Marine Scalefish Fishery Management Advisory Committee

Out-of-Session Meeting – 1 February 2023

The Marine Scalefish Fishery Management Advisory Committee (MSFMAC or 'the Committee') held an Out-of-Session meeting on 1 February 2023 via online video conference call.

Replacement MSF management plan and harvest strategies

The Minister for Primary Industries and Regional Development approved the Department of Primary Industries and Regions (PIRSA) to prepare a replacement draft *Management Plan for the South Australian Commercial Marine Scalefish Fishery* ("the Management Plan"), consistent with the processes outlined under Part 5 of the *Fisheries Management Act 2007*. An important and substantial part of this work will be the development of a harvest strategy framework.

The MSFMAC endorsed the proposed timeframe for delivery of the Management Plan and harvest strategy framework, to be completed and implemented by 1 July 2025. Significant work is required to develop the replacement Management Plan, including harvest strategy development, ESD Risk assessments, review of allocations, and a statutory consultation period. The current Management Plan expires on 1 October 2023. An extension of the current plan for 22 months is required.

The MSFMAC endorsed the development of a draft harvest strategy framework as suggested in the report 'Harvest strategies and reference points: a review of current practices' (Enclosure 1). An initial draft will be presented at the next MSFMAC meeting, before undertaking wider consultation.

Request to review advice

The MSFMAC received a request from the Marine Fishers Association (MFA) to review their recommendation of a reduction of the Total Allowable Commercial Catch (TACC) for King George Whiting in the West Coast (WC) Fishing Zone for the 2022/23 year. The MSFMAC noted the TACC decisions had been implemented and that there was no new information available at this time but that a new stock assessment would be available to inform a recommendation for the 2023/24 year. The MSFMAC noted PIRSA's Notices to Fishers that included information on the decision and scientific basis. They discussed that the development of the harvest strategy framework could provide clarity on the TACC setting process in the future. The discussion on consultation was progressed under agenda item 6. The MSFMAC did not support a review of their previous recommendation.

Improving stakeholder engagement

PIRSA proposed increased stakeholder engagement in the development of MSFMAC advice by inviting relevant peak bodies (and experts) to MSFMAC or Science Subcommittee meetings with sufficient notice and information to enable these stakeholders to provide sector positions to the MSFMAC / SSC meetings.

SARDI outlined their new process to provide scientific information needed for such matters as setting of catch limits, earlier in appropriate formats and in sufficient time for the MSFMAC members and stakeholders to consider the advice. The MSFMAC noted that the development of the harvest strategy framework and the new Management Plan was an important time to provide capacity building. The MSFMAC encouraged PIRSA and the peak bodies to investigate opportunities to undertake MSF focused capacity building.

Allocation issues

A draft discussion paper on regional allocation issues that has been developed in response to a MSFMAC action was discussed. Noting these discussions, the discussion paper will be further developed for future consideration.

Effective catch recording for all sectors

A draft discussion paper on catch reporting by sectors that has been developed in response to a MSFMAC action was discussed. Noting these discussions, the discussion paper will be further developed for future consideration.

It was the consensus of the MSFMAC for PIRSA to continue to develop the discussion paper. Two dissenting views from the MSFMAC Recreational Fishing Sector representatives were noted. These members did not support further development of the paper and noted that RecFish SA was already considering the matter.

The next MSFMAC meeting was expected in May 2023 at a time and date to be confirmed out-of-session.

Dr Ilona Stobutzki

Independent Chair, Marine Scalefish Fishery Management Advisory Committee

Enclosure 1: Harvest strategies and reference points: a review of current practices

Harvest strategies and reference points: a review of current practices

David C Smith and Jonathan Smart

Report to PIRSA

September 2022

Contents

Summary

Formal harvest strategies are a key component of modern fisheries management. In various forms they have been adopted in the United States, the European Union (through ICES), New Zealand, Iceland, Norway, Canada, South Africa and some Regional Fisheries Management Organisations (RFMOs) and are included in the Marine Stewardship Council Fisheries Standards. In Australia, harvest strategies were first adopted in Commonwealth fisheries and are increasingly being rolled out around the States and Northern Territory. They specify operational targets to deliver biological (yield), economic and/or social benefits, whilst ensuring the stock is not reduced to a level that may impair recruitment to the fishery. One of the main benefits of adopting a harvest strategy is the increased level of certainty and transparency provided for all fishery stakeholders, particularly in relation to how fishery management decision making processes operate.

Formal harvest strategies comprise a fully specified set of rules for making tactical management decisions including specifications for a monitoring program, the performance indicators to be calculated from monitoring data (often via a stock assessment), and the use of those indicators and their associated reference points in management decisions, through application of decision rules.

South Australia has implemented harvest strategies in several fisheries in accordance with its Fisheries Harvest Strategy Policy and guidelines for implementing the policy, that are broadly consistent with the National Guidelines to Develop Fisheries Harvest Strategies. However, these guidelines are not prescriptive and do not give specific values or defaults for reference points that should be used. South Australia's Marine Scalefish Fishery (MSF) is a complex, multi-species, multi-gear and multi sector fishery that has recently undergone significant change through a reform of its commercial fishery and there is a need to develop new harvest strategies for the fishery.

In this review, current practices used for harvest strategies and reference points in Australia and internationally (New Zealand, USA Pacific coast, the International Council for the Exploration of the Sea (primarily Europe), and two Regional Fishery Management Organisations) are reviewed to inform harvest strategy development in the MSF. The focus here is on the technical aspects including use of performance indicators, setting reference points, decision rules and dealing with risk and uncertainty. Implications for the MSF are discussed.

A performance indicator is a quantity that can be measured and used to track changes with respect to achieving an operational objective. In general, the types of performance indicators used in harvest strategies reflect the level of information available and the type of stock assessment that can be undertaken, and this will flow through to the reference points and decision rules that can be adopted for a particular species or fishery. In broad terms there are two types of performance indicators:

- Model-based – these usually refer to estimates of fishing mortality (F) and/or biomass (B).
- Empirical – these should provide a reasonable proxy for stock status, e.g., catch, effort, CPUE, biomass estimated from surveys, recruitment indices, and mean size or age.

Three types of reference points are used to assess the biological, economic and/or social performance of the fishery:

1. **Limit Reference Points** define the values of a performance indicator for a stock or management unit that identifies an undesirable outcome to be avoided with high probability, for example recruitment overfishing. Limit reference points refer to biomass (and are set as a percentage of the unfished biomass, termed B_{LIM}) and fishing mortality that avoids the biomass

limit (termed F_{LIM}). Commonly used defaults for the limit reference points (B_{LIM}) are 20% of the unfished biomass (B_{20}) or 0.5 B_{MSY} (the biomass that gives Maximum Sustainable Yield (MSY)).

2. **Target Reference Points** define the values of a performance indicator for a fish stock or management unit that are desirable or ideal and at which management should aim. Typically target reference points (B_{TARG}, F_{TARG}) have been set to achieve MSY, the fishing mortality giving MSY (F_{MSY}) and/or the average population biomass at MSY (B_{MSY}), usually expressed as a percentage of the unfished biomass (B_0). A widely used default for B_{MSY} is 40% of the unfished biomass B_{40}. Similarly, $F_{MSY,}$ is set at F_{40} or in some cases lower. Maximum Economic Yield (MEY) is also used as an objective with similar reference points (F_{MEY} and B_{MEY}). For Commonwealth fisheries the default is 48% of the unfished biomass (B_{48}, 1.2 B_{MSY}) but is set up to 60% in some jurisdictions, and F_{MEY} at F_{48} (the fishing mortality at B_{MEY}). Setting the target appropriately also avoids breaching the limit reference point.

3. **Trigger Reference Points** define the values of a performance indicator for a fish stock or fisheries management unit at which a change in the management is considered or adopted (see below). Target and limit reference points can also function as trigger reference points, and in particular the limit reference point is commonly used to trigger new and strenuous management intervention to rebuild the stock.

Empirical reference points can be based on the history of a fishery. For example, a target reference point might be set when the stock was thought to be in good shape and a limit when the stock was considered depleted. Often in a data-poor context reference levels are not set at a specific amount. Rather a change in the indicator will trigger a management response and a decision rule is directly applied. For example, if catch rate changes by a specified amount (up or down) then a management action is triggered.

A crucial component of harvest strategies is decision rules which are pre-determined management actions linked directly to the performance of the fishery, relative to reference points. A commonly used approach is that fishing mortality is reduced as the stock decreases and the closer it is to the limit, the greater the reduction. An example of this approach, in which fishing mortality ramps down, is called the “hockey stick” decision rule where fishing mortality is reduced below a particular reference point. In Australia, this approach has been explicitly adopted by the Commonwealth, Queensland, and WA. It is also a feature of the NZ, USA, and ICES harvest strategies. While this approach often requires model-based estimates of biomass and fishing mortality, it can also be applied to empirical harvest strategies. For example, in the South Australian Sardine Fishery, the Tier 3 decision rule is that the maximum exploitation rate declines from 20% to 10% as the stock declines and then is 0 at a biomass limit reference point.

Decision rules that use fishing catch rate data as the indicator to adjust catches (or effort) are also common. Other empirical decision rules that have been proposed and/or used are age composition through catch curves and mean length. In very data-poor situations, the decision rule can be a series of triggers that require greater data collection and analyses to be undertaken at each level due to changes in the fishery.

Harvest strategies should be tested for their robustness prior to implementation to demonstrate that they are likely to meet the core principles of the policy. They must explicitly consider risk and uncertainty. There is a trade-off between the catch that can be taken, the risk to the stock and the costs associated with monitoring, assessment, and management, called the ‘catch-cost-risk’ trade-off. In general, higher investment in monitoring and assessment will allow higher catch levels to be maintained because the stock status, and its response to management, is being monitored with greater precision.

Uncertainty can be included in a harvest strategy through selecting precautionary limit and trigger reference points and the probabilities of indicators being above the limit reference point. For example, most Australian harvest strategy policies have a requirement that there is greater than or equal to 90% probability that the stock will be above its biological limit reference point over a period of time (i.e., a 1-in-10-year risk that stocks will fall below B_{LIM}).

A tiered approach is commonly used to deal with different levels of information and uncertainty in assessments. Each tier corresponds to a given availability of data and a method to assess status (noting that this should not be confused with the Tiered Management Framework which groups stocks into specific management arrangements). This inevitably means that tiers based on less certain information will need to be more precautionary in nature to achieve acceptable levels of risk. In some cases, this uncertainty is dealt with through applying a buffer or discount to the recommended catch or effort level resulting from the decision rule.

Some harvest strategy policies and frameworks require explicit rebuilding plans and time frames for stocks assessed as overfished, that is below the limit reference point. The time to rebuild to the limit or target is estimated through projecting forward in the absence of fishing or through multiples of the mean generation time for the stock.

Multi-species fisheries present their own challenges. Given the number of species that can be caught in one fishing operation (for example target and untargeted catch) the range of data available to support an assessment can be limited and variable. A tier-based harvest approach, described above, is commonly used to deal with different levels of information and uncertainty in assessments and is particularly useful for multi-species fisheries harvest strategy framework. In addition, due to technological and ecological interactions, it may not be possible to exploit all target species at the same target reference point. This can be dealt with by allowing some species to be at or above the target, or to set targets above B_{MSY} and well below F_{MSY} to provide an additional buffer that minimises the risk of any one species falling below its biomass limit. Another approach is the concept of F_{MSY} ranges, formulated to enable managers to resolve conflicts between stocks by exploiting some at rates slightly above F_{MSY} and some below F_{MSY}. A completely different approach, used in WA, is using selected indicator species that define the risk status for the entire suite of species.

While harvest strategies need to be unambiguous, they also need to be adaptive. One way to build in flexibility is to identify the 'exceptional circumstances' that may trigger departure from or even suspension of the harvest strategy. This allows for flexibility in a structured way, but not so much flexibility that it undermines the intent of having a harvest strategy. Specifically, this could include defining the exceptional circumstances that may trigger such a change.

Based on the outcomes of this review, implications for the MSF were considered. An effective harvest strategy will not only need to consider the commercial sectors of the fishery but also the recreational and Aboriginal/Traditional sectors. The quality of the scientific assessments varies across stocks and ranges from integrated length and age structured models to basic catch and effort statistics. An example of a harvest strategy framework, comprising seven categories, that reflects this is outlined. Current and potential harvest strategy categories for MSF stocks based on current and potential assessment options are provided.

Introduction

Formal harvest strategies are a key component of modern fisheries management. In various forms they have been adopted in the United States, the European Union (through ICES), New Zealand, Iceland, Norway, Canada, and South Africa (Sloan et al., 2014; Dichmont et al., 2016). They have been adopted in some Regional Fisheries Management Organisations (e.g., CCAMLR) and are included in the Marine Stewardship Council Fisheries Standards. In Australia, harvest strategies were first adopted in Commonwealth fisheries (Smith et al., 2007) and are increasingly being rolled out around the States and Northern Territory. They specify operational targets to deliver biological (yield), economic and/or social benefits, whilst ensuring the stock is not reduced to a level that may impair recruitment to the fishery.

The (Australian) National Guidelines to Develop Fisheries Harvest Strategies defines a harvest strategy "as a framework that specifies pre-determined management actions in a fishery for defined species (at the stock or management unit level) necessary to achieve the agreed ecological, economic and/or social management objectives" (Sloan et al., 2014). The National Guidelines identify the following key principles to be applied when developing a harvest strategy: Consistent with legislative objectives, including the principles of ESD; Pragmatic and easy to understand; Cost effective; Transparent and inclusive; Unambiguous; Precautionary; and Adaptive.

Formal harvest strategies comprise a fully specified set of rules for making tactical management decisions including specifications for (i) a monitoring program, (ii) the indicators to be calculated from monitoring data (often via a stock assessment) and (iii) the use of those indicators and their associated reference points in management decisions, through application of decision (or control) rules (Smith et al., 2013; Dowling et al., 2015a). Ideally, the harvest strategy should account for all sources of mortality, including recreational and Aboriginal/Traditional catches.

While components of harvest strategies have been used for many decades (e.g., indicators and reference points) the main difference brought about by the adoption of formal harvest strategies was the inclusion of explicit decision rules. With the addition of these decision rules, management responses become predetermined based on the outcome of the assessment (Haddon et al., 2012). This provides a formal and more consistent approach to the management decision process by defining what actions will occur based on the current or likely future performance of a fishery in relation to one or more of its operational objectives (FAO, 2011). Consequently, this avoids *ad hoc* decision from different interpretations of fishery and stock dynamics and from external factors/pressures.

One of the main benefits of adopting a harvest strategy is the increased level of certainty and transparency provided for all fishery stakeholders, particularly in relation to how fishery management decision making processes operate. Creating improved certainty and transparency contributes to creating a climate of trust between fishery stakeholders, allows fishery managers and fishers to operate with greater confidence and allows for greater business planning by commercial fishers, as the fishery management responses to various levels of fishery performance are documented and more predictable (Sloan et al., 2014). In addition, it is argued that harvest strategies achieve longer term thinking and planning by fishers, a stronger role for stakeholders in decisions, therefore more responsible fishing, improved community confidence in fishing and improved transparency in fisheries status reporting (NSW Department of Primary Industries, 2021a).

South Australia has implemented harvest strategies in many fisheries guided by its Fisheries Harvest Strategy Policy and guidelines for implementing the policy (PIRSA, 2015a, b). These are broadly consistent with the national guidelines. South Australia's commercial Marine Scalefish Fishery (MSF) has been through major reform and there is a need to develop new harvest strategies for the fishery.

The aim of this paper is to review current practices used for harvest strategies and reference points in Australia and internationally to inform harvest strategy development in the MSF. The focus here is on the technical aspects including use of performance indicators, setting reference points, decision rules and dealing with risk and uncertainty. In undertaking this review, the complex nature of this multi-species fishery is considered and other aspects such as application to multi-species fisheries and data-poor fisheries are described. Note there is considerable variation in use of terms regarding components of harvest strategies (e.g., decision or harvest control rules, performance indicators or performance measures) so those adopted in South Australia's policy are used here.

First South Australia's policy and guidelines and relevance to this review are briefly described.

South Australian fisheries harvest strategy policy, and guidelines.

South Australia's Fisheries Harvest Strategy Policy and guidelines for implementing the policy (PIRSA, 2015a, b) identifies core policy principles and steps in the implementation of harvest strategies. The aim of the policy is to provide an overarching framework that integrates ecological, social and/or economic dimensions of fishery management into a single framework for fisheries management decisions. Ecological objectives such as protecting aquatic resources from over exploitation have primacy over economic and social objectives.

The policy and guidelines, while covering the key aspects of harvest strategies and their implementation, are not prescriptive regarding the settings for the more technical elements of a harvest strategy such as performance indicators, reference points and decision rules. However, acceptable levels of risk are dealt with in more detail. The policy advocates a risk management approach whereby exploitation levels reduce as uncertainty around biological stock status increases. This is the "catch-cost-risk" approach (Sainsbury, 2005). Specifically, regardless of the level of uncertainty in assessments, harvest strategies must ensure that there is a high likelihood that stocks will not fall below a limit reference point (the point below which recruitment overfishing may occur). This is set such that that there is a 90% probability that the stock will be above the limit reference point over time (i.e., no more than one year in ten falling below the limit). For species below the limit reference points, rebuilding timeframes are specified.

For the purpose of this review, the following core harvest strategy policy principles are considered:

- Fishery performance indicators related to the objectives;
- Reference points for performance indicators;
- A statement defining acceptable levels of risk;
- Assessing fishery performance relative to operational objectives;
- Decision rules that control the intensity of fishing activity and/or catch;
- Technical evaluation of a harvest strategy

Other core principles are consistent with the national guidelines; harvest strategies should be cost-effective and feasible, transparent, and easy to understand, be unambiguous and adaptive, and periodically reviewed.

Of particular relevance to the MSF is dealing with multi-species fisheries and data-poor fisheries which are not covered explicitly by the policy or guidelines but are considered in this review.

Performance indicators and reference points - Overview

A performance indicator is a quantity that can be measured and used to track changes with respect to achieving an operational objective (Fletcher et al., 2002). Operational management objectives are precise and formulated in such a way that the extent to which they have been achieved during a specified period can be measured (Fletcher et al., 2002; Sloan et al., 2014). To be effective, operational objectives should be consistent with higher level legislative and conceptual fishery management objectives articulated in the management plan and linked to performance indicators and reference points (PIRSA, 2015b). Performance is measured by comparing where a performance indicator sits in relation to a reference point (PIRSA, 2015a) (Figure 1).

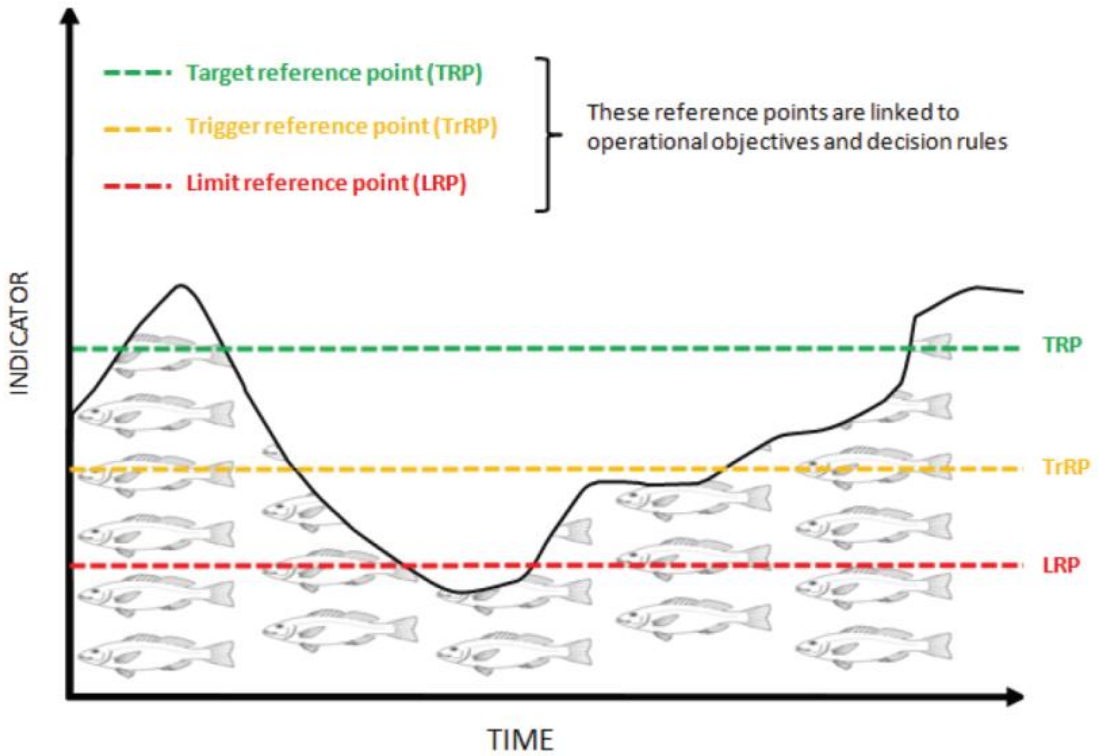

Figure 1. The relationship between a performance indicator (shown as dark grey line), the different types of reference points, operational objectives and decision rules (Sloan et al., 2014).

FAO (1997, cited in Sainsbury (2008)) defines a fishery reference point as “a benchmark against which to assess the performance of management in achieving an operational objective”. Similarly, the definition provided for use in the Australian context (Fletcher et al., 2002) is “the value of an indicator that can be used as a benchmark of performance against an operational objective”. In its broadest definition, a reference point is a particular value of a fisheries indicator corresponding to a situation that is important to management (Sainsbury, 2008).

Three types of reference points are used to assess the biological, economic and/or social performance of the fishery (Sainsbury, 2008; PIRSA, 2015a):

1. **Limit Reference Points** define the values of a performance indicator for a stock or management unit that identifies an undesirable outcome to be avoided with high probability, for example recruitment overfishing. Limit reference points are generally based on biological performance indicators.

2. **Trigger Reference Points** define the values of a performance indicator for a fish stock or fisheries management unit at which a change in the management is considered or adopted. Trigger reference points are an integral part of the management system for maintaining the fishery within acceptable bounds (i.e., close to the desired target and away from the undesired limits). Target and limit reference points can simultaneously function as trigger reference points, and in particular the limit reference point is commonly used to trigger new and strenuous management intervention to rebuild the stock.

3. **Target Reference Points** define the values of a performance indicator for a fish stock or management unit that are desirable or ideal and at which management should aim. Target reference points may be based on biological, economic and/or social performance indicators.

There is considerable literature on performance indicators and reference points. The history and development of reference points in fisheries is described by Caddy and Mahon (1995), and further expanded by Sainsbury (2008) and Haddon et al. (2012). Both biomass and fishing mortality reference points should be used (Sainsbury, 2008). While fishing mortality can be more directly controlled (e.g., TACs), biomass influences key ecological processes and function.

In general, the types of performance indicators used in harvest strategies reflect the level of information available and the type of stock assessment that can be undertaken (for example data-rich or data-poor), and this will flow through to the reference points and decision rules that can be adopted for a particular species or fishery.

In broad terms there are two types of performance indicators:

- Model-based – these usually refer to estimates of fishing mortality (F) and/or biomass (B). The latter includes spawning stock biomass, egg production, and available or exploitable biomass.
- Empirical indicators – should provide a reasonable proxy for stock status, examples include indicators such as catch, effort, CPUE, biomass estimated from surveys, recruitment indices, mean size or age (See Dowling et al., 2015).

Historically target reference points (B_{TARG}, F_{TARG}) have been set to achieve Maximum Sustainable Yield (MSY), typically the fishing mortality giving MSY (F_{MSY}) and/or the average population biomass at MSY (B_{MSY}), usually expressed as a percentage of the unfished biomass (B_0). MSY itself has also been used as a reference point (Sainsbury, 2008). Maximum Economic Yield (MEY) is also used as an objective with similarly derived reference points (F_{MEY} and B_{MEY}). Target reference points used may be set to reflect biological or ecological attributes of a species or species group. For example, reference points for small pelagic species and other low trophic level species are often set to reflect the ecosystem services they provide and in Australia reference points for small pelagic species are set at conservative levels (Smith et al., 2021). Smith et al. (2011) suggest a target of 75% of unfished biomass for key low trophic level species such as some small pelagic species.

B_{MSY} can be calculated using biomass dynamic (surplus production) models (Haddon, 2011) and from catches and absolute estimates of abundance from surveys (Hilborn, 2001). But stock assessment methods such as Stock Synthesis (Methot and Wetzel, 2013) are more commonly used. However, in most cases default values of B_{MSY} (and consequently F_{MSY}) are applied. This is primarily due to uncertainty around the stock and recruitment relationship which is often unknown and assumed. A widely used default for B_{MSY} is 40% of the unfished biomass B_{40} (see below). For B_{MEY} economic values are also required such as prices and input costs (e.g., Dichmont et al., 2010) presenting further challenges and hence default values are used here as well. Punt et al. (2013) found that a default value for B_{MSY} in the range of 35-40% of the unfished biomass over a range of uncertainties about stock dynamics minimised the loss in yield compared to if B_{MSY} was known exactly. Similarly, for B_{MEY} a default value of 50-60% was obtained although this was less certain due to uncertainties related to costs and prices in the simulations.

Commonly used defaults for the limit reference points (B_{LIM}) are 0.5 B_{MSY} (Restrepo et al., 1998) or 20% of the unfished biomass B_{20}. There is some empirical evidence to support these, particularly the latter (Sainsbury, 2008). F_{LIM} is usually set to minimise the probability of the stock approaching the limit reference point (e.g., F_{MSY}).

Much of the literature has centred around model-based approaches for data-rich species and fisheries. However, in recent years there has been greater focus on empirical harvest strategies for data-poor species including types of performance indicators and reference points (Dowling et al., 2015a). This has seen the development of the Fishpath tool, a decision support system for assessing and management of data- and/or capacity-limited fisheries. It is a comprehensive and standardised approach to guiding the selection of monitoring, assessment, and decision rule options for data-limited fisheries (Dowling et al., 2016).

Empirical reference points can be based on the history of a fishery. For example, a target reference point might be set when the stock was thought to be in good shape and a limit when the stock was considered depleted (Dowling et al., 2015b). Multiple indicators can also be used, together with hierarchical decision trees (Dowling et al., 2015a). Often in a data-poor context reference levels are not set at specific amount. Rather a change in the indicator will trigger a management response and the decision rule is directly applied. For example, if catch rate changes by a specified amount (up or down) then a management action is triggered.

Harvest strategy performance indicators and reference points can be set regardless of the data available, but empirical performance indicators and reference points are designed as proxies to meet the intent of an overarching policy. Uncertainty and risk are often dealt with in decision rules and through tiers and buffers (see below).

Performance indicators and reference points – Current usage

In this section, harvest strategy policies and current usage of performance indicators and reference points are briefly described for relevant Australian jurisdictions as well as international examples. They are summarised in Table 1.

Australia

National

The Status of Australian Fish Stocks (SAFS) reports on the biological status of each stock. Piddocke et al. (2021) reported on 148 species and 477 stocks. It combines information on both the current stock size and the level of catch into a single classification for each stock. To classify stocks into one of these categories, the current abundance and level of fishing pressure are compared with defined biological reference points. Each stock is then classified as sustainable, depleting, depleted, or recovering. Some stocks are classified as undefined or negligible (Figure 2). The reference points are B_{limit} and F_{limit} (Figure 2) but actual values for these are not prescribed. The classification does not include a target reference point.

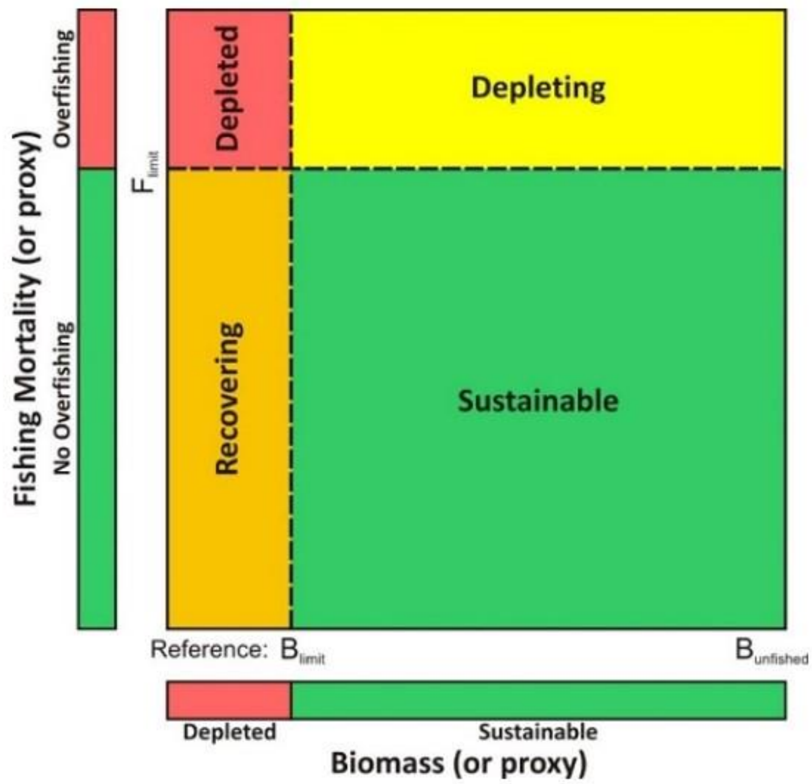

Figure 2. The SAFS classification system and reference points. Source: Piddocke et al (2021).

Commonwealth

The Commonwealth Harvest Strategy Policy (HSP), and associated Guidelines (Department of Agriculture and Water Resources, 2018a, b) is underpinned by target and limit reference points for biomass (B_{TARG} and B_{LIM}) and fishing mortality (F_{TARG} and F_{LIM}). The target biomass is specified as B_{MEY}, the biomass corresponding to maximum economic yield (MEY). The policy allows for the use of proxies for B_{MEY} (1.2B_{MSY}) and where B_{MSY} is unknown or poorly estimated, a proxy of 0.4 times unfished biomass (B_{40}) should be used giving a B_{MEY} target at 48% of the unfished biomass (B_{48}). The proxy for B_{LIM} is 20% of the average unexploited biomass.

The generic proxy for F_{TARG} is F_{48}, consistent with the biomass target reference point. F_{LIM} is not specified in the current policy. Although in the 2007 guidelines (Australian Government, 2007), a value for F_{LIM} as equivalent to or less than F_{MSY} is given.

Empirical indicators and reference points are also used (see for example Dowling et al., 2008; Smith et al., 2009).

South Australia

South Australia's policy and guidelines are not prescriptive regarding the settings for reference points for biomass or fishing mortality. The policy has been implemented in several fisheries and in most cases harvest strategies are empirically based. Examples are given below.

For the sardine fishery, the primary performance indicator is spawning stock biomass estimated from the daily egg production method (PIRSA, 2014). The target reference point is 150,000 t, and the limit reference point is 75,000t.

For the Southern Zone Rock Lobster Fishery, the indicators are commercial catch rates (legal sized lobsters in kg per pot lift) (PIRSA, 2020). The Trigger Reference Point for CPUE is 0.60 kg/potlift; and the limit reference point for CPUE is 0.40 kg/potlift. A secondary indicator is pre-recruit index (number of undersized lobsters per pot lift). This has trigger reference point of 1.32 per pot lift.

The abalone fishery harvest strategy uses CPUE (fishery dependent) and legal density (fishery independent) performance indicators (PIRSA, 2021). Each has a limit and target reference point based on a reference period. Scores are calculated for each Spatial Assessment Unit, combined, and then aggregated for the zone. A zonal score proxy is also used to set a fishing mortality limit reference point.

Queensland

The Queensland Harvest Strategy Policy applies to commercial, recreational, charter and indigenous (commercial) sectors (QLD Department of Agriculture and Fisheries, 2021). The policy also applies to target, secondary and by-product species. It is explicit regarding performance indicators and reference points. For target stocks the performance indicator is spawning biomass estimated from stock assessment models where possible, and the default measure is against unfished spawning biomass. The secondary performance indicators are proxy measures of abundance such as standardised fishery dependent or independent catch rates, and biological information such as age/length composition, and recruitment indices. Ecological risk assessments (ERAs, Hobday et al., 2011) can also be used as a performance indicator.

The target is moving towards MEY with a target reference point default for B_{MEY} at biomass B_{60} by 2027. The interim is MSY with a default B_{MSY} of 40% of unfished biomass B_{40}. The limit reference point default is B_{20}. The limit reference point may be set higher for some low productivity stocks but not lower. Trigger reference points are also advocated particularly for information poor situations where additional review, management action or assessment may be required. These should be based on a reference period in the fishery.

The target fishing mortality F_{TARG} is set at the fishing mortality for B_{MEY} or B_{MSY}.

Western Australia

The Western Australia harvest strategy policy and operational guidelines (WA Department of Fisheries, 2015) are broadly consistent with the national guidelines but include additional elements to meet WA requirements. Performance indicators include model-based biomass estimates and empirical indicators measured directly or indirectly (e.g., CPUE). The limit reference point default is set at 0.5 B_{MSY}. The target is greater than B_{MSY}, or B_{MEY} for some fisheries, where the proxy for B_{MEY} is 1.2 B_{MSY}, similar to the Commonwealth HSP. The policy and guidelines also identify a threshold (trigger) reference point at B_{MSY} or equivalent. Values for these reference points vary between species.

New South Wales

The New South Wales Harvest Strategy and guidelines (NSW Department of Primary Industries, 2021a, b) are consistent with the national guidelines. Performance indicators are not specified but the default limit reference point is 20% of the unfished biomass, B_{20}. The target reference point is B_{MSY}, and for some fisheries B_{MEY}, although the values for these are not specified.

Northern Territory

The Northern Territory Harvest Strategy Policy, and guidelines (NT Department of Primary Industry and Resources, 2016a, b) are consistent with the national guidelines. It does not specify performance indicators and reference points. These are being dealt with for specific fisheries and species.

Tasmania *and* ***Victoria*** do not currently have an overarching Harvest Strategy Policy, but harvest strategies are implemented for specific fisheries (e.g., rock lobster and abalone in Tasmania).

New Zealand

The New Zealand Harvest Strategy Standard (NZ Ministry for Primary Industries, 2008) and Operational Guidelines (NZ Ministry of Fisheries, 2011) are based on MSY compatible reference points B_{MSY} and F_{MSY}. The standard has two limit reference points:

a "soft" limit reference point equivalent to 0.5 B_{MSY} or 20% B_0, whichever is greater; and

a "hard" limit reference point equivalent to 0.25 B_{MSY} or 10% B_0

The former is breached if there is a greater than 50% probability of being below the soft limit. With a greater than 50% probability of being below the hard limit, consideration should be given to closure of the fishery.

Default values for B_{MSY} and F_{MSY} are recommended depending on the productivity level. B_{MSY} ranges from 25% (highly productive stocks) to greater or equal to 45% (very low productivity). Likewise, F_{MSY} ranges from F_{30} to F_{50}. However, it is noted that it is becoming increasingly difficult to justify MSY compatible targets less than 30-40% B_0.

USA

The Pacific Fisheries Management Council is one of 6 regional Councils. Specifications differ for different fisheries and Councils but all fall under the umbrella of their National Standards under the Magnusson-Stevens Act. The Groundfish Management Plan of the Pacific Fisheries Management Council (cited in Pacific Fisheries Management Council, 2022) established a default overfished threshold (limit reference point equivalent) at 25% of the unfished female spawning output (noting spawning biomass is often used) or 0.5 B_{MSY} if known. The target reference point is B_{MSY} but B_{40} is recommended for most groundfish. The target fishing mortality is F_{MSY} with F_{50} the default.

For flatfish which are regarded as highly productive (Pacific Fisheries Management Council, 2020), reference points were revised as different from other species. The target spawning output is $B_{25,}$ and the overfished threshold is $B_{12.5}$. The MSY default fishing mortality target is F_{30}.

A range of data-limited and data-moderate assessments are also undertaken, and increased uncertainty dealt with accordingly (see below).

ICES

The International Council for Exploration of the Sea (ICES) is an intergovernmental scientific body with 20 member countries (primarily from Europe) that undertakes stock assessments and provides advice on fish stocks for the ICES area, the Northeast Atlantic, and Baltic Seas, and that also extends into the Arctic, the Mediterranean Sea, the Black Sea, and the North Pacific Ocean.

The primary performance indicators are spawning stock biomass and fishing mortality, with associated reference points.

Stock status is evaluated against two types of reference points:

- The Precautionary Approach (PA) reference points that define acceptable boundaries for stock sustainability; and
- Maximum Sustainable Yield Reference Points that relate to optimum exploitation (Seafish, 2022a).

The biomass reference points are B_{LIM}, B_{PA} and MSY $B_{TRIGGER}$. The precautionary reference point is intended to reflect uncertainty in the estimates of spawning biomass, so B_{PA} is effectively a more conservative limit, and the proxy is equivalent to 1.4 B_{LIM} (ICES, 2021). MSY $B_{TRIGGER}$ is defined as the lower bound of the expected range of spawning stock biomass when the stock is fished at F_{MSY} (ICES 2021). B_{MSY} is not usually used as a reference point for ICES stocks (Seafish, 2022a). F_{LIM}, F_{PA} and F_{MSY} are the corresponding fishing mortality reference points.

The above reference points are for stocks with analytical assessments; for others ICES uses MSY proxy reference points as part of the Precautionary Approach to provide advice on stock status (ICES, 2018), and buffers are often applied (see below).

RFMOs

Some but not all Regional Fisheries Management Organisations (RFMOs) have formal harvest strategies in place. Two examples include:

Commission for the Conservation of Southern Bluefin Tuna (CCSBT) – the CCSBT Management Procedure (MP, essentially a fully specified harvest strategy that has been simulation tested for performance and adequate robustness to uncertainties) is used for stock rebuilding. The original "interim rebuilding target" was 20% of the unfished spawning stock biomass (by 2030 with 70% prob). This could be seen as a limit reference point, but is not formally referred to as such, with a higher probability of not dropping back below it. Now the longer-term rebuilding objective is 30% (by 2035 with 50% prob), which the MP is designed to stabilise at that level (CCSBT, 2020).

Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) – the current harvest strategy has a limit reference point for spawning biomass set at 20% and targets set at 50% of unfished levels for species considered in a single species context such as Patagonian toothfish and 75% for krill, important prey species (Constable et al., 2000). The CCAMLR Scientific Committee is currently reviewing the harvest strategy.

Table 1 Summary of reference points and decision rules referred to in the text (Australian and international harvest strategy policy examples). The break point is the point at which fishing mortality is reduced in the hockey stick decision rule.

Jurisdiction	Limit Reference Point	Target Reference Point	Decision rule
SAFS	B_{LIM} F_{LIM}	Not specified	Form not specified
Commonwealth	B_{LIM}, default 20% unfished biomass B_{20} F_{LIM} not specified	B_{MEY}, proxy 1.2 B_{MSY} Default 48% unfished biomass B_{48} F_{TARG}, default F_{48}	Hockey stick Break point at B_{TARG} where F reduces towards B_{LIM} in guidelines. In SESSF harvest strategy break point at B_{35}
South Australia	Limits not prescribed	Targets not prescribed	Form not specified
Queensland	B_{LIM}, default 20% unfished biomass B_{20} F_{LIM} not specified	Interim B_{MSY}, default 40% unfished biomass B_{40} Full target B_{MEY}, default B_{60} F_{TARG}, default F_{60}	Hockey stick Break point at B_{TARG} where F reduces towards B_{LIM}
Western Australia	B_{LIM}, default 0.5 B_{MSY} F_{LIM} not specified	Threshold (trigger) at B_{MSY}. Target > B_{MSY} or B_{MEY} default 1.2 B_{MSY} F targets not specified	Hockey stick Double break points - at B_{TARG} and B_{MSY} and where F reduces with increased steepness to B_{LIM}
New South Wales	B_{LIM}, default 20% unfished biomass B_{20} F_{LIM} not specified	B_{MSY} or B_{MEY} F targets not specified	Implied hockey stick
Northern Territory	Limits not prescribed	Targets not specified	Form not specified
New Zealand	Soft - 0.5 B_{MSY} or B_{20} whichever is greater Hard – 0.25 B_{MSY} or $B1_{0}$ whichever is greater F_{LIM} not specified	B_{MSY}, 25-45% unfished biomass. Note B_{MSY} below 30%-40% hard to justify. F_{MSY}, F_{30} - F_{50}	Hockey stick
USA Pacific coast groundfish fishery	25% of unfished biomass B_{25} or 0.5 B_{MSY} For flatfish $B_{12.5}$ F_{LIM} not specified	B_{MSY}, default B_{40} F_{MSY}, default F_{50} For flatfish B_{25}, F_{30}	Hockey stick Break point at B_{40}
ICES	B_{LIM} B_{PA}, default 1.4 B_{LIM} F_{LIM}, F_{PA}	Trigger reference point MSY $B_{TRIGGER}$ F_{MSY}	Hockey stick Break point at MSY $B_{TRIGGER}$ where F reduces to the origin
CCSBT	Informally B_{20}	B_{30} by 2035	Empirically based
CCAMLR	20% unfished biomass B_{20}	B_{50} or B_{75} (krill)	Projection based

Decision rules

A crucial component of harvest strategies is decision rules (also called harvest control rules) that are designed to achieve the operational objectives, such as having a high likelihood of maintaining stocks at or near the targets and meeting the probability or risk requirements in relation to avoiding depletion to, or below, the limits (Sloan et al., 2014). Decision rules are pre-determined management actions linked directly to the performance of the fishery, relative to reference points. Put simply, the pre-determined management action (e.g., a quota/effort decrease or increase) is implemented when a reference point is reached, as identified through the fishery monitoring and assessment (Sloan et al., 2014). The development of control rules is reviewed by Deroba and Bence (2008).

Decision rules can take many forms and in part this reflects the level of information and types of assessment that can be undertaken, from data-rich to data-poor. Regardless, the aim, however, is to meet the intent of a particular harvest strategy policy.

A commonly used approach is with a biomass break point after which fishing mortality is reduced and the closer the stock size is to the limit the greater the reduction. This decision rule in which fishing mortality ramps down is called the “hockey stick” decision rule where fishing mortality is reduced below a particular reference point (Summarised in Table 1). In general, this requires full quantitative stock assessments to be undertaken. In Australia, this approach has been explicitly adopted by the Commonwealth, Queensland, and WA. It is a feature of the NZ, USA, and ICES harvest strategies. The form varies somewhat but the basic approach is the same. It is illustrated in Figure 3.

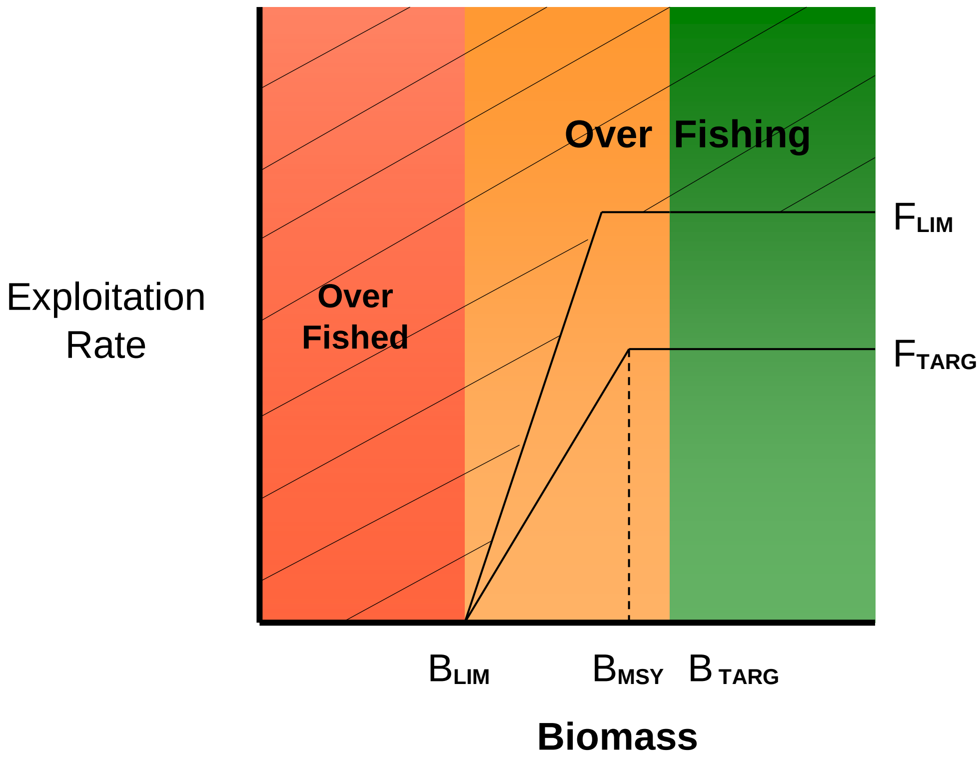

Figure 3 Example of a harvest control rule that is broadly consistent with the Commonwealth harvest strategy policy (HSP; B_{LIM} = limit biomass reference point; B_{MSY} = biomass that corresponds to maximum sustainable yield; B_{TARG} = target biomass reference point; F_{LIM} = limit fishing mortality rate; F_{TARG} = target fishing mortality rate). The HSP specifies B_{TARG} as B_{MEY}, the biomass that corresponds to the maximum economic yield. (After Smith et al., 2009).

In this example for the Southern and Eastern Scalefish and Shark Fishery (SESSF), B_{MSY} is the equivalent of a trigger reference point. The decision rule specifies that as the biomass reduces below B_{MSY}, F_{TARG} is progressively reduced to zero at B_{LIM} (Smith et al., 2009). Below B_{LIM} targeted fishing ceases but "bycatch" TACs allow for incidental catches. While Figure 3 is broadly consistent with the Commonwealth Harvest Strategy Policy, the revised HSP guidelines (Department of Agriculture and Water Resources 2018b) did not explicitly include a fishing mortality limit reference point. In addition, in the current SESSF harvest strategy framework, Tier 1 assessments now use B_{35} as the trigger reference point rather than the B_{MSY} default of B_{40} (AFMA, 2020). However, despite these differences Figure 3 provides a useful example of the approach.

The operational guidelines for the New Zealand harvest strategy standard recommends a similar decision rule but here the trigger reference point (threshold) is set at (1-M) B_{MSY} (Ministry of Fisheries, 2011) based on Restrepo et al. (1998). However, this hasn't been explicitly implemented although the general concept has (Pamela Mace, NZ Ministry for Primary Industries, pers. comm.). The hockey stick decision rule for ICES is applied at the MSY $B_{TRIGGER}$ trigger reference point (ICES, 2021), and in WA at the threshold (trigger) reference point at B_{MSY} or equivalent (WA Department of Fisheries, 2015).

Decision rules based on more data moderate approaches, such as spawner per recruit, surplus production models and depletion-based methods such as stock reduction analysis are used by ICES and in the USA (ICES, 2018; Pacific Fisheries Management Council, 2020). However, buffers are applied to reflect greater uncertainty in the assessments (see below).

While the approach that sees fishing mortality reduced as the stock size decreases is most commonly used with model-based estimates of biomass and fishing mortality, it can also be applied to empirical harvest strategies. For example, in the South Australian Sardine Fishery, the Tier 3 decision rule is that the maximum exploitation rates decline from 20% to 10% as the stock declines and is then set to 0 at the biomass limit reference point (PIRSA, 2014).

Decision rules that use fishing catch rate data as the indicator to adjust catches are common (Dowling et al., 2015). For example, the Tier 4 decision rule in the SESSF adjust catches based on the ratio of current CPUE against a reference period ($CPUE_{TARG}$) and a limit CPUE (0.4 $CPUE_{TARG}$) (Little et al 2011). The decision rule for South Australia's Southern Zone Rock Lobster Fishery is based on CPUE (kg/potlift) where the catch is adjusted upwards as the CPUE increases (PIRSA, 2020). There are also several meta-rules used in this decision rule.

Other empirical decision rules that have been proposed and/or used are estimates of total and fishing mortality from catch curves based on age composition (Wayte and Klaer, 2010) and mean length (Klaer et al., 2012). In very data-poor situations, the decision rule can be a series of triggers that require greater data collection and analyses to be undertaken at each level due to changes in the fishery. Such changes might include total catch, catch of key species, species composition or CPUE (Dowling et al., 2014).

Some harvest strategies also have over-arching meta rules. These are often designed to give greater certainty to industry through restrictions on how small or large changes in catch or effort should be in any year (see, for example, AFMA, 2020; QLD Department of Agriculture and Fisheries, 2021).

Dealing with uncertainty and risk.

A crucial component for harvest strategy policy and/or framework development and implementation is that it explicitly considers risk and uncertainty. Uncertainty can be included in a harvest strategy through selecting precautionary limit and trigger reference points and the probabilities of indicators being above the limit reference point (WA Department of Fisheries, 2015). For example, most Australian harvest strategy policies have a 90% risk criterion. This means that there is greater than or equal to a 90% probability that the stock or management unit will be above its biological limit reference point over a period of time (i.e., that is, a 1-in-10-year risk that stocks will fall below B_{LIM}) (PIRSA, 2015a).

The more uncertain the assessment of stock status, the more precautionary the reference points and/or decision rules should be to meet the required 'acceptable level of risk' to achieve the objective for the fish stock or fisheries management unit. This also allows choices to be made about the level of required investment in monitoring and assessment for a particular fishery. There is a trade-off between the catch that can be taken, the risk to the stock and the costs associated with monitoring, assessment, and management, called the catch cost risk trade-off (Sainsbury, 2005). In general, higher investment in monitoring and assessment will allow higher catch levels to be maintained because the stock status, and its response to management, is being monitored with greater precision. The costs of different stock assessment options will be relevant to the choice of performance indicators and the acceptable levels of risk that are defined for the fishery (Sloan et al., 2014).

Harvest strategies should be tested for their robustness prior to implementation to demonstrate that they are likely to meet the core principles of the policy (PIRSA, 2015a). This can involve a range of methods of increasing sophistication and cost, including: 1) the informal qualitative consideration of each option by those involved in the management of the fishery using some form of 'expert judgement'; or where there are sufficient resources and it is warranted, 2) several more formal qualitative (e.g., Smith et al., 2004), and semi-quantitative approaches; or 3) how well the approach worked in the past, in the fishery being assessed, or in similar fisheries (PIRSA, 2015b). However, where time and resources are available, the preferred method is 4) management strategy evaluation (MSE), where it can be applied, which can be used to test both model-based and empirical harvest strategies using simulation-based methods (Punt et al., 2016).

A tiered approach is commonly used to deal with different levels of information and uncertainty in assessments (for example in Commonwealth fisheries (e.g., Smith et al., 2008)) the USA (Pacific Fisheries Management Council, 2020) and ICES (ICES, 2020), noting tiers are also referred to as categories or levels. Dowling et al. (2013) and Dichmont et al. (2017) extended the 4 Tier approach of Smith et al. (2008) to comprise 9 tiers across a broader range of levels of data deficiency. Each tier corresponds to a given availability of data and a method to assess status. This inevitably means that tiers based on less certain information will need to be more precautionary in nature. To enable some consistency in the risk at each tier, a buffer or discount is applied to the recommended catch or effort level resulting from the harvest control rule (Dichmont et al., 2016). The buffers applied vary considerably across jurisdictions. In the Commonwealth SESSF, buffers of 5% and 15% are applied to Tiers 3 and 4 but no buffer is applied to Tier 1s. Stocks in the Pacific Coast Groundfish Fishery are placed into three categories (Data-rich, data-moderate, data limited) with 11 sub-categories (Pacific Fisheries Management Council, 2020). Buffers applied are to each category based on the degree of uncertainty based on Ralston et al. (2011). Application of these to a proposed tier structure (with 11 tier categories as data-rich, data-moderate and data-limited) in Commonwealth fisheries (Department of Agriculture and Water Resources, 2018b Appendix B) gives the following buffers Tier 1-2 (data rich) 0.91; Tier 3 (data-rich) 0.87; Tier 4-8 (data-moderate) 0.82-0.87; and Tier 9-11 (data-limited) 0.68. These are considerably higher than the current SESSF buffers. Fulton et al (2016) found that the USA west coast buffer approach gave improved performance in avoiding risk and came close to giving risk consistency across tiers. The Queensland harvest strategy policy also refers to these tiers and buffers (QLD Department of Agriculture and Fisheries, 2021).

The ICES framework has 6 categories (tiers) with categories 3-6 designated as data-limited. A precautionary approach (PA) buffer of 20% is applied to the TAC advice when there is significant uncertainty (Seafish, 2022b).

How often an assessment is undertaken is also considered in some harvest strategy systems. For example, in the Pacific Coast Groundfish Fishery, buffers are increased based on the number of years since the last assessment (Pacific Fisheries Management Council, 2020). In the Commonwealth Small Pelagic Fishery, the assessment is based on the daily egg production method (DEPM). The harvest strategy has 3 Tiers based on when the last DEPM was undertaken, and the maximum exploitation rate falls by 50% from Tier 1-2 and by a further 50% between Tier 2-3 (AFMA, 2017).

Rebuilding plans and time frames

Some harvest strategy policies and frameworks require explicit rebuilding plans and timelines for stocks assessed as overfished, that is below the limit reference point. The Commonwealth Harvest Strategy Policy states that the objective of a rebuilding strategy is to cease overfishing and rebuild the overfished stock to above its limit reference point with a reasonable level of certainty, within a specified time frame (Department of Agriculture and Water Resources, 2018a). However, this does not preclude a "bycatch" TAC to account for incidental catches. The specified time frames are typically between T_{MIN} and $2xT_{MIN}$, where T_{MIN} is defined as the time for recovery in the absence of fishing. Where it is not possible to estimate this, the mean generation time plus 10 years or 3x the mean generation time can be used (Department of Agriculture and Water Resources, 2018b).

The NT Harvest Strategy Policy (NT Department of Primary Industries and Resources, 2016) states that for any fish stock classified as overfished, there should be a high probability of stock recovery to levels above the limit reference point, within specified timeframes related to the generation time of the species.

The WA, NSW and Queensland harvest strategy policies also refer to the need for rebuilding strategies/plans and rebuilding timeframes but are not prescriptive.

Similarly, to the Commonwealth HSP, the New Zealand Harvest Strategy Standard specifies that where the probability that a stock is at or below the soft limit is greater than 50%, the stock should be rebuilt to the target with a 70% probability within a time period between T_{MIN} and $2*T_{MIN}$ (where T_{MIN} is the theoretical number of years required to rebuild a stock to the target with zero fishing mortality) (Ministry of Fisheries, 2011). The rebuilding plan should include the rebuild target, the expected timeframe for rebuilding and a minimum acceptable probability of achieving the rebuild, together with a set of management actions that will achieve the desired rebuild. However, unlike the Commonwealth example the rebuilding time frame is to the target not the limit.

Under the Magnuson-Stevens Fishery Conservation and Management Act, rebuilding plans are required for overfished stocks. Although some harvest can be accommodated to avoid severe economic consequences (Pacific Fisheries Management Council, 2022). The rebuilding plan has several components including a rebuilding analysis. The minimum time to recovery to B_{MSY} with a 50% probability is designated as T_{MIN}. Rebuilding analyses also report T_{MAX} where T_{MAX} is 10 years if T_{MIN} is less than 10 years. If T_{MIN} is greater than or equal to 10 years then T_{MAX} is T_{MIN} plus one generation time.

Multi-species and multi-sector fisheries

Multi-species fisheries present their own challenges. Many types of fishing gear (such as trawls, longlines and gillnets) catch a range of species, some of which are target species, while others are retained but of less commercial importance (by-product) and some generally discarded (by-catch). A challenge with multi-species fisheries management is to ensure that all species caught are fished sustainably and not just the target species (Sloan et al., 2014). Sloan et al. (2014) recommend that less important species should be considered in developing a harvest strategy, where possible, because they can be vulnerable to overfishing and contribute to the catch. However, they are often data-limited or data-poor. The tier-based harvest approach, described above, is commonly used to deal with different levels of information and uncertainty in assessments and is particularly useful for a multi-species fisheries harvest strategy.

In mixed-fisheries, due to technological and ecological interactions single-species MSY cannot be obtained for all or even most species at a time. This can lead to a dilemma between maximizing profits and ensuring the sustainability of less-productive stocks. These interactions may imply that fishing some economically important species in a sustainable manner would lead to under- or over-utilising other species (Smith et al., 2017). In response, Rindorf et al. (2017) developed the concept of pretty good multi-species yield, which accounts for the fact that not all combinations within single-species pretty good yield F-ranges are compatible with biological and technical interactions and a multi-objective approach. The Commonwealth Harvest Strategy Policy also recognises that managing individual stocks to different target reference points may be necessary to achieve fishery level maximum economic yield. However, sustainable harvesting of all stocks over the long term must still be ensured (avoiding approaching limit reference points) (Department of Agriculture and Water Resources, 2018a). Sloan et al. (2014) suggested that target reference points may be established for a subset of the species, but limit reference points should generally apply across all the species in the fishery.

One approach to dealing with multi-species fisheries is to set targets for mixed species above B_{MSY} and well below F_{MSY} to provide an additional buffer that minimises the risk of any one species falling below its biomass limit. Another is the concept of F_{MSY} ranges formulated to enable managers to resolve conflicts between stocks by exploiting some at rates slightly above F_{MSY} and some below F_{MSY}. (Seafish, 2022). Using a multi-species assessment method enables advice on TACs for individual stocks which would keep all stocks exploited at within 95% of maximum sustainable yield.

A completely different approach to dealing with multi-species fisheries is using selected indicator species that define the risk status for the entire suite of species. If, for example, one indicator species breaches the threshold or limit, then all species considered are deemed to have. (Western Australian Department of Fisheries, 2011).

A further aspect that needs to be considered is that because technological and/or ecological interactions are known to limit catches in multi-species fisheries where species of different productivity are caught together, the multi-species MSY is generally lower than the aggregate of the single species MSY (Forgery et al., 2012; Link et al., 2012). Aggregate surplus production models show that system-level harvest is approximately 25% less than summed individual MSYs (Patrick and Link, 2015), though it may be as much as 50% less in some tropical systems (Leadbitter et al., in press).

There is increasing interest in developing harvest strategies across multiple sectors (Pascoe et al., 2019; Dichmont et al., 2020). Different sectors may have different objectives and also multi-sector fisheries need special consideration in developing harvest strategies as the management tools used often differ between sectors (Sloan et al., 2014). Pascoe et al. (2019) used workshops and surveys to elicit stakeholder objectives and priorities in a reef fishery on the Great Barrier Reef. Potential harvest strategies were assessed against the objectives using a further qualitative impact survey to identify which frameworks were preferred by different stakeholder groups and why, considering the different objective priorities and trade-offs in outcomes. Dichmont et al. (2020) extended this analysis using a line fishery in the GBR as a case study, applying semi quantitative and quantitative analyses. They argued the need for a greater set of objectives, elicited from stakeholders, that are included in trade-off analyses of different harvest strategies.

Exceptional circumstances

While harvest strategies need to be unambiguous, they also need to be adaptive. One way to build in flexibility is to identify the 'exceptional circumstances' that may trigger departure from or even suspension of the harvest strategy (Sloan et al., 2014). This allows for flexibility in a structured way, but not so much flexibility that it undermines the intent of having a harvest strategy (which among other things values certainty of process). Specifically, this could include defining the exceptional circumstances that may trigger such a change. The 2007 Commonwealth Harvest Strategy Policy guidelines (Australian Government, 2007) gives the following examples that may warrant the use of exceptional circumstances provisions:

- Where assessments have not been completed due to unforseen circumstances (e.g., a planned resource survey did not eventuate)

- Where there has been an exceptional change in the nature of the fishery that cannot be accommodated in the existing assessment method (e.g., a closure to a substantial part of the fishery, unrelated to concerns about impacts of fishing, that substantially alters catch and effort data).
- Where there has been a change in the ecological environment of the fishery unrelated to impacts of fishing (e.g., a fish kill, or a climate induced regime shift).

Having flexibility to vary from the harvest strategy under certain clearly specified circumstances should not be seen as broad flexibility in interpreting the results of assessments and applying the harvest decision rules, which would undermine the harvest strategy (Smith et al., 2008). Once a harvest strategy is operational, if circumstances change significantly or there are substantiated reasons to doubt the accuracy of data inputs, then 'break-out rules' may be used. These may identify certain exceptional and specific circumstances that may trigger a variation from the harvest strategy (NSW Department of Primary Industries, 2021a, b).

In New Zealand, where proposed management options departed from the Harvest Strategy Standard, they must be justified in terms of the circumstances that warranted such departure (NZ Ministry for Primary Industries, 2008). The use of exceptional circumstances and breakout rules has been adopted widely in South Africa (de Moor et al., 2022) and in a number of RFMOs (e.g., Preece et al., 2017). Exceptional circumstances are defined here as events, or observations, that are outside the range of scenarios for which the management procedure was tested.

Implications for the Marine Scalefish Fishery

South Australia's MSF is a complex, multi-species, multi-gear and multi sector fishery that has recently undergone significant change through a reform of its commercial fishery. This reform included the regionalisation of the fishery through four new zones of management, fleet rationalisation that reduced the number of MSF licences from 307 to 207, and the implementation of ITQ based management which was supported by a new Tiered Management Framework (TMF, Smart et al., in press) to help determine which stocks required unitisation.

Following the MSF's reform, formal harvest strategies are needed. The South Australian Harvest Strategy Policy and guidelines are not prescriptive regarding reference points and decision rules. This review helps inform the development of a harvest strategy framework for this fishery. Some direction is given by the Commercial Marine Scalefish Fishery Reform Advisory Committee which in the final report presented in October 2019, recommended the South Australian Research and Development Institute (SARDI) develops recommended biological catch (RBC) limits for priority species that are assessed annually for each management zone based on maximum sustainable yield (MSY). This suggests that reference points of B_{20} and B_{40} as defaults could be considered and would be consistent with many jurisdictions reviewed in this paper.

An effective harvest strategy will not only need to consider the commercial sectors of the fishery (MSF, Rock Lobster, Prawn, and Lakes and Coorong fisheries) but also the recreational and Aboriginal/Traditional sectors. For all species, the Aboriginal/Traditional sector has a 1% allocation, as specified in the management plan. The recreational and charter boat fisheries have specified state-wide allocations for each species, which in some instances constitute a large component of the fishery. For example, the recreational allocation (recreational and charter combined) of King George Whiting is 48.5%. Therefore, species such as this must have the fishing mortality of recreational sectors included in the decision rules in order for the harvest strategy to be effective. Data from the recreational fishery is limited to surveys that occur every five years and can be quite coarse for many species. Therefore, it is unlikely that data from the recreational fishery can form part of any performance indicator for many species. However, recreational catches must be accounted for in the harvest strategy and decision rules, but any considerations around sector allocations should remain separate to the harvest strategy and determined through a separate process.

The TMF was recently used to determine which stocks should be assigned a Tier 1 classification and managed using a total allowable commercial catch (TACC) (Smart et al., 2022). It also assigned stocks to a Tier 2 status, where TACC management was not implemented but an RBC should be determined, and catches should be maintained below these levels. Tier 3 stocks do not have a prescribed management objective and should be monitored to ensure that a Tier 3 classification remains appropriate. These management tiers can be used to inform the decision rules for each stock. For example, Tier 1 stocks would benefit from decision rules that recommend a TACC based on the performance indicators. As Tier 2 stocks are not currently managed using TACCs, decision rules could be used to assign stock status and identify whether their management needs have changed. These are both indicators within the TMF (Smart et al., 2022) and therefore the harvest strategies could be used to support stocks being moved between management tiers. This could lead to a change in management measure, such as the introduction of a TACC if appropriate.

The four zones of management in the fishery were designed to encapsulate the stock structures of the MSF's key species (Snapper, King George Whiting, Southern Garfish and Yellowfin Whiting). However, several species have stock structures that are broader than these regions, and therefore their regional assessment may occur as management units rather than as biological stocks. Some consideration is required as to whether the harvest strategies for these stocks are applied to biological stocks with state-wide TACCs divided by zones or if harvest strategies should be determined for management units. Southern Calamari, which has a state-wide biological stock but is managed with regional TACCs, provides an important example.

The quality and certainty of the scientific assessments varies across stocks and ranges from integrated length and age structured models to basic catch and effort statistics. A potential harvest strategy framework that comprises multiple categories is shown in Table 2. Here, the term categories is used to avoid confusion with the TMF (note the term category is also used in the USA and by ICES). It is broadly consistent with approaches described above and informed by Smith at al. (2008) and the 9-tier level framework of Dowling et al. (2013) and Dichmont et al. (2017). The type of decision rule appropriate for each category is also suggested. With the adoption of any such framework meta rules would need to be developed to deal with any species below the limit reference point when the harvest strategy framework is implemented, with rebuilding plans and time frames agreed. A future research priority will be to improve the quality of assessments in order to provide appropriate harvest strategy indicators. This may mean that some stocks can move between harvest strategy categories over a short to medium period of time (Table 3). In the short term it is suggested that a single species approach as shown above is undertaken but a future option is the adoption of a multi-species harvest strategy framework. However, this will require additional research and analysis to develop a framework that is cost-effective and suitable for the fishery.

In summary, a sensible approach to harvest strategy development which is in line with current practices would be:

- Consider 'Hockey stick' decision rules with limit, trigger and target reference points where appropriate. Decision rules for data-limited species could be determined based on historical reference levels and/or trends in indicators.

- Estimates or proxies of B_{20} and B_{40} could be used for the limit and target reference points respectively, depending on whether the performance indicators are empirical or model-based. The trigger reference point (break point in the hockey stick rule) could be set at B_{35}.
- The performance indicators for each stock may need to consider commercial only data if data on recreational catch and effort is not available. However, fishing mortality from the recreational sector should be included in the harvest strategy.
- Decision rules will need to be developed for each sector.
- An example of a harvest strategy framework, comprising seven categories, that is broadly consistent with current assessments in the MSF is presented. Note the term category is used to avoid confusion with the Tiered Management Framework.
- The current assessment methods for several stocks result in their assignment to the lowest possible harvest strategy category. A research priority should be to improve these assessments and move stocks into higher categories.
- The harvest strategies can be used to determine TACCs for Tier 1 stocks and management responses for the other stocks, and act as a mechanism for the elevation of Tier 2 or Tier 3 stocks based on changes to stock status or management need.
- Exceptional circumstances provisions could be defined.

Input is required from stakeholders who are to be involved in harvest strategy development in the MSF, potentially using the initial framework presented here as a starting point and, more importantly, how the performance indicators and decision rules for each stock should be determined.

Table 2. Example of harvest strategy framework that is broadly consistent with current assessments in the Marine Scalefish Fishery. Note the term category is used to avoid confusion with the Tiered Management Framework.

Category	Assessment type	Decision rule
1	Robust integrated stock assessment model with fishery independent/dependent biomass indices	Hockey stick
2	Integrated stock assessment model with fishery independent/dependent biomass indices – less certain or preliminary assessment	Hockey stick
3	Biomass dynamic, surplus production models Stock reduction analysis	Relative to biomass at MSY
4	Empirical estimation of fishing mortality (size/age data) Spawner biomass per recruit	Relative to fishing mortality at MSY
5	Trends in standardised CPUE	Relative to reference periods
6	Catch only methods (eg Catch MSY)	Relative to MSY
7	Raw catch rates	Species/stock specific catch triggers

Table 3. Summary of current and potential harvest strategy categories for MSF stocks based on current and potential assessment options and draft tier classifications as developed by Smart et al. (in press).

Tier	**Stock**	**Current assessment type**	**Current Harvest Strategy Category**	**Potential assessment options**	**Potential Harvest Strategy Category**
Tier 1	Snapper (SG/WC)	Integrated stock assessment model/ DEPM Biomass	Category 1	No change	Category 1
Tier 1	Snapper (GSV)	Integrated stock assessment model/ DEPM Biomass	Category 1	No change	Category 1
Tier 1	Snapper (SE)	Integrated stock assessment model	Category 1	No change	Category 1
Tier 1	KGW (GSV)	Integrated stock assessment model	Category 1	No change	Category 1
Tier 1	KGW (SG)	Integrated stock assessment model	Category 1	No change	Category 1
Tier 1	KGW(WC)	Integrated stock assessment model	Category 1	No change	Category 1
Tier 1	Southern Garfish (GSV)	Integrated stock assessment model	Category 1	No change	Category 1
Tier 1	Southern Garfish (SG)	Integrated stock assessment model	Category 1	No change	Category 1
Tier 1	Southern Calamari (SG)	Raw CPUE	Category 7	Integrated stock assessment model	Category 1
Tier 1	Southern Calamari (GSV)	Raw CPUE	Category 7	Integrated stock assessment model	Category 1
Tier 2	Blue Crab (WC)	cMSY	Category 6	Standardised CPUE	Category 5
Tier 2	Yellowfin Whiting (SG)	cMSY	Category 6	Standardised CPUE/ Surplus production model	Category 3
Tier 2	Yellowfin Whiting (GSV)	cMSY	Category 6	Standardised CPUE/ Surplus production model	Category 3
Tier 2	Southern Calamari (WC)	Raw CPUE	Category 7	Standardised CPUE	Category 5
Tier 2	Australian Herring (GSV)	Raw CPUE	Category 7	Standardised CPUE	Category 5
Tier 2	Australian Herring (SG)	Raw CPUE	Category 7	Standardised CPUE	Category 5

Tier 2	Western Australian Salmon (GSV)	Raw CPUE	Category 7	Standardised CPUE	Category 5
Tier 2	Western Australian Salmon (SG)	Raw CPUE	Category 7	Standardised CPUE	Category 5
Tier 2	Whaler Sharks (GSV)	Raw CPUE	Category 7	Standardised CPUE	Category 5
Tier 2	Whaler Sharks (SG)	Raw CPUE	Category 7	Standardised CPUE	Category 5
Tier 2	Whaler Sharks (WC)	Raw CPUE	Category 7	Standardised CPUE	Category 5
Tier 3	Ocean Jacket (SG)	Raw CPUE	Category 7	Standardised CPUE/ Surplus production model	Category 5
Tier 3	Snook (GSV)	Raw CPUE	Category 7	Standardised CPUE/ Surplus production model	Category 5
Tier 3	Snook (SG)	Raw CPUE	Category 7	Standardised CPUE/ Surplus production model	Category 5
Tier 3	Yellow-Eye Mullet (SG)	Raw CPUE	Category 7	Standardised CPUE/ Surplus production model	Category 5

Acknowledgements

Drs Malcolm Haddon, Keith Sainsbury, Campbell Davies, and Professor Andre Punt are thanked for useful discussions on aspects of this report. Dr Tony Smith, Dr Mike Steer, Dr Stephen Mayfield and Mr Sam Stone are also thanked for reviewing this report.

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Appendix 1 Glossary

Biomass (*B*) Based Indicators	Quantitative values that refer to a given stock size. For example, B_{40} refers to the Biomass at 40% of the unfished stock size. Biomass based indicators can also align with specific reference points such as limit (B_{LIM}) and target (B_{TARG}) reference points.
Buffer/Discount	An additional reduction, usually applied as a percentage, to a Recommended Biological Catch (RBC) that accounts for uncertainty in an assessment. Stocks in a higher harvest strategy category would have smaller buffers applied (or possibly no buffer at all) in comparison to stocks in lower harvest strategy categories.
Catch-Cost Risk Trade-Off	The trade-off between the increased profits from larger catches against the increased costs of management and scientific assessments required to support the risk posed by higher exploitation.
Data-Limited Assessments	Stock assessment methods applied to stocks with limited fishery or biological data. These assessment methods provide greater levels of uncertainty than integrated stock assessments due to the reduced level of information or data available.
Decision Rules	Also referred to as Harvest Control Rules (HCRs). Decision rules are pre-determined management actions linked directly to the performance of the fishery, relative to reference points.
Fishing Mortality (*F*) Based Indicators	Quantitative values that refer to the fishing mortality that correspond to a given stock size or reference point. For example, F_{40} refers to the *F* that maintains Biomass at 40% of the unfished stock size. Fishing mortality based indicators can also align with specific reference points such as limit (F_{LIM}) and target (F_{TARG}) reference points.
Harvest Strategy Category	Each category corresponds to a given availability of data and a method to assess status. This inevitably means that categories based on less certain information will need to be more precautionary in nature. Harvest strategy categories are also referred to as 'Tiers'.
Hockey Stick Decision Rule	A decision rule where fishing mortality ramps down linearly following the breach of a trigger or target reference point. While the performance indicator remains above the trigger reference point the decision rule remains constant, thus giving a "hockey stick" shape.
Management Strategy Evaluation (MSE)	The testing of different management options using model-based assessments to examine the most desirable outcome(s).
Management Tier	Tiers are assigned to each stock in the MSF based on the Tiered Management Framework. These Tiers determine the level of management (TACC, RBC, or basic monitoring) required for each stock.

Maximum Economic Yield (MEY)	The level of sustainable catch that allows net economic returns to be maximised for a commercial fishery. i.e., at or above B_{MEY}.
Maximum Sustainable Yield (MSY)	The maximum sustainable yield (MSY) is the maximum long term catch that can be taken when a stock is at a healthy size, i.e., at or above B_{MSY}.
Operational Objectives	The overarching goal of a harvest strategy, such as having a high likelihood of maintaining stocks at or near the targets and meeting the probability or risk requirements in relation to avoiding depletion to, or below, the limits.
Performance Indicators	A quantity that can be measured and used to track changes with respect to achieving an operational objective. There are two types of performance indicators: model-based and empirical. Model-based indicators refer to estimates of fishing mortality (*F*) and/or biomass (*B*) determined through stock assessment models. Empirical indicators are not model-based and do not directly refer to estimates of *B* or *F.* Instead, they use proxies to infer these quantities such as catch, effort, CPUE, recruitment indices, and mean size or age.
Rebuilding Plan	A strategy is to cease overfishing and rebuild the overfished stock to above the limit reference point or to the target reference point with a reasonable level of certainty, within a specified time frame
Recommended Biological Catch (RBC)	The maximum annual biomass that can be sustainably harvested from a stock, as determined via the decision rules. An RBC accounts for stock size when determining what level of catch is sustainable. If a management goal was to increase stock size, then the appropriate measure would be to make sure that catches remain below the estimated RBC so that population growth can occur.
Reference Points	The value of a performance indicator that can be used as a benchmark of performance against an operational objective. Harvest strategies generally have three types of reference points. Limit reference points define the values of a performance indicator that identifies an undesirable outcome to be avoided with high probability, for example recruitment overfishing. Trigger reference points define the values of a performance indicator at which a change in the management is considered or adopted. Target Reference Points define the values of a performance indicator that are desirable or ideal and at which management should aim.