Management strategy evaluation and the precautionary approach to capture fisheries: a roadmap to improving fishery sustainability

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1.1 Purpose

Management strategy evaluation (MSE) is the most scientifically defensible and economically practical way to implement a precautionary approach to capture fisheries. This report uses practical experience developing and applying MSE to help fishery managers, stakeholders, and scientists better understand how to apply the approach to real fisheries regardless of size. We first clarify the original intent of the precautionary approach to capture fisheries and how elements of MSE are embedded within that guidance. This relationship is not surprising because the authors of the precautionary approach were also experienced developers and practitioners of MSE. The paper then defines the 7 core steps involved in a typical MSE process along with their specific purpose and key considerations for implementation. Finally, the report addresses two common arguments that most frequently stand in the way of initiating and completing an MSE.

1.2 Key takeaways

- Management strategy evaluation is the most scientifically defensible and economically practical way to implement a precautionary approach to capture fisheries.
- Simulation-tested management procedures provide a consistent and transparent approach to setting fishery regulations such as catch and effort limits
- An organized structured decision-making approach should be used to implement MSE in an efficient and timely manner.
- When implemented correctly, MSE is guaranteed to provide as good or better fishery outcomes compared to traditional stock assessment/management.

1.3 The precautionary approach to capture fisheries

Fisheries provide economic, social, and biological benefits to human society, yet they are also complex, somewhat unpredictable, and difficult to manage. The combination of complexity and uncertainty means that errors in fishery decisions are impossible to avoid. The precautionary approach to capture fisheries was developed to improve our chances of getting the most benefit from fisheries while minimizing the consequences of our mistakes. Specifically, the original FAO (1996) document states:

“Management according to the precautionary approach exercises prudent foresight to avoid unacceptable or undesirable situations, taking into account that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values.”

This carefully crafted statement from over 30 of the world’s top fishery scientists and managers at the time with practical experience over a wide range of fisheries made clear that a precautionary approach does not mean arbitrarily shutting fisheries down or being excessively risk-averse in decision-making, because such behaviour could have severe consequences for harvesting communities. Instead, the phrase – prudent foresight – simply suggests that fishery management be careful and forward-looking when formulating harvest strategies and management procedures taking into account both natural and human values. The FAO (1996) working group went on to define a fishery harvest strategy as one that:

(i) specifies broad management objectives, specific operational targets, and constraints;
(ii) specifies the procedure to apply and adjust management measures such as catch or effort limits;
(iii) uses prospective evaluation of the procedure to ensure its ability to meet the objectives stated in (i); and
(iv) implements, monitors, and enforces all elements of the strategy.

Developing such a strategy involves several key considerations. For instance, the objectives in (i) must be realistic given the biological, economic, and scientific context since there is no point aiming at targets that cannot be achieved given the resources available. The objectives also must specifically consider the needs of fishing communities. Similarly, the types of management procedures considered in (ii) must be feasible and economically practical given the way a fishery is monitored and regulated. The prospective evaluation component in (iii) implements prudent foresight by testing proposed management procedures against statistical variation in the data, as well as a broader range of uncertain future situations where possible. In other words, prospective evaluation shows the possible consequences of the unavoidable errors that arise from our limited knowledge and lack of predictability. The prospective evaluation aims to filter out management procedures that fail in computer simulations since they will almost surely fail in practice (Punt et al. 2016). Development of the overall harvest strategy involves a collaborative process among managers, stakeholders, and scientists in what has come to be known as MSE.

1.4 Management strategy evaluation

MSE is a fisheries-specific example of a structured decision-making process (Gregory et al 2012) as represented in 7 general steps (Figure 1). This section provides a brief description of each step along with considerations to improve efficiency of implementation based on practical experience. Note that the modelling in steps 3-5 can be highly technical and we refer interested readers to more specific guides on those topics (e.g., Punt et al. 2016). Our purpose here is to help managers and stakeholders better understand the broader context of the MSE approach and, most importantly, what is needed to ensure delivery of a high-quality result in a reasonable time.

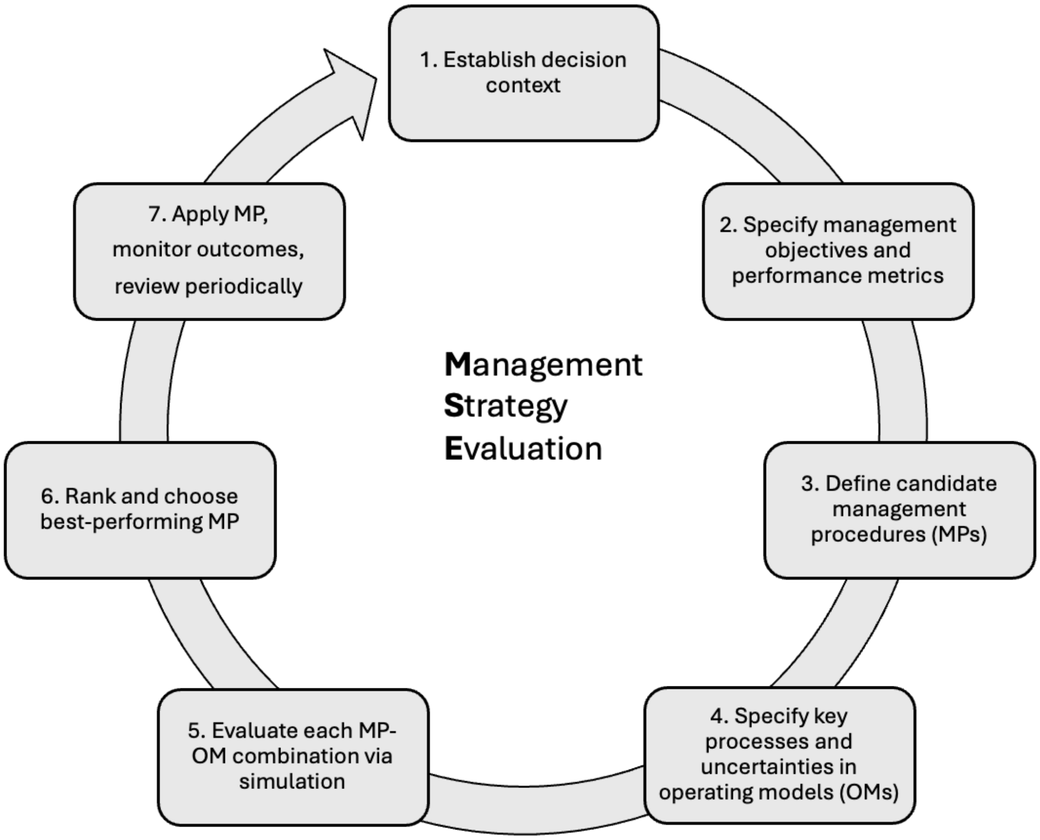

Figure 1 The management strategy evaluation cycle represented in 7 general steps that are common to most structured decision-making processes.

1.4.1 1. Establish the decision context

Effective management of an MSE process requires, at a minimum, a clear purpose, specific roles for scientists, managers, and stakeholders, and a specific timeline for completion. The degree of model complexity and uncertainties examined within the process should then be fit to the resources and timeline, not the other way around. Establishing the decision context at the beginning of a structure decision-making process clarifies the ultimate goal and provides a clear roadmap for how to get there (Gregory et al. 2012). Key questions to guide this definition include, for example:

a) *What exact decision needs to be made?* The ultimate goal of MSE is to find a single management procedure that can provide acceptable performance against the stated objectives in the presence of uncertainty. This might seem obvious but, surprisingly, some MSE processes go on for years without actually deciding to adopt and use a repeatable management procedure (MP) as the intended goal. That is like hiring a contractor to build a bridge that you are not actually committed to driving over. In fisheries, commitment to adopting an MP is roughly proportional to the degree of crisis in a fishery, such as where conservation risks threaten imminent fishery closures. Conversely, fisheries on healthy, abundant stocks usually see little need for the constrained decision-making of a formal MP. While the latter case may not imply urgency, there is not a fish stock in history that did not decline at some point and it is be better to have a plan in place for that situation (see below).

b) *What is the timeframe for adopting the MP?* Realistically, executing all 7 steps of each MSE cycle (Figure 1) requires at least the same amount of time as a typical stock assessment with longer times needed depending on management complexity (i.e., governance, multiple stakeholder sectors, management areas, etc). For many situations, the technical evaluation components in steps 4-5 require adding only slightly more effort to an existing stock assessment, whereas the management-related activities in Steps 1-3 and 6-7 require coordination, planning, and execution. As Ray Hilborn once said, “Fisheries management is about managing people” and that is mostly what these steps are about.

c) *What are the limits to objectives and management procedure options?* This is perhaps the most difficult question in the entire MSE process because it establishes the boundaries of (i) *what is important* and (b) *what is acceptable to each party* in the process. While the important issues might be clear, it could be difficult drawing boundaries. For example, some objectives will be clearly important, but cannot be accommodated, or deemed acceptable, by one party or another, especially where cultural significance and governance issues need to be accommodated.

d) *What are the specific roles of management, science, stakeholders, Indigenous peoples, and academia?* Ultimately, management regulations arising from a formal MP need to be legitimate in the eyes of all fishery participants and this is more likely where ownership of the process and a clear understanding of roles and expectations exists (Smith et al. 1999).

e) *How will the final decision be made?* For fisheries in which stakeholder and management objectives are aligned, it is relatively straightforward to rank MP performance against the objectives and choose the best one (see step 6). In complex multi-stakeholder contexts, this choice may also be straightforward if performance against diverse objectives is correlated (e.g., better ecological outcomes also lead to better cultural and economic outcomes). However, it is also possible that performance against some objectives may conflict to the point where trade-offs need to be made and/or objectives need to be arranged in some priority order. Some specific considerations about trade-offs are given in step 2 below but the point here is that possible conflicting objectives and key trade-offs should be identified early in the process so that potential solutions can be explored.

The decision context step is rarely included in the expanding literature on MSE, which tends to favor the technical aspects of the process. However, investing a modest amount of effort in answering such questions is critical to creating the transparency and sense of ownership needed to complete the process and benefit from the results (Smith et al. 1999; Cox and Kronlund 2008). The label “our MSE” is a reliable indicator that ownership exists and that stakeholders and managers view an MSE process as a legitimate means of developing (and following) a harvest strategy. On the other hand, “your MSE” is an equally reliable indicator of lack of buy-in and potential future challenges to legitimacy.

Motivation and commitment to developing a simulation-tested MP via the MSE process varies among fisheries. For example, a looming economic or ecological crisis brought about by low and/or severely declining biomass were obvious motivators for Southern bluefin tuna (Figure 2, top) and British Columbia sablefish (Figure 2 middle, Johnson et al. 2022). On the other hand, fisheries may seek a transparent MP to stabilize business planning during a stock increase. The latter case occurred for Atlantic halibut around 2015 (Figure 2 bottom; Cox et al. 2016) but revisions were recently made to the MP in anticipation of a possible stock decline (Johnson et al. 2024).

1.4.2 2. Specify management objectives and performance metrics for the stock and fishery

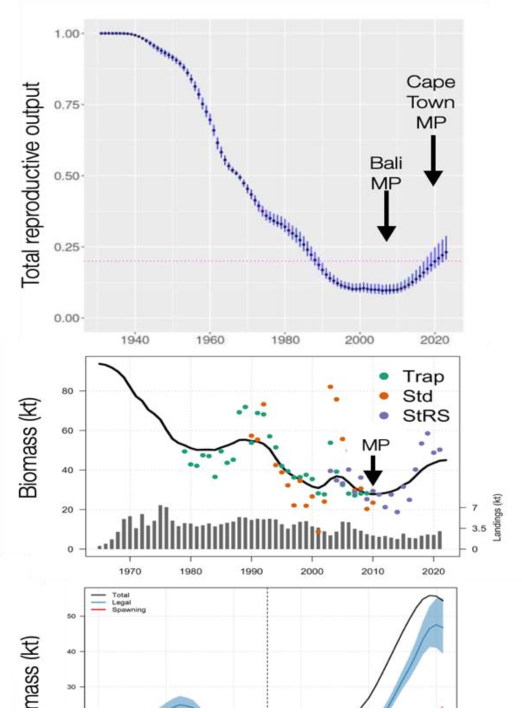

Figure 2 Timing of MP adoption in two fisheries experiencing low/declining biomass and one fishery experiencing rapidly increasing biomass. (top) Southern bluefin tuna; (middle) British Columbia sablefish; (bottom) Atlantic halibut.

It is probably safe to say that most fisheries lack a concise set of operating objectives that are important and acceptable to fishery stakeholders and managers. A few clearly stated, measurable objectives give purpose to the scientific work and transparency to management decisions. Ideally, the number of fishery objectives should be limited (e.g., 4-5) because there are only a few independent dimensions involved in fishery performance. For example, when the stock biomass is high, fishery catch rates will also tend to be high and vice versa, which means performance against stock size and fishery catch rate objectives will be correlated. In this case, a concise objective should be chosen based on biomass or catch rate, but not both. On the other hand, total catch could be high when the stock is small or large, so catch and biomass will be less correlated meaning both a biomass (or catch rate) and catch objective could be included. When there are too many objectives, the more correlated ones will tend to become over-weighted relative to others and this may inadvertently favor certain stakeholder or management groups over others.

It is always possible, and sometimes desirable, to compute more performance metrics than formal objectives since some participants may seek more specific information on a particular dimension. For example, fishery managers typically require at least one spawning biomass objective for policy compliance while stakeholders may be more interested in fishery catch rates. The main point here is to be somewhat ruthless in keeping the formal objectives to the smallest set possible but using additional metrics where needed to improve communication and transparency.

An overarching objective to avoid unacceptable outcomes, such as spawning biomass below a limit reference point, is common to most precautionary fishery policies. Unless a stock is extremely depleted, such objectives rarely influence final MP choices because even the most basic MPs involve automatic feedback between monitoring data and management actions; in other words, declining stocks are automatically fished less and increasing stocks are fished more. Such feedback combined with reasonably scaled target fishing mortality rates is remarkably effective at steering fish stocks away from very low abundance. One obvious exception to the need for extreme precaution is where stocks are already severely depleted and in need of rebuilding without causing undue economic hardship upon the fishery. These cases typically involve a tight balance between avoiding limit reference points in the short-term while steering the fishery toward more productive levels over the long-term. Southern bluefin tuna and British Columbia sablefish (Figure 2) are two cases in which clearly stated objectives and simulation-tested MPs helped guide these fisheries away from ecologically and economically difficult situations in a reasonable time.

Otherwise, fishery objectives are highly dependent on the context. For stocks in need of rebuilding, specific future targets and timeframes are needed, whereas fisheries on abundant stocks have greater flexibility in choosing between catch levels, biomass or catch rates, and catch variability. In most cases, measurable objectives need (i) a state to be achieved (or maintained or avoided); (ii) a timeframe over which to accomplish the state; and (iii) a probability of (i) and (ii) occurring together.

It is common for fisheries to include an objective related to maintaining stable catches over time and there are two general ways to accomplish this. One involves defining a fishery objective such as “maintain less than 15% interannual variation in catch” and then choosing an MP that comes closest to meeting that objective in the evaluation step. The result may or may not come close to 15% depending on the situation and how performance objectives interact. An alternative approach hard-wires a 15% change limit into the MP; that is, the annual catch limit cannot change more than 15% from year-to-year no matter what the assessment indicates. This may seem simpler but, in general, lower change limit constraints increase risk to the fish stock because such constraints reduce beneficial feedback effects of the MP. For example, constraining catch limit reductions while a stock is decreasing may cause a rapid increase in the effective fishing mortality rate and potentially faster decline of the stock. Either way, change constraints on fishery regulations should always be evaluated via simulation even for abundant stocks since the cost of doing so (i.e., via MSE) is much less for a healthy stock than for one in need of rebuilding.

Finally, while it is tempting to accept any stakeholder and/or manager input on objectives, it is equally important to distinguish between “means” vs “ends” objectives (Gregory et al. 2012). MSE should always involve “ends” objectives describing a desired outcome such as “achieve at least 1,000 tonnes average annual catch over the next 10 years”. An objective describing some specific action to influence an outcome, such as “avoid the ramp on the harvest control rule”, represents a “means” objective. Any means objective can be converted to an ends objective by iteratively asking why that “means” is important. For example, asking why the above “means” is important might lead to an “ends” objective that stakeholders want to “maintain less than 15% interannual variation in catch”.

1.4.3 3. Define feasible set of candidate management procedure options

A MP represents the repeatable sequence of steps leading from fishery monitoring data to a harvesting decision. Although many fisheries claim to have management procedures, most of those are filled with *ad hoc* choices that make it nearly impossible to trace the rationale behind changes in fishery regulations over time. The critical feature for MPs is *repeatability*; that is, the same data inputs lead to the same output decisions. Repeatability means that the MP can be programmed in computer code and tested against any number of possible future scenarios, thus establishing their expected reliability.

An MP is not the same thing as a harvest strategy. A strategy represents an aspirational goal or direction (e.g., “rebuild the stock to B_{MSY}”), while an MP represents the operational method to implement the strategy. In other words, a strategy determines *what* to do and an MP determines *how* to do it. For instance, if a stock needs rebuilding to some target (the strategy) then an MP is designed to utilize specific data, an assessment method, and decision rule to meet that goal in the presence of uncertainty about stock dynamics and future data.

A basic MP (Figure 3) includes (i) a data collection protocol (e.g., survey and fishery data types, frequency, quantity, and quality), (ii) a stock assessment method or some other way of analyzing the data to extract signals about stock status, trend, productivity, etc., and (iii) a pre-specified harvest control rule (HCR) that sets fishery regulations (e.g., catch or effort limits) based on the assessment output (de la Mare 1998). The HCR may be more or less complex than simply setting one annual catch limit based on a single biomass estimate. The point is that an MP provides a repeatable response to whatever information is collected on a fishery.

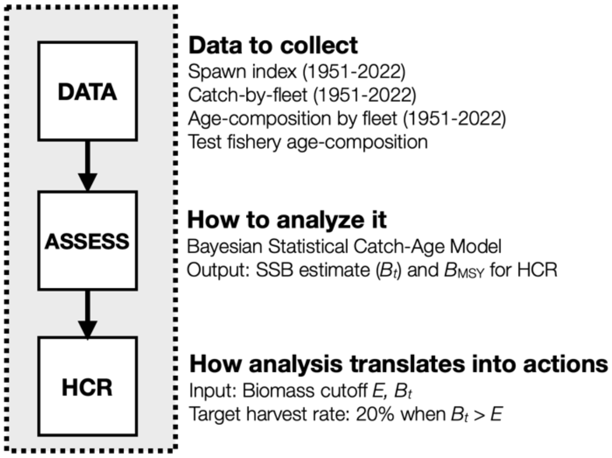

Figure 3 Schematic of the management procedure for British Columbia Pacific herring.

It is important to note at this stage how the role of the stock assessment within the MP differs from the stand-alone best-assessment described in the sections below. In both cases, the stock assessment produces some measure(s) of stock status as indicated by the monitoring data; however, unlike a traditional best assessment, the MP assessment does not need to be the most statistically robust option or even unbiased. For at least a couple of reasons, some MP assessment methods, such as the running average survey method used for Atlantic halibut in Figure 2 include no biology at all. First, the assessment output from an MP is filtered through an HCR that can be adjusted to compensate for its biases and second, as described below, the MP is adapted and tuned via simulation within the operating model to achieve the desired performance despite its potential biases. For example, the fitted model for sablefish in Figure 2 (middle panel, solid line) clearly under-estimates the survey biomass in recent years and would probably not be acceptable as a stand-along best assessment; however, within the context of a simulation-tested MP, the bias is a design feature that limits the ability of the MP assessment to over-estimate fishable biomass, which limits the frequency and magnitude of over-fishing. When viewed simply as a method for interpreting signals in data, the purpose of the assessment method is to help the MP set fishery regulations that are consistent with the assumptions and uncertainties represented within the operating models. This important feature helps to simplify and stabilize short-term decision-making because there is no need to spend considerable resources every year debating the merits of the stock assessment. Instead, scientists, stakeholders, and managers can focus on developing a set of operating models that adequately capture the key processes and uncertainties affecting the future of the fishery. This approach, in general, leads to a more scientific and defensible approach to fishery decision-making.

1.4.4 4. Define a set of operating models representing the key processes and uncertainties

Computer simulation models are central to MSE because they provide the testing environment for MPs and, in some cases, as periodic formal stock assessments. Rather than trying out MPs on real-world fisheries, which can lead to expensive and irreversible damage to stocks and fishing communities, MPs are tested via computer simulation.

Simulation replaces real-world fish stocks and fisheries with one or more mathematical models (i.e., operating models) that reflect alternative hypotheses about the ‘true’ dynamics of the fish population and the fishery, as well as properties (e.g., measurement noise) of the monitoring data. Fishery operating models are used to test and train MPs the same way that flight simulators are used to train and test airline pilots. Alternative fishery operating models represent assumptions about various processes affecting the outcomes, including those that may not be well-understood such as the future impacts of predation or climate change.

In some cases, especially fisheries attempting MSE for the first time, a single operating model can be used to complete the MSE cycle to MP adoption. The Altantic halibut case in Figure 2 is an example where a stock assessment was converted to an operating model that was then used to evaluate several MP options (Cox et al. 2016). The chosen MP was then applied to setting annual catch limits for 7 years before the cycle was repeated a second time, in which objectives, MPs, and operating models were all revised based on the updated data (Johnson et al. 2024). In this case, as in others, a repeatable MP freed up considerable time for other science work aimed at improving data and operating models for future MSE cycles.

Operating model development does not appear until Step 4 of the MSE process for a specific reason. While it may seem logical to first define the ecological context and operating model in step 1 of the process, doing so implies a model-oriented approach, as if the operating model is the single most critical feature needed to manage a fishery. In fact, there are many fisheries operating today that are doing fine without operating models or even formal quantitative stock assessments. An extremely conservative management approach probably does not even require formal assessments. Operating models and stock assessments are needed most within a management-oriented paradigm (de la Mare 1998) where decisions attempt to balance risk-reward trade-offs.

Operating models should be carefully scoped in the same way as objectives and MPs based on independence and feasibility of implementation. Although it is tempting to consider a wide range of ecological hypotheses for operating models, too many options may lead scientists down a model-oriented path away from timely decision-making. Without spending excessive research time, it can be challenging to find a large set of operating models that are not highly correlated in their structure and behaviour and, therefore, provide little new information beyond some minimal set (Walters 1986). As noted above, the automatic and repeatable feedback between stock abundance and exploitation provided by an MP is the critical feature to maintain fishery sustainability. Adopting an MP that has been tested against one operating model is much better than having none, especially when operating models can be added and/or revised during future MSE cycles.

1.4.5 5. Evaluate each MP via computer simulation for each Operating Model and compute Performance Indicators

The evaluation step involves embedding the MP within the operating model so that repeated application of the MP generates realistic feedback effects on future fishery performance (as measured against the objectives). A specific simulation may involve the following steps: (i) simulate data (e.g., spawn biomass estimates, age-composition, fishery spatial distribution) from the operating model similar to those that would occur under the proposed MP and operating model scenario; (ii) from the simulated data, estimate quantities needed by the harvest control rule such as stock status, productivity, recent harvest rates, recruitment indices, etc.; and (iii) generate a management response (e.g., catch limit, season length) from the harvest control rule; and (iv) apply the management response to the operating model fish stock(s). This process is repeated for a pre-determined time horizon and then again over hundreds of random trials to account for uncertainty in the stock dynamics, environmental processes, fishery dynamics, and observational data.

The evaluation step typically generates forecast distributions of outcomes (e.g., stock size, annual catch, catch rates) under each combination of management procedure and operating model. Initial evaluation results are sometimes used to revisit the original objectives. In particular, fisheries engaging in MSE for the first time usually struggle to articulate and/or commit to specific objectives as early as step 2 and the initial evaluation results can inform the practicality and implications of the original objectives. For example, Figure 4 shows example evaluation output for the British Columbia sablefish MSE completed in 2011 (Cox and Kronlund 2016). An early objective in that process was to reverse the stock decline within 7 years, yet initial evaluations showed that no MP could achieve that objective without closing the fishery. Objectives were revised to rebuild spawning biomass to B_{MSY} within 10 years. A final cycle showed that a highly constrained MP could rebuild median biomass within 10 years (top left) while a weakly constrained MP could rebuild the biomass faster within 7 years (top right). Here, the MP with the 10-year rebuilding time was chosen because it showed far less drastic reductions in catch over the first few years of the MP (bottom row).

1.4.6 6. Rank management procedures according to performance metrics

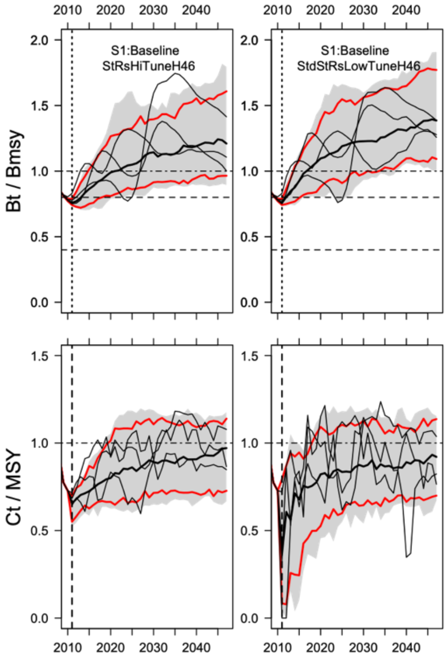

Figure 4 Forecast distributions of spawning biomass (top row) and catch (bottom row) relative to their MSY benchmarks the British Columbia sablefish MSE. Left column - highly constrained assessment in the MP. Right column - weakly constrained assessment

Performance measures in MSE provide a concise summary of the forecast distributions generated in the evaluation step. If there are no revisions to the objectives after the evaluation, then MPs would be ranked according to performance measures in some priority order of objectives. For instance, some objectives, such as minimum biomass limits, will have clear priority as determined by governing fishery policies and can be simply evaluated on a pass/fail basis. Ranking other performance metrics such as rebuilding rates and timeframes depends on stakeholder and manager preferences.

An explicit method for weighting objectives could be necessary where stakeholders do not strictly agree on objectives or their priority order. Conflict resolution, negotiation, and trade-off analysis methods are beyond the scope of this report but should be explored in the decision context (step 1) where diverse stakeholder objectives are anticipated (Gregory et al. 2012).

Fishery managers or commissioners are ultimately responsible for adopting a specific MP although some other party could have been chosen in setting the decision context. Regardless of who decides, MP adoption should be relatively straightforward given the steps leading up to this point. In particular, MPs are now ranked according to performance against the objectives and there is a defensible process justifying the choices made along the way. Deciding on some other way to set fishery regulations besides the top-ranked MP would be a more difficult choice.

1.4.7 7. Apply the MP, monitor outcomes, and review/revise periodically.

It is no trivial matter to switch from a model-oriented stock assessment approach with *ad hoc* management adjustments to a repeatable, machine-like management procedure. Hopefully, the above sections makes this switch seem easier. Fishery managers and stakeholders can also take some comfort in knowing that an MP is not a “set and forget” approach and opportunities for monitoring and revision can begin almost immediately. In particular, realized fishery outcomes such as catch or effort limits, survey indices, catch composition, etc. can now be compared to their expected outcomes as forecasted in the evaluation step. For example, actual fishery catches have been overlaid on the forecast distributions for Southern bluefin tuna and BC sablefish in Figure 4 to ensure that realized MP catch limits are within their original expectations.

Some fisheries managed via MPs define criteria needed to trigger “exceptional circumstances” in case observable outcomes depart from their expected ranges. Exceptional circumstances are especially important where participants are skeptical of formal MPs or the whole MSE process. Clearly defined conditions for exceptional circumstances, along with a planned response, provide a mechanism for any party to challenge MP outcomes in an objective way. It is important to distinguish between exceptional circumstances and simpler issues like missing data. The impact of the latter on MP performance can be tested in the evaluation step to determine a tolerable amount of missing data, after which exceptional circumstances would be triggered (Butterworth 2007).

1.5 Common obstacles to implementing the MSE approach

This section addresses two common obstacles to implementing MSE. The first is the idea that “we already have a stock assessment”. Although such an argument seems logical, it unfortunately ignores the key limitations of stock assessment models that MSE aims to overcome. As discussed in the following section, stock assessments do not meet basic precautionary standards. The second obstacle is that “MSE is too complicated and takes too long”, which is quite often true but doesn’t need to be. There are some well-known process killers that could “turn our MSE into a Management Strategy Elephant!”, as expressed by one stakeholder in the British Columbia Sablefish fishery when that process went through a difficult phase.

1.5.1 Obstacle 1: “We already have a stock assessment.”

In contemporary fisheries, the term “stock assessment” is generally associated with the highly technical process of fitting mathematical and statistical models to abundance and size-composition data for a fishery with outputs being estimates of biomass, fishing mortality, and recruitment or productivity. Since the 1990s, stock assessment model complexity has increased in almost direct proportion to the increase in computing power and use of Bayesian statistical methods. Unfortunately, most of the added complexity hasn’t generated valuable insights into fish population dynamics and the effects of fishing. Instead, the complexity is mainly needed to compensate for poor data quality that arises from unobserved confounding factors. On the bright side, a complex model with poor data is probably better than nothing and at least has some utility in designing better approaches to data collection in the future.

In any case, stock assessment has become the cornerstone of risk-informed decision-making in fisheries because it provides quantitative estimates of fish abundance and productivity from the available data, as well as the uncertainty associated with these estimates. The list below presents a few relevant problems with the standard stock assessment approach followed by examples ways that MSE deals with these issues (additional issues can be found in Butterworth (2007)).

Problem 1: Judging assessment model utility based on statistical fit is potentially dangerous. The quality of contemporary stock assessments is mainly determined by the statistical fit (or agreement) of a small sample of models (usually only 1 “best model”) to past data. Deliberately seeking a single "best statistical assessment” is not that scientific or precautionary. On the contrary, the scientific method seeks to define multiple working hypotheses and then deliberately attempts to challenge and/or disprove these hypotheses. In a fishery context, the “disproof” is usually statistical, where very implausible models are thrown out or highly down-weighted. For example, Figure 5 shows two stock assessment model formulations fitted to the same data for British Columbia Pacific Herring (Benson et al. 2022). The models are barely distinguishable by eye over most of the historical period, although the more highly parameterized Model A fits the past data slightly better. Note especially how the two models are completely opposite in their assessment of current spawning biomass and the biomass trend. Model A suggests the stock is at the highest abundance ever and rapidly increasing, while Model B suggests the stock is about average size and declining. Choosing the best statistical model (Model A) ignores the potentially serious yet reasonably probable harm of an aggressive catch limit, which would not be precautionary for the stock. Conversely, choosing Model B would imply immediately lower catches, which may not be precautionary for the fishery [using “precautionary” in a general sense here]. So, statistical fit alone fails to provide the information that managers actually need about the future consequences of each decision.

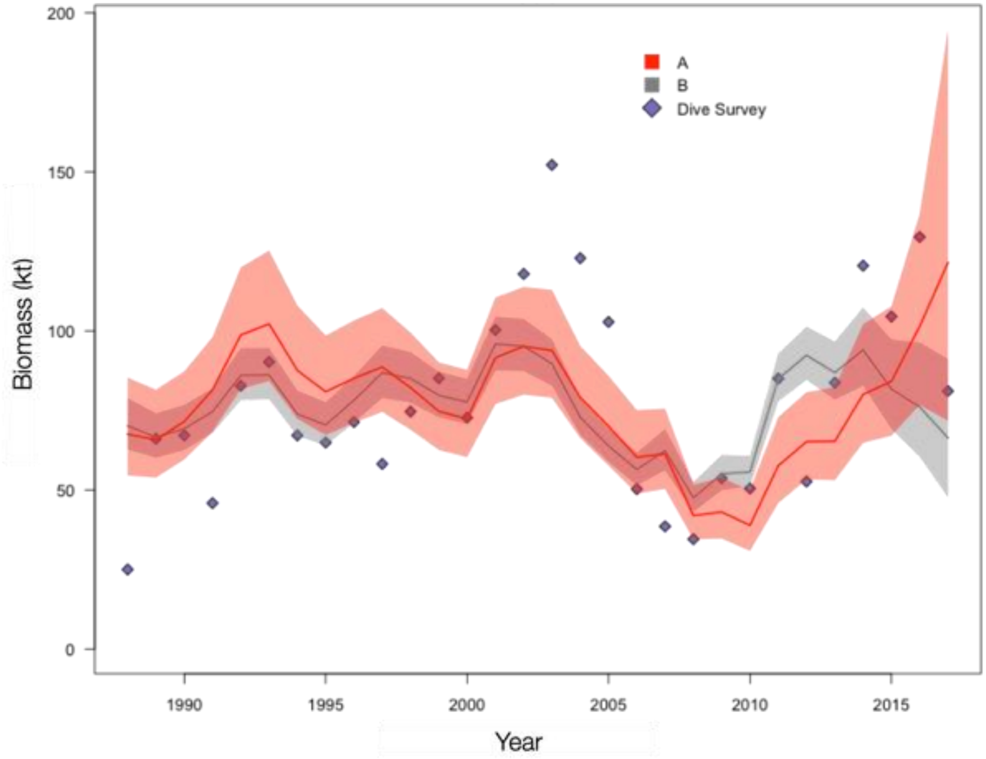

Figure 5 Alternative stock assessment models fitted to the same data for British Columbia Pacific herring. Model A (red) allows natural mortality to vary over time and Model B (grey) assumes it is constant. An MSE approach, as described in the 7-step process, would have clear stock and fishery objectives for the short- and long-term and would consider the consequences of both Model A and Model B being wrong. Then, rather than disproof on statistical grounds, management procedures are eliminated (disproved) on expected future performance (i.e., precautionary grounds).

Problem 2: Highly parameterized assessment models give the false impression that stock dynamics are well-understood and, therefore, are predictable. As noted earlier, stock assessment model complexity is mostly about dealing with bad data, which has the effect of producing very good-looking model fits to past data. However, there is a well-established relationship in statistics showing that over-parameterized models fit past data well at the cost of greater forecast uncertainty (Walters 1986). In other words, modern stock assessment models might be good at describing “what happened” but they are generally poor at predicting “what could happen”. And the latter – dealing with the future – is what really matters to fishery managers and stakeholders.

The MSE process is a forward-looking exercise that requires explicitly stated preferences for the future and scenarios showing how that future might play out under alternative MPs. Some scenarios are simply not quantifiable based on past data. Impacts of climate change on marine ecosystems is one obvious example, but others might include how recovery of marine mammal predators might affect the future of some fisheries.

Problem 3: Stock assessment models are short-term decision tools. Even though a good assessment model might be unbiased on average, you cannot know exactly when, and by how much, they will be biased when you use them in practice. And, since you don't know the bias, you also cannot know the future costs (e.g., in lost yield due to low abundance or fishery closure) of those errors. Again, the MSE process aims to reveal how sequentially linked decisions under an MP may play out over time in the presence of uncertainty and assessment biases.

The above limitations are not intended to discredit stock assessment models. On the contrary, stock assessment models are a critical component of the management strategy for a fishery, for example, when they are converted into operating models. As a core element of the management procedure, stock assessments translate input signals from the data to output management measures. As such, they need to be carefully developed, tested, and reviewed by experts who understand these limitations. But on their own, stock assessments do not meet precautionary standards as defined in FAO (1996 paragraph 35):

"A management plan should not be accepted until it has been shown to perform effectively in terms of its ability to avoid undesirable outcomes…The evaluation should attempt to determine if the management plan is robust to both statistical uncertainty and to incomplete knowledge"

In other words, the precautionary approach emphasizes the need to judge stock assessments within the larger context of a management strategy based on how the management procedure affects fishery performance. The MSE defines the fishery performance criteria and uses the evaluation phase to determine whether proposed MPs meet these criteria under a wide range of noise (statistical uncertainty) and incomplete knowledge (alternative hypotheses for the stock dynamics). This process, which is both scientific and precautionary, offers a more reliable way to ensure high-quality fishery decisions.

1.5.2 Obstacle 2: “MSE is too complicated and takes too long”

MSE represents a deeper level of due diligence in fishery decision-making, so it is not surprising that it generally takes longer than a traditional stock assessment. Unfortunately, MSE processes that remain open-ended for too long often stall because of a loss of momentum, shifting priorities for analytical and/or management expertise, loss of funding, etc. But stalling rarely arises from technical modelling issues. There are, of course, challenges to defining “incomplete knowledge” and the computer simulation models needed to implement realistic future scenarios for data collection, stock assessments, decision-making, stock dynamics, climate, etc. But the time and resources needed to complete these tasks are generally straightforward and predictable.

MSE processes get too complicated and too slow for one main reason – the lack of commitment to a decision perspective from the beginning. In his book, *Adaptive Management of Renewable Resources*, Walters (1986) pointed out how “further research” is too easily used as an excuse to delay difficult choices, especially for large projects with considerable incomplete knowledge. The fact is, we are always making decisions with incomplete knowledge in fisheries, whether we use MSE or not. Unfortunately, the fishery scientists often leading MSE processes are trained to embrace a research perspective that emphasizes uncertainty and the search for new questions and alternative hypotheses. MSEs that take too long typically chase too many issues that come up in meetings along the way instead of applying the hard filters needed to ensure timely progress toward a decision. The decision context step in MSE aims to establish a clear decision perspective from the beginning, noting that opportunities will be available in future cycles for constructing more elaborate operating models or more detailed objectives. In general, larger fisheries with more complex structure and governance (e.g., multi-sector, international RFMOs, transboundary resources), as well as more scientists and managers will take more effort and time compared to a single-sector, single-manager fishery. As indicated in Figure 1, MSE is an iterative process, so there is no reason not to complete one MSE cycle as soon as possible, even with a limited scope, to facilitate the feedback and collective learning needed to adopt the MSE approach as a long-term management paradigm.

1.6 Conclusions

In terms of overall fishery performance, MSE will always produce as good or better long-term outcomes compared to the traditional best-assessment approach. This fact follows from the expected value of including uncertainty (EVIU), which is a fundamental quantity in decision theory (Morgan and Henrion 1990). In a fishery context, EVIU basically says that if the traditional management approach (i.e., vague objectives, best-assessment, ad hoc adjustments, etc.) is, in fact, the correct approach for a fishery, then MSE will just confirm that and return the same outcomes. On the other hand, if there are uncertain and potentially damaging consequences of being wrong, then MSE will reduce those potential losses and return higher expected value (Walters 1998). It is therefore not surprising that examples where the MSE approach has been abandoned because of poor performance are hard to find. In fact, stakeholders appreciate the transparency and stability of decision-making; scientists appreciate the scientific rigour and defensibility; and managers appreciate the procedural approach to risk management and accountability to the precautionary approach.

1.7 References

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