, $F_{40\%}$). For stock sizes above B_{40}, F_{TARG} is set to F_{40}. For stock sizes less than B_{40}, F_{TARG} decreases linearly between B_{40} and B_{20} and is set to zero for stock sizes below B_{20} (Fig. 1). The Tier 2 harvest control rule differs in selecting a higher target stock size (and corresponding lower target fishing mortality rate). To date, F_{LIM} has not been formally defined within the SESSF harvest strategy framework.

Each Tier level has a formula used to estimate the RBC, corresponding to a total mortality due to fishing (from all sources). The HCR for Tiers 1 and 2 involves calculating the catch corresponding to applying the target fishing mortality, itself a function of relative depletion of the spawning stock (Fig. 1), to the estimate of the exploitable biomass at the start of the quota year for which a RBC is required. The HCRs for Tiers 3 and 4 are of a different form, and involve applying a "multiplier" (a function of some measure of current stock status) to recent average catch levels (see Appendix A). The multiplier for Tier 3 is a function of the ratio of current F to M, increasing catch levels when $F < 0.7M$, and decreasing catch levels where $F > M$. The multiplier for Tier 4 is a function of recent trends in catch rates, increasing catch levels when CPUE is increasing and decreasing catch levels when CPUE is decreasing. The TAC will generally be lower than the RBC as it takes into account mortality from other fleets (e.g. state catches from fleets not managed by AFMA that are not part of the quota management system) and from discards.

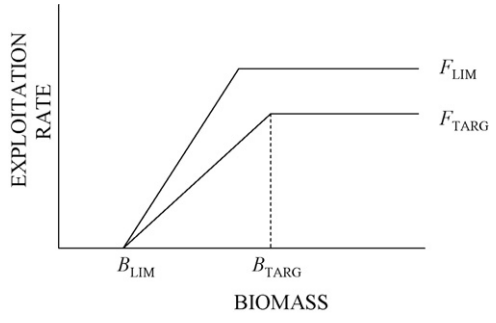

Fig. 1. Tier 1 harvest control rule in 2005. The default value for B_{LIM} was B_{20} and for B_{TARG} was B_{40}, with F_{TARG} being the fishing mortality rate corresponding to B_{TARG}.

4. Experience in implementation

The harvest strategy framework was first applied in 2005 to set TACs for 2006. Of the 34 species/stock units in the fishery, RBCs were calculated for 25 (six Tier 1, seven Tier 2, five Tier 3, and seven Tier 4). This resulted in TAC increases for 7 stocks and decreases for 6 stocks. Overall there was a net decrease in the total quota level set for the fishery due to large decreases in the TACs for several stocks. RBCs were not calculated for any of the shark species or species groups, and TACs did not change for any of these.

Application of the harvest strategy framework in 2005 resulted in several significant achievements, but also highlighted some problems. Achievements included a generally favourable response from industry and managers, and a commitment to continued use of the framework—largely due to the greater certainty the process provided. The process to develop recommendations for TACs was both quicker and less contentious than in previous years, with many fewer instances of failure of the MACs to agree on a clear recommendation. One feature of the framework had an unanticipated but positive outcome. As noted above, TACs are generally set below the RBC levels to account for discards (and state catches). The framework therefore provides a direct incentive to industry to reduce the amount of quota species that are discarded. There had been debate in the fishery for several years about increasing mesh sizes in the trawl sector to reduce discards of quota species (and also reduce bycatch more generally). As part of the TAC setting process in 2005, the trawl industry asked for mandated increases to mesh sizes with a view that this would increase TACs in the future (by reducing the amount subtracted to account for discards). The industry also adopted voluntary spatial closures for several species as part of a package of measures to protect stocks and improve chances of recovery for overfished species.

However, several problems were encountered in applying the harvest strategy framework in 2005:

- There was more resistance to decreasing TACs for Tier 3 and 4 species than for Tier 1 or 2 species; industry members on MACs were less willing to act to reduce catches where assessments were less certain (the need to act was harder to establish).
- In cases where large portions of the stock were taken under state jurisdiction, there was significant industry resistance to reducing TACs below RBCs due to state catches. This was viewed as an explicit reallocation issue between sectors, especially where state catches were not limited.
- There were problems in applying Tier 3 and 4 assessments and rules due to uncertainties about spatial structure of some stocks and to the absence of agreed catch histories for several species new to the quota system or where species identification was uncertain.
- It was clear that there were problems with the Tier 4 rule, application of which for several stocks resulted in higher RBCs than applications of other Tier rules for the same stock (for Tier 1 stocks, all other Tier rules can also be applied). Thus Tier 4 failed to meet design criterion 4 discussed above.
- Also, under Tier 4, there were specific cases where industry had self-imposed catch restraints due to limited markets or to stop

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discarding unnecessarily. Such voluntary reduction in catches resulted in reductions in future RBCs under Tier 4.
- For stocks where the RBC was zero (Tier 1 or 2 stocks assessed to be currently below B_{20}), there were no agreed rules for setting "bycatch" TACs (small catch levels to account for unavoidable bycatch in a multi-species fishery).

An important change to the application of the harvest strategy framework between 2005 and 2006 arose from the development of the Commonwealth Harvest Strategy Policy during 2006. Although the starting point for this Policy derived from the SESSF harvest strategy approach, the Policy specified B_{MEY} (maximum economic yield), rather than B_{MSY} (maximum sustainable yield) as the target. In the absence of better information, the default level for B_{MEY} suggested in the Policy was 20% above B_{MSY}. This resulted for Tier 1 stocks in the biomass target shifting from a default of B_{40}–B_{48}, with a commensurate decrease in the target fishing mortality rate to F_{48} although the default limit reference point remained at B_{20}. This change resulted in significant uncertainty about the form of the Tier 1 control rule itself, including where the break point in the rule should lie (at B_{40} or B_{48}). In 2006, Tier 1 RBCs were calculated for three different control rules reflecting different choices of a target and a break point (Fig. 2). Other changes in 2006 included shifting the target fishing mortality for Tier 2 from M to F_{50} (or F_{60} for an MEY target), and smoothing the saw-toothed nature of the Tier 3 control rule (Fig. 3).

Several other issues were identified by the RAGs and assessment scientists in 2006. The main issues and interim solutions included:

- The absence of any benchmarks (either targets or limits) in the Tier 4 rule. This meant that the Tier 4 rule acts as a "status quo" strategy, i.e. irrespective of the initial level of depletion of the stock, the Tier 4 rule tends to keep the TAC at its current level. This is clearly an undesirable feature of the rule, and steps are underway to identify target levels or ranges for catch rates.
- For Tier 3, it was recognised that fishing mortality rates derived from catch curves were unlikely to respond quickly to changes in TAC levels and resulting catches, particularly for longer lived species. The interim AFMA recommendation was that Tier 3 RBCs only be updated every 2 or 3 years for longer lived species.
- For several species with Tier 1 assessments, changes in aspects of the assessment methods themselves resulted in quite large changes in RBCs (2006 saw a general shift to use of Stock Synthesis 2 (Methot, 2007) as the preferred assessment software for SESSF species. This in itself did not generally result in substantial changes to assessments, but some assessments were sensitive to other aspects, including approaches to standardisation of catch rates). Large year-to-year changes in RBCs associated with changes in assessment methods were seen as disruptive and also tended to reduce confidence in the new harvest strategy framework. AFMA managers therefore recommended that no TACs should change by more than 50% from one year to the next, either up or down. They also recommended that, where the change in a TAC was less than 10% (in either direction) from the previous year, the TAC would not change in that year.

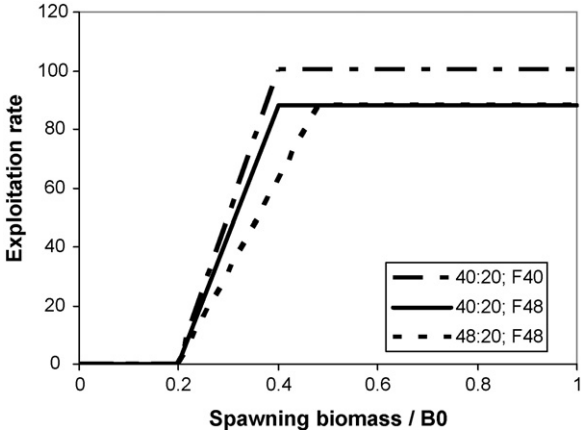

Fig. 2. Alternative Tier 1 harvest control rules under the Commonwealth Harvest Strategy Policy in 2006, with alternative target biomass at B_{40} and B_{48} corresponding to B_{MSY} and B_{MEY}. Exploitation rate is expressed relative to F_{40}.

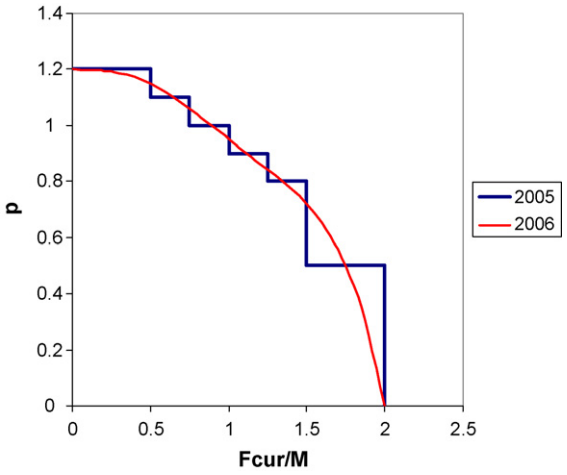

Fig. 3. Tier 3 harvest control rules used in 2005 and in 2006. p is the multiplier on current catch used to calculate the RBC. F_{cur}/M is the ratio of the estimate of current fishing mortality (from the catch curve) to the estimate of natural mortality.

In 2006, RBCs were calculated for four Tier 1 stocks, five Tier 2 stocks, six Tier 3 stocks, and nine Tier 4 stocks, with TACs for other species determined outside the harvest strategy framework. Relative to 2006, the 2007 TACs (based on 2006 assessments) resulted in decreases for 21 stocks with an increase for only one stock. A large number of the decreases were for deepwater species or stocks, including orange roughy, various oreo species, and deepwater sharks. This coincided with the listing of orange roughy as a "conservation dependent" species under Australian environmental legislation late in 2006, and a related decision by the AFMA to close nearly all waters deeper than 700 m to trawling. Apart from these deepwater species, the AFMA Board was also under considerable pressure to be seen to address the 2005 Ministerial Direction to cease overfishing and recover overfished species, and was under external scrutiny from the Australian Bureau of Rural Sciences with regard to the latter's annual report on stock status. Not surprisingly, the 2006 TAC decisions resulted in a great deal of concern within the fishing industry and a much more critical view of the harvest strategy framework used to justify those decisions.

2007 has seen further development of the SESSF harvest strategy framework. Some of this has been "tidy up" work, involving standardisation of approaches for dealing with discards and state catches, formalisation of details of RBC calculations, protocols for determining base-case assessments, and standardisation of reporting across RAGs. Some new issues have also arisen, including the identification of a "ratchet" or time lag effect in the Tier 3 and 4 rules that results in decreases in TACs over time even in the absence of changes in stock status. This arises from the multiplier in the Tier 3 and 4 rules being applied to recent average catches. A reduction in the previous year in the RBC will reduce TACs and catches and result in further reductions in the current year, even if the "assessment"

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does not require this. Solutions to deal with the "ratchet" effect and previously identified issues with Tiers 3 and 4 have been proposed, but not yet tested or implemented. Standardisation of catch rates has also emerged as an important issue, given large sensitivity to assumptions and statistical models for some key species. There has also been renewed interest in multi-year TACs, and for shorter lived species in particular, in smoothing out annual fluctuations in TACs arising from recruitment variability. Failure to fully resolve all these issues combined with disquiet about aspects of the AFMA Board decisions in 2006 has resulted in much greater scrutiny from industry on the assessments themselves, and at times expressions of no confidence in the science underlying the assessments. This greater scrutiny and criticism is not really surprising given the much tighter relationship between stock assessment outcomes and TACs under the harvest strategy framework. Active involvement of industry on RAGs is long standing and RAG reports are adopted by consensus (Smith et al., 1999), but the pressure on RAGs, and on industry members on RAGs, has increased markedly since introduction of the harvest strategy framework in 2005 resulting in recommendations for reduced TACs for a number of species.

5. Discussion

Several general lessons emerge from the experience in implementing harvest strategies in Australia's south-eastern fisheries. The first and most obvious is that it would have been preferable to spend more time developing and testing the framework and strategies prior to their implementation. Several of the issues that have arisen during implementation, particularly those around Tiers 3 and 4, could have been avoided with more consideration and formal testing. Research commenced in 2006 to formally test the harvest strategies using MSE techniques, but it would have been better to undertake this work prior to implementation. This MSE work has been facilitated, however, by the release of the Commonwealth Harvest Strategy Policy which has defined not only the targets and limits to be achieved, but also the acceptable levels of risk in not meeting the limits. This information on "objectives" is crucial in developing the performance measures needed to assess alternative strategies, and was not available at the time the SESSF harvest strategies were introduced in 2005.

A second general observation is that the response, particularly by the fishing industry, to the adoption and implementation of a harvest strategy framework can be strongly influenced by other features of the broader management and operating environment. For the SESSF, the framework was introduced at a period of economic stress in several sectors of the fishery, with management and operating costs rising sharply, and considerable competition from imported seafood. Despite this, the strong negative response to the near across-the-board reductions in TACs in 2006 was somewhat mitigated by the announcement of a major structural adjustment (effort buy-out) package which was implemented during 2006, resulting in a reduction of almost 50% in the number of vessels in the south-east trawl fleet. The political pressure to stall or reduce or undermine the substantial quota reductions in 2006 would have been much greater had industry not known that they had the opportunity to leave the fishery. On the other hand, the introduction by the federal environment department of a network of marine protected areas in south-eastern Australia during 2006 increased uncertainty and reduced confidence in management arrangements generally, including the harvest strategy framework. The external imposition of closed areas was seen as a reduction in property rights, and the process itself was lengthy with the objectives not clearly spelled out resulting in uncertainty about outcomes and impacts on fisheries (Buxton et al., 2006).

The multi-species and multi-fleet nature of the fishery has posed some interesting challenges in applying a general harvest strategy framework. Some of these issues were of course already inherent in the fishery (the quota management system has been in place for 15 years), but particular challenges have emerged in defining rules to deal with "bycatch TACs" where RBCs are zero (stocks are below limit reference points). Research is underway on several fronts to better define effort and targeting in the fishery, with a view to providing more transparent rules for determining acceptable catch levels (and formal recovery plans) for species in the "overfished" category. This takes management of the fishery beyond the more narrow focus on harvest strategies implemented through the quota management system alone, into consideration of broader management arrangements that encompass aspects of spatial management, gear controls, and other input controls. A separate MSE analysis has been undertaken to evaluate these broader "whole of fishery" management arrangements, using an "Atlantis" model developed for south-eastern Australia (Fulton et al., 2007; Smith et al., 2007). These analyses have concluded (not surprisingly) that sole reliance on the quota management system is insufficient to manage the fishery effectively and that a broader package of management tools is needed.

The most significant change in the harvest strategy framework since 2005 has been the policy decision that B_{MEY} rather than B_{MSY} is the target. This change was consistent with the government's aim to achieve economically as well as ecologically healthy fisheries. However the change was opposed by some sections of industry, which considered maximizing economic returns their business and not that of the government. Moreover, the change from F_{40} to F_{48} leads to a reduction in RBC (and hence TAC) for stocks that were assessed previously to be in a satisfactory state from a biological view point (i.e. stocks close to the B_{MSY} proxy of B_{40}). The lack of documented basis for the default $B_{MEY} = B_{48\%}$ has raised concerns among scientists as well as industry. While the move from a biologically based to an economically based target is a valid policy decision, implementing it at the same time as the introduction of a formal harvest strategy framework was difficult.

Another potential concern is "Tier shopping". While RAGs have attempted to avoid basing the choice of the Tier level (and hence RBC) on the outcome of the Tier rules (i.e. selecting the Tier level which gives the "right" answer), this remains a temptation for some RAG members, especially for depleted but otherwise stable species for which Tier 1 requires cessation of targeted fisheries while Tier 4 suggests TACs close to current levels. A related issue is that several stakeholder groups understand how the simpler Tiers 3 and 4 operate and are aware that Tiers 3 and 4 use less information than Tiers 1 and 2 and should result in lower RBCs on average to take account of this greater uncertainty. The model-based assessments used for Tiers 1 and 2 are less well understood by stakeholders, which can result in more resistance to TAC cuts arising from their application. Further education of the benefits of the model-based Tier levels coupled with the demonstration that Tiers 3 and 4 lead to lower RBCs (or modification of the details of Tiers 1 and 2 so that this is the case) is clearly warranted.

The harvest strategy framework was not phased-in. While this was appropriate given the lack of a formal basis for determining TACs in the past, the first two applications of the harvest strategy framework have led to major changes to TACs which has, in part, been a reason for some of the distrust of the system. Some stakeholders have been concerned that the reason for the lower TACs is the use of a formal harvest strategy framework, rather than the specific policy choices that underlie the harvest strategy framework.

A key feature of implementation has been the need for flexibility and pragmatism along the way. RAGs, MACs and AFMA managers have shown a commendable ability to identify problems as they

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have arisen and to develop rapid and pragmatic responses. While some of these responses will be interim pending further development and testing of the framework, the adaptive response has allowed the system to continue to function with a reasonably good level of acceptance by all stakeholders. The increased pressure on assessment scientists and on the RAG process in particular is not unexpected, and the pragmatic approach has allowed both groups to weather any temporary storms. The development and recent adoption of the Commonwealth Harvest Strategy Policy provides a firm underpinning to the whole process that should ensure that the "pragmatism" is not taken too far, and the system does not revert to prior "business as usual".

While by no means novel to the SESSF, the adoption of a Tier approach to the harvest strategy framework has been a real success, notwithstanding the need to improve several aspects of how the Tiers work to achieve similar levels of risk across different levels of uncertainty. The Tier approach has allowed relatively rapid "assessment" for a number of species, which has been an important component in meeting the needs of the quota management system given the limited resources available. Further refinement of some of the Tier rules should also improve the efficiency of the process, as will a likely future move to multi-year TACs for some species. The Tier approach also opens the prospect of linking the harvest strategy framework to a broader process in the fishery that has involved development of ecological risk assessments for by-product and by-catch species (Smith et al., 2007). With further development of suitable decision rules, these species might also be brought into the harvest strategy framework with the ecological risk assessments supporting a Tier 5 or 6 level in the overall system.

In summary, the introduction of the harvest strategy framework into the SESSF can be judged a success. One measure of this success is the time and effort taken to reach agreement within the MACs on TAC recommendations. Prior to implementation of harvest strategies, this process involved meetings that took up to a week and frequently resulted in failure to reach agreement. After 3 years within the harvest strategy framework, the process takes a day and a half and in 2007 only one species did not achieve a consensus recommendation. Apart from adding certainty and efficiency to the advisory process, other strengths of the framework include streamlining the assessment process, and the ability of the Tier approach to deal with stocks with a range of information, from data-rich to data-poor. The most important lesson learned is the need for flexibility to change the framework itself between years based on problems identified in application. This should not be confused with flexibility in interpreting the results of assessments and applying the harvest control rules within years, which will tend to undermine the process itself. The flexibility to change the framework is likely to be a feature of any system, irrespective of the amount of prior testing. It is almost certainly better to implement a harvest strategy system recognizing explicitly that it will change, rather than delay implementation until a "perfect" system is devised. The latter is likely to be an illusion in any case. While the harvest strategy framework in the SESSF will continue to evolve, it looks set to play an ongoing and key role in the overall management of the fishery for many years to come.

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Appendix A. The 2005 harvest strategy framework

A.1. Tier 1

The Tier 1 harvest control rule will apply to stocks where there is a robust quantitative assessment that provides estimates of current biomass, B_{CUR}, from a base-case stock assessment and where estimates are available for B_{40}, B_{20} and F_{40}. The RBC for Tier 1 stocks is calculated by applying the target fishing mortality, F_{TARG}, to the current biomass. F_{TARG} is calculated as follows:

$$F_{TARG} = \begin{cases} 0 & \text{if } B_{CUR} < B_{20} \\ F_{40}\left(\frac{B_{CUR}}{B_{20}} - 1\right) & \text{if } B_{20} \le B_{CUR} \le B_{40} \\ F_{40} & \text{if } B_{CUR} \le B_{40} \end{cases} \quad (A.1)$$

A.2. Tier 2

The Tier 2 harvest control rule will apply to stocks where there is a less robust quantitative assessment that provides estimates of B_{CUR} and where estimates are available for $B_{F=M}$ (the equilibrium biomass corresponding to a fishing mortality rate equal to M), B_{20} and M. F_{TARG} is calculated as follows:

$$F_{TARG} = \begin{cases} 0 & \text{if } B_{CUR} < B_{20} \\ M\left(\frac{B_{CUR}}{B_{20}} - 1\right) & \text{if } B_{20} \le B_{CUR} \le B_{F=M} \\ M & \text{if } B_{CUR} > B_{F=M} \end{cases} \quad (A.2)$$

A.3. Tier 3

The Tier 3 harvest control rule will apply to stocks where there are robust estimates of M and current fishing mortality rate F_{CUR}, but no direct estimates of current biomass. Under Tier 3, the RBC is calculated by varying the current catch level up or down depending on whether F_{CUR} is above or below an estimate of M. The current catch level C_{CUR} is calculated as the average catch over the past 4 years (where catch = landings + estimated discards). The formula for calculating the RBC for Tier 3 stocks is:

$$\text{RBC} = \begin{cases} 0 & \text{if } F_{CUR} > 2M \\ 0.5C_{CUR} & \text{if } 2M \ge F_{CUR} > 1.5M \\ 0.8C_{CUR} & \text{if } 1.5M \ge F_{CUR} > 1.25M \\ 0.9C_{CUR} & \text{if } 1.25M \ge F_{CUR} > M \\ C_{CUR} & \text{if } M \ge F_{CUR} > 0.75M \\ 1.1C_{CUR} & \text{if } 0.7M \ge F_{CUR} > 0.5M \\ 1.2C_{CUR} & \text{if } F_{CUR} < 0.5M \end{cases} \quad (A.3)$$

Estimates for F_{CUR} will generally be derived from catch curve analyses. Additional issues that will need to be examined by RAGs when applying the Tier 3 harvest control rule include: (a) robustness of sample data for age and length, (b) when/how to extrapolate from length to age, (c) which is the most appropriate sector to use to estimate F_{CUR} (for species caught by multiple sectors), (d) the impact of selectivity being dome-shaped, and (e) how to average estimates of fishing mortality when such estimates vary considerably from one year to the next.

A.4. Tier 4

The Tier 4 harvest control rule will apply to stocks with the least amount of information about current stock status. At this Tier level, there is no reliable information available on either current biomass or current fishing mortality, but there is information on current

catch levels and on trends in catch rates. The steps in calculating the RBC for Tier 4 stocks are as follows:

1. Set the current catch, C_{CUR}, to the average catch (landings plus discards) over the past N_C years, where N_C will depend on the period of "stable" effective (=binding) TACs. The default for N_C is 4.
2. Calculate the slope of the trend in CPUE over the past N_S years. N_S will depend on whether trends in CPUE tend to be relatively stable, or cyclic. For "stable" stocks, it is suggested that $N_S = N_C$ (i.e. 4 years). For "cyclic" stocks, N_S would need to be set at about 2 cycle periods.
3. Calculate the RBC as

$$\text{RBC} = (1 + \alpha\,\text{slope})C_{CUR} \quad \text{(A.4)}$$

where the value of α is yet to be determined, and may need to increase as the (negative) slope increases (the default values for α since 2005 have been 1, 2 and 4).

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