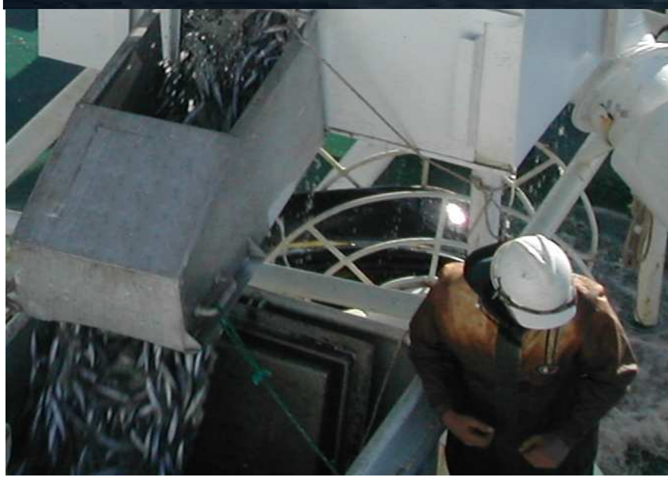
R2008/843 15/06/2008

Australian Government
Australian Fisheries Management Authority

Review of the Draft Harvest Strategy for the Commonwealth Small Pelagic Fishery



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Published: Fishwell Consulting Pty Ltd
22 Bridge St Queenscliff VIC 3225

ISBN: xxx

General disclaimer

Preferred way to cite:

Knuckey, I. Bergh, M., Bodsworth, A., Koopman M. and Gaylard J. (2008). Review of the Draft Harvest Strategy for the Commonwealth Small Pelagic Fishery. AFMA Project R2008/843. Fishwell Consulting.

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Executive Summary

The Australian Fisheries Management Authority (AFMA) through its SPF Resource Assessment Group (RAG) and the SPF Management Advisory Committee (MAC) has overseen the development of a draft harvest strategy for the Commonwealth Small Pelagic Fishery (SPF). At AFMA's request, the Draft HS has been subsequently evaluated for consistency with the Commonwealth Harvest Strategy Policy (HSP) and the policy guidelines.

This HS review is presented in sub-sections that incorporate consideration of SPF species' life history and biology; a qualitative review of the proposed Draft HS against the HSP and Guidelines; a quantitative Management Strategy Evaluation (MSE) of the operation of the proposed harvest strategy against the key Policy settings of the Commonwealth HSP; and an initial evaluation of alternative industry based fishery monitoring options and their implementation costs. The review conclusions, and recommendations for improvement to the proposed SPF harvest strategy, are then presented.

For the SPF, the combination of a developing fishery, difficult economic circumstances, high levels of broad stakeholder interest and engagement, and a paucity of scientific knowledge on the target species makes for a complex operating environment. Within the limited time and resources available, the SPF RAG and MAC have worked hard to overcome these challenges, and develop a Draft HS that balances these complex operational circumstances.

This review of the SPF Draft HS should be considered in this context. It is intended to build on the work already done, and to provide further advice and information to help refine the Draft HS against key policy requirements, and fishery specific objectives. The preliminary quantitative MSE of the proposed HS has been valuable, and has identified key areas for further consideration and development.

The Draft HS has been designed to be explicitly precautionary on the basis of the SPF species being important ecological species and due to scientific uncertainty in assessments and key biological and life history characteristics of the target species. Essentially, the Draft HS has a Tiered framework that sets very small catches where little information is available at the lowest Tier. In the top Tier, maximum catches of 20% of the median spawning biomass are allowed when regular surveys and assessments are undertaken using the Daily Egg Production Method (DEPM).

The analysis of key biological and life history characteristics of SPF target species suggests they should be categorised into two broad groups. The first are moderately long-lived species that inhabit shelf and slope waters (redbait, Peruvian jack mackerel, yellow tail scad, and jack mackerel). The second group are shorter lived species that inhabit shelf waters (blue mackerel and Australian sardines). The Draft HS appears to be more targeted towards the latter and the development of alternative harvest strategy approaches specific to each of these groups should be considered. The larger number of age classes in the spawning biomass of longer lived species could enable more appropriate harvest strategies to be developed. This may also reduce the likelihood of highly variable TACs that could result from application of the DEPM based approach.

The review included a preliminary MSE, comprising stochastic and deterministic analyses to evaluate the performance of the Draft HS at Tier 1 against key settings of the HSP. Stochastic MSE analyses were performed to determine if the proposed Draft HS harvest proportions were consistent with the overarching HSP objectives (i.e. harvesting resources at or near MEY, whilst keeping biomass above B_{lim} 90% of the time). Deterministic MSE analyses were performed to establish what harvest proportion of the spawning biomass would drive the

resource to B_{48} (referred to as p_{MEY}), and what was the economic difference (expressed as a percentage of catch) between an MEY harvesting policy and the catches suggested by the proposed HS. The analysis of risk quantified during the MSE was influenced by the scope of uncertainty and stochasticity considered in the simulations. This was addressed by running additional simulations which considered a number of variants of the base case scenarios. The MSE simulations were only tested against the proxy settings of the HSP, rather than against potentially more conservative targets as may be envisaged under the policy for keystone or key prey species. This was largely because no targets have been established for such species; an issue that will need to be addressed for the SPF HS.

The Draft HS exploitation rates at Tier 1, in which a maximum of 20% of median spawning biomass can be harvested in a year, are conservative in the context of the biology and life history of SPF target species, and the default settings of the Commonwealth's HSP. Not unexpectedly due to its conservative approach, application of the Draft HS led to the biological policy objectives being exceeded, but performance was sub-optimal with respect to the economic objectives. The spawning biomass ended up being managed >> B_{48} for most cases with negligible risk of dropping below B_{lim}. The proportion of the DEPM spawning biomass that could be removed to achieve B_{48} (p_{MEY}) was therefore larger than allowed under the Draft HS decision rules. In other words, a more 'aggressive' harvest rate (i.e. larger Tier 1 harvest proportions) was possible for all SPF species whilst still meeting the overarching HSP objectives with respect to an MEY target. Under the proposed HS approach this potential catch will be forgone as a consequence of greater stock conservation.

Importantly, the degree to which the resultant biomass was higher than B_{48} (more precautionary) and the level of forgone catch, depended critically on the life history of the different species. It was not clear that this was intended by the Draft HS. The preliminary MSE revealed application of the Draft HS has different and far more conservative results for these shorter-lived (resultant biomass levels of about 70%) than for the longer lived SPF species (eg. resultant biomass levels about 55% for redbait). The importance of having agreed life history parameters for each species (especially natural mortality) was highlighted as a result of the preliminary MSE.

Thus, there is a significant economic cost arising from the more conservative approach being adopted in the HS in light of the species key role in the ecosystem. The preliminary MSE suggests that the conservative exploitation rates are likely to result in substantially reduced yields from stocks when compared to an MEY target (ranging between a 10-50% reduction depending on species) and thus are likely to adversely impact aggregate profitability of the commercial fishery over time. To some extent this has confounded performance of the Draft HS against the overarching HSP objectives of sustainability and profitability. Consequently, the likely trade-off between these objectives arising from implementation of the Tier 1 decision rules warrants further consideration and justification in the HS. This issue was discussed at some length during the presentation of review findings at the SPF RAG and MAC meeting (29-30 May 2008), where members reiterated the importance of conservative exploitation rates for key prey species. Nonetheless, noting the significant economic impacts of such an approach, and the importance of pursuing economic efficiency for Commonwealth fisheries, the review suggests the rationale for adopting these conservative harvest levels across the full range of SPF target species should be made much clearer. This should include reference to the supporting literature and, where possible, a quantitative analysis of the costs and benefits along the lines of the preliminary MSE conducted during this review. This would enable a more efficient and transparent approach to one of the most important elements of the proposed HS. For each SPF species, the HS needs to justify and be explicit about the reasons for departing from an MEY target for conservation reasons. If not targeting MEY, there is even more necessity for the HS to ensure the most cost-effective research and management strategy is in place for the fishery.

The HSP and Guidelines suggest that target stocks, managed to levels approximating B_{MEY}, are likely to enable healthy ecological function. It is not clear from the draft HS that maintaining stocks above this level will deliver substantial ecological benefit, yet it is likely to result in foregone yield and potential fishery profits. If the SPF target species are all designated as keystone species, or as key prey species, the foregone yields arising from conservative exploitation rates may be acceptable. There remains, however, an important judgement to be made about the quantum of exploitation rates or target biomass reference points, and whether or not they should be the same for all species. This is not explicit in the Draft HS. The proposed conservative HS approach suggests a significantly greater premium has been attached to ecological values, and possibly other fishing sectors, in the SPF context. This raises the question whether the standard fisheries management research cost recovery approach requiring 80% commercial industry funding is appropriate.

The concept of Tiers used in the draft HS to account for greater precaution at lower information levels is consistent with the HSP and Guidelines. The justification and demonstration of the precaution adopted at the Tier 2 level is not clear in the Draft HS. Further, a more obvious consideration of the likely costs to industry and government arising from application of the HS at all Tier levels will improve the proposed HS. This is particularly so for Tier 1 of the HS which should represent an efficient synergy between the cost of gathering scientific information, and the subsequent management confidence needed if more aggressive exploitation rates are to be considered. Similarly, details of the information required to underpin decisions at Tiers 2 and 3; the costs of obtaining and interpreting this information, and the reasons why this level of knowledge equates to the catch quantities proposed could be made clearer.

At the lower tiers the proposed HS also relies on the expert judgement of the RAG to determine harvest levels after consideration of relevant catch and effort information. To enable consistent and objective decision making there could be more information provided about what specific information will be considered, and how it will be interpreted to develop catch recommendations in the absence of a clear decision rule such as that proposed for Tier 1.

The proposed HS suggests considerable weight is given to subsidiary management objectives like “localised depletion”. Despite the significant management responses, this term is not well defined in the HS and subsequent RAG/MAC discussion at the 29 May meeting illustrated different stakeholder interpretations of this term. The definition and quantification of localised depletion in the SPF HS context should be clarified to allow due consideration of alternative management/mitigation strategies, including their potential impacts on stocks, ecosystems, and/or stakeholder interests.

The Draft HS also includes management responses to address impacts on threatened, endangered or protected species which may be better placed in the Fishery Management Plan, or Bycatch Action Plan, and cross-referenced to the HS.

The costs of regular DEPM based assessments for key SPF target species are likely to be high relative to the state of development and profitability of the fishery. There is a question whether the level of assessment confidence, and hence cost, generated by regular DEPM assessments for Tier 1 species is warranted – particularly noting the conservation buffer provided when deliberately conservative exploitation rates are incorporated for Tier 1.

For shared stocks the HSP advocates shared responsibility across jurisdictions. The proposed SPF HS does not explicitly cater for this and has the potential to disadvantage Commonwealth operators and undermine the strength of SPF entitlements. It may be more appropriate to encourage shared management responsibility by reducing catches from all jurisdictions consistent with historic catch ratios.

The suggestion that the Draft HS should cater in advance for possible mass mortality events or similar dramatic environmental perturbations through the application of more conservative harvest settings should be reconsidered. This approach has the potential to further contribute to reduced yields over time and yet may not be the most efficient way to target this specific risk – particularly for species other than sardine. If such events are considered a key management risk, it may be more efficient to address them through the use of meta-rules or exceptional circumstance provisions within the HS that could apply if and when such an event occurs.

The current information on SPF stocks is patchy on both a spatial and temporal basis. Efforts should be taken to improve this situation but given the extent of the fishery, the current Tier 1 HS will require a prohibitive budget if ongoing annual DEPMs are required for all stocks in all regions, especially if it is conducted in addition to normal fishing activities. It is possible that aerial survey methods could be used for broad-scale, qualitative identification of the timing and location of SPF aggregations to help target more quantitative surveys.

There are well-developed, cost-effective acoustic methods of quantitative biomass estimation used on international small pelagic species that could be applied to the SPF to augment or replace the need for annual DEPMs. It should be a high priority to develop a cost-effective, scientifically rigorous research plan to be conducted from commercial fishing vessels that enables the collection of DEPM data and begins the process of developing quantitative acoustic techniques. This should be an integral part of any HS and form the basis of any development of the fishery. In the short term, however, it is likely that DEPM will remain as the primary research survey tool for SPF biomass estimation until further development of acoustic methods for Australian SPF species takes place.

The opportunity to enable higher catches in the very early stages of the development of the fishery so that these methods can be developed and better information obtained should be realised.

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Introduction

In December 2005, the Australian Government Minister for Fisheries, Forestry and Conservation issued a Ministerial Direction to the Australian Fisheries Management Authority (AFMA) under section 91 of the Fisheries Administration Act 1991 (FA Act). The Ministerial Direction included a requirement for AFMA to develop and implement harvest strategies for Commonwealth fisheries in accordance with the Commonwealth's recently developed Harvest Strategy Policy (HSP).

The HSP provides a consistent framework for applying an evidence-based, and precautionary approach to setting ecologically sustainable and economically efficient harvest levels on a fishery-by-fishery basis. The Policy is intended to provide the fishing industry with a more certain operating environment by setting target and limit reference points for target species and pre agreed decision rules to maintain fishing effort or catch at levels consistent with agreed reference points. This approach is intended to introduce a new degree of stability for the fishing industry, one which encourages business confidence, investment, and sustained profitability for Commonwealth fisheries.

The Policy recognises that it is a significant challenge to develop harvest strategies consistent with the Policy settings for small or developing fisheries which are typically data-poor and have only basic or no formal stock assessments for one or more key target species. The generally low Gross Value of Production (GVP) for such fisheries requires that harvest strategies for these fisheries must be carefully designed to ensure that the costs of supporting science are not prohibitive. This is particularly important for developmental fisheries.

A draft harvest strategy has been developed by a small project team operating within the SPF RAG process. This Draft HS has been presented at recent Resource Assessment Group meetings and, in line with the HSP objectives, is intended to provide stakeholders and the broader community with a high degree of confidence that SPF species are being managed for long-term biological sustainability and economic profitability.

The stated objective of the SPF HS is for "The sustainable and profitable utilisation of the Small Pelagic Fishery in perpetuity through the implementation of a harvest strategy that maintains key commercial stocks at ecologically sustainable levels and, within this context, maximises the economic returns to the Australian Community". Certain characteristics of the SPF suggest that alternatives to the default HSP settings are appropriate and the Draft HS reflects strategies that have been successfully applied in other large fisheries for small pelagic species (e.g. South Australian Sardine Fishery, USA Pacific Sardine Fishery). Nonetheless there are other characteristics of the SPF that make it quite different from other highly variable and large scale fisheries for sardines and anchovies, and these pose some challenges for HS development and cost effective implementation as required by the HSP.

The SPF HS applies to the following key commercial species for the fishery:

- Jack mackerels (*Trachurus declivis, T.murphyi, T.symmetricus*)
- Blue mackerel (*Scomber australasicus*)
- Redbait (*Emmelichthys nitidus*)
- Australian sardine (*Sardinops sagax*) in Commonwealth waters adjacent to NSW.

The draft SPF HS currently applies to the entire area of fishery (including Zone A off Tasmania) and will be used to develop advice on Recommended Biological Catch (RBC) and Total Allowable Catches (TACs) for known stocks of the key target (and future quota) species. RBCs are to apply to SPF stocks throughout their range, and will include mortality resulting from all types of fishing, including catches from other jurisdictions. In addition, the Draft HS has been designed to be explicitly conservative to account for the ecological importance of these species.

During more recent SPF RAG and MAC consultation on the Draft HS, industry members have raised concerns that a number of technical (e.g. proposed Tier 1 decay rules and subsequent RBC reductions), and cost-benefit issues remained unresolved. The pressing deadline for completion of the HS has also made it difficult to clearly understand the commercial implications of the proposed approach, including obtaining additional scientific advice on the likely catch limits imposed by decision rules for the lower catch tiers. It was acknowledged at the most recent SPF RAG and MAC meetings that the proposed HS had been evolving continuously and the latest version was tabled for further consideration and discussion and had the advantage of containing material that was already somewhat familiar to RAG and MAC members.

Noting industry's concerns about the potential impacts and costs of the proposed HS, and that the HS will be central to the fishery's future development, industry members identified the need to seek independent advice on both technical and more policy-focussed elements of the Draft HS. Whilst affirming their confidence in the work done by SPF RAG and MAC to date on the HS, industry nonetheless considered that such a review process would provide additional rigour to the HS development process, and improve the management basis for the fishery in the medium to longer term.

AFMA recognised that Industry's request tied in with the co-management approach to developing the SPF Harvest Strategy, in which industry and AFMA are seeking a cost-effective Harvest Strategy that minimises risks to sustainability and economic efficiency, while enabling catch levels that promote the development of the fishery. AFMA (Dr Rayns) accepted this rationale and agreed to grant additional time and funding to facilitate an independent review. AFMA then advised that final SPFRAG advice on a preferred HS for fishery must be submitted to the AFMA Board no later than its 26-27 June 2008 meeting. SPFRAG welcomed AFMA's support to conduct a review and agreed to defer finalising its advice on the Draft HS until late May 2008 at which time the outcomes of the independent review could be considered.

In conducting this review, we fully recognise that the SPF Draft HS was work in progress and was not yet in its final form. It is also recognised that due to the significant time constraints involved, a review was not necessarily planned for this stage of the development of the final SPF HS. Nevertheless, the review and evaluation of the Draft HS are in line with the requirements of the HSP and should provide all stakeholders with a better and more quantitative understanding of the implications of the Draft HS for the ecological sustainability of the resource and economic viability of the fishery.

SPF Harvest Strategy Review Objectives

The agreed objectives for the SPF HS review are to:

- Review available information on key biological characteristics of the SPF stocks with particular emphasis on recruitment variability.
- Assess whether the proposed maximum exploitation rates are appropriate in view of the biological characteristics of the SPF stocks, wider ecological considerations, and economic factors relating to the costs of information gathering and efficiency of harvesting.

- Assess whether the Draft Harvest Strategy framework provides the SPF industry with an appropriate and cost effective mechanism to facilitate the large scale investments necessary for fishery development.
- Evaluate the Draft Harvest Strategy against the Commonwealth Harvest Strategy Policy and Guidelines in relation to both HSP standards and design criteria.
- Advise on a strategy to develop a cost effective, industry based approach to acquiring information relevant to stock assessment to supplement or replace the DEPM approach.

Material and Methods

Review Methodology

The harvest strategy review has been conducted against the terms of reference and objectives outlined above. Relevant literature and articles covering biological data, daily egg production assessments and alternative monitoring approaches, records of SPF consultative groups (MAC and RAG), and other relevant material has been reviewed. Similarly, literature detailing assessment, monitoring and management approaches being used by other management agencies for similar small pelagic species have also been reviewed.

The review outcomes are presented in sub-sections that incorporate consideration of SPF species life history and biology; a qualitative review of the proposed Draft HS against the HSP and Guidelines; a quantitative Management Strategy Evaluation (MSE) of the operation of the proposed harvest strategy against the key Policy settings of the Commonwealth HSP; and an initial evaluation of alternative industry based fishery monitoring options and their implementation costs.

The review conclusions, and recommendations for improvement to the proposed SPF harvest strategy, are then presented.

SPF Species Biology and Life History

Characteristics reported in this report include:

- The maximum age, t_{max}, (years);
- The rate of natural mortality, M (yr^{-1}). In cases when maximum ages were reported but formal estimates of M were not, M was derived from the maximum age using the formula $M = -\ell n(0.01)/t_{max}$.;
- The parameters of the von Bertalanffy growth equation:

  $$L_a = L_{inf}(1 - \exp(-\kappa(a - t_0)))$$

  where the units for L_{inf} and t_0 are cm and years respectively;
- The age at 50% maturity for females, a_m (years);
- The length at 50% maturity for females, L_m (years);
- Diet and depth preferences and habitat usage. Codes were assigned to represent diet preference, depth preference and habitat usage according to Koopman *etal* (2000), and are summarised in Table 1. The categories for diet, depth and habitat are necessarily quite crude. This is to enable rough comparisons to be made among species to allow “similar” species to identified automatically with relative ease.

These biological parameters were chosen because (a) they are well-defined so that most analysts will be estimating comparable quantities, (b) the first five are relatively easy to estimate from data collected from a fishery, and (c) they are important when conducting stock assessments, performing population projections and for developing fisheries reference points.

Defining similar species

Methods to compare similarity of other species to SPF species were taken from Koopman *etal* (2000). A brief description is given below.

The following formula is used to rank species in terms of how well they match a given target species:

$$I_{i,j} = w_1\left|(1-t^i_{\max}/t^j_{\max})/0.2\right| + w_2\left|h^i - h^j\right| + w_3\left|e^i - e^j\right| + w_4\left|d^i - d^j\right| \quad (1)$$

where $I_{i,j}$ measures the 'difference' between species *i* and *j*, and

$t^k_{\max}$ is the maximum age for species *k*,

h^k is the value of the habitat code for species *k*,

e^k is the value of the depth code for species *k*,

d^k is the value of the diet code for species *k*, and

$w_{1,2,3,4}$ is the weight assigned to each piece of information.

The value of *I* determines the relative 'similarness' of species *i* and *j*. Two species are identical if *I* is zero while large values for *I* indicate a major lack of similarity between two species. The value for w_1 (the weight assigned to the maximum age) is set equal 1 (i.e. a 20% difference in maximum age for two species that are identical in terms of habitat and diet leads to a value of 1 for *I*). The values assumed for w_2, w_3 and w_4 are essentially guestimates and have been taken to be 0.2, 0.2 and 0.5.

SPF Harvest Strategy Evaluation

This section provides both a qualitative and quantitative analysis of the proposed Small Pelagic Fishery Harvest Strategy (SPF HS) against the requirements of the Commonwealth Harvest Strategy Policy and Guidelines. Whilst the HSP and guidelines provide flexibility for the design and implementation of fishery specific harvest strategies, there are nonetheless key HSP objectives that must be achieved.

Similarly, the Commonwealth *Fisheries Management Act 1991* details the legislative objectives to be pursued by AFMA in its management of Commonwealth fisheries. Whilst these legislative objectives have primacy over the HSP, the Policy is articulated in a way that ensures the two are largely complementary.

Qualitative Evaluation

The HSP Guidelines provide detailed advice about applying the HSP to the diverse range of Commonwealth managed commercial fisheries. They are focused on providing detailed technical and practical advice to stakeholders involved in the development and implementation of harvest strategies. There is a particular emphasis on developing harvest strategies that best fit the Policy objectives whilst being tailored to the unique circumstances of individual fisheries.

The qualitative analysis reviews key elements of the proposed SPF harvest strategy against the relevant HSP objectives, and against the recommended approaches detailed in the HSP guidelines. The recommended design criteria to be applied in the development of Commonwealth harvest strategies are also explicitly considered.

The key technical elements of the proposed SPF HS, including the application of exploitation rates and related decision rules are then further evaluated against the Policy settings using a quantitative Management Strategy Evaluation (MSE) process.

Quantitative Evaluation

Specification of different SPF 'species'

The methods involve the use of a simple model of the stock and the fishery to explore the outcome of a large number of simulations using different DEPM frequencies and harvest proportions. The population model we used is described in Appendix 2. The important quantitative features of the model are the following:

1. Life history characteristics, i.e. natural mortality-at-age, fecundity-at-age, weight-at-age. These depend on the kind of fishery involved.
2. Recruitment characteristics – we used the so-called hockey-stick recruitment relationship illustrated in Figure 1. The main variable in this relationship is the kink, which is the sharp 'corner' below which significant reductions in recruitment start to occur, in direct proportion to declines in spawning biomass. The base case model assumes that this kink occurs at 20% of the pristine spawning biomass as is generally accepted in international fisheries science and supported by the empirical work of Myers *et al.* (1995). Certain sensitivity tests have been run using a kink of 40%, but this is conservative and such an eventuality would normally be considered *a priori* to have a low probability. A further important variable in the simulations is the standard deviation of deviations in the logarithm of recruitment about the deterministic hockey stick function. We use a base case value of 0.6. Figure 2 illustrates a time series of recruitment with this degree of variability. In Figure 2 there is no serial correlation in the time sequence of recruitments ($\rho = 0.0$). A sensitivity analysis was also run in which there is serial correlation in recruitment from year to year. For this, a correlation value of 0.5 was used ($\rho = 0.5$). Figure 3 illustrates a time series of recruitment with this degree of variability and serial correlations.
3. Biomass characteristics, i.e. the current spawning biomass of the stock (fishery dependent), the current spawning biomass as a % of the pristine spawning biomass (30%, 48% or 75%). In this context, current means at the start of the simulation period (the term 'planning horizon' is also used to described the 20 year simulation period).
4. Fishery characteristics, i.e. the selectivity-at-age of the fishery (fishery dependent).

Table 11 details the essential characteristics of four different fisheries which are used for the computer simulations, i.e. Redbait (a), Redbait (b), Jack mackerel, Blue mackerel. The basis for the distinction between Redbait (a) and Redbait (b) is essentially that there is a level of uncertainty about the natural mortality estimates of redbait in the literature. Redbait (a) is based on estimations from the catch curve derived from Eastern Zone A and has larger natural mortality than Redbait (b), both for ages 4 and above (0.25 instead of 0.22) and for ages 3 and below (0.6 instead of 0.22). Details of this are provided in the last section of Appendix 2. Redbait (b) has a smaller natural mortality estimated from the maximum age through the Hoenig method; it also has a slightly different model of the onset of sexual maturity. The life history characteristics for Redbait (b), Jack mackerel and Blue mackerel is based on information provided in the section on biology and life history of SPF species. In addition it is assumed that fish body weight is a cube of fish length and we used an assumed fishing selectivity curve that was the same for each species. This curve allows for some fishing of recruits, at a selectivity that is 30% of the full selectivity applied for age classes 1 to 10.

Note about biomass assumptions: For the purposes of the simulation results presented here, the actual absolute biomasses relevant to each of the species considered are not seen as relevant to the discussion about the merits of Draft HS harvest proportions. Thus, the actual biomasses cited in output statistics presented here have not been deliberately set at actual best estimates of biomass for each species, where such best estimates have been outlined for example in some of the tables accompanying the Draft HS.

MSE Simulation Framework

The MSE section of the Draft HS review involved setting up specific simulations to test the performance of the proposed Tier 1 HS against the key requirements of the HSP. The Draft HS proposes that key SPF species be managed through annual analysis of fishery data, and indicators, as well as DEPM surveys. The most recent DEPM survey is used to establish a maximum TAC, where this TAC is expressed as a percentage of the most recent DEPM survey estimate of spawning biomass for the stock. The percentage that determines the maximum permissible TAC decays (declines) over time as illustrated below:

Age of DEPM assessment (years)	Maximum harvest rate as a percentage of median spawning biomass estimated from a DEPM assessment
5	10
4	12.5
3	15
≤2	17.5
2 in 3 OR 3 in 5	20

For stocks assigned to Tier 2, absolute maximum TACs are established. Annual assessments are carried out using catch and effort information as well as catch-at-age. For Tier 3, an absolute maximum TAC of 500 MT is in place, although TACs smaller than that may be determined based on available information including biology, historical catch and the spatial area of a management zone.

The MSE is focused on two main issues:

- Are the harvest proportions in the above table consistent with the key Policy objectives enunciated in "Australian Government Department of Agriculture, Fisheries and Forestry. 2007. Commonwealth Fisheries Harvest Strategy, Policy and Guidelines, September 2007". In other words, do they typically drive the fishery to, or close to B_{MEY} (for B_{MEY} defined as the proxy B_{48}) and do they keep the population above B_{lim} 90% of the time? If not, how should the maximum harvest percentage and the decay rate be altered to achieve these goals?

- There is an implied 'risk equivalence' between different frequencies of DEPM surveys. In other words, if DEPM assessments are only run every four years instead of two years, then the lesser knowledge about stock dynamics that this allows is compensated for by the lower harvest percentages. The MSE tests whether the implied risk equivalence holds, and if not how should the maximum harvest percentage and the decay rate be altered to achieve improved equivalence.

The MSE presents simulation outcomes for Tier 1 of the HS derived from a modelling framework which assumes that any species and area combination can be modelled using a standard single species population approach. In constructing this model, certain assumptions were made about fishing selectivity, which provides for exploitation of recruits of a particular year class. Recruitment was related to spawning biomass via a so-called 'hockey-stick' relationship, with a kink at 20% of pristine spawning biomass (Figure 1). Risk and uncertainty is built into this simulation framework primarily as error in the DEPM estimate of spawning biomass (C.V. ~ 30%), errors in the stock assessment based spawning biomass estimates (C.V. ~ 30%), and/or errors in the stock assessment based estimates of a safe (MEY based) harvest proportion (C.V. ~ 10%), as well as stochasticity (i.e. random fluctuations) in annual recruitment (log-recruitment deviations with an S.D. of 0.6). The simulation results are presented in either deterministic or stochastic format for four species, denoted Redbait (a), Redbait (b), Jack mackerel, and Blue mackerel.

The primary purpose of the deterministic analyses was to establish (given the basic assumptions about population dynamics):

(a) what harvest proportion of the spawning biomass would drive the resource to 48% of pristine (pMEY, a proxy for MEY); and

(b) what is the economic difference (as % of catch) between an MEY harvesting Policy and catches determined by the Draft HS.

The purpose of the stochastic analyses was to:

(a) determine whether certain overarching Policy objectives (i.e. harvesting resources at MEY, keeping biomass above B_{lim} 90% of the time) were consistent with the Draft HS harvest proportions; and

(b) test for 'risk equivalence', meaning that biological risks are (or are not if risk equivalence is not achieved) equal regardless of the DEPM frequency used.

It should be noted that *risk* as evaluated during the MSE is influenced by the scope of uncertainty and stochasticity considered in the simulations. This was addressed by running additional simulations that included variants of the standard results presented. A key additional factor was the possibility of 50% positive bias in the DEPM based stock assessment results. Other key variants were an assumption that at present stocks are in a very depleted condition (15% of pristine), and that recruitment was related to spawning biomass via a so-called 'hockey-stick' relationship with a kink at 40% of pristine spawning biomass (instead of the more likely 20%). The most serious issue identified here is firstly the possibility that the resource is already in a heavily over-exploited state, and secondly the possibility that there is positive bias in the DEPM based spawning biomass estimate.

A quantitative evaluation of the Draft HS implies using unambiguous logic and mathematics to simulate the HS. The proposed SPF Draft HS has not yet been specified unambiguously and thus differs from the management procedure concept defined, for example, in De Oliveira and Butterworth (2004) - where the management procedure is an unambiguous mathematical formula for setting the TAC, with no provision for human judgement. The unambiguous mathematical characteristics of a management procedure lends itself to simulation testing. Proponents of management procedures argue that steps involving human judgement cannot be evaluated.

The key areas where the proposed HS relies on human judgment are:

- More frequent DEPMs are optional, if one wishes to move to a higher tier – this suggests a decision based on human judgement that is not amenable to codification, and hence quantitative investigation via computer simulations.
- Other, CPUE and catch-at-size or catch-at-length based, stock assessments are referred to as providing some indication of resource trends, and informing the choice of a TAC. The Draft HS emphasises that the harvesting percentages in terms of the most recent DEPM survey estimate serve as a maximum TAC only, and TACs less than the maximum may be chosen in the event that stock assessment results suggest that this is a preferred course of action. It is appreciated that these other decision making processes cannot be specified unequivocally. Nevertheless it becomes necessary to make additional assumptions in order to pursue a quantitative evaluation of the Draft HS.

In order to evaluate the Tier 1 characteristics of the Draft HS, the following two approaches have been adopted:

1. Part I results are produced under the assumption that the maximum TAC constraint from the Tier 1 percentages are always active (i.e. the maximum TAC is always applied).
2. Part II results are produced by simulating a parallel stock assessment process, which could under certain circumstances (precisely defined) lead to a TAC which is smaller than the maximum possible. The essential features of the simulated stock assessment process we have used are (a) it is assumed that the stock assessment model provides an annual absolute estimate of spawning biomass, (b) it is assumed that the Policy that drives TAC decisions is an MEY harvesting Policy, i.e. TAC = a proportion p_{MEY} of the spawning biomass, where p_{MEY} will drive the stock to B_{MEY}.

Implementation of the simulated stock assessment based MEY harvesting Policy

The basic implementation of the proposed HS is described in Appendix 2. We generate an estimate of p_{MEY} from its true value with error, with one value for each simulation which stays the same from year 1 to year 20 of the simulation period. This is then applied to a projected spawning biomass estimate for the forthcoming year. The assessments are assumed to yield an annual unbiased estimate of spawning biomass. In years in which there is a DEPM survey, the DEPM based spawning biomass estimate and the stock assessment based values are combined to produce a single value. Although the principle underlying their combination is inverse variance weighting, since they are both subject to the same C.V., they are in effect just averaged. A linear regression of annual spawning biomass versus time (i.e. year) is then carried out and the 'projected spawning biomass for current year' is calculated by extrapolation from the linear regression. The TAC = 'projected spawning biomass for current year' x erroneous estimate of p_{MEY}.

MSE Deterministic Analyses

Values of p_{MEY} and p_{CRASH} for four representative species

Harvest proportion results for Redbait (a), Redbait (b), Jack mackerel and Blue mackerel: p_{MEY}, the harvest proportion (of most recent DEPM) which drives the stock to B_{MEY} and p_{CRASH}, the harvest proportion (of most recent DEPM) which drives the stock to extinction.

Exploration of pMEY and pCRASH for a broader class of fisheries

The calculation of the values of p_{MEY} was extended to consider all fisheries of the following general form where the uniform distributions, U(a,b), are priors (this just means that for variable, eg. natural Mortality (M), it is assumed that it could lie between, 0.2 and 0.8 with equal probability):

1. Natural mortalities M (the age class independent natural mortality): U(0.2,0.8)
2. The von Bertalanffy parameter K in the length (L) to age (a) relationship $L = L_\infty(1-e^{-K(a-T0)})$: U(0.15,0.30) (the other parameters are L_∞ and T0)
3. The von Bertalanffy parameter T_0: U(-1.5,0)
4. Hockey stick kink: U(0.2,0.4)
5. Somatic weights are assumed to be a perfect cube of fish length (= L^3)
6. A plus group is assumed at age class 10, using 0 to index the year of recruitment
7. Fishing selectivities at age, S_a: $S_0 \sim U(0,0.3)$; S_a, for 1<a<4 ~ $U(S_{a-1},1)$; S_a, for a>4 = 1.00.
8. Fecundities-at-age, f_a: $f_0 = 0.00$; f_a, for 1<a<4 ~ $U(f_{a-1},1)$; f_a, for a>4 = 1.00.

A large number of draws from each of these uniform distributions were made using a random number generator in Excel, and the value of p_{MEY} was calculated for each draw. A histogram (posterior distribution) for p_{MEY} was built up from the set of all results. The final histogram gives an estimate of the probability distribution of p_{MEY}, subject to the priors and assumptions in 1-8 above. This is more efficient than, say, dividing each variable into ten equally spaced values on its assumed uniform range, and calculating each possible combination of values for, say 7 variables (10^7 calculations required instead of 30 000).

HS Performance against MEY as reflected by the HSP, and against the draft SPF HS.

A series of calculations were carried out for the four representative species under deterministic conditions. Catch and biomass, as well as cumulative catch under three different conditions were considered:

- An MEY harvesting Policy using the true known value of p_{MEY} ;
- 2/3 DEPM survey frequencies, under the assumption that the proposed harvesting constraints are always applied; and
- 1/5 DEPM survey frequencies, under the assumption that the proposed harvesting constraints are always applied.

The critical output quantity is the cumulative catch of a fishery managed solely by the constraints of the Draft HS, expressed as a percentage of the cumulative catch for the same fishery managed by an F_{MEY} harvesting Policy, a Policy which under deterministic conditions leads to the fishery arriving at B_{MEY} at the end of the simulation period (which is 20 years long in this document).

MSE Stochastic Analyses

The simulation framework used and described in Appendix 2 produces a range of output statistics, as follows:

1. Risk statistics, of which there are two, as discussed in Appendix 3. These are the 'once-off risk' and the 'percentage risk', both expressed relative either to a B_{lim} of B_{20} (i.e. spawning biomass at 20% of pristine) or B_{30} (i.e. spawning biomass at 30% of pristine). Note, the HSP uses a percentage risk.
2. Biomass statistics: (a) the spawning biomass at the end of a 20 year simulation period, either in absolute terms, or relative to pristine, as well as its standard deviation.
3. Catch statistics: The mean catch over a 20 year planning horizon, and the variation in catch defined as the average absolute percentage change in the catch.

The following notation for performance statistics is used in the presentation of the stochastic results:

freq ; this is the frequency of DEPM surveys assumed for the simulations

p_{max} ; the maximum harvest proportion assumed for the TAC formula (20% in the Draft HS)

Δp ; the rate of decline per year for the harvest proportion assumed for the TAC formula (2.5% in the Draft HS)

B_{lim} ; the limit biomass used for calculating biological risk ; spawning biomass at 20% of pristine

K ; the pristine spawning biomass

B_{start} ; the first year spawning biomass in the simulations

B_{start} / K ; the first year spawning biomass in the simulations divided by the pristine spawning biomass

B_{end} S.D. ; the standard deviation of the last year spawning biomass in the simulations (i.e. year 20)

B_{end} mean ; the mean of the last year spawning biomass in the simulations (i.e. year 20)

B_{end} / K ; the last year spawning biomass in the simulations divided by the pristine spawning biomass

Percentage risk (B_{lim}) ; the proportion of years across all simulations that the spawning biomass is < B_{lim} (see Appendix C definition of this measure of risk)

Once-off risk (B_{lim}) ; the proportion of simulations in which there is at least one year in which the spawning biomass is < B_{lim} (see Appendix C definition of this measure of risk)

Percentage risk (B_{30}) ; the proportion of years across all simulations that the spawning biomass is < B_{30}, where B_{30} is 30% of the pristine spawning biomass. *Note that the use of B_{30} does not imply a proposal to set B_{lim} = B_{30}. The reason is that the risks at B_{lim} were very small, so small that this measure of risk did not provide an adequate basis for discrimination between results for different variants of the model, and/or different harvesting policies. At B_{30}, however, more substantial risks are encountered which are thus more useful for discriminating results and drawing comparisons.*

Once-off risk (B_{30}) ; the proportion of simulations in which there is at least one year in which the spawning biomass is < B_{30}.

Mean catch ; the mean annual catch across all simulations and all years.

S.D. catch ; the standard deviation of the catch across all simulations and all years

Catch mean % change ; the mean of the absolute proportional change in catch from one year to the next

There are numerous factors that give rise to risk in the management of a fishery. In the simulation framework considered here, recruitment stochasticity and error in the spawning biomass estimates from the DEPM are the main factors which lead to risk.

For a number of variants of the models, a change is compared to a base case model. For the purpose of this document, the base case analysis is defined as follows:

1. Recruitment variability (S.D. of log of deviations from the deterministic model) = 0.6 as described above, and illustrated in Figure 2. Practically this means that there is a 32% chance that recruitment will deviate by more than between $e^{-0.6}$ and $e^{0.6}$ (0.55 and 1.82) of the deterministic value read off the hockey stick relationship in Figure 1.
2. Recruitment serial correlation = 0.0
3. Uncertainty in DEPM spawning biomass estimates, lognormal S.D. = 0.30%
4. Bias in DEPM spawning biomass estimates = 0%
5. Kink in hockey stick recruitment, spawning biomass as % of pristine = 20% (after the work of Myers *et al.* (1995))
6. Spawning biomass at beginning of simulation period as % of pristine = 48%
7. Spawning biomass at beginning of simulation period in MT: this will just scale the situation but does not alter the important performance statistics
8. Maximum harvest proportion for 2/3 or 3/5 DEPM frequencies = 20%
9. Decay rate of harvest proportion for 2/3 to 1/5 DEPM frequencies in steps = 2.5%
10. Part II (i.e. the simulated stock assessment process is enacted each year in the simulations).

Results

Biological Parameters of SPF species

Redbait is distributed throughout the off western Cape coast in south Africa, Australia, New Zealand, St. Paul and Amsterdam islands, and inhabiting depths of 86 – 500 m (Froese and Pauly, 2008). They grow to a maximum of 33.5 cm in Australian waters and up to 49.3 cm in south African waters (Welsford and Lyle, 2003). The maximum age recorded in Australian waters is 21 years (Neira *et al.* 2008). Redfish mature at 2 – 4 years of age in Tasmanian waters (Neira *et al.* 2008). They are bathy-demersal and feed mainly on large zooplankton (Froese and Pauly, 2008).

Jack mackerel is distributed throughout New Zealand and southern Australia, from Western Australia to New South Wales, inhabiting depths of 27 – 460 m (Froese and Pauly 2008). They grow to a maximum of 47.0 cm cm and live for a maximum of 16 years in Australian waters (Webb, B.F. and C.J. Grant, 1979). Jack mackerel mature at 2 – 4 years of age in Tasmanian waters (Kailola *et al.* 1993). They are benthopelagic and feed mainly planktonic crustaceans and small fish (Froese and Pauly 2008).

Yellowtail scad are distributed throughout New Zealand and southern Australia, from Western Australia to New South Wales, inhabiting depths of 22 – 500 m (Froese and Pauly, 2008). They grow to a maximum of 50 cm (Gomon *et al.* 1994) and a maximum age of 14 years in Australian waters (Stewart and Ferrell 2001). Yellowtail scad mature at 3 – 4 years (Kailola *et al.*, 1993). They are pelagic and feed mainly on small invertebrates (Froese and Pauly 2008).

Peruvian jack mackerels are distributed mainly throughout the eastern Pacific, New Zealand and Australia, in depths of 0 – 400 m (Froese and Pauly 2008). They grow to a maximum of 81 cm (Eschmeyer *et al.* 1983) and live for up to 30 years (Fitch 1956) off the west coast of the USA. Peruvian jack mackerels mature at 3 years of age (Hart 1973). They are a pelagic species and feed on zooplankton (Froese and Pauly 2008).

Australian sardines are distributed throughout the Pacific Ocean, as well as aournd southern Africa, inhabiting depths of 0 – 200 m (Froese and Pauly 2008). They grow to a maximum of 21 cm (Whitehead 1985) and a maximum age of 7 years in Australian waters (Whitehead 1985, Rogers *et al.* 2004). Australian sardines mature at 1 – 2 years (Rogers *et al.* 2004). They are pelagic and feed on zooplankton and phytoplankton (Froese and Pauly 2008).

Blue mackerel are distributed throughout the western Pacific Ocean, as well as some parts of the eastern Pacific Ocean (eg Mexico) inhabiting depths of 87 – 200 m (Froese and Pauly 2008). They grow to a maximum length of 44 cm (Froese and Pauly 2008) and a maximum age of 7 years in Australian waters (Stewart and Ferrell 2001). Blue mackerel mature at 2 years in New Zealand (Ministry of Fisheries 2008). They are pelagic and feed on zooplankton and phytoplankton (Froese and Pauly 2008).

Similarity between SPF species

When basic biological characteristics of SPF species are compared to each other, the species can be categorised into two broad groups (Table 2, Table 3). Redbait, Peruvian jack mackerel, yellow tail scad and jack mackerel form one group characterised as being moderately long lived and whose depth distribution extends over the shelf and slope (Table 4). The other group consisting of blue mackerel and Australian sardines have identical key biological characteristics to each other. Both are short lived species that inhabit shelf waters. Blue mackerel and Australian sardines both feed on zooplankton, and both mature at about 2 year of age.

Similarity of 'other species' to SPF species

Various stocks of herring and silver warehou were species most similar to red bait (Table 5), despite redfish being classified as demersal (bathy-demersal). If redfish was classified as bentho-pelagic or pelagic, the similarity to these species would be even closer.

Herring, American plaice and horse mackerel were the species most similar to Peruvian jack mackerel (Table 6). Relative similarity to the flatfish reflects identical maximum ages, and not other key biological characteristics. For example, American plaice are a demersal species that prey of invertebrates and fish. In comparison, Peruvian jack mackerel are a pelagic species that prey on zooplankton, however, both have a maximum age of 30 year, and inhabit shelf and slope waters.

Yellowtail scad were most similar to King mackerel, Mackerel icefish, black anglerfish and scup (Table 7). Grey mullet, herring and Spanish sardine were the most similar species to jack mackerel (Table 8).

Species similar to blue mackerel and Australian sardine are northern anchovy, gulf menhaden, sprat and sardine (Table 9, Table 11), all short lived, pelagic species that inhabit shelf waters (apart from northern anchovy that also inhabit shelf and slope waters).

In summary SPF species can be separated into two broad groups:

1. Moderately long lived species that inhabit shelf and slope waters — redbait, Peruvian jack mackerel, yellow tail scad, and jack mackerel; and
2. Short lived species that inhabit shelf waters — blue mackerel and Australian sardines.

When key biological characteristics were compared to 'other species', the moderately long live species were similar to herring, spotted warehou, American plaice, horse mackerel, grey mullet, Spanish sardines, King mackerel, Mackerel icefish, black anglerfish and scup. The short live group were similar to northern anchovy, gulf menhaden, sprat and sardines.

Qualitative SPF HS Review

Harvest Strategy Policy Objectives

The primary objective of the Commonwealth HSP is to ensure the sustainable and profitable harvest from Commonwealth fisheries in perpetuity. The stated objective of the draft SPF HS is consistent with this, being described as "The sustainable and profitable utilisation of the Small Pelagic Fishery in perpetuity through the implementation of a harvest strategy that maintains key commercial stocks at ecologically sustainable levels and, within this context, maximise the economic returns to the Australian Community".

As outlined below, with respect to biological and sustainability goals, there is good overall alignment between the overarching HSP objective and the Draft HS objectives detailed above. The Draft HS has recognised that some species harvested in this fishery may be "keystone" ecological species which might require special consideration as outlined in the HSP such as higher biomass reference points and the need to actively manage risks of localised depletion. These sub-objectives are evident in the Draft HS.

The Draft HS is less clear in its alignment with the HSP with respect to profitable utilisation and maximising economic returns. Understandably, many aspects of the Draft HS that endeavour to ensure ecological sustainability, necessarily have the potential to substantially impact on catches and/or vessel operations in the fishery. Justification of the purpose and extent of the ecological requirements and an explicit statement of the constraints that this places on the sustainable utilisation of these resources should be much clearer in the final SPF HS. A clear articulation of such sub-objectives, and their explicit purpose, will make the harvest strategy a more effective and strategic platform for future management and development of the fishery. If these sub-objectives are an important part of the SPF management environment but not well suited to inclusion in the HS, they could be included in the statutory management plan currently under development, or in subordinate documents.

The key elements of the Draft SPF HS objective are to ensure sustainability of target stocks, and to then ensure that these are harvested in the most cost effective and efficient manner (insofar as this can be accounted for and controlled within the HS framework). Despite this, the likely total costs (and specific costs attributable to industry or other stakeholders) arising from application of the Draft HS at each of the three management Tiers are not detailed in the document, or available in supporting information. This is a current deficiency in the Draft HS and the development process to date, even though it relates to one of the key objectives of the HSP.

It will be difficult for the SPF HS to encourage business confidence and certainty (another key objective of the HSP) where even the Tier 1 level research and monitoring costs are unknown and have not been evaluated. The HSP Guidelines note that economic efficiency implies that the fish stock is protected and that the net returns (profits) of fishers are maximised. Whilst the Draft HS delivers well against stock protection its economic performance is very difficult to quantify without substantially more information about monitoring and assessment costs.

At its Feb 2008 meeting during discussion about the likely costs of future DEPM agreed that costs are difficult to estimate and would be species and area specific…It is important that these costs are made explicit and more transparent if the DEPM approach is to form the cornerstone of Tier 1 assessments and exploitation levels.

Based on input from research providers a cost for a robust DEPM survey for one species in one known spawning area has been estimated to be in the vicinity of $50,000 plus survey vessel costs. Depending on the species, region and the vessel used, this could results in Tier 1 total reasearch costs between $0.6 m and $1.6 m per year (Table 18). Please note that these are very rough estimates that need to be refined by the research providers.

Core Elements of the Policy - HSP Reference Points

In relation to stock reference points the Policy requires that harvest strategies seek to:

- Pursue a target reference point (B_{TARG}) equivalent to Biomass at Maximum Economic Yield (B_{MEY})
- Maintain stocks above the limit reference point (B_{lim}) at least 90% of the time

In doing this, harvest strategies are required to consider ecosystem interactions - particularly where the species in question are a keystone species of the ecosystem.

Members of SPF MAC and RAG appear to largely agree that a longer term MEY based target for SPF stock levels is desirable. In the short to medium term, and noting that stocks are currently considered healthy, some industry members considered it more important to implement the Management Plan, allocate quota, and let any autonomous adjustment of fishing rights occur before focusing further on MEY based targets.

The current commercial environment is such that existing trigger catch levels and TACs where these are established are not being reached. There is little doubt that this is for economic reasons not because of reduced stock abundance. The proposed conservative exploitation rates suggested at Tier 1 of the HS should ensure that all of the target species for the fishery are maintained at high stock levels. Similarly such conservative harvest levels, and ensuing high levels of spawning stock will ensure that fishing mortality is very unlikely to deplete stocks below the HSP limit reference point more often than one year in ten on average, as required under the Policy. This is discussed in more detail in the MSE section of this review.

Nonetheless the likely costs of regular DEPM based assessments to maintain target species at Tier 1 levels of harvest are likely to substantially reduce aggregate fishery profits. There is a question whether this level of assessment confidence, and hence cost, is warranted where exploitation rates are deliberately conservative in an attempt to achieve broader ecosystem management objectives. The added ecosystem benefits of maintaining stocks at a level greater than B_{MEY} need to be well documented and quantified in order to justify foregone yield and potential fishery profits.

Straddling stocks or Joint Authority managed fisheries

This aspect of the HSP does not strictly apply to the SPF because it is not managed under a joint authority or an international management body. Nevertheless, the SPF stocks do straddle, and are managed by, different jurisdictions. Whilst there has been welcome collaboration in recent research and management of SPF species across their range, there is still a challenge to maintain the relative rights of Commonwealth SPF entitlement holders under the proposed SPF HS. The maintenance of strong access rights should facilitate improved stewardship of the resource by entitlement holders.

The Draft HS suggests that recommended SPF TAC's will be calculated by subtracting mortality arising from other measured sources of fishing mortality from the HS derived RBC's. It is not clear whether this refers only to mortality from other Commonwealth fisheries, or mortality arising from all other States and fishing sectors. A more appropriate approach in the event that catches need to be reduced, as used in the SESSF HS, is to encourage shared management responsibility by reducing catches from all jurisdictions consistent with historic catch ratios. It is unclear what the implications of previous allocation decisions would have on this approach.

Technical Evaluation of HS using Management Strategy Evaluation (MSE)

There is no reference throughout the Draft HS to an MSE process being carried out to date. This is not surprising with respect to the tight deadlines under which AFMA has responded to its HS development obligations. There is reference in the record of the December 2006 SPF RAG meeting to a MSE workshop in February 2007 however there is no further reference to this meeting being convened, or any outcomes from such a meeting. On a related front there is also a general absence of recorded discussion on detailed management objectives for the fishery. Such objectives could provide useful detail in relation to the overarching sustainability and profitability objective, and would enable a more accurate evaluation (ideally through MSE) of the various tradeoffs when balancing objectives, or assessing alternate objectives. For example should industry suggest that they value catch stability over a 5 year period with TAC changes of no more than 20% for economic reasons, rather than highly variable maximum catches as set by the exploitation rate against DEPM results, this may focus the MSE process and enable a more tailored and efficient HS approach. The quantitative evaluation of the Draft HS has been conducted as part of this review and highlights the potential variability of the TACs under such an approach.

HSP Guidelines Section 4.1 - Efficient and Cost Effective

The HSP and AFMA's legislative objectives require cost effective and efficient fisheries management. The guidelines recommend that harvest strategies and associated data collection and evaluation processes be carefully evaluated against this objective. It is not clear from the Draft HS, or associated meeting records, that this has been done explicitly for the SPF HS. A realistic total, as well as industry attributable cost estimate for supporting science associated with each Tier level should be available. This would enable a more objective assessment of the costs and benefits of different research and monitoring programmes, as well as the trade off in catches against costs when moving from one Tier to another.

AFMA's cost recovery Policy, as described in its Cost Recovery Impact Statement (CRIS) applies a beneficiary test to determine apportionment of research and monitoring costs. There has been some discussion of this in relation to the proposed SPF HS during recent stakeholder meetings – notably SPF MAC 4 in August 2006. The issue warrants further consideration in that the proposed HS is deliberately conservative to allow for an ecological allocation (presumably beyond that required to meet the standards of EBFM applied for other stocks in Commonwealth fisheries). This also results in the maintenance of higher than normal (normal being the suggested exploitation rates under the HSP for stocks approximating MEY) stock status. This may also reflect a desire to account for recreational and charter fishing interest in SPF stocks due to their importance in sustaining productive fisheries for key predators like marlin and tuna.

Although the HSP states that HS must recognise the trophic importance of certain key predator and prey species this is a difficult issue to quantify. Arguably the best expression of a healthy ecosystem would be one in balance at a point in time – say B_0. This suggests a consistent exploitation rate for all commercial species unless there is an explicit reason for preserving a greater portion of the stock, or allocating a portion to another user group. The Policy suggests that it is acceptable to harvest commercial species to maintain populations around B_{48} for example whilst for SPF species the draft approach suggests populations be maintained at higher values. In cost recovery terms, this appears inconsistent and suggests there is a significantly greater premium given to the environment, and possibly other fishing sectors in the SPF context. This raises the question whether an alternative to the standard fisheries management research apportionment of 80% industry funding should continue to apply in the SPF.

In the section titled Key Operational Objectives of the HSP the Guidelines suggest that some harvest strategies may maintain higher levels of stock protection than required by the HSP reference points where it is cost effective and efficient to do so. In the Draft HS, the basis for maintaining higher biomass levels appears to be because the species are keystone species ecologically; they are subject to high inter-annual variability in spawning output and productivity generally; and they are vulnerable to adverse environmental impacts and mass mortality events from time to time. As noted previously, there is a substantial economic impact from the maintenance of the proposed conservative exploitation rates and the real basis for these should be made clearer. It is not clear from the Draft HS or supporting information that such a conservative harvest approach is either cost effective or efficient. A harvest strategy with exploitation rates more aligned to the Policy settings for some target species may be more consistent with the HSP objectives.

Recognising that the SPF is to some extent a developing fishery, the HS should be structured to enable orderly, sustainable and profitable fishery development. It is difficult to meet this test when there is a real absence of information on the costs of various monitoring and assessment options. This is contrary to the intent of the HSP which seeks to allow an informed judgment of the relative costs and benefits of different approaches. Whilst Tiers 2 and 3 refer to analysis of fishery dependent data on catch and effort, and age structure of the catch, it is not clear what this entails, what indicators might be used to inform decision making, and indeed what is the difference between this analysis at Tier 2 and the dramatically reduced catches underpinned by similar analysis at Tier 3.

There is very little explicit discussion about the industry objectives for the HS, and how the HS relates to these both for the fishery as it presently operates, and in a more strategic sense as the fishery develops over time. The HS ideally will be part of a strategic plan for the SPF that offers a cost effective way to move forward with exploitation rates up to the point where they average around the agreed target reference points (whatever they may be).

HSP Guidelines Section 4.2 - Consistent with ESD principles.

The key principles of Ecologically Sustainable Development (ESD) are broadly recognised as:

- inter and intra-generational equity;
- improvement in material and non material well being;
- recognition of the global dimension of sustainable development;
- maintenance of ecological systems and protection of biodiversity; and
- application of precaution in decision making.

The Draft HS is broadly consistent with these key ESD principles however the highly precautionary nature of exploitation rates across species groups makes it very conservative in relation to the HSP target exploitation rates. Whilst conservation focused, this attribute may compromise performance against the ESD principle of improvement in material and non material well being (as previously discussed under economic efficiency).

The Draft HS also relies heavily on an assessment approach at Tier 1 that is relatively untested in the species context of redbait, blue mackerel, and jack mackerel species. The preferred DEPM method is also expensive relative to the current and likely near term GVP of the fishery. For these reasons it is likely to undermine aggregate profitability of the fishery and thus limit sustainable development.

The Draft HS explicitly addresses stakeholder and management concerns about localised depletion of SPF stocks. This is referred to both in the background section of the SPF HS, and catered for in the HS meta-rules.

It is unclear whether the concern relates to localised ecosystem impacts such as depletion in the vicinity of a seabird rookery, whether it relates to concerns by stakeholders such as recreational and charter fishers in relation to their own bait gathering needs and possible impacts on abundance and/or catchability of popular recreational species that prey on SPF species, or whether it is a concern that heavy localised depletion may adversely impact on stock sustainability or otherwise adversely impact stock dynamics. The management objectives in relation to localised depletion should be clarified to allow proper consideration of mitigation strategies. Importantly, any type of fishing causes localised depletion by its very nature, so it is very important to have a robust and quantitative definition of localised depletion that can be easily measured and interpreted in order to trigger an appropriate management response. This definition is missing from the Draft HS.

In one specific meta-rule it is stated that "To mitigate the threat of localised depletion SPFRAG also recommends that no more than 50% of any one catch limit be taken within a single five degree square". Given the localised nature of fishing for aggregated species, an analysis of the spatial pattern of commercial catches would need to be undertaken to ascertain the value of this rule and whether it is appropriate to apply to commercial fishing activities.

HSP Guidelines Section 4.3 - Decisions should be made within a process where the full costs and benefits of alternative approaches are made.

This is a key aspect of the HSP guidelines and a review of the information available suggests that HS development and discussions to date have been inadequate in this regard. It is a particularly important design criterion for smaller or developing fisheries which may suffer from an imbalance between harvest levels and research and management costs. As a minimum, cost estimates for all of the supporting research and data activities under the Draft HS should be determined, and then considered alongside possible harvest levels at each Tier. This will enable an informed evaluation of costs and benefits of alternate approaches, appropriate Tier Levels and facilitate longer term business planning.

Whilst a ratio of management expenses to GVP is a relatively simple measure of management efficiency it may prove a useful first step in cost effectively evaluating the suitability of proposed SPF HS approaches. It may be useful to separate this into an industry recoverable management cost ratio, and a total management cost to GVP ratio to benchmark the efficiency of both industry and government expenditure.

This approach, particularly if it identifies the additional information cost, or foregone catch value, arising from conservative harvest rates may also inform consideration of whether or not there are some SPF HS management costs levied to industry that should more appropriately be levied against the public good (e.g. Broader Marine Research funding under AFMA's CRIS).

HSP Guidelines Section 4.4 – a high level of transparency in decision making.

This is a key element of the HSP guidelines with a basis in ensuring due process and administrative fairness in regulatory decision making. There are two suggested improvements for the SPF HS development process. The first is that the structure and operation of the research and assessment strategies being proposed to underpin HS decision making are made clearer to stakeholders through plain English descriptions. This should include reasonable clarity on how information will be analysed to inform decisions on catch levels at various Tiers.

The second relates to the absence of detailed estimates of implementation cost for the various SPF HS Tiers. This has also been an area of some discussion within the RAG and MAC with the RAG acknowledging at its February 2008 meeting that DEPM costs are difficult to estimate and would be species and area specific. An accurate estimate of these costs is essential to enable adequate stakeholder consideration and facilitate informed decision making. This is particularly important for a developmental fishery where current economic pressures are significant and will remain an important determinant of fisher behaviour.

HSP Guidelines Section 4.5 – A high level of confidence that objectives will be met.

With regard to sustainability and conservation objectives of the HSP the proposed conservative approach to exploitation generally delivers high confidence that these objectives will be met (but see quantitative evaluation of Redbait b).

With regard to economic efficiency, the proposed approach, particularly in the absence of management cost information, warrants improvement. In accepting very conservative exploitation rates, even at Tier 1 of the HS, it is likely that substantial yield from the fishery will be foregone. Whilst this may yet prove to be the most appropriate approach, the basis for adopting it should be made clearer. This is particularly relevant where the HSP default settings suggest lower biomass targets than those proposed for SPF species.

The available information provides limited insight into the explicit management objectives of industry within the constraints of the HSP framework. Until these are clearly articulated it will be difficult to assess the suitability of the proposed HS approach, or to conduct detailed MSE to quantify HS performance against these important but more commercially focussed management objectives.

HSP Guidelines Section 4.6 – Taking species life history into account

The HS appears to recognise the biological and life history characteristics of target species for the SPF although there are some important underlying assumptions that should be further examined. The proposed approach appears predominantly designed to cater for short lived highly variable stocks like sardine. Whilst there is a paucity of information on life history and key biological parameters of other SPF species such as redbait, blue mackerel, and jack mackerels, it is known that they are significantly longer lived than sardine and adult stock levels are less likely to be highly variable over a one or two year period. These attributes are discussed in more detail in the section on biology and life history characteristics of SPF species.

There is also some reference to boom and bust cycles, and mass mortality events for SPF species used to support the conservative exploitation rates underpinning the proposed HS. Again these assumptions may be more relevant to sardines and anchovy than blue mackerel, redbait, and jack mackerels. If further consideration suggests this is a key management risk then it may be more cost effective to address it through the use of meta-rules or exceptional circumstance provisions within the HS. These could apply if and when such an unlikely event occurs rather than a consistent strategy of precaution underpinning the HS.

HSP Guidelines Section 5 – Economics and Harvest Strategies

This section of the HSP guidelines provides detailed advice on the importance of maintaining stocks at levels that approximate Maximum Economic Yield (MEY), and the challenges therein. This issue and its relevance to the SPF HS at this point in time are addressed in more detail in the analysis of Core Elements of the HSP. Noting the relatively low value of the SPF, its developmental nature, and the current business climate for the fishery, a detailed analysis and estimate of yield levels that might equate to MEY is premature. The current approach to adopt very conservative stock exploitation levels, whilst it has the potential to significantly limit catches in the fishery, is likely to ensure that stock levels of SPF species are maintained well above the HSP reference points. It is important to understand that any stock biomass either above or below B_{MEY} is sub-optimal for a MEY goal. Nevertheless, the maintenance of high stock levels should ensure that the transition to an MEY based reference point in the future (if this is deemed appropriate), will be simplified and easier than if stock are below their biomass target.

It should be recognised that under the current SPF fishing permit based system there is a risk that fishery profits will be diluted through competitive behaviour of permit holders. Whilst perhaps unlikely in the current economic climate, the risk will increase substantially should the fishery begin to realise significant profits through further efficiencies, or a change in key economic variables. Whilst the proposed conservative TAC and triggers, and the high levels of investment needed to capitalise on the fishery will mitigate this risk, the importance of ensuring more secure access rights for entitlement holders with the allocation of Statutory Fishing Rights under a Management Plan should not be underestimated.

HSP Guidelines Section 6 – Management Tools

The proposed SPF HS uses a range of contemporary management tools to meet its stated objectives. In general terms these are consistent with the HSP and guidelines. Whilst the strategies and management instruments used under the HS should be relatively efficient, the management objectives for the fishery are less clear. A tighter connection between the stated management objectives (and any sub-objectives), and how the management tools and proposed decision rules will efficiently achieve these objectives will be valuable.

The HSP Guidelines note that there should be *a strong connection between the fishery's management objectives, the selection of appropriate management tools, the data strategy and supporting research and scientific work, and the available resources.* The nature of these relationships could be made more explicit in the proposed HS.

HSP Guidelines Section 7 – Dealing with Different Levels of Information, Assessments and Data Poor Species.

The proposed HS approach recognises the limitations arising from the paucity of scientific understanding of most SPF species. Nonetheless it is clear that there are a range of species characteristics across the SPF that suggest life history and biology should be further considered and incorporated in the proposed HS. In particular it appears that SPF species can be reasonably characterised into two key groups. The first is the shorter lived and probably more productive sardine and blue mackerel stocks; the second is the group of species comprising redbait, jack mackerels and scad. The consequences of not including these key biological differences in the stock specific harvest strategies are further evaluated in the quantitative MSE section of this review.

Importantly the guidelines note that where information is generally good, but insufficient to reliably estimate MSY or MEY based reference points, the HSP specifies that certain stock levels should be used as proxies for these reference points. These are:

- For B_{MSY} a proxy of equal to or greater than 40% of the unfished adult biomass; and an equivalent level of fishing mortality to maintain stocks around this point.

Whilst a judgement on whether or not the supporting information in relation to SPF species is generally good and thus whether these proxies should apply is difficult there appears significant scope to reconsider the target exploitation rates so that they are more representative of the levels specified in the HSP. The Policy explicitly recognises the need to tailor key HS settings to each fishery and its unique management objectives however the chosen settings should be consistent with those of the Policy.

In the current management context of the SPF, harvest levels that will be based on application of both Tier 1 and two appear to apply. In qualitative terms these Tiers appear to operate efficiently relative to each other with respect to managing risk, and the cost of information gathering. In absolute terms there is a significant question as to whether ongoing application of the DEPM approach is the most cost effective and efficient approach at Tier 1, and whether the additional cost associated with a Tier 1 approach delivers an appropriate dividend in terms of both stock protection and higher exploitation rates.

The catch levels suggested at Tier 3 appear very conservative and it is not clear how the level of information, analysis and cost applied respectively at Tiers two and three differ substantially so as to justify the major difference in allowed catch between those Tiers. Similarly the circumstances under which Tier 3 would be expected to apply are not clear. It may be intended for previously unexploited species where there is very little or no data and knowledge available.

In general, the use of Tiers within the HS is consistent with the Policy and guidelines. The Tiers recognise that the management risk associated with a particular harvest level of SPF species increases as the level of knowledge on those species reduces. Tiers one through three manage this risk by a corresponding reduction in TAC through Tiers.

HSP Guidelines Section 8 – Dealing with Uncertainty and Risk

The risk that the proposed SPF exploitation rates alone will result in stock depletion below the standards required from the Policy appears very low. The chosen approach performs strongly in this context however as discussed previously there is a significant trade off between this performance and the subsequent reduction in available yield from the fishery. This trade off does not appear entirely consistent with the stated objectives for the draft SPF HS which appear to place significant emphasis on economic performance of the fishery.

The uncertainty inherent in applying the DEPM approach for Tier 1 assessments is also not explained clearly in the HS. The assumption is that the chosen exploitation rates which vary from 10 to 20% of estimated biomass depending on the age and reliability of assessments implicitly account for errors and uncertainty in those assessments. Similarly the issues around whether or not such surveys are likely to represent the true adult population of the target species, and if not what correction may be applied to account for this are unclear.

The MSE section of this review provides more detailed analysis of the performance of the proposed HS with respect to balancing exploitation rates against adverse impacts on stock sustainability.

HSP Guidelines Section 9 – Dealing with High Variability

The Draft HS suggests that the life history characteristics of SPF species have "*the potential for large, unpredictable inter-annual variations in availability and/or abundance*" and "*high inter-annual variations in biomass that are a characteristic of small pelagic fishes, and incidences of mass mortality episodes that are fishing independent…*" From this, it is suggested that the "*SPF fishery is vulnerable to boom and bust cycles*". These assumptions are an integral part of the approach taken in the Draft HS, yet the information supporting this is not apparent for most of the species and some of the information points to the opposite conclusion – that recruitment is somewhat consistent over time and the populations seem reasonable stable. This is concerning and warrants a much closer investigation of the evidence of "boom and bust" as a reason for taking a more conservative approach to the HS.

Information suggests that SPF species are highly dependent on oceanic conditions and associated production for both stock productivity and availability to the fishery. The proposed approach recognises this at Tier 1 with harvest levels set at a consistent proportion of estimated Biomass depending on the assumed reliability of the DEPM assessment. The likely outcome of variability with respect to ocean currents / temperatures is that there will be considerable spatial fluctuations in the fishery. The ability to capture this spatial dynamic in the DEPM and account for it in Draft HS is not clear. Whilst the DEPM approach may be quite suitable, the cost of the DEPM is substantial and a more cost effective approach to the frequency / location of DEPM surveys (or alternate assessment approaches) to cater for spatial and temporal variability in the stocks needs to be determined. It is important that this information is augmented by other population information – particularly the age composition of the stock.

HSP Guidelines Section 10 – Stock Rebuilding Strategies and Stock Recovery Plans

Not applicable to the SPF.

HSP Guidelines Section 11 – Translating Recommended Biological Catch (RBC) into Total Allowable Catch/Effort

The Draft HS approach recognises the Policy requirement to ensure that fishing mortality from all sectors and jurisdictions be taken into account when setting TAC/TAE. Under the proposed approach mortality from other sectors is subtracted from the RBC to give the TAC for a particular stock. This effectively gives primacy to catches from other fisheries or sectors, both State and Commonwealth, and thus has the potential to reduce the property rights of SPF entitlement holders. Current catches suggest that this is not currently a major issue however should the business environment change in this or other fisheries, unconstrained catches in other jurisdictions may exacerbate this problem.

At the lower tiers the Draft HS also relies on the expert judgement of the RAG to determine harvest levels after consideration of relevant catch and effort information. There is very little detail provided on what information will be considered, and how this will be interpreted to develop catch recommendations in the absence of a clear decision rule such as that proposed for Tier 1. Whilst expert judgement is an important element of cost effective decision making, there is a risk that unless the parameters for such judgements are adequately explained such an approach may reduce the consistency and objectivity of advice and subsequent decision making. This in turn may undermine a key objective of the HSP that is to increase the business certainty, transparency, and efficiency of decision making.

HSP Guidelines Section 12 – Developing Fisheries

In some respects the SPF is best characterised as a developing fishery, however in others it is relatively stable. Nonetheless the key fishery characteristics of a paucity of quantitative stock assessment information for most parts of the fishery, incomplete knowledge of stock structure, including spatial boundaries, and evolving fishing practices and marketing strategies that may substantially change the SPF business environment mean that many of the approaches suggested for developing fisheries are relevant.

The Guidelines note that where there is a genuine paucity of biological, life history or stock structure information then precautionary initial catch setting, good fishery independent and fishery dependent information, and ongoing feedback are key elements. These attributes are present in the existing SPF Management Policy to varying degrees, and are similarly represented in the Draft HS. The challenges of suitable and cost effective fishery monitoring remain and are further addressed later in this review. The importance of collecting age and size structure of exploited populations to assist in determining unfished stock parameters is key and is reflected in the suggested monitoring program as a baseline monitoring requirement for any SPF fishing activity.

In general terms the proposed SPF harvest strategy strikes a good balance between the developmental aspects of the fishery and the more established harvest sectors. The rationale for highly conservative harvest levels at Tier 3 warrants further explanation, particularly when compared with the information requirements at Tier 2, and its markedly higher exploitation rates.

SPF MAC and RAG have identified the importance of a strategic research and monitoring plan for the fishery. The nature of the information required, and how it relates to the stated management objectives for the fishery (and can be most efficiently obtained) is an important element of the Draft HS which could be better quantified.

Cost issues remain a key consideration in a developing fisheries context and the harvest strategy should aim to ensure that the monitoring and assessment regime for the HS allows for the best possible dividend from the knowledge gained. This is difficult to ascertain under the current proposed approach due to the lack of detailed cost information on monitoring and assessment costs, and how expert judgement is likely to be applied to recommend catch levels at Tiers two and three.

The suggest Draft HS meta-rule which allows for "*potentially higher catches for short periods (few years) if conducted in conjunction with a significant research program*" is an acknowledgement of the developing nature of the fishery. It needs to be accompanies by an indication of the extent of the higher catches and requirement of the research program. These need to be developed and agreed at the RAG / MAC level with adequate input from all stakeholders.

HSP Guidelines Section 13 – Exceptional Circumstances

These are catered for in the Meta-rules section of the SPF HS. The inclusion of meta-rules and their content are a valuable part of the proposed approach. The opportunity for SPF RAG and/or MAC members to request further consideration of the application of a decision rule is sensible, as is the requirement that this consideration be evidence based. It is important to recognise that there may be aspects of the proposed harvest strategy that relate to legislation and or Policy requirements outside of the scope of the HSP, and that may still impact on exploitation levels in the fishery. An avenue for due consideration of these is important.

In addition to unspecified events catered for in General Application of the SPF HS Meta-rules, there are a range of actions prescribed to manage broader ecological impacts of the fishery. The suggested response to significant interactions with threatened endangered or protected species may be better detailed within the SPF Management Plan or subordinate documents such as the Bycatch Action Plan, and then cross referenced to the HS in the context of possible reductions in the TAC for SPF target species. The broader environmental impacts described are by-catch management issues rather than decision rules to manage the harvest of key commercial species as envisaged by the HSP.

As discussed previously the true meaning of the term localised depletion could be described more accurately, particularly if it is a subsidiary management objective for the fishery and is likely to have significant impacts on vessel operations. Similarly changes in age/size structure as described in meta-rule number two may not actually warrant a reduction in catch, or another form of management intervention. Whilst well intended, the real purpose of this rule is unclear and it has the potential to undermine business confidence, transparency, and objectivity in HS derived decision making.

HSP Guidelines Section 14 – Management Strategy Evaluation

Whilst both the HSP and guidelines recognise the importance of some form of Management Strategy Evaluation in the development and refinement of harvest strategies it should also be acknowledged that extensive MSE can be a highly technical and resource intensive undertaking. A key challenge in the development of many of AFMA's harvest strategies has been achieving a balance between the Policy requirements for MSE, the large number of harvest strategies being developed for a diverse range of fisheries, the short timeframe available to AFMA and harvest strategy developers, and the limited resources with which to undertake MSE for these various HS.

The HSP suggests that "Harvest Strategies should be formally tested in order to demonstrate that they are highly likely to meet the Core Elements of the Policy". There is reference in the record of the December 2006 SPF RAG meeting to a MSE workshop in February 2007 however there is no further reference to this meeting being convened, or any outcomes from such a meeting.

An initial quantitative MSE of the proposed SPF HS has been undertaken as part of this review. This is not meant to replace the potentially more detailed MSE that might be undertaken at the request of the RAG at some future time. There is potential, however, for the modelling framework that has been developed as part of this project to be adapted to a more specific MSE.

HSP Guidelines Section 15 – Amending Harvest Strategies

The Policy acknowledges the developmental nature of harvest strategies, particularly in their initial stages. The Draft HS provides for a HS review process within the first 12 months and then every three years after that. The meta-rule section also makes provision for SPF MAC and RAG members to seek a review of the application of decision rules on an evidentiary basis. These are all sound initiatives that recognise the realities of applying new HS in a diverse range of Commonwealth fisheries in a short timeframe.

It is hoped that this review process will also substantially improve the performance of the final SPF HS against the Policy requirements and relevant fishery specific management objectives.

MSE Deterministic Analyses

Values of p_{MEY} and p_{CRASH} for the four representative species

The basic values of p_{CRASH} and p_{MEY} for the four fisheries as defined are as given in Table 12 for the base case 20% hockey stick kink (for the stock recruitment relationship). A sensitivity test at a kink of 40% was also run – see Table 13.

For jack mackerel and blue mackerel the values of p_{CRASH} and p_{MEY} for the four fisheries (see Table 12) are well in excess of the 20% which is the maximum permitted in terms of the Draft HS. For Redbait (a and b) they exceed the 20% maximum permitted in terms of the Draft HS, but the margin of error is not as large as in the case of jack mackerel and blue mackerel.

Note that based on its value of natural mortality, Redbait, either (a) or (b), seems to be 'non-SPF like', taking as the archetype for small pelagics of the world, anchovy and sardine species. For these species, natural mortalities usually exceed 0.5, while the published natural mortality estimate for Redbait is in the order of 0.25. This has implications for the merits of the Draft HS for something like Redbait, which provides for an upper constraint on the TAC calculated as a percentage of the most recent DEPM spawning biomass estimate (or the last two in certain cases). The greater 'memory' in populations with $M < 0.5$ (the higher number of age classes in the spawning biomass) could mean that superior harvesting strategies could be developed by using a longer data history (e.g. the last 6 years of spawning biomass estimates) in the formula underlying the HS. This may also reduce the likelihood of highly variable TACs based on the DEPM method. However, out of Redbait, Jack mackerel and Blue mackerel, Redbait (a or b) is also the species where it is most likely that the harvest proportion constraints of the Draft HS will not become activated. This is because Redbait (a or b) has the smallest values of p_{MEY}, so that when one pursues an MEY harvesting strategy, there is a greater chance that the TAC will be less than allowed by the draft constraints of the proposed HS.

The converse to this is that the Draft HS constraints are more likely to come into effect for the more genuine SPF-like species with higher natural mortalities, where safe harvest proportions (of spawning biomass) are apparently in excess of the proposed harvest proportion constraints.

Exploration of p_{MEY} and p_{CRASH} for a broader class of fisheries

The histogram of p_{CRASH} and p_{MEY} for the fisheries given by the set of uniform priors defined in the Methods is presented in Figure 4. Figure 5 - Figure 9 show the relationship between some of the individual variables in the list and the values of p_{MEY}.

The histogram in Figure 4 has a mode which is smaller than 20%. However, Figure 5 - Figure 9 show that natural mortality is the crucial determinant of $p_{MEY.}$ By using a prior on M of U(0.2,0.8) we have deliberately extended the analysis beyond the realm of what would normally be considered a small pelagic species, i.e. allowed for natural mortality values smaller than 0.5. Under management by the Draft HS, redbait b performs closest to the HSP with respect to the MEY target. This is mainly because redbait b has an estimated natural mortality which is smaller than 0.3, while for redbait a, Jack mackerel and Blue mackerel, natural mortality is larger than 0.6 during part of their life history.

Economic comparison between the two management objectives: MEY as specified in the HSP, and as proposed in the draft SPF HS

These results are presented in Table 14 - Table 17 and Figure 10 - Figure 13.

The potential economic value (using gross catch as an approximation) of the fishery under Draft HS management compared to MEY management is expressed in percentage terms. Draft HS based catches (i.e. catches in which the Draft HS harvest proportions are always enacted) as % of the MEY catches vary depending on the frequency of DEPM surveys, and the initial resource abundance relative to pristine. For the four species considered, the percentages are (see Table 14 - Table 17):

Redbait (a): 74% - 87.2%,

Redbait (b): 78.8% - 92.3%,

Jack mackerel: 47.4% - 58.0%,

Blue mackerel: 56.9% - 67.9%.

Particularly for the species with a high natural mortality (M>0.5, i.e. Jack mackerel and Blue mackerel), the proposed Draft HS suggests a substantially reduced cumulative catch compared to an MEY harvesting Policy (under the base case conditions simulated). Further, the biomass levels achieved for these species under the Draft HS are well above B_{48} stipulated in the HSP, ranging from 53% for Redbait b, 56% for Redbait a, 67% for Blue mackerel and 72% for Jack mackerel.

MSE Stochastic Analyses

Where Bstart = 0.48 K, Base Case, considering slightly different HS proportions

Table 19 - Table 22 shows Part II (i.e. dual stock assessments are included in the simulations) stochastic results for the base case where the initial spawning biomass is at 48% of the pristine spawning biomass. Results are shown as a set for the 3/5, ½ and 1/5 DEPM survey frequencies.

This same set of results is repeated for two alternative HS harvest proportions, i.e.

Alternative HS I: Maximum proportion = 20%, decay rate = 2%

Alternative HS II: Maximum proportion = 25%, decay rate = 2.5%

The stochastic results presented in Table 19 - Table 22 illustrate a number of features and issues for the evaluation of the Draft HS:

- In all cases, despite the fact that the stock assessment process is modelled with an MEY harvesting Policy, the resource ends up at larger than 48% of pristine. The closest value to 48% in the set is a spawning biomass of 51.5% of pristine (Redbait (b) 7th column in Table 20).
- The biological risks, measured as the percentage of time the resource falls below B_{lim}, are very small. All values obtained for risk are less than 1%.

When these results are considered in aggregate they suggest that the Draft HS is more conservative than either (a) the stated objective of MEY, or (b) a 10% risk level with respect to B_{lim}. Less conservative harvest proportions could be entertained and the MSE suggests that these could be constructed to nevertheless be more conservative than the default settings of the Commonwealth's HSP. This is illustrated by the last three columns of each of Table 19 - Table 22, which use harvest percentages 2.5% larger (e.g. 22.5% instead of 20%) than those in the Draft HS. *This statement needs to be seen in the context that the measures of risk are subject to the size and scope of uncertainty built into the simulation model. This could be expanded or increased, in which case risks may increase.*

Risk equivalence as described above can be assessed by inspection of changes in risk for different DEPM survey frequencies. The Draft HS risks in Table 19 for B_{lim} are all smaller than 0.05% and are thus not useful for such comparative purposes. Risks at 30% of pristine are more useful, and for Redbait (a) the values are 0.007, 0.007 and 0.008, suggesting a degree of equivalence for the DEPM survey frequencies of 3/5, ½ and 1/5. If anything, this result points to the use of a slightly larger decay rate to offset the slightly larger risk at 1/5 of 0.008. Interestingly, the mean catches decline as the DEPM frequency declines. This supports the performance of the proposed SPF HS whereby for less research input, less value can be extracted from the fishery at the same biological risk. This applies for all Table 19 - Table 22, although one needs to verify risk equivalence in each case.

The use of maximum 20% and decay rate 2% gives risks at 30% of pristine of 0.009, 0.008 and 0.009, and the use of maximum 22.5% and decay rate 2.5% gives risks at 30% of pristine of 0.017, 0.013 and 0.014, perhaps indicating the use of a smaller decay rate to achieve equivalence (Note this suggests a 1.3% to 1.7% chance of breaching B_{30} – the risk of breaching B_{lim} would be much smaller).

The variation in the catch implied by the Draft HS is considerable, ranging from a mean of 19.2% (see Table 20 - 20% / 2% 1/5) to 47.8% (see Table 21 - 22.5% / 2.5% 1/5). It should be noted that a HS that induces such a high degree of variability in the TAC may substantially undermine economic efficiency in that overcapitalisation could occur as companies/fleets struggle to efficiently use the occasional large TAC that might arise as a result of an unusually large DEPM estimate. Related infrastructure and employment impacts may also arise. In some other fisheries where management procedures or decision rules are applied (see for example De Oliveira and Butterworth, 2004), an objective may be to limit annual changes in future TAC to a set percentage of current TAC. Such an approach may be appropriate here. For the Draft HS, the proposal is limited to the consideration that "*If two successive DEPM assessments produce significantly different spawning biomass estimates SPFRAG will, on the merit of the assessments and all other supporting information, exercise its judgement on which assessment to use when deciding on an RBC for a particular stock*." Given that there is a large element of judgement involved, this decision process has not been modelled except for the extent to which a stock assessment process has been simulated.

Table 19 - Table 22 shows a large variance in the resource biomass at the end of the simulation period, with a C.V. of 30 – 40%. This is a fairly typical result, and further refinements of the HS may aim to narrow the bounds on this, which has obvious spin-offs for the reduction of risk.

Where Bstart = 0.48 K, Base Case, the role of the stock assessment process

Table 23 compares the Part I and II results as defined previously, where Part I enacts the Draft HS harvest proportion at all times, while for Part II a parallel stock assessment process is assumed to occur. In some cases the stock assessment leads to a TAC which is smaller than that which is given by exploitation rates proposed in the Draft HS.

Table 23 shows that the presence of the parallel stock assessment process makes very little impact on the simulation results. This means that the Draft HS harvest proportion constraints are usually active, and it is only very occasionally that a smaller TAC is recommended from the stock assessments.

Exploration of a number of variants to the base case

The following variants of the base case analysis are presented for each of the four species:

1. B_{start} = 0.15 K

2. B_{start} = 0.30 K
3. B_{start} = 0.75 K
4. ρ, the serial correlation of the log-recruitment deviation from deterministic = 0.5 (instead of 0.0 in the base case)
5. DEPM survey biomass estimates are positively biased by 50%.
6. Kink in the recruitment relationship is at 40% of pristine (not 20% as in the base case).

The results are presented as follows:

Redbait (a) – Table 24
Redbait (b) – Table 25
Jack mackerel – Table 26
Blue mackerel – Table 27

Note that for these results (Table 24 - Table 27) a parallel stock assessment was included in the simulations.

1. B_{start} = 0.15 K; as one would expect the risks increase for this variant because the resource is in a very depleted condition at the start of the simulation period.
2. B_{start} = 0.30 K; as for the above, the risks increase for this variant compared to the base case.
3. B_{start} = 0.75 K; for obvious reasons, risks are reduced.
4. ρ, the serial correlation of the log-recruitment deviation from deterministic = 0.5 (instead of 0.0 in the base case) ; this seems to produce a reduction in risk, but the exact reasons for this were not elucidated in the analyses.
5. DEPM survey biomass estimates are positively biased by 50%. Here we see an increase in risks, since this leads to larger catches being taken overall.
6. Kink in the recruitment relationship is at 40% of pristine (not 20% as in the base case). Larger risks are associated with this sensitivity test.

Where Bstart = 0.48 K, considering substantially different HS proportions

As a result of the results obtained using Alternative HS I and Alternative HS II (see above), additional stochastic results were produced using an alternative that is substantially more aggressive than the Draft HS, i.e.

Alternative HS III: Maximum proportion = 30%, decay rate = 2%.

The results of this set of simulations are presented in:

Redbait (a) – Table 28
Redbait (b) – Table 29
Jack mackerel – Table 30
Blue mackerel – Table 31

For these simulation runs, results are compared at three different DEPM survey frequencies, and both with and without the parallel stock assessment process.

Results for Redbait (a) with no parallel stock assessments, or Redbait (b) with or without stock assessments suggest that the stock would fall to slightly below B_{48}. All other cases considered can cope with the more aggressive approach to harvesting suggested by this alternative to the Draft HS with the stock remaining well above B_{48} at between 55% and 65%

B_0. It would be advisable, however, to check this against the variants to the base case which was not done during the simulations. Risk equivalence is not satisfied suggesting that a higher decay rate needs to be considered.

Harvest Strategy Research and Monitoring Costs

At Tier 1 the proposed draft SPF HS uses the daily egg production method (DEPM) to estimate stock size prior to TAC recommendation via the HS decision rules. Alternative approaches have been discussed at meetings of the SPF RAG and MAC and one objective of this review is to *advise on a strategy to develop a cost effective, industry based approach to acquiring information relevant to stock assessment to supplement or replace the DEPM approach.*

The discussion below considers international examples of acoustic and aerial surveys conducted on small pelagic species, and provides an estimate of the costs involved in implementing such an industry based monitoring programme for the SPF.

Acoustic Surveys

Acoustic surveys are used throughout the world to estimate biomass of many small pelagic species. Acoustic methods have the advantage of collecting large volumes of data very cheaply, and the ability to estimate absolute biomass over the area sampled. Acoustic surveys are ideal for species such as small pelagics that form patchily distributed, mobile schools (Everson *et al.* 1996).

Simrad ecosounders (models EK60 and EK 500) were most common equipment reported in acoustic surveys for small pelagics. Ecosounders were usually operated at frequencies of 38 kHz and 120 kHz, however many surveys used multiple frequencies which were analysed simultaneously (eg Massé *et al*., 2005). For example, the EK60 can operate seven echo sounder frequencies simultaneously ranging from 18 to 710 kHz. Standard methods for calibration of acoustic equipment were usually cited as being the standard sphere method (Foote *et al*., 1987).

Acoustic Mark Composition

Acoustic surveys were nearly always accompanied by either bottom or mid-water trawling (depending on behaviour of target species and time of day) to obtain the species composition of marks (eg Ohshimo, 2004). Ecotrace characteristics can also be used in conjunction with trawl catches to identify species composition of marks (Bertrand *et al*., 2004). RAG members have suggested that dual Sabiki jigs have been successful in determining species composition of acoustic marks in the SPF.

The frequency of trawl shots varied in these studies, but were usually determined by one of two methods. The first was by spacing them at regular intervals along the transects with the number of sites determined by available resources. This strategy is most appropriate for broad-scale, multi-species surveys. Alternatively trawl shots can be conducted on an ad-hoc basis, when ever a large school of fish are acoustically observed.

Once on-board, the trawl catches were separated into species and the weight of each component measured or estimated. Species composition was used in analyses of biomass. Biological samples can also be taken from these trawl catches.

Survey timing

Timing of the surveys was dependent on the aims of the survey and the biology or behaviour of the target species. Some surveys estimate recruitment (eg Barange and Hamilton, 1997) and so are conducted just after spawning time, while others aim to estimate the spawning biomass, and so are conducted during the formation of spawning aggregations (eg Reiss *et al*., 2008). Vertical migration of fish can influence effectiveness of acoustic survey through school dispersal, and also avoidance of the nets (Ohshimo, 2004). Massé *et al*. (2005) found that schools of anchovy grouped very close to the surface during night and so "disappear" in the blind layer from the echo sounder between the surface and 10 m depth. Conversely, schools that are too close to the sea floor can be difficult to discriminate from the bottom mark.

Survey design

Surveys aimed at estimating total biomass usually employed parallel transects that were either equal distances apart (Zhao *et al*., 2003) or randomly stratified (Hampton, 1996) (Figure 14). Random stratification of transects based on expected biomass or variance of biomass improves estimates of mean biomass and variance (Jolly and Hampton, 1990). Survey transects were usually conducted perpendicular to the shore line, and the distance between transects varied depending on the size of the area to be sampled, and on the available resources. Surveys covering large areas had transects that were 12–35 nm apart, while surveys aimed at smaller areas or specific schools of fish work on transects that were much closer together (ie 0.1 nm). Vessel speeds during acoustic surveys were rarely reported, but were usually close to 10 knots and ranged 3.5–10 knots.

Acoustic Survey Techniques - Ancillary Data

Conductivity, temperature and depth (CTD) data are essential in the interpretation of results. CTD data were usually collected in during surveys using one of three methods:

- stand alone CTD units with are lowered independently of other gears and log salinity, temperature, depth and time;
- net mounted units which are deployed during trawl shots; and
- moored CTD stations.

Acoustic surveys used to estimate biomass small pelagic species and methods used are shown in Appendix 1.

Egg Production Surveys

Egg production surveys are sometimes carried out in conjunction with acoustic surveys. Combining the two different estimates of biomass can improve confidence in results. Eggs are normally sampled using either continuous under-water fish egg sampler (CUFES) or towed/hauled plankton nets at sampling stations. CUFES has the advantage of sampling a wide area at a high flow rate (up to 650 l/minute) without interrupting the acoustic survey by slowing the vessel down. However, the depth range of samples is limited to within 3 m of the surface. The continuous nature of CUFES makes this technique particularly useful to sampling species whose distribution of eggs is highly patchy, allowing more precise estimates of egg abundance and population biomass (van der Lingen *et al*., 1998). CUFES consists of a submersible pump, concentrator, and sample collector. CUFES has been successfully used to sample the eggs of sardine (*Sardinops sagax*), round herring (*Etrumeus whiteheadi*), menhaden (*Brevoortia tyrannus*), pinfish (*Lagodon rhomboids*) and northern anchovy (*Engraulis mordax*) (van der Lingen *et al*. 1998). Plankton nets can be either towed or lowered to nominated depths and retrieved vertically to sample through the entire water column. Vertical tows are generally considered the best sampling methods for fish eggs (Allen *et al*., 2006), with the CalCOFI Vertical Egg Tow (CalVET) Net being one of the most commonly used vertical nets (eg Lo *et al.,* 2001).

Aerial surveys

While aerial surveys are commonly used to estimate abundance and/or school size of marine mammals, sharks and large pelagics such as tunas, few studies describing successful aerial surveys for small pelagic species were found in the literature. Nakashima and Borstad (1997) used an aircraft mounted imaging spectrometer to estimate school sizes of capelin in near-shore waters of Newfoundland. Capelin are suited to such methods because they school at the surface, and are easily identified from the air. Similarly, aerial surveys were used to estimate biomass of the near-shore, schooling Australian salmon in South Australia (Cappo 1987).

Aerial surveys for mackerel have been carried out in the Norwegian Sea since 1986 (Anon, 2002). Aircraft are equipped with several different remote sensing sensors including IR-radiometer and scanner, LIDAR, SAR-system (with electromagnetic wavelengths of 4 and 23 cm), microwave radiometer, photo- and video cameras). This survey type has the ability to cover a large area quickly, but can not collect biological data, and may miss schools inhabiting deep water than the equipment can be used. The Norwegian Sea aerial survey is conducted in conjunction with egg and acoustic surveys.

While aerial surveys are not so good at estimating biomass of small pelagics by themselves, several studies used them in conjunction with acoustic methods to improve biomass estimates. The extreme patchiness of *Sardinops ocellata* in the Southeast Atlantic, as well as their mobility and tendency to avoid vessels of shoals, may invalidate the results of quantitative acoustic surveys on the stock (Cram and Hampton, 1976). It was suggested that a direct estimate of stock size might be obtained by employing an aerial/acoustic strategy where the aircraft locates and measures the shoal area, and the vessel makes synchronous measurements of shoal thickness and packing density from as many shoals as possible.

Wespestad and Jagielo (2008) have also planned aerial/acoustic surveys to estimate biomass of sardines of the Washinton-Oregan coast. Aerial surveys will estimate the area (size) of the schools, while vessels will use sonar to measure the depth of the schools, thereby getting and estimate of total school volume. The method will be validated by weighing captured schools whose volume was estimated.

Industry members of the RAG have suggested that there may be a few very skilful people in Australia that are able to identify species and get a reasonable ball-park estimate of school size and density from aerial surveys. If this is possible, it would be worth further investigations as an alternative cost-effective technique for broad spatial application.

Alternatives to DEPM survey methods

Currently, DEPM methods are the only survey techniques that can be included in the assessments in a quantitative manner. Quantitative acoustic survey methods have been successfully deployed in small pelagic fisheries in other countries, but would require significant trialling and development before they could be used in a quantitative manner for SPF stock assessments. As such, DEPM will remain as the primary research survey tool for SPF biomass estimation in the short term until further development of acoustic methods for Australian SPF species takes place. It is likely that aerial survey methods could only be used for broad-scale, qualitative identification of the timing and location of SPF aggregations and will always need to be run in conjunction with either acoustic or DEPM methods.

Fishery Dependent Monitoring

Vessel charter / running costs are the largest expense in SPF surveys. Australian SPF entitlement holders have proposed an industry-led programme to collect broad scale information on the abundance of the major SPF species across the extent of the fishery during commercial fishing operations. The proposal has the following objectives:

1) Determine spatial extent of SPF stocks across the extent of the fishery;
2) Collect biological material (length frequency, otoliths, gonad condition) to enable determination of the size/age structure of the stocks and the size at maturity;
3) Obtain information on the spatial and temporal patterns of spawning;
4) Conduct plankton samples to facilitate identification of eggs/larvae of major SPF species; and,
5) Use acoustic methods alongside Objective 4 to determine if this may be a suitable alternative to DEPM for stock biomass estimation.

A map of the survey areas and proposed timing for the surveys is shown in Figure 15. Vessel/s would search for schools acoustically. Once found, vessels would conduct an acoustic survey across the extent of the school. This would be followed by collecting egg samples, environmental data, and trawl tows through the school. Catch composition of tows would be measured and biological samples taken to examine size, age and growth, and reproduction.

Estimated cost of Industry based survey

The initial set-up costs below include the purchase of a conductivity, temperature, depth (CTD) recorder, and a plankton net (eg Bongo net) with flow meters to measure the flow of water going into the nets to estimate the volume of water sieved.

CTD recorder (Model CT2X Conductivity/Temperature Cableless Version) = $3,449

Bongo net (General Oceanics Model BF20 Bongo Net with flow meters) = $5,124

Wire cable and fasteners $700

Total initial setup cost = $9,291

Including initial set-up costs, and assuming 5 trips are needed to cover the entire fishery, estimated cost of sampling (excluding vessel costs), sample processing, analysis and reporting is $168,866.

It is difficult to determine the relative cost-efficiencies of commercial vessels conducting DEPM surveys compared to acoustic surveys. Whilst the ongoing costs of conducting DEPM surveys may be higher and require specialist training of crew members, the initial outlay for the purchase of a SIMRAD EK60 is considerable (>$250,000). Once purchased, however, the ability of a vessel to collect quantitative acoustic biomass estimates is cheaper and easier than may be required of a DEPM survey. It should be stressed that regardless of which method of survey is adopted, close collaboration with assessment scientists is required to ensure the design of the survey and the collection of data is of sufficient quality to be used in a quantitative manner in the assessment.

More details of the at-sea costs for the research and monitoring are provided in Table 32.

Conclusions

The development of contemporary harvest strategies for the diverse range of Commonwealth fisheries in the timeframe available is a significant achievement for AFMA. For the SPF the combination of a developing fishery, difficult economic circumstances, high levels of stakeholder interest and engagement, and a paucity of scientific knowledge on the target species makes for a complex operating environment. Within the limited time and resources available the SPF RAG and MAC have developed a draft HS that endeavours to balance these complex operational circumstances.

This review of the proposed SPF HS should be considered in this context. It is intended to build on the work already done, and to provide further advice and information to refine the Draft HS against key policy requirements, and fishery specific objectives. The opportunity to conduct an initial quantitative Management Strategy Evaluation of the proposed HS has been valuable, and has identified key areas for further consideration and development.

The review of biology and life history of SPF species suggests that SPF target species can be reasonably categorised into two broad groups. The first are moderately long lived species that inhabit shelf and slope waters (redbait, Peruvian jack mackerel, yellow tail scad, and jack mackerel). The second group are shorter lived species that inhabit shelf waters (blue mackerel and Australian sardines). In an overall sense the Draft HS appears to be most relevant to the shorter lived, highly variable, and more productive SPF species like Australian sardine. The larger number of age classes in the spawning biomass of longer lived, lower productivity species could enable more appropriate harvest strategies to be developed that do not solely depend on one or two DEPM assessments. This may also reduce the likelihood of highly variable TACs that could result from application of the DEPM based approach.

For Tier 1 stocks the proposed HS exploitation rates, where a maximum of 20% of unfished biomass is harvested on the basis of regular DEPM assessments, are conservative taken in the context of biology and life history across the range of SPF target species, and the default settings of the Commonwealth's HSP. The MSE process suggests none of the harvest strategies at Tier 1 come close to triggering the B_{lim} reference point, and for most species will lead to biomass levels well above the B_{MEY} proxy of B_{48} stipulated in the HSP. This suggests that for all species these conservative exploitation rates are likely to result in substantially reduced yields against an MEY benchmark. This will adversely impact aggregate profitability of the commercial fishery over time.

The costs of regular DEPM based assessments for key SPF target species are likely to be high relative to the state of development and profitability of the fishery. There is a question whether the level of assessment confidence, and hence cost, generated by regular DEPM assessments for Tier 1 species is warranted – particularly noting the conservation buffer provided when deliberately conservative exploitation rates are incorporated for Tier 1. The HSP and Guidelines suggest that target stocks managed to levels approximating B_{MEY} are likely to enable healthy ecological function. It is not clear from the draft HS that maintaining stocks above this level will deliver substantial ecological benefit, yet it is likely to result in foregone yield and potential fishery profits. If the SPF target species are all designated as keystone species, or as key prey species, the foregone yields arising from conservative exploitation rates may be acceptable however there remains an important judgement to be made about where exploitation rates should be set, and whether or not they should be the same for all species. The proposed conservative HS approach suggests a significantly greater premium has been attached to ecological values, and possibly other fishing sectors, in the SPF context. This also raises the question whether the standard fisheries management research cost recovery approach requiring 80% industry funding is appropriate.

If stakeholders and ultimately AFMA consider that more conservative exploitation rates and correspondingly high stock levels than envisaged by the policy settings are appropriate for the SPF due to the ecosystem importance of the species then the underlying basis for this approach should be made clearer. This would enable a more transparent approach to management, and provide for a more certain operating environment for industry, both of which are important objectives of the HSP.

The concept of Tiers used in the draft HS to account for greater precaution at lower information levels is consistent with the HSP and Guidelines. The justification and demonstration that the lower Tier levels are more precautionary is not clear in the Draft HS. The proposed HS approach at Tiers 2 and 3 refers to analysis of fishery dependent data on catch and effort, and age structure of the catch. It is not clear what this entails, what indicators might be used to inform decision making, and what it is likely to cost per assessment cycle. The difference between this type of data analysis at Tier 2, and the similar analysis at Tier 3 where the TAC is dramatically reduced should also be made clearer.

In the pursuit of cost effective and efficient management, the proposed HS should provide substantially more information about the likely costs to industry and government arising from the assessment processes underpinning application of the HS at all Tier levels. This is particularly so for Tier 1 stocks which should represent an efficient synergy between the cost of gathering and interpreting scientific information, and the subsequent risk assessment needed to underpin more aggressive exploitation rates for target species whilst maintaining ecological function. Similarly, details of the information required to underpin decisions at Tiers 2, and 3; the costs of obtaining and interpreting this information, and the reasons why this level of knowledge equates to the catch quantities proposed could be made clearer. With respect to the transparency of the proposed HS approach, the HS would be improved by a plain English description of the structure and operation of the HS research and assessment approaches. This should include reasonable clarity on the type of information required and how that information will be analysed and used to inform scientific recommendations on catch levels at various Tiers.

At the lower Tiers the proposed HS also relies on the expert judgement of the RAG to determine harvest levels after consideration of relevant catch and effort information. There could be more information provided about what specific information will be considered, and how it will be interpreted to develop catch recommendations in the absence of a clear decision rule such as that proposed for Tier 1. Whilst expert judgement can be a cost effective and efficient element of decision making, there is a risk that unless the parameters for such judgements are adequately considered and explained the approach may reduce the consistency and objectivity of decision making. This may reduce business confidence, transparency, and the efficiency of decision making, all of which are important objectives of the HSP.

In the absence of a detailed cost benefit analysis of the proposed HS, a simple ratio of management expenses to GVP may prove a useful first step in evaluating the suitability of proposed SPF HS approaches in terms of economic considerations, and its relative efficiency with regard to other fisheries. This could be presented as an industry recoverable management cost ratio, and a total management cost to GVP ratio, to benchmark the efficiency of both industry and government expenditure.

In addition to the key sustainability and profitability objectives, the proposed HS suggests considerable weight is given to subsidiary management objectives like localised depletion however this term is not well defined and appears to mean different things to different stakeholders. The definition taken for the SPF should be clarified to allow proper consideration of management/mitigation strategies, including their potential impacts on stocks, ecosystems, and/or stakeholder interests. Similarly the HS includes management responses to address impacts on threatened, endangered or protected species. Whilst a key element of the SPF management environment these may be better placed within the SPF Management Plan or the Bycatch Action Plan and cross referenced to the HS.

The preliminary quantitative MSE conducted has provided a good basis for initial evaluation of the performance of the HS against the policy benchmarks. The MSE comprised both deterministic and stochastic analyses of the proposed HS decision rules for Tier 1. For the deterministic analyses the primary intent was to establish what harvest proportion of the spawning biomass would drive the resource to 48% of pristine (denoted p_{MEY}, being a proxy for MEY), and what is the economic difference – as a percentage of catch – between an MEY harvesting policy and the catches suggested by the proposed HS. The analyses found that the p_{MEY} values (and hence the potential exploitation rates) were all larger than those suggested by the Draft HS decision rules.

For the stochastic analyses the objective was to determine if certain overarching policy objectives (i.e. harvesting resources at or near MEY, whilst keeping biomass above B_{lim} 90% of the time) were consistent with the proposed draft SPF HS harvest proportions. Not unexpectedly the draft SPF HS harvesting proportions led to the overarching policy objectives being exceeded. The spawning biomass ended up being managed > B_{48}, and the risk of dropping below B_{lim} was much less than the required 10%. For the results incorporating a simulated stock assessment process with decision making based on an MEY harvesting policy, the proxy setting for MEY is nevertheless attained for all species. Because of the nature of the Draft HS it is not possible to be definitive about the more subjective nature of the stock assessment based decision making process, and thus its ability to usefully inform management. For SPF species, more 'aggressive' harvesting (i.e. larger harvest proportions) could be entertained whilst still meeting the overarching HSP objectives. It should be noted again that the HSP does canvas the option of more conservative exploitation rates for keystone species.

Importantly the analysis of risk during the MSE process is influenced by the scope of uncertainty and stochasticity considered in the simulations. This was addressed by running additional simulations which considered a number of variants of the base case scenarios. A key additional factor was the possibility of 50% positive bias in the DEPM based stock assessment results.

In relation to the management of shared stocks, the HSP advocates shared responsibility across jurisdictions. The proposed SPF HS suggests that all other catches be subtracted from the proposed RBC before SPF TACs are established. This has the potential to disadvantage Commonwealth operators and undermine the strength of SPF entitlements. It may thus adversely impact on fisher behaviour and ultimately management performance. A more appropriate solution to this scenario may be to encourage shared management responsibility by reducing catches from all jurisdictions consistent with historic catch ratios as has been done under the Commonwealth's SESSF harvest strategy.

The suggestion that the Draft HS should cater in advance for possible mass mortality events or similar dramatic environmental perturbations through the application of conservative harvest settings should also be further considered. This approach has the potential to further contribute to reduced yields over time and yet may not be the most efficient way to target this specific risk. If such events are considered a key management risk for one or several SPF species then it may be more efficient to address them through the use of meta-rules or exceptional circumstance provisions within the HS that could apply if and when such an event occurs.

The current information on SPF stocks is patchy on both a spatial and temporal basis. Given the extent of the fishery, the current Tier 1 HS will require a prohibitive budget if ongoing annual DEPMs are required for all stocks in all regions, especially if it is conducted in addition to normal fishing activities. There are well-developed, cost-effective acoustic methods of quantitative biomass estimation used on international small pelagic species that could be applied to the SPF to augment or replace the need for annual DEPMs. It should be a high priority to develop a cost-effective, scientifically rigorous research plan to be conducted from commercial fishing vessels that enables the collection of DEPM data and begins the process of developing quantitative acoustic techniques. This should be an integral part of any HS and form the basis of any development of the fishery. The opportunity to enable higher catches in the very early stages of the development of the fishery so that this information can be collected should be realised.

Recommendations

The review of biology and life history of SPF species suggests that target species can be reasonably categorised into two broad groups. The first are moderately long lived species that inhabit shelf and slope waters (redbait, Peruvian jack mackerel, yellow tail scad, and jack mackerel). The second group are shorter lived species that inhabit shelf waters (blue mackerel and Australian sardines).

Consider whether different harvest strategy approaches should be adopted for these two groups of species.

The proposed HS exploitation rates, where a maximum of 20% of spawning biomass is harvested at Tier 1 on the basis of regular DEPM assessments, is, in most cases, very conservative when considered in the context of biology and life history of SPF species, and the default settings of the Commonwealth's HSP (which calls for exploitation rates approximating MEY for target stocks). Presumably, this has been done to reflect that some or all of these species are keystone ecological species. The MSE conducted as part of the review identifies that for all of the considered species this conservative exploitation rate is likely to result in high biomass levels relative to B_{48}. No targets have been established for keystone species and this issue needs to be addressed for the SPF HS.

Justify which of the SPF species are "keystone" ecological species and be explicit about their suitable target biomass levels if divergent from the HSP.

This approach will also lead to substantially reduced yields from all stocks against an MEY benchmark. This will adversely impact aggregate profitability of the fishery over time and should be carefully considered.

Be explicit about the expected amount and value of the forgone catch through the adoption of a more conservative HS for ecosystem requirements.

The proposed conservative HS approach suggests a significantly greater premium has been attached to ecological values, and possibly other fishing sectors, in the SPF context. This raises the question whether the standard fisheries management research cost recovery approach requiring 80% commercial industry funding is appropriate.

Consider if the current 80:20 industry split is appropriate when a more conservative HS is adopted for ecosystem requirements.

A clear articulation of principal and subsidiary harvest strategy (or management) objectives and how the HS is likely to perform against these would be valuable. At the moment there appears to be a disconnect between the stated objectives of the HSP and the Draft HS and its decision rules, particularly with respect to the profitability / economic efficiency objective.

Make a clear statement of the profitability / economic efficiency objectives of the HS.

Evidence of localised depletion is an important aspect of the Draft HS. The sub-objective of managing localised depletion should be more clearly defined as it has the potential for significant impacts on SPF fishing activities.

Define and quantify the term "Localised depletion" and clearly articulate the management response to such a situation.

The Tier 1 HS can results in highly variable TACs based on the DEPM approach. The larger number of age-classes in the spawning biomass of longer lived species allows for TACs to be set on more information and over a longer time period than just the last one or two DEPMs as stipulated in the Draft HS. This may reduce the likelihood of highly variable TACs that could result from application of the DEPM based approach. An additional sub-objective that could be considered is the opportunity for SPF entitlement holders to clarify their preferred operating environment with regard to catches and catch stability over time. For example should industry suggest that they value catch stability over a 5 year period with TAC changes of no more than 20% for economic reasons, rather than highly variable maximum catches as set by the exploitation rate against one or two DEPM results.

Determine and state the preferred economic operating environment of the SPF licence holders and incorporate this into the HS approach.

For shared stocks, and to encourage shared management responsibility, the approach whereby RBCs are reduced by the amount of other jurisdictional and sectoral catches of SPF species before SPF TACs are determined should be reconsidered.

Although insignificant at this stage, the principal of only the Commonwealth sector supporting changes in the RBC is not sound for a shared resource and should be altered to be more equitable.

A realistic total cost estimate for supporting science associated with each Tier level of the HS should be made available. This may also be broken down into industry attributable costs with consideration being given to revising the cost recovery ratio because of the apparent catch foregone to achieve greater environmental protection, and possibly cater to the desires of the recreational and charter fishing sectors for greater stock conservation than that envisaged under the HSP.

Provide detailed information of the costs associated with research, monitoring, analysis and assessment required by the HS at each Tier level.

The nature of the analysis of fishery dependent data on catch and effort, and age structure of the catch, at Tiers 2 and 3 should be clarified. Similarly the differences between such analysis at Tier 2 and then at Tier 3 should be explained in the context of the dramatically reduced catch levels that apply at Tier 3 of the proposed HS.

Better define the distinction, need and outcomes of Tier 3 versus Tier 2.

A ratio of management expenses to GVP that includes the total cost of applying the HS at the separate Tier levels could provide a simple benchmark of management cost effectiveness.

This could be provided as an industry recoverable management cost ratio, and a total management cost to GVP ratio to benchmark both industry and government attributable costs. This is particularly important for a developmental fishery where current economic pressures are significant and will remain an important determinant of fisher behaviour.

Develop estimates of management costs for the HS and compare these with benchmarks from other fisheries.

In the interests of transparency the structure and operation of the research and assessment approaches proposed at all Tiers could be made clearer to stakeholders through plain English descriptions.

The proposed HS refers to potential mass mortality events across the range of SPF species. If further consideration suggests this is a key management risk for species other than sardine then it may be more cost effective to address it through the use of meta-rules or exceptional circumstance provisions within the HS. These could apply if and when such an event occurs.

Be explicit about what species have sufferance mass mortality events and how often this has occurred. Based on this, decide whether precaution against this occurrence should underlie all species HS or should be an exceptional management response.

The HSP Guidelines note that there should be a strong connection between the fishery's management objectives, the selection of appropriate management tools, the data strategy and supporting research and scientific work, and the available resources.

The nature of the relationships between management objectives and tools could be made more explicit in the description and context of the proposed HS.

The frequency of proposed DEPM surveys (or alternate assessment approaches) should be carefully evaluated with a view to minimising the assessment frequency (and cost) whilst meeting an acceptable risk profile. The reasons for adopting a particular survey frequency should be clearly explained.

At the lower Tiers the SPF HS also relies on the expert judgement of the RAG to determine harvest levels after consideration of relevant catch and effort information. There is very little detail provided on what information will be considered, and how this will be interpreted to develop catch recommendations in the absence of a clear decision rule such as that proposed for Tier 1. The provision of such information will increase business certainty, transparency, and the efficiency of decision making.

Provide more information and detail how expert judgement will be incorporated into the HS for the lower Tier Levels.

SPF MAC and RAG have identified the importance of a strategic research and monitoring plan for the fishery. The nature of the information required, and how it relates to the stated management objectives for the fishery (and can be most efficiently obtained) is an important element of the HS that will add to the transparency of the proposed approach.

Develop a detailed and costed strategic research and monitoring plan for the fishery.

The HS is designed primarily to set the harvest strategy for target species. The suggested response to significant interactions with threatened endangered or protected species may be better detailed within the SPF Management Plan or subordinate documents such as the Bycatch Action Plan. These could then be cross referenced to the HS in the context of possible reductions in the TAC for SPF target species. The broader environmental impacts described are by-catch management issues rather than decision rules to manage the harvest of key commercial species as envisaged by the HSP.

Consider what aspects of the broader ecosystem impacts belong in the HS compared to other documentation pertaining to the fishery.

Given the extent of the fishery, the current Tier 1 HS will require a prohibitive budget if ongoing annual DEPMs are required for all stocks in all regions, especially if it is conducted in addition to normal fishing activities. The current information on the stocks is patchy on both a spatial and temporal basis. There is a need for better information on the spatial and temporal dynamics of the stocks across the broad area of the SPF. Aerial surveys may be useful in this respect but will need to be augmented with robust quantitative methods. Currently, DEPM methods are the only survey techniques that can be included in the assessments in a quantitative manner. Quantitative acoustic survey methods have been successfully deployed in small pelagic fisheries in other countries, but would require trialling and development before they could be used in a quantitative manner for SPF stock assessments. The opportunity and flexibility to undertake this work during the developmental stages of the fishery is enabled in the current Draft HS through a meta-rule that allows higher catches than would be recommended under the current Draft HS. Such an opportunity to develop the most cost-effective survey methods and collect extensive information on the fishery should be realised.

Develop an agreed research plan for the fishery that collects relevant information to support DEPM assessments while exploring the potential of acoustic methods and aerial surveys as alternative quantitative biomass estimation techniques.

The MSE conducted in this project was preliminary and contained general stock parameters and assumptions. These can be improved by the RAG, especially with respect to how natural mortality estimates are derived and incorporated.

Further MSE should be fine-tuned and conducted once a final SPF HS is agreed.

Acknowledgments

The authors wish to thank the members of the Small Pelagics Fishery MAC and RAG for their input and advice in conducting this review.

References

Allen, L.G., Pondella, D.J. and Horn, M.H. (eds.). (2006). The ecology of marine fishes: California and adjacent waters. University of California Press, Berkeley, 660 p.

Anon. (2007b). Cruise Report International Acoustic Survey for Pelagic Fish Stocks in the North Sea R/V "SOLEA" 28.06. – 17.07.2007. Cruise No. 576. Federal Research Centre for Fisheries. Institute for Fishing Technology and Fishery Economics, 4 p.

Anon. 2002. Report of the planning group on aerial and acoustic surveys for mackerel. ICES CM 2002/G:03.

Anon. 2007a. Survey report from the joint Norwegian/Russian ecosystem Survey in the Barents Sea August-October 2007 (vol.1). IMR/PINRO Joint Report Series, No. 4/2007. 97 pp.

Australian Government Department of Agriculture, Fisheries and Forestry. 2007. Commonwealth Fisheries Harvest Strategy, Policy and Guidelines, September 2007.

Barange, M., and Hamilton, I. (1997). Spatial structure of co-occurring anchovy and sardine populations from acoustic data: implications for survey design. Fisheries Oceanography. 6:94–108.

Barange, M., Pillar., S.C., Huse, I., and Hutchings, L. (2005). Vertical migration, catchability and acoustic assessment of semi-pelagic Cape horse mackerel *Trachurus trachurus* capensis in the southern Benguela. African Journal of Marine Science. 27: 459–469.

Bertrand, A., Segura, M., Gutiérrez, M., and Vásquez, L. (2004). From small-scale habitat loopholes to decadal cycles: a habitat-based hypothesis explaining fluctuation in pelagic fish populations off Peru. Fish and Fisheries. 5: 296–316.

Cappo, M.C. (1987) The biology and exploitation of Australian salmon in South Australia. SAFISH, 12 (1), 4 – 14.

Cram, D.L., and Hampton, I. (1976). A proposed aerial/acoustic strategy for pelagic fish stock assessment. ICES Journal of Marine Science. 37: 91–97.

Cutter, G. R., Jr., and Demer, D.A. (eds.). (2008). California Current Ecosystem Survey 2006 acoustic cruise reports for NOAA FSV Oscar Dyson and NOAA FRV David Starr Jordan. U.S. Department of Commerce, NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFSC-415, 98 p.

De Oliveira, J.A.A. and D.S. Butterworth 2004. Developing and refining a joint management procedure for the multispecies South African pelagic fishery. ICES Journal of Marine Science, 61: 1432 – 1442.

Draft Small Pelagic Fishery Harvest Strategy. February 2008

Eschmeyer, W.N., E.S. Herald and H. Hammann, 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Company, Boston, U.S.A. 336 p.

Everson, I., Bravington, M., and Goss, C. (1996). A combined acoustic and trawl survey for efficiently estimating fish abundance. Fisheries Research, 26: 75–91.

Fitch, J., 1956. Jack mackerel. CalCOFI Rep. 1955-1956:27-28.

Foote, K.G., Knudsen, H.P., Vestnes, G., McLennan, D.N., Simmonds, E.J., 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report 144.

Froese, R. and D. Pauly. Editors. 2008.FishBase. World Wide Web electronic publication. www.fishbase.org, version (02/2008).

Glazer, J.P. and Butterworth, D.S. 2005. Results obtained from projecting the squid resource Loligo vulgaris reynaudii 10 years into the future. MCM working group document WG/05/08/SQ1. Marine and Coastal Management, Department of Environmental Affairs and Tourism, South Africa.

Gomon, M.F., C.J.M. Glover and R.H. Kuiter (eds), 1994. The fishes of Australia's south coast. State Print, Adelaide. 992 p.

Gutiérrez, M., Swartzman, G., Bertrand, A., and Bertrand, S. (2007). Anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) spatial dynamics and aggregation patterns in the Humboldt Current ecosystem, Peru, from 1983–2003. Fisheries Oceanography. 16: 155–168.

Hamano, A., Nakamura, T., and Maeda, H. (2002). Improvement in school-size estimates of pelagic fish using information from sector-scanning sonar. Fisheries Oceanography. 11: 361–365.

Hampton, I. (1996). Acoustic and egg-production estimates of South African anchovy biomass over a decade: comparisons, accuracy, and utility. ICES Journal of Marine Science. 53: 493–500.

Hart, J.L., 1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180:740 p.

Hollowed, A.B., Wilson, C.D., Stabeno, P.J., and Salo, S.A. (2007). Effect of ocean conditions on the cross-shelf distribution of walleye pollock (*Theragra chalcogramma*) and capelin (*Mallotus villosus*). Fisheries Oceanography. 16: 142–154.

Jolly, G.M., and Hampton, I. (1990). A Stratified Random Transect Design for Acoustic Surveys of Fish Stocks. Canadian Journal of Fisheries and Aquatic Sciences. 47: 1282–1291.

Kailola, P.J., M.J. Williams, P.C. Stewart, R.E. Reichelt, A. McNee and C. Grieve, 1993. Australian fisheries resources. Bureau of Resource Sciences, Canberra, Australia. 422 p.

Knuckey, I. and M.T. Koopman. 2008. Review of key biological parameters of species from the Small Pelagic Fishery.

Koopman, M.T,. Punt, A.E., and Smith, D.C. 2000 Production parameters from the fisheries literature for SEF-like species. Report of ARF Project R99/0308.

Lawson, G. L., Barange, M., and Fre´on, P. 2001. Species identification of pelagic fish schools on the South African continental shelf using acoustic descriptors and ancillary information. – ICES Journal of Marine Science, 58: 275–287.

Lo, N.C.H., Hunter, J.R., and Charter, R. (2001).Use of a continuous egg sampler for ichthyoplankton surveys: application to the estimation of daily egg production of Pacific sardine (*Sardinops sagax*) off California. Fisheries Bulletin. 99: 554–571.

Massé, J., Beillois, P., and Duhamel, E. 2005. Direct assessment of anchovy by the PELGAS05 acoustic survey. Working Document to the ICES Working Group on the assessment of Mackerel, Horse Mackerel, Sardine and Anchovy. Vigo, 5–15 September 2005.

Ministry of Fisheries (2008) http://www.fish.govt.nz/en-nz/SOF/Species.htm?code=EMA&list=scientific

Myers, R.A., J. Bridson and N.J. Barrowman. 1995. Summary of Worldwide Spawner and Recruitment Data. Canadian Technical Report of Fisheries and Aquatic Sciences 2024.

Nakashima and Borstad (1997). Abundance and Behavior of Capelin Schools (*Mallotus villosus)* from Aerial Surveys. Forage Fishes in Marine Ecosystems Alaska Sea Grant College Program, AK-SG-97-O1, 1997.

O'Driscoll, R. L., and Macaulay, G. J. 2005. Using fish-processing time to carry out acoustic surveys from commercial vessels. ICES Journal of Marine Science. 62: 295–305.

Ohshimo, S. (2004). Spatial distribution and biomass of pelagic fish in the East China Sea in summer, based on acoustic surveys from 1997 to 2001. Fisheries Science. 70:389–400.

OLRAC, 2007. Bayesian estimates of risks and trends in the chokka squid (Loligo vulgaris reynaudii) resource. MCM working group document WG/10/07/SQ3. Marine and Coastal Management, Department of Environmental Affairs and Tourism, South Africa.

Porteiro, C., Carrera, P., and Miquel, J. 1996. Analysis of Spanish acoustic surveys for sardine, 1991–1993: abundance estimates and inter-annual variability. – ICES Journal of Marine Science, 53: 429–433.

Punt, A.E., Smith, D.C., and Koopman, M.T. 2005 Using information for 'data-rich' species to inform assessments of 'data-poor' species through Baysian stock assessment methods. Final report to Fisheries Research and Development Corperation Project No. 2004/094. Primary Industries Research Victoria, Queenscliff.

Reid, D.G., Walsh, M. and Turrell, W.R. (2001). Hydrography and mackerel distribution on the shelf edge west of the Norwegian deeps. Fisheries Research. 50: 141–150.

Reiss, C.S., Checkley, D.M., and Bograd, S.J. (2008). Remotely sensed spawning habitat of Pacific sardine (*Sardinops sagax*) and Northern anchovy (*Engraulis mordax*) within the Californian Current. Fisheries Oceanography. 17: 126–136.

Rogers, P.J., Stephenson, P., McLeay, L.J., Dimmlich, W.F. and Ward, T.M. 2004. SARDI Aquatic Sciences Fishery Assessment Report (Series 84). Sardine (*Sardinops sagax*) Publication No. RD03/0198-2. 75p.

Staunton-Smith, J. and Ward, T.M. 2000. Stock Assessment of Pelagic Bait Fishes in Southern Queensland. Report of FRDC projects 95/043 and 98/130. Department of Primary Industries, Queensland. 126p.

Stewart, J.; Ferrell, D.J. 2001. Age, growth, and commercial landings of yellowtail scad (Trachurus novaezelandiae) and blue mackerel (Scomber australasicus) off the coast of New South Wales, Australia. New Zealand Journal of Marine & Freshwater Research 35:541-551.

Van der Lingen, C.D., Checkley, D., Barange, M., Hutchings, L. and Osgood, K. (1998). Assessing the abundance and distribution of eggs of sardine *Sardinops sagax*, and round herring, *Etrmeus whiteheadi*, on the western Agulhas Bank, South Africa, using a continuous, underway fish egg sampler. Fisheries Oceanography. 7: 35–47.

Ward, T.M. and Rogers, P.J., (eds.) 2007. Development and evaluation of egg based stock assessment methods for blue mackerel *Scomber australasicus* in southern Australia. Final report to the FRDC for project 2002/061. South Australian Research and Development Institute, Adelaide. 468p.

Webb, B.F. and C.J. Grant, 1979. Age and growth of jack mackerel, Trachurus declivis (Jenyns), from southeastern Australian waters. Aust. J. Mar. Freshwat. Res. 30(1):1-9.

Welsford, D.C. and J.M. Lyle. 2003. Redbait (Emmelichthys nitidus): A synopsis of fishery and biological data. July 2003. Technical Report Series Number 20. Tasmanian Aquaculture & Fisheries Institute, University of Tasmania.

Welsford, D.C. and J.M. Lyle. 2004. Research and Assessment of the Zone A Small Pelagic Fishery, 2003-04: A summary of data presented to the Zone A Small Pelagics Research Assessment Group (ZASPRAG), August 24 2004.

Wespestad, V.G. and Jagielo, T. (2008). Proposal for a study of the feasibility of using an aerial survey to determine sardine abundance off the Washington-Oregon coast in conjunction with fishing vessel observation of spotted schools. Supplemental Informational Report 4, Northwest Sardine Survey Materials. Portland, Oregon, April 2008.

Whitehead, P.J.P., 1985. FAO species catalogue. Vol. 7. Clupeoid fishes of the world (suborder Clupeioidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. Part 1 - Chirocentridae, Clupeidae and Pristigasteridae. FAO Fish. Synop. 125(7/1):1-303.

Zhao, H., Harme, J., Li, F., Jin, X., and Tang., Q. (2003). Recruitment, sustainable yield and possible ecological consequences of the sharp decline of the anchovy (*Engraulis japonicus*) stock in the Yellow Sea in the 1990s. Fisheries Oceanography. 12: 495–501.

Table 1. The codes used to identity the diet and depth preferences and habitat usage of the species considered in this study.

Diet preference
1. Phytoplankton or zooplankton
2. Salps
3. Invertebrates
4. Invertebrates and fish
Depth
1. Shelf (0-200m)
2. Shelf-slope (0-700m)
3. Upper slope (200-700m)
4. Lower slope (700m+)
Habitat
1. Demersal
2. Benthopelagic
3. Pelagic

Table 2. Biological characteristics of jack mackerel, yellowtail scad, redbait and Peruvian jack mackerel.

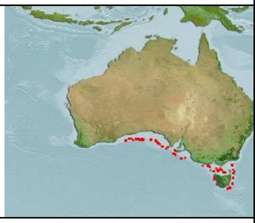
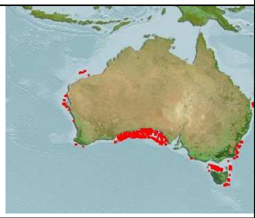
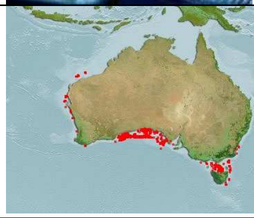
Species	Redbait	Jack mackerel	Yellowtail scad	Peruvian jack mackerel
Appearance				
Catch distribution				
Max. length	33.5 cm TL	47.0 cm FL	50.0 cm SL	81.0 cm TL
Environment	bathydemersal; marine; depth range 86–500m	benthopelagic; brackish–marine; depth range 27–460m	pelagic; brackish–marine; depth range 22–500m	pelagic; marine; depth range 0–400 m
Resilience	Medium, minimum population doubling time 1.4 - 4.4 years (Assuming tmax > 3)	Medium, minimum population doubling time 1.4 - 4.4 years (tm=2-4; tmax=25)	Medium, minimum population doubling time 1.4 - 4.4 years (K=0.30; tm=3-4; tmax=25)	Low, minimum population doubling time 4.5 - 14 years (K=0.09-0.21;tm=2-3; tmax=30; fec<50,000)
Age and growth	Tmax=21 years L_{inf}=28.4 cm K=0.27 /year T_0=-1.54 year	Tmax=16 years L_{inf}=36.2 cm K=0.267 /year T_0=-1.21 year	Tmax=14 years L_{inf}=36 cm K=0.3 /year T_0=	Tmax=30 years L_{inf}=46.4 cm K=0.683 /year T_0=
Age at maturity	T_m =2–4 years	T_m =3–4 years	T_m =3–4 years	T_m =3 years
Biology	A schooling species. Adults are found near the bottom in deeper water. Juveniles occur near the surface, often with schools of clupeids. Feeds mainly on larger zooplankton.	Found near the bottom, in midwater and occasionally at the surface in shelf waters. They form pelagic schools for most of the year but may move near the sea bed during winter. Juveniles inhabit coastal and estuarine waters sometimes offshore. Feed mostly during the day mainly on krill and planktonic crustaceans, light fish and lantern fish at the edge of the continental shelf.	Occur in coastal waters, including estuaries, mostly in waters shallower than 150 m and warmer than 13°C. Commonly found on the bottom, in midwater and occasionally at the surface), in large schools. Adults are generally found over offshore rocky reefs, while juveniles are generally found in shallow, soft substrate areas.	Often found offshore, up to 500 miles from the coast. Forms large schools. Young frequently occur in school near kelp and under piers. Feeds mainly on small crustaceans and fish larvae. Large individuals often move inshore and north in the summer.
Mortality	M = 0.22 / year (calculated from M=-ln(0.01)/tmax	M = 0.67 / year	M = 0.33 / year (calculated from M=-ln(0.01)/tmax	M = 0.15 / year

Table 3. Biological characteristics of Australian sardine, and Blue mackerel.

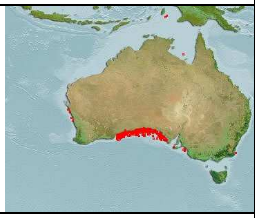
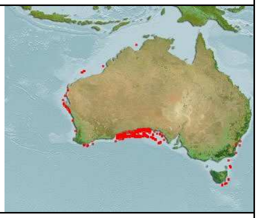
Species	Australian sardine	Blue mackerel
Appearance		
Catch distribution		
Maximum length	39.5 cm SL	44 cm
Environment	pelagic; oceanodromous; marine; depth range 0 – 200 m	pelagic; oceanodromous; marine; depth range 87 – 200 m
Resilience	Medium, minimum population doubling time 1.4 - 4.4 years (K=0.45; tm=2; tmax=13-25; Fec=10,000)	Medium, minimum population doubling time 1.4 - 4.4 years (K=0.28)
Age and growth	Tmax=6.5 years L_{inf}=16.9 cm K=1.29 /year T_0=	Tmax=7 years L_{inf}=44.1 cm K=0.24 /year T_0=
Age at maturity	T_m =1–2 years	T_m =2 years
Biology	Neritic. A coastal species that forms large schools. Feed mainly on planktonic crustaceans. Young fish feed on zooplankton such as copepod and adults on phytoplankton. Oviparous, with pelagic eggs, and pelagic larvae.	Occurs in coastal waters and also in oceanic waters. They are plankton feeders filtering copepods and other crustaceans, but adults also feed on small fish and squids.
Mortality	M = 0.66 / year (calculated from M=-ln(0.01)/tmax	M = 0.66 / year (calculated from M=-ln(0.01)/tmax

Table 4. Similarities of SPF species. Values for similarities of less than 2.00 are in bold text.

	Redbait	**Blue mackerel**	**Peruvian jack mackerels**	**Yellowtail scad**	**Jack mackerel**
Blue mackerel	10.60				
Peruvian jack mackerels	**1.90**	4.03			
Yellowtail scad	2.90	2.70	5.71		
Jack mackerel	**1.96**	3.01	4.38	**0.63**	
Australian sardine	10.60	**0.00**	16.63	5.20	6.63

Table 5. 'Other species' rated as similar (similarity <2.00) to redbait.

Common name	**Family**	**Species**	**Stock**	**Similarity**
Herring	Clupeidae	Clupea harengus	Gulf of Maine	0.83
Herring	Clupeidae	Clupea harengus	Norway (Spring spawners)	1.03
Herring	Clupeidae	Clupea harengus	Newfoundland(EF)	1.13
Spotted warehou	Centrolophidae	Seriolella punctata	SEF	1.13
Herring	Clupeidae	Clupea harengus	NAFO 4T (Fall spawners)	1.40
Herring	Clupeidae	Clupea harengus	Iceland (Summer spawners)	1.43
Lepidonotothen	Nototheniidae	Lepidonotothen squamifrons	Kerguelen Islands	1.73
Haddock	Gadidae	Melanogrammus aeglefinus	Georges Bank	1.73
Rock sole	Pleuronectidae	Lepidopsetta bilineata	Hecate Strait, B.C.	1.73
Saithe	Gadidae	Pollachius virens	Iceland	1.73
Herring	Clupeidae	Clupea harengus	Southern Central Baltic	1.77
Sea bream	Sparidae	Chrysophrys major	Yellow Sea	1.95
Yellowfin sole	Pleuronectidae	Limanda aspera	E. Bering Sea	1.97
Grey mullet	Mugilidae	Mugil cephalus	Taiwan	1.97

Table 6. 'Other species' rated as similar (similarity <2.00) to Peruvian jack mackerel.

Common name	**Family**	**Species**	**Stock**	**Similarity**
Herring	Clupeidae	Clupea harengus	NAFO 4T (Fall spawners)	1.20
American plaice	Pleuronectidae	Hippoglossoides platessoides	West Greenland	1.40
Horse mackerel	Carangidae	Trachurus trecae	N.W. Africa	1.50
Alaska plaice	Pleuronectidae	Pleuronectes auadrituberculatus	West Kamchatka Shelf	1.57
Plaice	Pleuronectidae	Pleuronectes platessa	ICES VIId	1.60
Herring	Clupeidae	Clupea harengus	Norway (Spring spawners)	1.73
Hake	Gadidae	Merluccius australis	NZ, HAK 1	1.90

Table 7. 'Other species' rated as similar (similarity <2.00) to yellowtail scad (63 different species/stocks had similarity values less than <2.00 so only the first 20 species/stocks are shown).

Common name	**Family**	**Species**	**Stock**	**Similarity**
King mackerel	Scombridae	Scomberomorus cavalla	W. Gulf of Mexico	0.70
Mackerel icefish	Channichthyidae	Champsocephalus gunnari	South Georgia, Antarctic Ocean	0.78
Black anglerfish	Lophiidae	Lophius budegassa	ICES VIIb-k and VIIIa,b.	0.90
Scup	Sparidae	Stenotomus chrysops	Cape Cod - Cape Hatteras USA	0.93
Atlantic bluefin tuna	Scombridae	Thunnus thynnus	West Atlantic	1.03
Hairtail	Trichiuridae	Trichiurus haumela	East China Sea	1.03
North Pacific hake	Gadidae	Merluccius productus	US, West Coast	1.08
Hake	Gadidae	Merluccius hubbsi	Argentina	1.23
Atka mackerel	Hexagrammidae	Pleurogrammus monopterygius	Eastern Bering Sea	1.23
English sole	Pleuronectidae	Parophrys vetulus	Hecate Strait	1.28
Chub mackerel	Scombridae	Scomber japonicus	Pacific Coast of Japan	1.28
Peruvian hake	Gadidae	Merluccius gayi	Peru	1.28
Notothenia rossii	Nototheniidae	Notothenia rossii	Kerguelen Islands, Antarctic Ocean	1.33
Med. horse mackerel	Carangidae	Trachurus mediterraneus	Black Sea	1.33
Flounder	Pleuronectidae	Platichthys flesus	Baltic Areas 24 and 25	1.43
Sea bass	Moronidae	Dicentrarchus labrax	English Channel	1.43
Lepidonotothen	Nototheniidae	Lepidonotothen squamifrons	Kerguelen Islands, Antarctic Ocean	1.52
Spanish sardine	Clupeidae	Sardina pilchardus	West Iberian (ICES VIIIc-IXa)	1.53
Bluefish	Pomatomidae	Pomatomus saltatrix	East Coast, USA	1.53
Blue warehou	Centrolophidae	Seriolella brama	SEF	1.53

Table 8. 'Other species' rated as similar (similarity <2.00) to jack mackerel).

Common name	Family	Species	Stock	Similarity
Grey mullet	Mugilidae	Mugil cephalus	Taiwan	0.40
Herring	Clupeidae	Clupea harengus	Southern Central Baltic	0.50
Spanish sardine	Clupeidae	Sardina pilchardus	West Iberian	0.53
Herring	Clupeidae	Clupea harengus	Iceland (Summer spawners)	0.76
Herring	Clupeidae	Clupea harengus	Newfoundland(EF)	0.99
Herring	Clupeidae	Clupea harengus	Downs stock	1.36
Sardine	Clupeidae	Sardinops sagax	California	1.36
Herring	Clupeidae	Clupea harengus	Gulf of Maine	1.57
English sole	Pleuronectidae	Parophrys vetulus	Hecate Strait	1.70
Notothenia rossii	Nototheniidae	Notothenia rossii	Kerguelen Islands	1.70
Herring	Clupeidae	Clupea harengus	Norway (Spring spawners)	1.73
Herring	Clupeidae	Clupea harengus	Northern Irish Sea	1.87
Scup	Sparidae	Stenotomus chrysops	Cape Cod - Cape Hatteras	1.93
Lepidonotothen	Nototheniidae	Lepidonotothen squamifrons	Kerguelen Islands	1.99
Mackerel	Scombridae	Scomber scombrus	Black Sea	1.99
Mackerel	Scombridae	Scomber scombrus	Western ICES	1.99

Table 9. 'Other species' rated as similar (similarity <2.00) to Australian sardine.

Common name	Family	Species	Stock	Similarity
Nth. anchovy	Engraulidae	Engraulis mordax	California	0.20
Gulf Menhaden	Clupeidae	Brevoortia patronus	Gulf of Mexico	0.83
Sprat	Clupeidae	Sprattus sprattus	Baltic Areas 22-32	0.83
Sardine	Clupeidae	Sardinops sagax	Sea of Japan	1.11
Sandeel	Ammodytidae	Ammodytes marinus	Northern North Sea	1.31
Pacific Saury	Scophthalmidae	Cololabis saira	Soledad Basin, Baja California	1.39
Herring	Clupeidae	Clupea harengus	Baltic areas 25-29, 32	1.50
Blueback herring	Clupeidae	Alosa aestivalis	Chowan River, USA	1.63
Atl. Menhaden	Clupeidae	Brevoortia tyrannus	U.S. Atlantic	1.82
Greater lizardfish	Synodontidae	Saurida tumbil	East China Sea	1.90

Table 10. 'Other species' rated as similar (similarity <2.00) to blue mackerel.

Common name	Family	Species	Stock	Similarity
Northern anchovy	Engraulidae	Engraulis mordax	California	0.20
Gulf Menhaden	Clupeidae	Brevoortia patronus	Gulf of Mexico	0.83
Sprat	Clupeidae	Sprattus sprattus	Baltic Areas 22-32	0.83
Sardine	Clupeidae	Sardinops sagax	Sea of Japan	1.11
Sandeel	Ammodytidae	Ammodytes marinus	Northern North Sea	1.31
Pacific Saury	Scophthalmidae	Cololabis saira	Soledad Basin, Baja California	1.39
Herring	Clupeidae	Clupea harengus	Baltic areas 25-29, 32	1.50
Blueback herring	Clupeidae	Alosa aestivalis	Chowan River, USA	1.63
Atl. Menhaden	Clupeidae	Brevoortia tyrannus	U.S. Atlantic	1.82
Greater lizardfish	Synodontidae	Saurida tumbil	East China Sea	1.90

Table 11. Four SPF 'species' considered in this study, and typical life history characteristics.

Quantity	Redbait (a)	Redbait (b)	Jack mackerel	Blue mackerel
M(0-10)	0.6,0.6,0.6,0.6,0.25,0.25 0.25,0.25,0.25,0.25,0.25	0.22	0.67	0.66
f(0-10)	0,0.1,0.3,0.55,0.75, 0.9,1,1,1,1,1,	0,0,0.25,0.50,0.75, 1,1,1,1,1,1	0,0,0.33,0.67,1, 1,1,1,1,1,1	0,0,1,1,1, 1,1,1,1,1,1
W(0-10)	0.7,17.9,46.6,72.0,89.9,101.4, 108.4,112.5,114.9,116.3,117.1	***L^3***	***L^3***	***L^3***
S(0-10)	0.3,1,1,1,1,1,1,1,1,1,1	0.3,1,1,1,1,1,1,1,1,1,1	0.3,1,1,1,1,1,1,1,1,1,1	0.3,1,1,1,1,1,1,1,1,1,1
K (vB)	0.27	0.27	0.267	0.24
T_0 (vB)	-1.54	-1.54	-1.21	***-1.3***
L_∞ (vB)	28.4 cm	28.4 cm	36.2 cm	44.1 cm

[Bold italicised - value assumed!]

Table 12. Estimates of p_{CRASH} and p_{MEY} for the four SPF 'species' considered in this study and defined in Table 11, using the base case assumption, after Myers et al. (1995), of a kink in the hockey stick recruitment function at 20% of the pristine spawning biomass.

	Base case: kink in hockey stick at 20% of pristine spawning biomass (most likely, after Myers *et al.* (1995))			
Quantity	**Redbait (a)**	**Redbait (b)**	**Jack mackerel**	**Blue mackerel**
	20%	**20%**	**20%**	**20%**
p_{CRASH}	0.897	0.843	1.678	1.27
p_{MEY}	0.281	0.255	0.530	0.42

Table 13. Sensitivity test: Estimates of p_{CRASH} and p_{MEY} for the four SPF 'species' considered in this study and defined in Table 11, using a kink in the hockey stick recruitment function at 40% of the pristine spawning biomass. Although this is not supported by the work of Myers et al. (1995), it could be considered as a low possibility in certain management contexts.

	Sensitivity test: kink in hockey stick at 40% of pristine spawning biomass			
Quantity	**Redbait (a)**	**Redbait (b)**	**Jack mackerel**	**Blue mackerel**
	40%	**40%**	**40%**	**40%**
p_{CRASH}	0.371	0.339	0.698	0.547
p_{MEY}	0.281	0.255	0.530	0.42

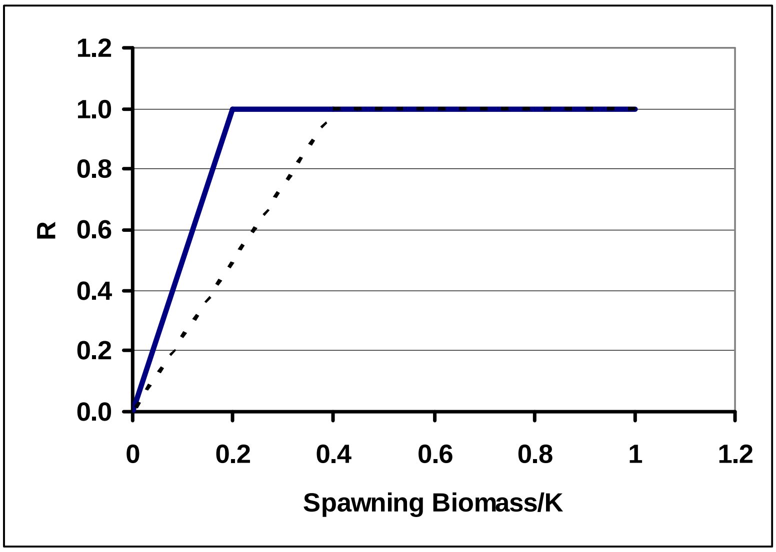


Figure 1. The so-called 'hockey-stick' stock recruitment relationship used in the simulation models employed for this study. The kink at 20% is the base case value used in this document, consistent with the work of, e.g., Myers *et al*. (1995). The 40% assumption or something similar to that is often considered a priori to be a low probability and is thus often used as a sensitivity test in MSE's.

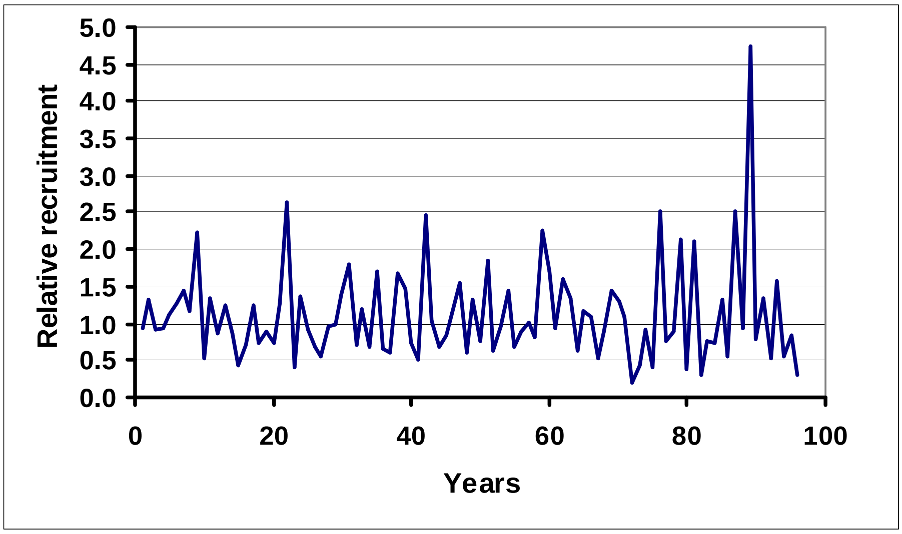


Figure 2. Typical relative fluctuations in recruitment when the logarithm of recruitment deviations have a standard deviation of 0.6 and there is no serial correlation.

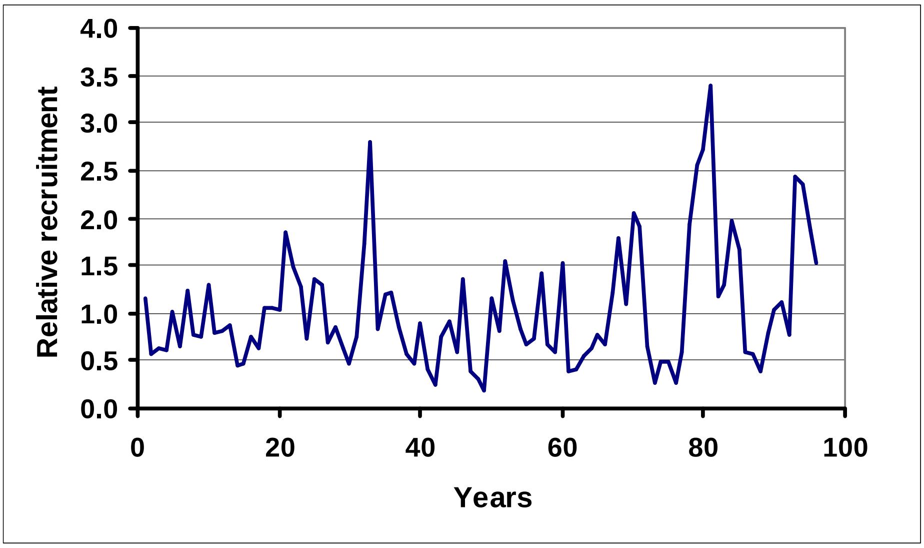


Figure 3. Typical relative fluctuations in recruitment when the logarithm of recruitment deviations have a standard deviation of 0.6, but there is serial correlation with a correlation coefficient of 0.5.

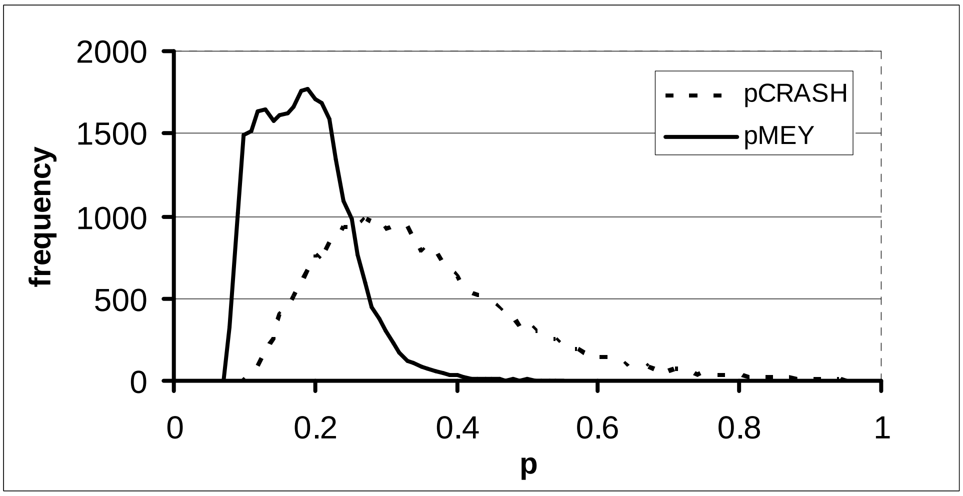


Figure 4. The posterior distribution of p_{CRASH} and p_{MEY} subject to the priors chosen for the essential life history and fishery characteristics as described in the text, based on 30 000 random draws from these priors.

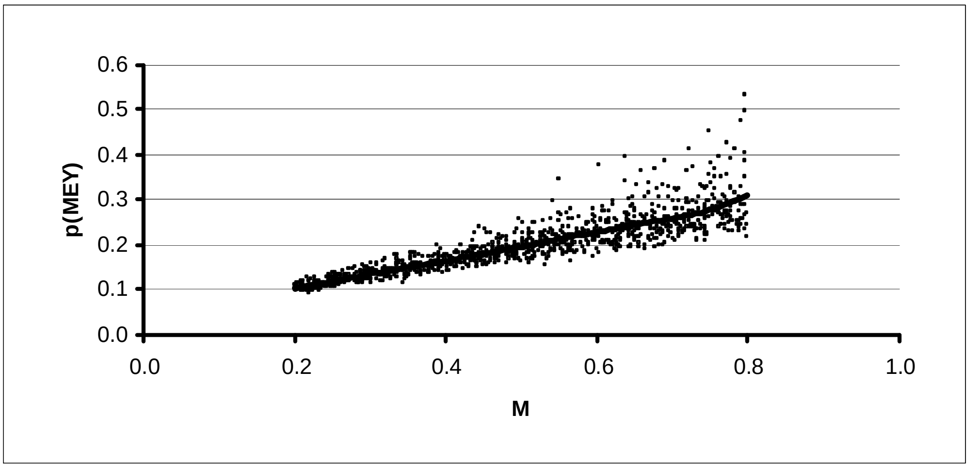


Figure 5. Plot of p_{MEY} versus M (natural mortality) for the first 1000 realisations used to produce the histogram in Figure 4 (these 1000 realisations were found to be suitably representative of the full set of 30 000 realisations).

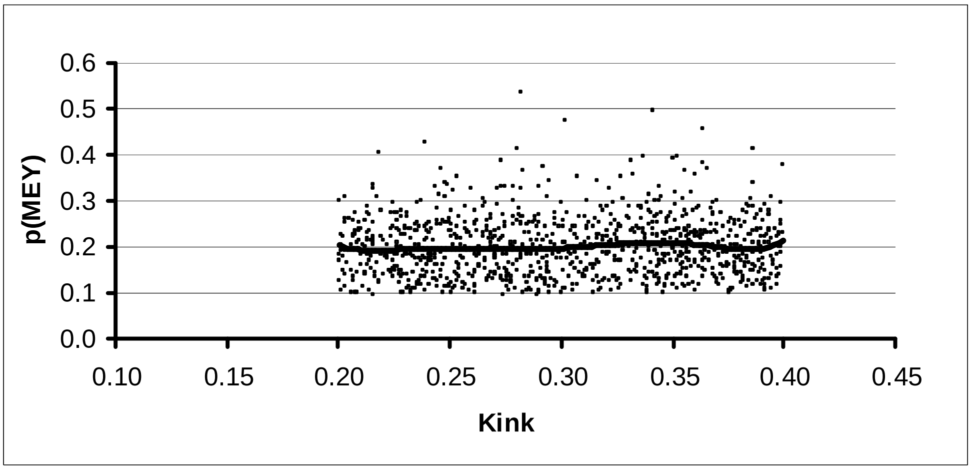


Figure 6. Plot of p_{MEY} versus Kink for the first 1000 realisations used to produce the histogram in Figure 4.

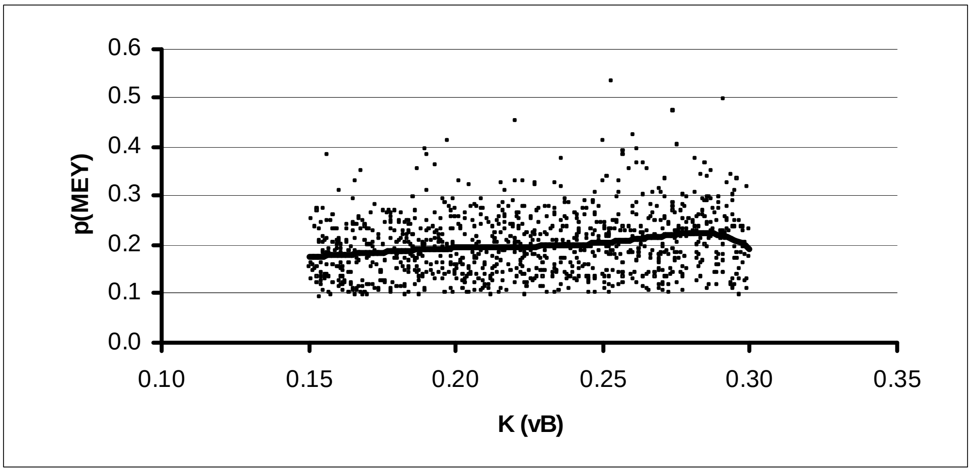


Figure 7. Plot of p_{MEY} versus Kink for the first 1000 realisations used to produce the histogram in Figure 4.

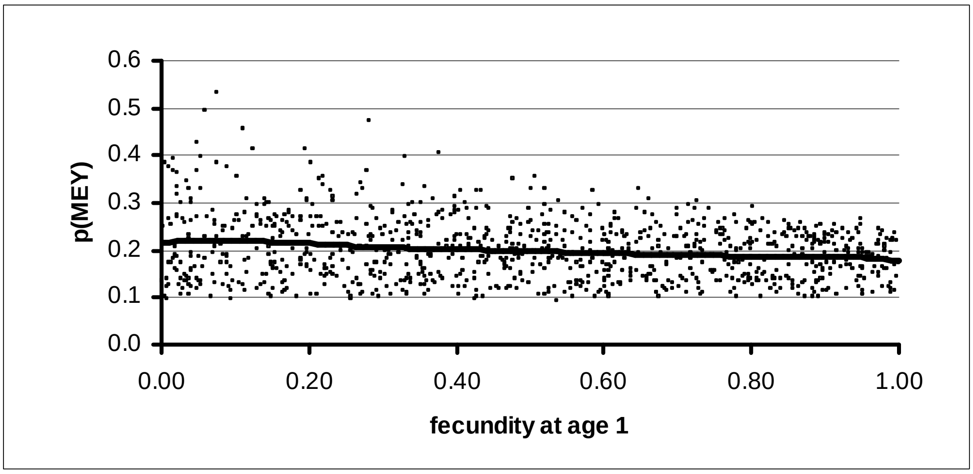


Figure 8. Plot of p_{MEY} versus the fecundity-at-age 1 for the first 1000 realisations used to produce the histogram in Figure 4.

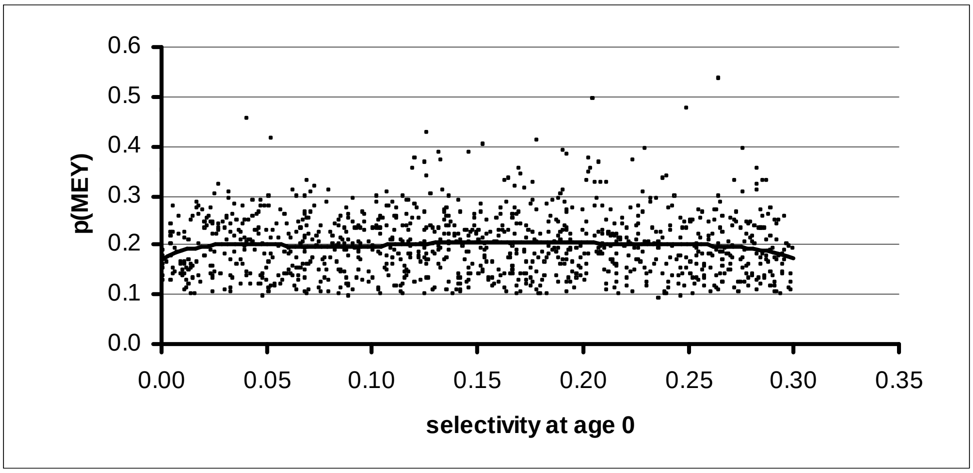


Figure 9. Plot of p_{MEY} versus the selectivity-at-age 1 for the first 1000 realisations used to produce the histogram in Figure 4.

Redbait (a)

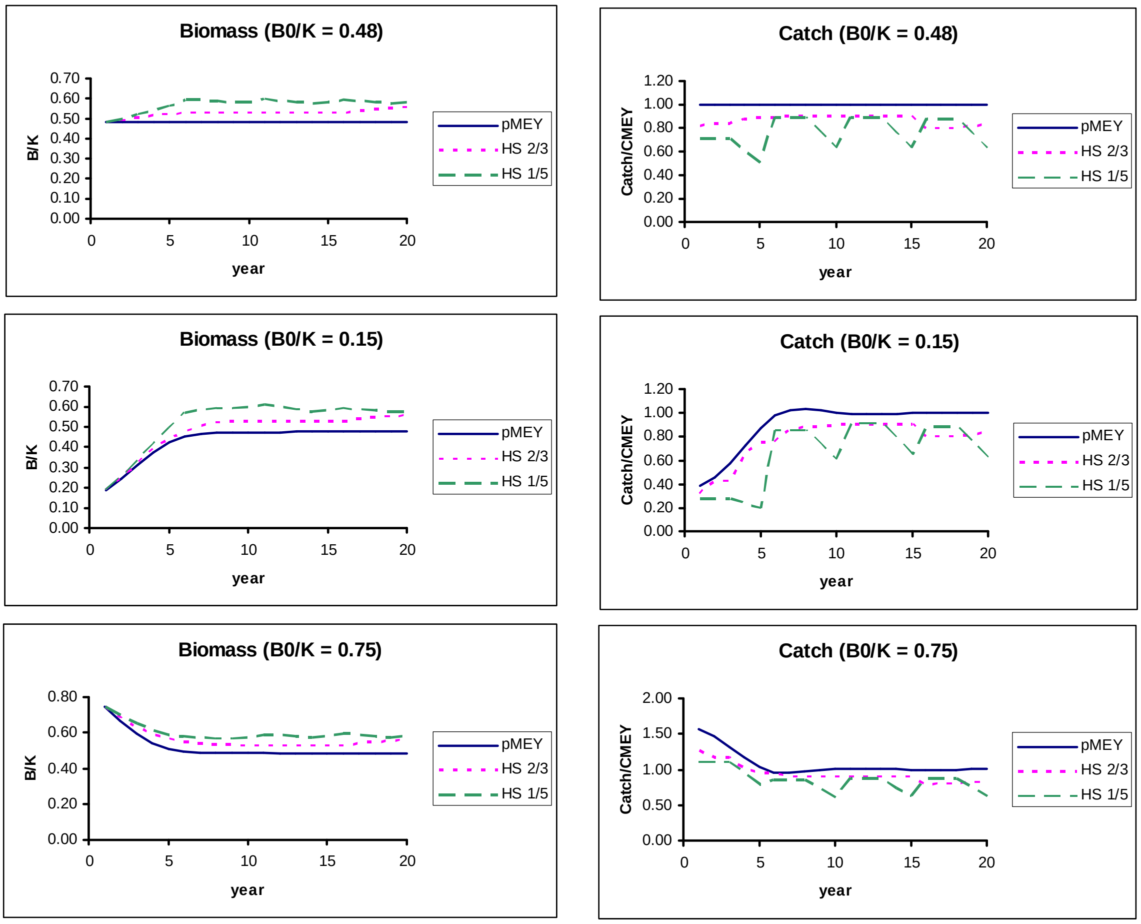


Figure 10. Deterministic results for base case Redbait (a) model comparing biomass and catch under three harvesting approaches, i) the MEY harvesting policy which harvests pMEY of the true spawning biomass (assumed known), ii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 2/3 years, iii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 1/5 years.

Table 14. Deterministic results for base case Redbait (a) from the analyses above. Bend/K are the spawning biomass at the end of the 20 year simulation period as a proportion of pristine. ΣC/ΣCMEY% are the cumulative catch over the 20 year period as a percentage of the catch achieved with the MEY harvesting policy – there are three different harvesting policy results shown: MEY, HS 2/3 and HS 1/5.

	Redbait (a)					
	B_{start}/K			B_{start}/K		
	0.15	**0.48**	**0.75**	**0.15**	**0.48**	**0.75**
Policy	B_{end}/K			$\Sigma C/\Sigma C_{MEY}\%$		
p_{MEY}	0.480	0.480	0.480	100.0%	100.0%	100.0%
HS 2/3	0.559	0.559	0.559	85.8%	86.6%	87.2%
HS 1/5	0.579	0.579	0.580	74.0%	77.0%	79.5%

Redbait (b)

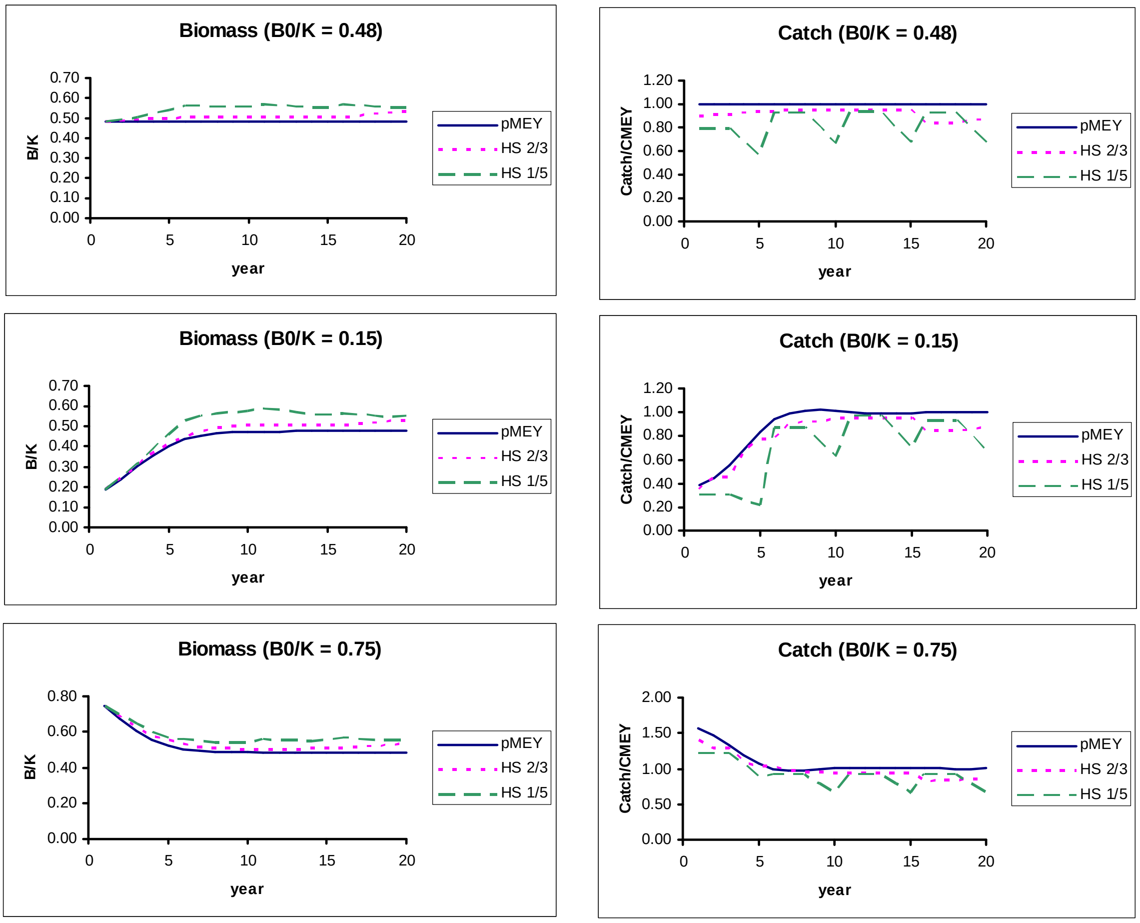


Figure 11. Deterministic results for base case Redbait (b) model comparing biomass and catch under three harvesting approaches, i) the MEY harvesting policy which harvests pMEY of the true spawning biomass (assumed known), ii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 2/3 years, iii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 1/5 years.

Table 15. Deterministic results for base case Redbait (b) from the analyses above. Bend/K are the spawning biomass at the end of the 20 year simulation period as a proportion of pristine. ΣC/ΣCMEY% are the cumulative catch over the 20 year period as a percentage of the catch achieved with the MEY harvesting policy – there are three different harvesting policy results shown: MEY, HS 2/3 and HS 1/5.

	Redbait (b)					
	B_{start}/K			B_{start}/K		
	0.15	0.48	0.75	0.15	0.48	0.75
Policy	B_{end}/K			$\Sigma C/\Sigma C_{MEY}\%$		
p_{MEY}	0.480	0.480	0.480	100.0%	100.0%	100.0%
HS 2/3	0.533	0.533	0.533	90.8%	91.7%	92.3%
HS 1/5	0.554	0.555	0.556	78.8%	82.0%	84.6%

Jack Mackerel

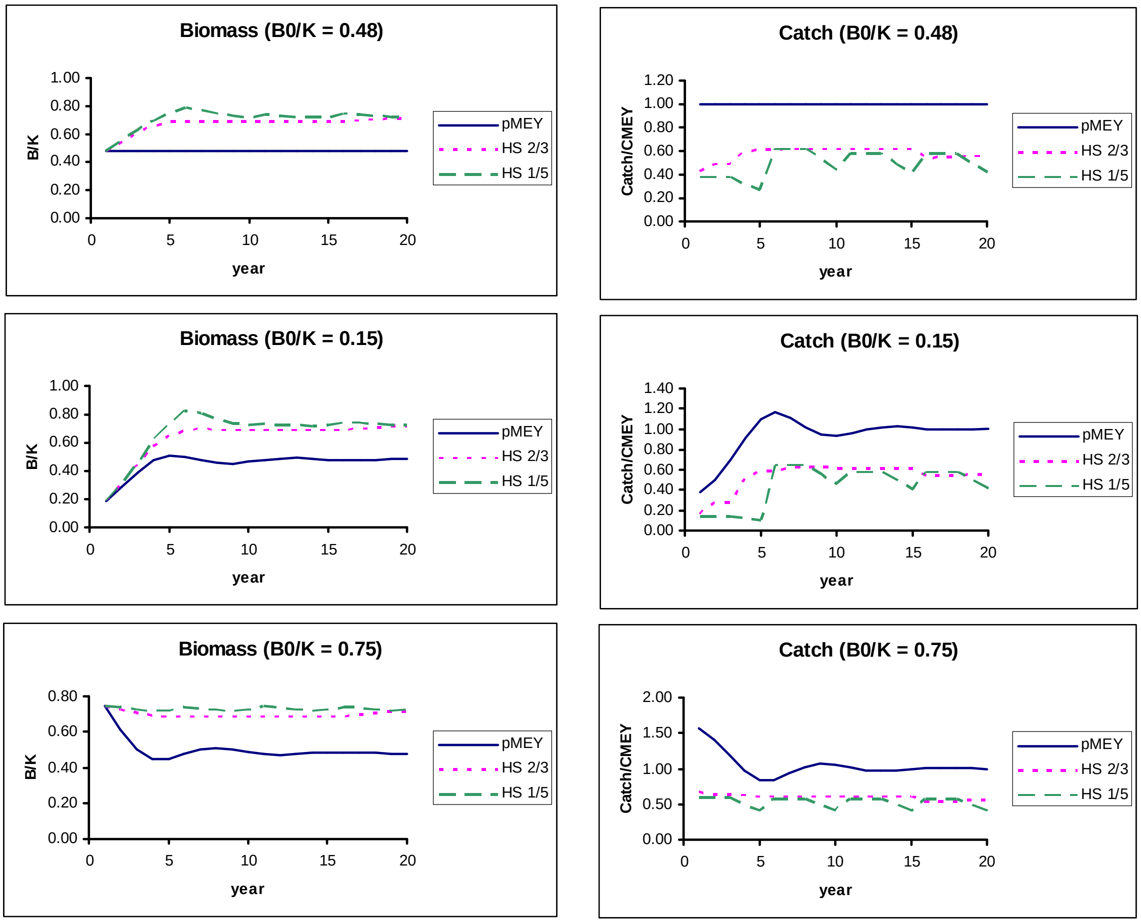


Figure 12. Deterministic results for base case Jack mackerel model comparing biomass and catch under three harvesting approaches, i) the MEY harvesting policy which harvests pMEY of the true spawning biomass (assumed known), ii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 2/3 years, iii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 1/5 years.

Table 16. Deterministic results for base case Jack mackerel from the analyses above. Bend/K are the spawning biomass at the end of the 20 year simulation period as a proportion of pristine. ΣC/ΣCMEY% are the cumulative catch over the 20 year period as a percentage of the catch achieved with the MEY harvesting policy – there are three different harvesting policy results shown: MEY, HS 2/3 and HS 1/5.

	Jack mackerel					
	B_{start}/K			B_{start}/K		
	0.15	0.48	0.75	0.15	0.48	0.75
Policy	B_{end}/K			$\Sigma C/\Sigma C_{MEY}\%$		
p_{MEY}	0.482	0.480	0.478	100.0%	100.0%	100.0%
HS 2/3	0.716	0.716	0.716	57.2%	57.7%	58.0%
HS 1/5	0.726	0.726	0.726	47.4%	49.3%	51.0%

Blue Mackerel

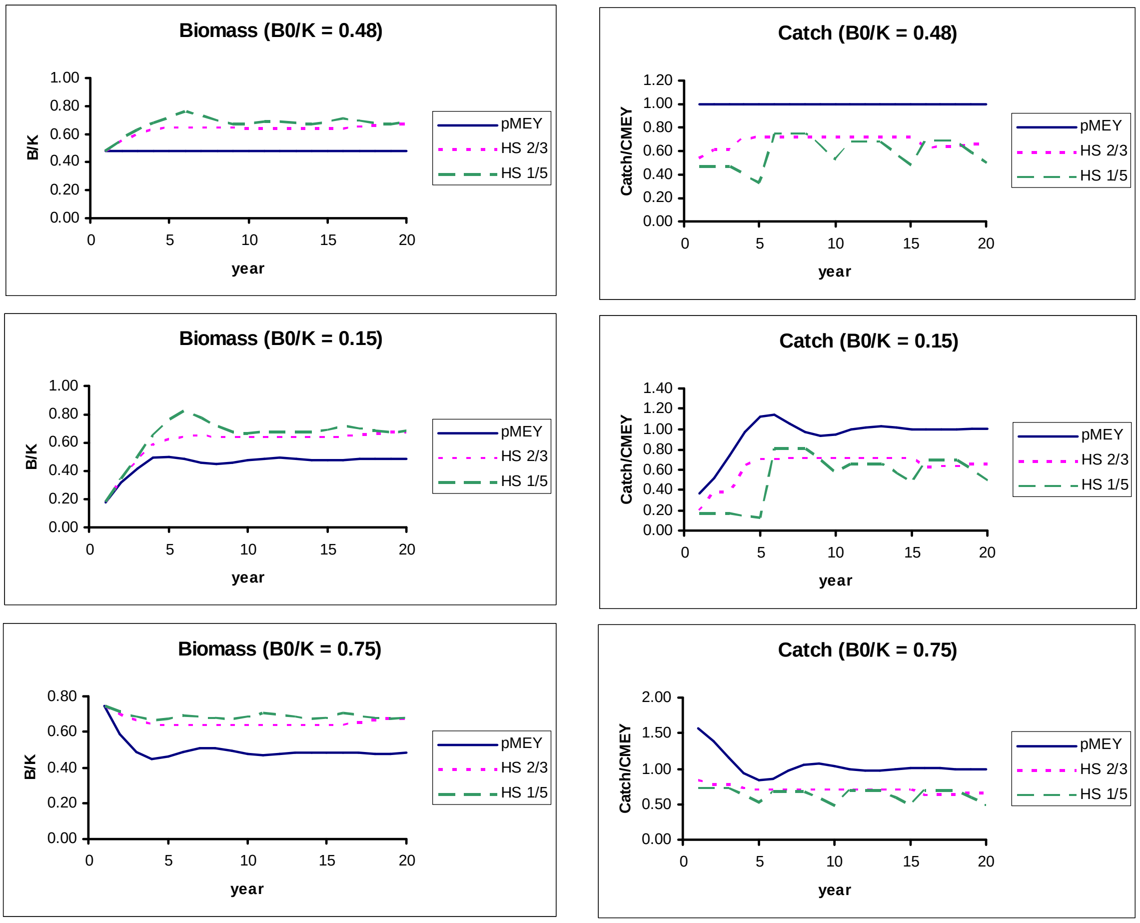


Figure 13. Deterministic results for base case Blue mackerel model comparing biomass and catch under three harvesting approaches, i) the MEY harvesting policy which harvests pMEY of the true spawning biomass (assumed known), ii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 2/3 years, iii) application of the draft HS harvest proportions to the true spawning biomass assumed known in 1/5 years.

Table 17. Deterministic results for base case Blue mackerel from the analyses above. Bend/K are the spawning biomass at the end of the 20 year simulation period as a proportion of pristine. ΣC/ΣCMEY% are the cumulative catch over the 20 year period as a percentage of the catch achieved with the MEY harvesting policy – there are three different harvesting policy results shown: MEY, HS 2/3 and HS 1/5.

	Blue mackerel					
	B_{start}/K			B_{start}/K		
	0.15	0.48	0.75	0.15	0.48	0.75
Policy	B_{end}/K			$\Sigma C/\Sigma C_{MEY}\%$		
p_{MEY}	0.481	0.480	0.480	100.0%	100.0%	100.0%
HS 2/3	0.674	0.674	0.674	67.4%	67.9%	68.2%
HS 1/5	0.682	0.683	0.684	56.9%	59.1%	61.2%

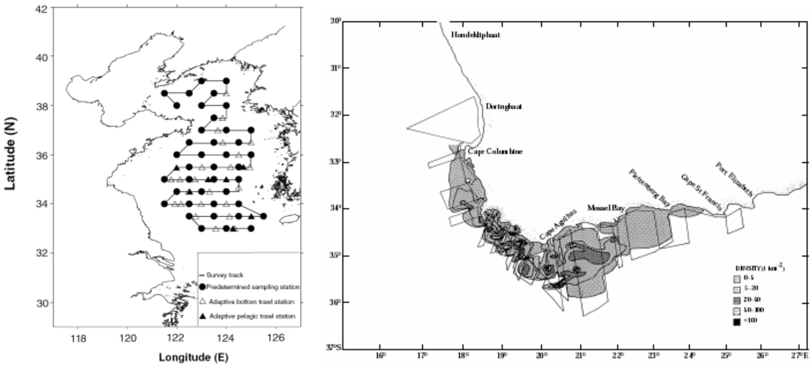


Figure 14. Examples of two different survey designs. The first uses parallel transects that are equal distances apart (Zhao et al., 2003), the second uses randomly stratified parallel transects (Hampton, 1996).

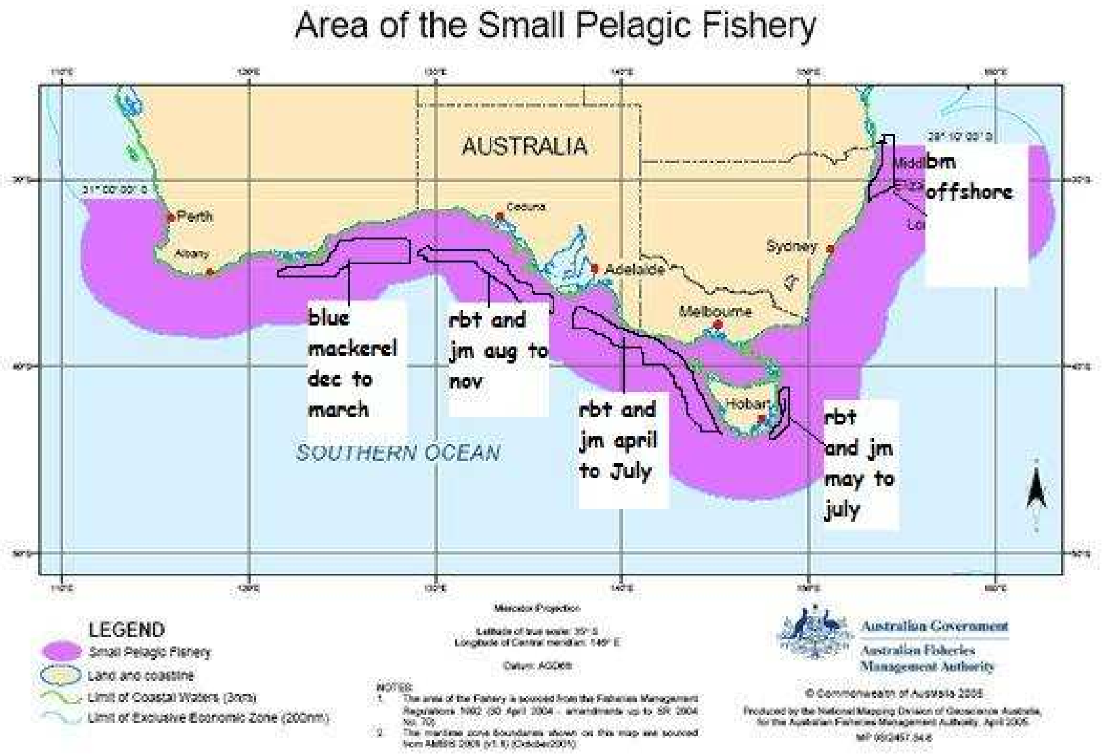


Figure 15. Areas and timing of industry-based survey of SPF fishery.

Table 18. Indicative Tier 1 Survey and Assessment Costs using DEPM (For Discussion)

Species and Stock Region	Estimated Survey Duration in days	Standard Commercial Vessel $10,000 day	Large Freezer Vessel $20,000 day	Govt Research Vessel $5,000 day	Estimated total cost of survey and assessment work[1]
Blue Mack: East - Nth Offshore	10.00	100,000.00	200,000.00	50,000.00	150,000.00
Redbait, Jack Mack: Tas East	10.00	100,000.00	200,000.00	50,000.00	150,000.00
Redbait, Jack Mack: Tas West, SA and Vic central	20.00	200,000.00	400,000.00	100,000.00	300,000.00
Redbait, Jack Mack: Head of Bight	20.00	200,000.00	400,000.00	100,000.00	350,000.00
Blue Mack: Western Bight cost shared SA sardine 50:50	20.00	100,000.00	200,000.00	50,000.00	175,000.00
Lab Analysis - including egg sorting and identification (sample # dependent)[2]	Histology for samples est 10K; sorting samples approx 4mths of tech @ 60K/year	30,000.00 for each survey*	30,000.00*	30,000.00*	
Data entry, analysis and reporting and Quality Assurance[3]	Senior Scientist for 8 weeks at 100K/year	17,000.00 for each survey*	17,000.00*	17,000.00*	
RAG meetings	2 meetings per year @ 15K per meeting to recommend TACs	30,000.00	30,000.00	30,000.00	
Office and Lab Consumables	estimated 3K per survey	3,000.00	3,000.00	3,000.00	
Estimated Total Cost each vessel type		**968,000.00**	**1,668,000.00**	**618,000.00**	**1,125,000.00**

[1] This is an indicative total cost provided by SARDI estimated on the basis of recent DEPM assessments for similar species.
[2] Estimate $30,000 per survey for a Lab Tech, actual time needed will vary according to number of samples
[3] Estimate $17,000 per survey - will also vary according to the size of the survey, number of samples etc.

Table 19. Simulation results for Redbait (a), using Part II, i.e. there is a parallel stock assessment process taking place, coupled with an MEY harvesting Policy. Results are shown for the Draft HS harvest proportions, and two alternatives to the Draft HS harvest proportions.

	Draft HS harvest proportions			**20% maximum, 2% decay rate**			**22.5% maximum, 2.5% decay rate**		
freq	**3/5**	**1/2**	**1/5**	*3/5*	*1/2*	*1/5*	**3/5**	**1/2**	**1/5**
p_{max}	0.200	0.200	0.200	0.200	0.200	0.200	0.225	0.225	0.225
Δp	0.025	0.025	0.025	0.020	0.020	0.020	0.025	0.025	0.025
B_{lim}	10090	10090	10090	10090	10090	10090	10090	10090	10090
K	50451	50451	50451	50451	50451	50451	50451	50451	50451
B_{start}	24216	24216	24216	24216	24216	24216	24216	24216	24216
B_{start} / K	0.480	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	28331	28869	29571	28530	28374	29258	27197	27312	28090
B_{end} S.D.	7323	7339	8626	7275	7311	8527	7528	7264	8334
B_{end} mean / B_{start}	1.17	1.192	1.221	1.178	1.172	1.208	1.123	1.128	1.160
B_{end} / K	0.56	0.572	0.586	0.565	0.562	0.580	0.539	0.541	0.557
Percentage risk (B_{lim})	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Once-off risk (B_{lim})	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.000	0.002
Percentage risk (B_{30})	0.007	0.007	0.008	0.009	0.008	0.009	0.017	0.013	0.014
Once-off risk (B_{30})	0.062	0.057	0.076	0.078	0.062	0.079	0.139	0.103	0.116
Mean catch	4862	4760	4339	4949	4834	4438	5136	5094	4682
S.D. catch	1858	1839	1887	1880	1857	1885	1917	1937	1932
Catch mean % change	0.241	0.281	0.233	0.245	0.254	0.198	0.235	0.249	0.217

Table 20. Simulation results for Redbait (b), using Part II, i.e. there is a parallel stock assessment process taking place, coupled with an MEY harvesting Policy. Results are shown for the Draft HS harvest proportions, and two alternatives to the Draft HS harvest proportions.

	Draft HS harvest proportions			**20% maximum, 2% decay rate**			**22.5% maximum, 2.5% decay rate**		
freq	3/5	1/2	1/5	3/5	1/2	1/5	3/5	1/2	1/5
p_{max}	0.200	0.200	0.200	0.200	0.200	0.200	0.225	0.225	0.225
Δp	0.025	0.025	0.025	0.020	0.020	0.020	0.025	0.025	0.025
B_{lim}	7090	7090	7090	7090	7090	7090	7090	7090	7090
K	35452	35452	35452	35452	35452	35452	35452	35452	35452
B_{start}	17017	17017	17017	17017	17017	17017	17017	17017	17017
B_{start} / K	0.480	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	19180	19401	20253	19204	19208	19845	18269	18519	19199
B_{end} S.D.	4601	4599	5501	4747	4626	5432	4545	4412	5097
B_{end} mean /B_{start}	1.13	1.140	1.190	1.129	1.129	1.166	1.074	1.088	1.128
B_{end} / K	0.54	0.547	0.571	0.542	0.542	0.560	0.515	0.522	0.542
Percentage risk (B_{lim})	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Once-off risk (B_{lim})	0.003	0.000	0.000	0.001	0.000	0.003	0.001	0.000	0.004
Percentage risk (B_{30})	0.009	0.006	0.007	0.008	0.007	0.008	0.014	0.011	0.012
Once-off risk (B_{30})	0.066	0.056	0.059	0.064	0.055	0.061	0.107	0.083	0.092
Mean catch	3232	3183	2908	3254	3226	3001	3416	3363	3143
S.D. catch	1143	1143	1208	1155	1165	1208	1196	1185	1248
Catch mean % change	0.227	0.252	0.224	0.227	0.238	0.192	0.223	0.233	0.203

Table 21. Simulation results for Jack mackerel using Part II, i.e. there is a parallel stock assessment process taking place, coupled with an MEY harvesting Policy. Results are shown for the Draft HS harvest proportions, and two alternatives to the Draft HS harvest proportions.

	Draft HS harvest proportions			20% maximum, 2% decay rate			22.5% maximum, 2.5% decay rate		
freq	3/5	1/2	1/5	3/5	1/2	1/5	3/5	1/2	1/5
p_{max}	0.200	0.200	0.200	0.200	0.200	0.200	0.225	0.225	0.225
Δp	0.025	0.025	0.025	0.020	0.020	0.020	0.025	0.025	0.025
B_{lim}	5321	5321	5321	5321	5321	5321	5321	5321	5321
K	26605	26605	26605	26605	26605	26605	26605	26605	26605
B_{start}	12770	12770	12770	12770	12770	12770	12770	12770	12770
B_{start} / K	0.480	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	18825	18997	19488	18952	18709	19426	18217	18287	18886
B_{end} S.D.	6021	6022	7398	6352	6047	7525	6093	5928	6971
B_{end} mean /B_{start}	1.47	1.488	1.526	1.484	1.465	1.521	1.426	1.432	1.479
B_{end} / K	0.71	0.714	0.733	0.712	0.703	0.730	0.685	0.687	0.710
Percentage risk (B_{lim})	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.002
Once-off risk (B_{lim})	0.004	0.002	0.012	0.001	0.002	0.017	0.003	0.001	0.026
Percentage risk (B_{30})	0.006	0.004	0.009	0.005	0.005	0.010	0.008	0.007	0.013
Once-off risk (B_{30})	0.074	0.053	0.093	0.059	0.061	0.107	0.090	0.086	0.143
Mean catch	3347	3252	2834	3361	3316	2954	3654	3551	3161
S.D. catch	1573	1524	1551	1599	1589	1601	1771	1718	1724
Catch mean % change	0.297	0.334	0.294	0.302	0.323	0.268	0.309	0.327	0.478

Table 22. Simulation results for Blue mackerel using Part II, i.e. there is a parallel stock assessment process taking place, coupled with an MEY harvesting Policy. Results are shown for the Draft HS harvest proportions, and two alternatives to the Draft HS harvest proportions.

	Draft HS harvest proportions			20% maximum, 2% decay rate			22.5% maximum, 2.5% decay rate		
freq	3/5	1/2	1/5	3/5	1/2	1/5	3/5	1/2	1/5
p_{max}	0.200	0.200	0.200	0.200	0.200	0.200	0.225	0.225	0.225
Δp	0.025	0.025	0.025	0.020	0.020	0.020	0.025	0.025	0.025
B_{lim}	7745	7745	7745	7745	7745	7745	7745	7745	7745
K	38726	38726	38726	38726	38726	38726	38726	38726	38726
B_{start}	18589	18589	18589	18589	18589	18589	18589	18589	18589
B_{start} / K	0.480	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	25803	26417	26880	25741	26236	26369	25051	25310	25758
B_{end} S.D.	9225	9665	11295	9768	10119	11173	9722	9577	11913
B_{end} mean /B_{start}	1.39	1.421	1.446	1.385	1.411	1.419	1.348	1.362	1.386
B_{end} / K	0.67	0.682	0.694	0.665	0.677	0.681	0.647	0.654	0.665
Percentage risk (B_{lim})	0.001	0.000	0.004	0.001	0.001	0.005	0.002	0.002	0.007
Once-off risk (B_{lim})	0.015	0.006	0.049	0.014	0.015	0.065	0.031	0.028	0.092
Percentage risk (B_{30})	0.019	0.016	0.023	0.019	0.016	0.026	0.030	0.026	0.037
Once-off risk (B_{30})	0.239	0.217	0.265	0.234	0.206	0.290	0.357	0.311	0.379
Mean catch	4640	4517	3912	4678	4543	4051	4973	4895	4340
S.D. catch	2321	2322	2232	2393	2367	2295	2540	2485	2478
Catch mean % change	0.353	0.382	0.313	0.351	0.371	0.337	0.384	0.417	0.322

Table 23. Simulation results for each species, comparing the results with and without the assumption of a parallel stock assessment process. When there is no parallel stock assessment, then the Draft HS harvest proportions determine the TAC based on the most recent DEPM estimate.

	Blue Mackerel		Jack Mackerel		Redbait A		Redbait B	
	Constraint only	With assessment	Constraint only	With assessment	Constraint only	With assessment	Constraint only	With assessment
freq	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
p_{max}	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Δp	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
B_{lim}	7745	7745	5321	5321	10090	10090	7090	7090
K	38726	38726	26605	26605	50451	50451	35452	35452
B_{start}	18589	18589	12770	12770	24216	24216	17017	17017
B_{start} / K	0.480	0.480	0.480	0.480	0.480	0.480	0.480	0.480
B_{end} mean	26609	25993	18916	18997	28181	28869	18916	19401
B_{end} S.D.	9661	9861	6035	6022	7270	7339	4695	4599
B_{end} mean /B_{start}	1.431	1.398	1.481	1.488	1.164	1.192	1.112	1.140
B_{end} / K	0.687	0.671	0.711	0.714	0.559	0.572	0.534	0.547
Percentage risk (B_{lim})	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Once-off risk (B_{lim})	0.023	0.008	0.000	0.002	0.001	0.000	0.000	0.000
Percentage risk (B_{30})	0.019	0.017	0.003	0.004	0.009	0.007	0.011	0.006
Once-off risk (B_{30})	0.236	0.222	0.047	0.053	0.084	0.057	0.093	0.056
Mean catch	4481	4443	3242	3252	4853	4760	3270	3183
S.D. catch	2331	2268	1577	1524	2041	1839	1337	1143
Catch mean % change	0.373	0.380	0.333	0.334	0.290	0.281	0.283	0.252

Table 24. Simulation results for Redbait (a), comparing the results of variations from the base case. The variations are: Initial spawning biomass is 75% of pristine; 30% of pristine and 15% of pristine; serial correlation in the recruitment deviations is 0.5; the DEPM biomass estimate is biased upwards by 50%; the kink point in the stock recruit relationship is at 40% of pristine spawning biomass.

	base case	**B_0/K = 0.75**	**B_0/K = 0.30**	**B_0/K = 0.15**	**rho = 0.5**	**survey bias = 1.5**	**kink = 0.4**
B_{lim}	10090	10090	10090	10090	10090	10090	10090
K	50451	50451	50451	50451	50451	50451	50451
B_{start}	24216	37838	15135	7568	24216	24216	24216
B_{start} / K	0.480	0.750	0.300	0.150	0.480	0.480	0.480
B_{end} mean	28571	28572	28869	28941	29792	25129	28944
B_{end} S.D.	7259	7259	7339	7556	7556	6825	7556
B_{end} mean /B_{start}	1.18	0.76	1.91	3.82	1.23	1.04	1.20
B_{end} / K	0.57	0.57	0.57	0.57	0.59	0.50	0.57
Percentage risk (B_{lim})	0.000	0.000	0.000	0.112	0.000	0.001	0.000
Once-off risk (B_{lim})	0.000	0.000	0.000	1.000	0.000	0.008	0.000
Percentage risk (B_{30})	0.006	0.005	0.064	0.211	0.003	0.033	0.007
Once-off risk (B_{30})	0.058	0.050	1.000	1.000	0.023	0.249	0.062
Mean catch	4744	5094	4506	4036	4916	5653	4751
S.D. catch	1846	1890	1955	2123	1871	2011	1828
Catch mean % change	0.266	0.251	0.303	0.342	0.268	0.235	0.267

Table 25. Simulation results for Redbait (b), comparing the results of variations from the base case. The variations are: Initial spawning biomass is 75% of pristine; 30% of pristine and 15% of pristine; serial correlation in the recruitment deviations is 0.5; the DEPM biomass estimate is biased upwards by 50%; the kink point in the stock recruit relationship is at 40% of pristine spawning biomass.

	base case	**B_0/K = 0.75**	**B_0/K = 0.30**	**B_0/K = 0.15**	**rho = 0.5**	**survey bias = 1.5**	**kink = 0.4**
B_{lim}	7090	7090	7090	7090	7090	7090	7090
K	35452	35452	35452	35452	35452	35452	35452
B_{start}	17017	26589	10635	5318	17017	17017	17017
B_{start} / K	0.480	0.750	0.300	0.150	0.480	0.480	0.480
B_{end} mean	19317	19502	19531	19698	19967	17091	19168
B_{end} S.D.	4678	4639	4836	4745	5046	4619	5121
B_{end} mean /B_{start}	1.14	0.73	1.84	3.70	1.17	1.00	1.13
B_{end} / K	0.54	0.55	0.55	0.56	0.56	0.48	0.54
Percentage risk (B_{lim})	0.000	0.000	0.000	0.120	0.000	0.000	0.000
Once-off risk (B_{lim})	0.000	0.000	0.000	1.000	0.001	0.003	0.002
Percentage risk (B_{30})	0.006	0.006	0.080	0.227	0.004	0.034	0.018
Once-off risk (B_{30})	0.046	0.043	1.000	1.000	0.030	0.234	0.084
Mean catch	3166	3428	2989	2692	3284	3664	3115
S.D. catch	1167	1199	1232	1373	1192	1238	1144
Catch mean % change	0.253	0.245	0.276	0.320	0.254	0.211	0.248

Table 26. Simulation results for Jack mackerel, comparing the results of variations from the base case. The variations are: Initial spawning biomass is 75% of pristine; 30% of pristine and 15% of pristine; serial correlation in the recruitment deviations is 0.5; the DEPM biomass estimate is biased upwards by 50%; the kink point in the stock recruit relationship is at 40% of pristine spawning biomass.

	base case	**B_0/K = 0.75**	**B_0/K = 0.30**	**B_0/K = 0.15**	**rho = 0.5**	**survey bias = 1.5**	**kink = 0.4**
B_{lim}	5321	5321	5321	5321	5321	5321	5321
K	26605	26605	26605	26605	26605	26605	26605
B_{start}	12770	19954	7981	3991	12770	12770	12770
B_{start} / K	0.480	0.750	0.300	0.150	0.480	0.480	0.480
B_{end} mean	18206	18498	18604	18206	18903	16137	18327
B_{end} S.D.	5933	6388	6253	5933	6201	5866	6279
B_{end} mean /B_{start}	1.43	0.93	2.33	4.56	1.48	1.26	1.44
B_{end} / K	0.68	0.70	0.70	0.68	0.71	0.61	0.69
Percentage risk (B_{lim})	0.000	0.000	0.000	0.066	0.000	0.003	0.001
Once-off risk (B_{lim})	0.000	0.004	0.004	1.000	0.002	0.035	0.005
Percentage risk (B_{30})	0.007	0.007	0.058	0.144	0.003	0.039	0.012
Once-off risk (B_{30})	0.082	0.089	1.000	1.000	0.036	0.364	0.108
Mean catch	3546	3720	3430	3167	3647	4632	3522
S.D. catch	1720	1676	1787	1888	1693	2239	1706
Catch mean % change	0.328	0.311	0.373	0.441	0.326	0.387	0.327

Table 27. Simulation results for Blue Mackerel, comparing the results of variations from the base case. The variations are: Initial spawning biomass is 75% of pristine; 30% of pristine and 15% of pristine; serial correlation in the recruitment deviations is 0.5; the DEPM biomass estimate is biased upwards by 50%; the kink point in the stock recruit relationship is at 40% of pristine spawning biomass.

	base case	**B_0/K = 0.75**	**B_0/K = 0.30**	**B_0/K = 0.15**	**rho = 0.5**	**survey bias = 1.5**	**kink = 0.4**
B_{lim}	7745	7745	7745	7745	7745	7745	7745
K	38726	38726	38726	38726	38726	38726	38726
B_{start}	18589	29045	11618	5809	18589	18589	18589
B_{start} / K	0.480	0.750	0.300	0.150	0.480	0.480	0.480
B_{end} mean	26212	26336	26762	26419	26786	22850	26295
B_{end} S.D.	9331	10189	10140	9684	9909	9573	9996
B_{end} mean /B_{start}	1.41	0.91	2.30	4.55	1.44	1.23	1.41
B_{end} / K	0.68	0.68	0.69	0.68	0.69	0.59	0.68
Percentage risk (B_{lim})	0.000	0.001	0.001	0.055	0.000	0.008	0.002
Once-off risk (B_{lim})	0.004	0.012	0.013	1.000	0.006	0.120	0.021
Percentage risk (B_{30})	0.015	0.015	0.067	0.155	0.010	0.065	0.024
Once-off risk (B_{30})	0.203	0.199	1.000	1.000	0.120	0.592	0.233
Mean catch	4468	4675	4343	4063	4651	5617	4383
S.D. catch	2296	2256	2396	2550	2358	2954	2256
Catch mean % change	0.378	0.373	0.431	0.540	0.377	0.448	0.378

Table 28. Simulation results for Redbait (a), comparing the results with and without the assumption of a parallel stock assessment process for 3 different DEPM survey frequencies at a harvest proportion of 30%.

	With assessment			**Constraint only**		
freq	3/5	1/2	1/5	3/5	1/2	1/5
p_{max}	0.300	0.300	0.300	0.300	0.300	0.300
Δp	0.020	0.020	0.020	0.020	0.020	0.020
B_{lim}	10090	10090	10090	10090	10090	10090
K	50451	50451	50451	50451	50451	50451
B_{start}	24216	24216	24216	24216	24216	24216
B_{start} / K	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	24401	24685	25063	22146	22502	21736
B_{end} S.D.	6749	6766	7798	6684	6859	9484
B_{end} mean /B_{start}	1.008	1.019	1.035	0.914	0.929	0.898
B_{end} / K	0.484	0.489	0.497	0.439	0.446	0.431
Percentage risk (B_{lim})	0.000	0.001	0.001	0.009	0.009	0.049
Once-off risk (B_{lim})	0.004	0.010	0.015	0.092	0.086	0.277
Percentage risk (B_{30})	0.038	0.036	0.043	0.127	0.103	0.148
Once-off risk (B_{30})	0.285	0.268	0.315	0.661	0.598	0.634
Mean catch	5732	5731	5518	6324	6265	5991
S.D. catch	2037	2023	2058	2741	2681	2915
Catch mean % change	0.215	0.218	0.191	0.273	0.272	0.183

Table 29. Simulation results for Redbait (b), comparing the results with and without the assumption of a parallel stock assessment process for 3 different DEPM survey frequencies at a harvest proportion of 30%.

	Redbait (b)					
	With assessment			**Constraint only**		
freq	3/5	1/2	1/5	3/5	1/2	1/5
p_{max}	0.300	0.300	0.300	0.300	0.300	0.300
Δp	0.020	0.020	0.020	0.020	0.020	0.020
B_{lim}	7090	7090	7090	7090	7090	7090
K	35452	35452	35452	35452	35452	35452
B_{start}	17017	17017	17017	17017	17017	17017
B_{start} / K	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	16688	16867	17089	14689	14923	14469
B_{end} S.D.	4324	4262	4889	4245	4309	6066
B_{end} mean / B_{start}	0.981	0.991	1.004	0.863	0.877	0.850
B_{end} / K	0.471	0.476	0.482	0.414	0.421	0.408
Percentage risk (B_{lim})	0.000	0.001	0.000	0.011	0.010	0.052
Once-off risk (B_{lim})	0.001	0.007	0.006	0.093	0.086	0.276
Percentage risk (B_{30})	0.036	0.033	0.039	0.155	0.127	0.166
Once-off risk (B_{30})	0.249	0.230	0.277	0.697	0.641	0.672
Mean catch	3735	3740	3629	4227	4189	4033
S.D. catch	1258	1244	1260	1782	1740	1899
Catch mean % change	0.201	0.202	0.176	0.265	0.263	0.171

Table 30. Simulation results for Jack Mackerel, comparing the results with and without the assumption of a parallel stock assessment process for 3 different DEPM survey frequencies at a harvest proportion of 30%.

	With assessment			**Constraint only**		
freq	3/5	1/2	1/5	3/5	1/2	1/5
p_{max}	0.300	0.300	0.300	0.300	0.300	0.300
Δp	0.020	0.020	0.020	0.020	0.020	0.020
B_{lim}	5321	5321	5321	5321	5321	5321
K	26605	26605	26605	26605	26605	26605
B_{start}	12770	12770	12770	12770	12770	12770
B_{start} / K	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	16272	16516	16836	16127	16374	16105
B_{end} S.D.	5823	6150	7174	5814	6152	7656
B_{end} mean /B_{start}	1.274	1.293	1.318	1.263	1.282	1.261
B_{end} / K	0.612	0.621	0.633	0.606	0.615	0.605
Percentage risk (B_{lim})	0.001	0.002	0.007	0.003	0.003	0.028
Once-off risk (B_{lim})	0.018	0.028	0.087	0.036	0.036	0.176
Percentage risk (B_{30})	0.025	0.027	0.043	0.031	0.031	0.069
Once-off risk (B_{30})	0.266	0.274	0.388	0.317	0.301	0.441
Mean catch	4422	4376	4041	4483	4427	4128
S.D. catch	2127	2109	2118	2234	2192	2318
Catch mean % change	0.313	0.356	0.547	0.314	0.315	0.249

Table 31. Simulation results for Blue Mackerel, comparing the results with and without the assumption of a parallel stock assessment process for 3 different DEPM survey frequencies at a harvest proportion of 30%.

	With assessment			**Constraint only**		
freq	3/5	1/2	1/5	3/5	1/2	1/5
p_{max}	0.300	0.300	0.300	0.300	0.300	0.300
Δp	0.020	0.020	0.020	0.020	0.020	0.020
B_{lim}	7745	7745	7745	7745	7745	7745
K	38726	38726	38726	38726	38726	38726
B_{start}	18589	18589	18589	18589	18589	18589
B_{start} / K	0.48	0.48	0.48	0.48	0.48	0.48
B_{end} mean	22353	22313	23177	21658	21634	20540
B_{end} S.D.	9462	9563	11583	9498	9626	12791
B_{end} mean /B_{start}	1.203	1.200	1.247	1.165	1.164	1.105
B_{end} / K	0.577	0.576	0.598	0.559	0.559	0.530
Percentage risk (B_{lim})	0.007	0.009	0.021	0.019	0.018	0.086
Once-off risk (B_{lim})	0.116	0.133	0.240	0.239	0.227	0.452
Percentage risk (B_{30})	0.074	0.070	0.081	0.101	0.090	0.152
Once-off risk (B_{30})	0.664	0.631	0.660	0.758	0.708	0.749
Mean catch	5818	5785	5329	6023	5967	5418
S.D. catch	2928	2961	2854	3342	3327	3356
Catch mean % change	0.396	0.422	0.358	0.402	0.396	0.469

Table 32. Estimated costs of sampling and reporting per ten day trip during SPF survey.

Sampling costs per trip	
Observer sea day salary per trip @ $700 per day	$ 7,000.00
Observer land day salary per trip @ $400 per day	$800.00
PI co-ordination per day	$ 3,875.00
Lab consumables per trip (collecting 10 plankton tow samples per day)	$300.00
Other consumables per trip (data sheets, mobile phones, photocopying, mailings etc)	$250.00
Airfare per trip	$1,200.00
Accommodation per trip	$240.00
Vehicle hire/trip	$250.00
Total sampling costs per trip	**$13,915.00**
Analysis and reporting per trip	
CSIRO scientists to download and verify echo-integration data	$2,000.00
Laboratory sorting of plankton samples salary trip (5 samples sorted per day)	$8,000.00
Data analysis and report per trip (allowing 4 weeks)	$8,000.00
Total analysis and reporting costs per trip	**$18,000.00**
Total cost per trip	**$31,915**

Appendix 1

The Draft HS upon which the quantitative results are based.

Decision Rules

The limit RBCs and exploitation rates (catch/spawning biomass) assigned in the tier's below were selected on the basis of: i) SPFRAG's understanding of the status of stocks; ii) previously accepted harvest limits for the fishery; and iii) precautionary harvest rates successfully applied in other fisheries for small pelagic species. These limits are considered to be interim boundaries noting that a complete review of the HS is required within 12 months from the commencement of the HS.

Importantly the values applied are maximum limits only. As prescribed in the decision rules, SPFRAG must consider all available information on the status of the stocks when forming its advice on RBCs.

TIER 3

Assessment and monitoring

Assessment is done biannually based on only catch and effort data from logbooks and/or observers. Aim of assessment is to determine likelihood of overfishing, particularly localised depletion. The biannual report is to provide advice regarding the level of fishing that should be permitted.

RBC decision rules

1. The RBC for each stock within each management zone will be recommended by SPFRAG based on available information including biology, historical catch and spatial area of zone but may not exceed 500t.

TIER 2

Assessment and monitoring

Assessment is done annually and includes catch and effort data as well as annual information on the age structure of catch. Aim of assessment is to determine likelihood of localised depletion or change in the size/age structure of the catch that cannot be adequately explained by reasons other than a decline in abundance. The annual report is to provide advice regarding the level of fishing that should be permitted.

RBC decision rules

1. The RBC for each stock within each management zone will be recommended by SPFRAG based on available information including biology, historical catch and spatial area of zone but may not exceed the values (shown in tonnes) listed in the table below.

Species	**Western zone**	**Eastern zone**
Redbait	10,000	9,000
Blue mackerel	10,000 Possibly to be divided between the far west and the inner west sub-areas	5,000
Jack mackerels	10,000	9,000

Australian sardine	N/A	3,000

2. If 50% of the catch limit of any one species is caught, SPFRAG must meet within one month to discuss any potential implications for the stock.

To mitigate the threat of localised depletion SPFRAG also recommends that no more than 50% of any one catch limit be taken within a single five degree square.

TIER 1

Assessment and monitoring

Assessment based on a robust spawning biomass estimate derived from DEPM and annual assessments which include catch and effort data and up to date information on the size/age structure of catch. The assessment report is to provide advice regarding the level of fishing that should be permitted.

RBC decision rules

1. The RBC for each stock within each management zone will be recommended by SPFRAG based on the DEPM assessment and all available information including biology, historical catch and spatial area of zone. The RBC must not exceed levels resulting from relevant harvest rate listed in the table below.

Age of DEPM assessment (years)	Maximum harvest rate as a percentage of median spawning biomass estimated from a DEPM assessment
5	10
4	12.5
3	15
≤2	17.5
2 in 3 OR 3 in 5	20

2. If two successive DEPM assessments produce significantly different spawning biomass estimates SPFRAG will, on the merit of the assessments and all other supporting information, exercise its judgement on which assessment to use when deciding on an RBC for a particular stock.

NOTE: If the last DEPM assessment is greater than five years old for a particular stock, that stock must be assessed under Tier 3.

Appendix 2

Description of the mathematical model used for simulation studies

Population dynamics

The population dynamics are represented by:

$$N_{y+1,0} = R_{y+1} \quad (1)$$

$$N_{y+1,a} = N_{y,a-1} e^{-M_a} (1 - S_a . F_y) \qquad \text{for } 1 \le a \le m-1 \quad (2)$$

$$N_{y+1,m} = N_{y,m-1} e^{-M_{m-1}} (1 - S_{m-1} . F_y) + N_{y,m} e^{-M_m} (1 - S_m . F_y) \quad (3)$$

where:

$N_{y,a}$ is the number of fish of age *a* at the start of year *y*,

R_y is the number of 0 year olds at the start of year *y*,

M_a is the instantaneous rate of natural mortality at age *a*.

S_a is the fishing selectivity at age a,

F_y is the harvest proportion in year *y*,

m is the largest age considered (i.e. the “plus group”, taken to be 10 years).

The stock-recruit relationship.

The true spawning biomass at the start of year *y* is given by:

$$B_y^{sp} = \sum_{a=1}^{m} N_{y,a} . w_a . f_a \quad (4)$$

where:

w_a is the mass of a fish of age *a* at the start of the year

f_a is the proportion of sexual maturity at age *a*

A “hockey-stick” recruitment form is assumed with recruitment given by:

$$R_y = R^* . e^{r_y} \qquad \text{if } B_y^{sp} \ge B^* \quad (5)$$

$$R_y = R^* . \frac{B_y^{sp}}{B^*} e^{r_y} \qquad \text{if } B_y^{sp} < B^* \quad (6)$$

where

R^* is the maximum recruitment

B^* is the biomass level above which maximum recruitment occurs.

r_y is a random number drawn from a normal distribution with mean zero, variance ${\sigma_R}^2$ and serial correlation ρ_R

Spawning biomass estimates from egg production surveys

For years in which an egg production survey is conducted, we simulate the spawning biomass estimate resulting from this survey by

$$B_y^{surv} = B_y^{sp} e^{\omega} \quad (7)$$

Where

ω is a random number drawn from a normal distribution with mean zero and variance σ_{surv}^2

σ_{surv} = 0.3 is the assumed survey CV.

Catches

The TAC in the simulations is set by

$$TAC_y = p.B_y^{surv} \tag{8}$$

where

B_y^{surv} is the most recent available spawning biomass estimate from egg production surveys in year y

p is the proportion of estimated spawning biomass which may be taken as catch, as stipulated by the prevailing management rule.

In accordance with Pope's approximation, the catches are assumed to be taken as a pulse at midyear with catches constrained to no more than 95% of the exploitable biomass.

The mid-year exploitable biomass is calculated by

$$B_y^{ex} = \sum_{a=1}^{m} N_{y,a}.e^{-M_a/2}.w_{a+1/2}.f_a \tag{9}$$

Where

f_a is the fecundity at age a relative to sexually mature fish

$$w_{a+1/2} = \sqrt{w_a.w_{a+1}} \tag{10}$$

$$F_y = TAC_y / B_y^{ex} \qquad \text{if} \qquad TAC_y / B_y^{ex} \leq 0.95 \tag{11}$$

$$F_y = 0.95 \qquad \text{if} \qquad TAC_y / B_y^{ex} > 0.95 \tag{12}$$

The realised catch in year *y* is then:

$$C_y = F_y.B_y^{ex} \tag{13}$$

Unexploited equilibrium

Under equilibrium, we assume that the recruitment is biased by comparison with the deterministic recruitment by a factor $e^{\sigma_R^2/2}$ where $\sigma_R{}^2$ is the recruitment deviation variance. The unexploited equilibrium numbers at age a are calculated by:

$$N_{eq,0} = R^* e^{\sigma_R^2/2} \tag{14}$$

$$N_{eq,a} = N_{eq,a-1}e^{-M_a} \qquad \text{for} \quad 1 \leq a \leq m-1 \tag{15}$$

$$N_{eq,m} = N_{eq,m-1}e^{-M_{m-1}} / (1 - N_{y,m}e^{-M_m}) \tag{16}$$

The equilibrium spawning biomass (carrying capacity) is then:

$$K^{sp} = \sum_{a=1}^{m} N_{eq,a}.w_a.f_a \tag{17}$$

Equilibrium under fishing

In the forward projections, we assume that the resource begins (at year 0) in equilibrium at a specified level relative to pristine. This equilibrium is governed by the following equations:

$$N_{0,0} = R_0 \tag{18}$$

$$N_{0,a} = N_{0,a-1}e^{-M_a}(1 - S_a.F_0) \qquad \text{for } 1 \le a \le m-1 \tag{19}$$

$$N_{0,m} = N_{0,m-1}e^{-M_{m-1}}(1 - S_{m-1}.F_0) + N_{0,m}e^{-M_m}(1 - S_m.F_0) \tag{20}$$

$$B_0^{sp} = \sum_{a=1}^{m} N_{0,a}.w_a.f_a \tag{21}$$

which can be solved for the harvest portion F_0 to obtain the required level of depletion.

Simulation of Stock-Assessment driven management advice.

It is assumed that the net effect of the ongoing stock assessments is to provide an annual absolute estimate of the spawning biomass. In order to simulate such an effect, an abundance index is simulated for each year of the simulation period (which is 20 years long) by random sampling from a lognormal distribution about the true spawning biomass with a log-normal standard deviation of 0.30 (approximately a C.V. of 30%). Each of these indices is down-weighted by a factor $e^{-0.3^2/2}$ to account for bias in the mean lognormal error.

In addition, for years in which a DEPM-based spawning biomass estimate is available, the abundance index is modified by variance-weighted averaging it with the DEPM-based estimate.

In each year, a spawning biomass estimate for the current year is obtained by conducting a linear regression on the abundance indices for the 6 preceding years, and projecting the linear trend to the current year.

A simulated estimate of the TAC as a proportion of the spawning biomass which is equivalent to an F_{MEY} harvesting policy, p_{MEY}, is generated by random sampling from a normal distribution about the true value of p_{MEY} with a 10% CV. This estimate is generated only once for each simulation and is assumed to be constant throughout the 20 year planning period.

The 'assessment-based TAC recommendation' is calculated as the product of the estimate of *pMEY* with the estimate of spawning biomass. If this is larger than the TAC that results by using the formulation in the draft HS, i.e. TAC = draft HS harvest proportion multiplied by the most recent DEPM based spawning biomass, then the latter TAC is applied. Otherwise the stock assessment based TAC is applied.

Base case natural mortality assumptions for Redbait A

Exponential regression of age frequencies in the 2003 redbait catch in Zone A against age suggest total mortality of 0.3 for age zero, 0.7 for ages 1 to 3 and 0.3 for ages 4 + assuming uniform selectivity (Welsford and Lyle, 2004). Assuming a fishing mortality of about 0.1, this implies a natural mortality of 0.2 at age zero, 0.6 at ages 1 to 3 and 0.2 for ages 4 +. The low mortality at age zero is unlikely. More likely is an M of 0.6 coupled with a selectivity at age zero which is 1/3 that of age 1+. This is the assumption made in the base case for Redbait.

Appendix 3

Two measures of biological risk considered in computer simulations

Glazer and Butterworth (2005) propose a measure of risk that, stated verbally, is the proportion of scenarios in which the resource biomass falls below 10% or 20% (both are cited) of the pristine level one or more times. In this context a scenario is a single realization of future biomasses, catches and CPUE's over a ten year planning horizon, i.e. 2003 – 2012. We refer to the definition of risk contained in the Glazer and Butterworth (2005) document as the 'once-off risk'.

An alternative to the 'once-off risk' is the 'percentage risk'. The 'percentage risk' is the proportion of future years for which the resource biomass lies below 10% or 20% of its pristine level. The following table illustrates the difference between the 'once-off risk' and the 'percentage risk'.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 4
Pristine	1000	1200	900	800	1050
2005	300	340	250	230	300
2006	300	340	250	230	300
2007	300	340	***135***	230	300
2008	300	340	250	230	300
2009	***150***	340	250	***120***	300
2010	***140***	340	250	***135***	300
2011	***120***	340	250	230	300
2012	220	340	250	230	300
2013	230	340	250	***111***	300
2014	***120***	340	250	230	300

The bold italicised values indicate that the resource biomass has fallen below 20% of the pristine level. There are 5 scenarios. Since three of these scenarios contain one or more bold italicised values, the 'once-off risk' is 3/5, or 60%. On the other hand, there are a total of 5x10 = 50 years in all scenarios taken together. There are a total of 4+1+3 = 8 bold italicised values. Thus the 'percentage risk' is 8/50, or 16%. There could thus be a vast difference between the two measures of risk, and in general

'once-off risk' >> 'percentage risk'.

In this document we present both versions of biological risk. The second version of biological risk is the one referred to in the HSP.

Appendix 4

The relative similarity of "other" species with the 5 SPF species species (similarity values less than 2.00 are in bold)

Other species			Similarness to					
Common name	Family	Species	Redbait	Blue mackerel	Peruvian jack mackerels	Yellowtail scad	Jack mackerel	Australian sardine
Albacore tuna	Scombridae	Thunnus alalunga	7.60	3.40	11.70	2.70	4.70	3.40
Alaska pollack	Gadidae	Theragra chalcogramma	7.20	3.80	12.10	3.10	5.10	3.80
Alaska plaice	Pleuronectidae	Pleuronectes auadrituberculatus	2.61	5.47	**1.56**	3.14	3.82	5.47
American plaice	Pleuronectidae	Hippoglossoides platessoides	2.50	5.43	**1.40**	3.07	3.73	5.43
Northern anchovy	Engraulidae	Engraulis mordax	21.65	3.95	32.50	13.50	15.00	3.95
Anchovy	Engraulidae	Engraulis encrasicolus	30.40	6.87	45.00	19.33	21.67	6.87
Northern anchovy	Engraulidae	Engraulis mordax	10.40	**0.20**	16.43	6.00	6.43	0.20
Atlantic argentine	Argentinidae	Argentina silus	3.90	6.50	3.01	4.30	5.01	6.50
Atka mackerel	Hexagrammidae	Pleurogrammus monopterygius	3.50	4.77	6.90	**1.23**	2.23	4.77
Blueback herring	Clupeidae	Alosa aestivalis	9.73	1.63	14.95	3.95	6.20	**1.63**
Bigeye Tuna	Scombridae	Thunnus obesus	6.85	3.92	10.54	2.26	4.17	3.92
Blue-eye trevalla	Centrolophidae	Hyperoglyphe antarctica	3.20	5.47	2.53	4.43	4.20	5.47
Blue grenadier	Merlucciidae	Macruronus novaezelandiae	2.70	5.70	2.90	3.10	3.70	5.70
Bluefish	Pomatomidae	Pomatomus saltatrix	5.85	3.58	9.20	**1.53**	3.37	3.58
Blue moki	Latridae	Latridopsis ciliaris	3.02	5.34	2.05	3.48	4.18	5.34
Blue warehou	Centrolophidae	Seriolella brama	4.45	2.98	8.20	**1.53**	2.37	2.98
Black anglerfish	Lophiidae	Lophius budegassa	4.00	4.60	7.61	0.90	2.61	4.60
Black oreo	Oreosomatidae	Allocyttus niger	5.41	6.07	5.12	5.64	5.58	6.07
Branquillo	Branchiostegidae	Branchiostegus japonicus	5.45	3.98	9.60	**1.93**	3.77	3.98
Bream	Cyprinidae	Abramis brama	3.08	4.64	5.72	**1.78**	2.19	4.64
Atlantic bluefin tuna	Scombridae	Thunnus thynnus	4.10	4.17	6.70	**1.03**	2.03	4.17
Butterfish	Stromateidae	Peprilus triacanthus	22.15	4.45	33.40	13.40	15.90	4.45
Blue whiting	Gadidae	Micromesistius poutassou	2.15	5.35	4.40	2.40	2.90	5.35
Canary rockfish	Scorpaenidae	Sebastes pinniger	2.23	5.06	4.99	2.42	2.89	5.06
Cape Hake	Gadidae	Merluccius capensis	5.25	4.18	9.40	**1.73**	3.57	4.18
Capelin	Osmeridae	Mallotus villosus	17.90	3.70	26.50	9.50	12.50	3.70
Champsocephalus gunnari	Channichthyidae	Champsocephalus gunnari	4.08	3.91	7.94	0.78	2.55	3.91
Chilipepper rockfish	Scorpaenidae	Sebastes goodei	3.50	6.10	2.61	3.90	4.61	6.10
Chub mackerel	Scombridae	Scomber japonicus	5.25	4.18	9.40	**1.73**	3.57	4.18
Chub mackerel	Scombridae	Scomber japonicus	4.58	4.41	8.44	**1.28**	3.05	4.41
Cod	Gadidae	Gadus morhua	2.70	5.30	2.90	3.10	3.70	5.30
Cod	Gadidae	Gadus morhua	7.40	3.20	11.90	2.90	4.90	3.20
Cod	Gadidae	Gadus morhua	2.70	5.30	2.90	3.10	3.70	5.30
Canary rockfish	Scorpaenidae	Sebastes pinniger	5.45	6.48	4.91	4.87	5.75	6.48
Common dab	Pleuronectidae	Limanda limanda	5.45	3.98	9.60	**1.93**	3.77	3.98
English sole	Pleuronectidae	Parophrys vetulus	2.18	4.54	5.22	**1.28**	**1.69**	4.54
Eastern school whiting	Sillaginidae	Sillago flindersi	9.33	2.03	15.35	4.35	6.60	2.03
Flathead flounder	Pleuronectidae	Hippoglossoides elassodon	2.31	5.50	2.16	3.01	3.64	5.50
Flounder	Pleuronectidae	Platichthys flesus	3.70	4.57	7.10	**1.43**	2.43	4.57
Gemfish	Gempylidae	Rexea solandri	3.08	5.04	5.72	**1.78**	2.19	5.04
Gemfish	Gempylidae	Rexea solandri	3.08	5.04	5.72	**1.78**	2.19	5.04
Grey mullet	Mugilidae	Mugil cephalus	**1.96**	3.01	4.78	2.03	**0.40**	3.01
Haddock	Gadidae	Melanogrammus aeglefinus	**1.73**	5.51	3.72	2.72	3.26	5.51
Hake	Gadidae	Merluccius australis	3.40	5.93	**1.90**	3.57	4.23	5.93
Hake	Gadidae	Merluccius hubbsi	3.90	4.37	6.90	**1.23**	2.23	4.37
European hake	Gadidae	Merluccius merluccius	5.25	4.18	9.40	**1.73**	3.57	4.18
North Pacific hake	Gadidae	Merluccius productus	5.18	3.81	8.24	**1.08**	2.85	3.81
Peruvian hake	Gadidae	Merluccius gayi	4.58	4.41	8.44	**1.28**	3.05	4.41
Hake	Gadidae	Merluccius merluccius	5.25	4.18	9.40	**1.73**	3.57	4.18
Hake	Gadidae	Merluccius hubbsi	3.90	4.37	6.90	**1.23**	2.23	4.37
Herring	Clupeidae	Clupea harengus	6.10	**1.50**	10.20	3.20	3.20	**1.50**
Hoki	Gempylidae	Macruronus novaezelandiae	2.70	5.70	2.90	3.10	3.70	5.70
Hairtail	Trichiuridae	Trichiurus haumela	3.70	4.57	6.70	**1.03**	2.03	4.57
Jackass morwong	Cheilodactylida	Nemadactylus macropterus	3.44	5.48	2.65	3.76	4.49	5.48
John dory	Zeidae	Zeus faber	22.95	5.65	34.60	13.60	17.10	5.65
John dory	Zeidae	Zeus faber	5.45	3.98	9.60	**1.93**	3.77	3.98
King mackerel	Scombridae	Scomberomorus cavalla	4.60	4.00	7.41	**0.70**	2.41	4.00
Lepidonotothen	Nototheniidae	Lepidonotothen squamifrons	**1.73**	4.56	4.09	**1.52**	**1.99**	4.56
Ling	Ophidiidae	Genypterus blacodes	3.20	6.13	2.10	3.77	4.43	6.13
Ling	Ophidiidae	Genypterus capensis	2.33	5.84	3.35	3.18	3.77	5.84
Ling	Ophidiidae	Genypterus blacodes	2.95	6.05	2.46	3.60	4.24	6.05
Greater lizardfish	Synodontidae	Saurida tumbil	11.70	**1.90**	18.53	6.10	8.53	**1.90**
Mackerel	Scombridae	Scomber scombrus	2.35	4.75	4.20	2.20	2.70	4.75
Mackerel	Scombridae	Scomber scombrus	3.28	4.44	5.52	**1.58**	**1.99**	4.44
Mediterranean horse mackerel	Carangidae	Trachurus mediterraneus	5.65	3.78	9.00	**1.33**	3.17	3.78
Horse mackerel	Carangidae	Trachurus trachurus	6.45	3.52	10.14	**1.86**	3.77	3.52
Horse mackerel	Carangidae	Trachurus trecae	3.40	5.53	1.50	3.17	3.83	5.53
Horse mackerel	Carangidae	Trachurus trachurus	6.45	3.52	10.14	**1.86**	3.77	3.52
Mackerel	Scombridae	Scomber scombrus	3.28	4.44	5.52	**1.58**	**1.99**	4.44
Atlantic Menhaden	Clupeidae	Brevoortia tyrannus	5.15	**1.82**	8.84	2.56	2.47	**1.82**
Gulf Menhaden	Clupeidae	Brevoortia patronus	13.10	**0.83**	20.20	7.87	8.53	**0.83**
Monkfish	Lophiidae	Lophius piscatorius	8.37	3.41	13.77	3.88	5.99	3.41
Notothenia rossii	Nototheniidae	Notothenia rossii	3.26	4.71	6.08	**1.33**	**1.70**	4.71
Norway pout	Gadidae	Trisopterus esmarkii	17.70	3.90	26.70	9.70	12.70	3.90
New Zealand snapper	Sparidae	Pagrus auratus	3.70	5.90	2.41	3.70	4.41	5.90
Ocean perch	Sebastidae	Helicolenus percoides	4.47	6.56	3.91	4.61	5.40	6.56
Orange roughy	Trachichthyidae	Hoplostethus atlanticus	6.29	7.03	5.95	5.56	6.48	7.03
Orange roughy	Trachichthyidae	Hoplostethus atlanticus	6.40	7.07	6.10	5.63	6.57	7.07
Peruvian anchoveta	Engraulidae	Engraulis ringens	30.60	6.67	45.20	19.53	21.87	6.67
Pacific cod	Gadidae	Gadus macrocephalus	2.50	5.90	3.10	3.30	3.90	5.90
Pacific ocean perch	Scorpaenidae	Sebastes alutus	5.63	6.94	5.57	5.39	6.28	6.94

Pacific halibut	Pleuronectidae	Hippoglossus stenolepis	4.79	6.66	4.37	4.83	5.65	6.66
Plaice	Pleuronectidae	Pleuronectes platessa	2.70	5.23	**1.60**	3.27	3.93	5.23
Pollock or saithe	Gadidae	Pollachius virens	2.50	5.50	3.10	3.30	3.90	5.50
Pacific Saury	Scophthalmidae	Cololabis saira	12.75	**1.38**	19.28	5.97	8.51	**1.38**
Petrale sole	Pleuronectidae	Eopsetta jordani	2.30	5.70	2.90	3.10	3.70	5.70
Deepwater redfish	Scorpaenidae	Sebastes mentella	4.91	6.57	3.98	4.64	5.43	6.57
Redfish	Berycidae	Centroberyx affinis	4.08	6.03	2.95	3.95	4.70	6.03
Redfish	Scorpaenidae	Sebastes marinus	4.91	6.57	3.98	4.64	5.43	6.57
Red hake	Gadidae	Urophycis chuss	5.45	3.98	9.60	**1.93**	3.77	3.98
Red porgy	Sparidae	Pagrus pagrus	3.08	4.64	5.72	**1.78**	2.19	4.64
Red Snapper	Lutjanidae	Lutjanus campechanus	3.26	4.71	6.48	**1.73**	2.10	4.71
Rock sole	Pleuronectidae	Lepidopsetta bilineata	**1.73**	5.51	3.72	2.72	3.26	5.51
Sablefish	Anoplopomatidae	Anoplopoma fimbria	5.21	6.94	4.88	5.17	6.01	6.94
Saithe	Gadidae	Pollachius virens	**1.73**	5.51	3.72	2.72	3.26	5.51
Kingklip	Ophidiidae	Genypterus capensis	2.13	5.64	3.15	2.98	3.57	5.64
Sardine	Clupeidae	Sardinops sagax	3.68	2.31	6.74	**1.58**	**1.35**	2.31
Sardine	Clupeidae	Sardinops sagax	3.68	2.31	6.74	**1.58**	**1.35**	2.31
Sardine	Clupeidae	Sardinops sagax	7.27	1.11	11.87	3.98	4.09	**1.11**
Spanish sardine	Clupeidae	Sardina pilchardus	2.60	2.67	5.20	**1.53**	**0.53**	2.67
Sea bass	Moronidae	Dicentrarchus labrax	3.70	4.57	7.10	**1.43**	2.43	4.57
Sea bream	Sparidae	Chrysophrys major	**1.95**	5.15	4.60	2.60	3.10	5.15
Southern bluefin tuna	Scombridae	Thunnus maccoyii	2.35	4.75	4.20	2.20	2.70	4.75
Southern blue whiting	Gadidae	Micromesistius australis	2.00	5.00	2.20	2.40	3.00	5.00
Scup	Sparidae	Stenotomus chrysops	3.20	4.07	6.60	0.93	**1.93**	4.07
Sandeel	Ammodytidae	Ammodytes marinus	7.07	**1.31**	12.07	4.18	4.29	**1.31**
Silver hake	Gadidae	Merluccius bilinearis	6.25	3.72	10.74	2.46	4.37	3.72
Snapper	Sparidae	Pagrus auratus	4.45	5.82	4.10	4.43	5.27	5.82
Silk Snapper	Lutjanidae	Lutjanus synagris	14.20	2.73	21.70	7.37	10.03	2.73
Sole	Soleidae	Solea vulgaris	2.16	5.05	2.37	2.91	3.52	5.05
Smooth oreo	Oreosomatidae	Pseudocyttus maculatus	4.88	5.89	4.36	5.29	5.17	5.89
Spotted warehou	Centrolophidae	Seriolella punctata	**1.13**	4.38	2.22	2.66	2.22	4.38
Sprat	Clupeidae	Sprattus sprattus	13.10	**0.83**	20.20	7.87	8.53	0.83
Round herring	Clupeidae	Etrumeus teres	16.60	2.00	25.20	10.20	11.20	2.00
Silver trevally	Carangidae	Pseudocaranx dentex	4.12	5.44	3.14	3.88	4.66	5.44
Striped bass	Moronidae	Morone saxatilis	3.20	5.73	2.10	3.77	4.43	5.73
Swordfish	Xiphiidae	Xiphias gladius	8.57	2.81	13.17	3.28	5.39	2.81
Tiger flathead	Platycephalidae	Neoplatycephalus richardsoni	2.88	4.84	5.92	**1.98**	2.39	4.84
Shortspine thornyhead	Scorpaenidae	Sebastolobus alaskanus	4.63	6.48	4.22	4.65	5.47	6.48
Black Sea turbot	Bothidae	Psetta maeotica	2.66	5.55	2.87	3.41	4.02	5.55
White hake	Gadidae	Urophycis tenuis	2.13	5.78	3.62	3.06	3.62	5.78
Black Sea whiting	Gadidae	Merlangius merlangus	2.15	4.95	4.40	2.40	2.90	4.95
Widow rockfish	Scorpaenidae	Sebastes entomelas	5.09	6.10	3.91	4.29	5.12	6.10
Walleye pollock	Gadidae	Theragra chalcogramma	2.95	5.65	2.06	3.20	3.84	5.65
Widow rockfish	Scorpaenidae	Sebastes entomelas	5.12	6.11	3.96	4.31	5.14	6.11
Yellowtail flounder	Pleuronectidae	Pleuronectes ferrugineus	5.45	3.98	9.60	**1.93**	3.77	3.98
Yellowfin tuna	Scombridae	Thunnus albacares	10.23	2.13	15.45	4.45	6.70	2.13
Yellowtail rockfish	Scorpaenidae	Sebastes flavidus	4.83	6.28	4.42	4.85	5.67	6.28
Yellowfin sole	Pleuronectidae	Limanda aspera	**1.96**	5.25	2.17	2.71	3.32	5.25