Sixth National Meeting of the
Scientific Coordination Subcommittee
of the Council Coordination Committee

The Use of Management Strategy Evaluation to Inform Management Decisions Made by the Regional Fishery Management Councils

Kona Kai Resort, San Diego, California
January 16-19, 2018
Hosted by the Pacific Fishery Management Council

John DeVore and Jennifer Gilden, editors

U.S. Regional Fishery Management Councils

Front cover: People fishing on the Oceanside Pier in northern San Diego County, March 2019.
Back cover: Boats at Fishermen's Wharf in San Francisco. Both photos: Shutterstock.

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Use of Management Strategy Evaluation to Inform Management Decisions Made by the Regional Fishery Management Councils

A report on the Sixth National Meeting of the Scientific Coordination Subcommittee of the Council Coordination Committee

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"Management strategy evaluation is a systematic approach to fisheries management in a geographically specified area that contributes to the resilience and sustainability of the ecosystem; recognizes the physical, biological, economic, and social interactions among the affected fishery-related components of the ecosystem, including humans; and seeks to optimize benefits among a diverse set of societal goals."

NMFS Ecosystem-Based Fishery Management Roadmap


KONA KAI
MARINA

Kona Kai in January

The Use of Management Strategy Evaluation to Inform Management Decisions Made by the Regional Fishery Management Councils

Introduction/Executive Summary

The Pacific Fishery Management Council was pleased to host the sixth national meeting of the Scientific Coordination Subcommittee, or SCS (formerly known as the national SSC meeting) in January 2018. The SCS is charged with advancing understanding of scientific issues of national importance to inform decisions made by the Regional Fishery Management Councils.

Theme of the Sixth National Meeting of the Scientific Coordination Committee Meeting

The theme of the Sixth National SCS meeting was "the use of management strategy evaluation (MSE) to inform management decisions made by the Regional Fishery Management Councils." An MSE assesses the consequences of management actions by analyzing trade-offs associated with alternative management strategies. MSEs are increasingly used by Councils and in natural resource management settings worldwide. MSEs provide the opportunity for greater stakeholder involvement, fuller characterization of uncertainty in management decision-making, and exploration of social and economic effects of management decisions.

Four invited speakers with expertise in conducting MSEs provided their insights to inform three sub-themes of the meeting:

1. Use of MSEs in evaluating and modifying harvest control rules;
2. Estimating and accommodating uncertainty; and
3. Adjusting harvest control rules in changing environments/non-static maximum sustainable yield.

An open discussion followed the presentations of the invited experts to synthesize findings and recommendations and to answer questions.

Front row: Désirée Tommasi (SWFSC), Éva Plagányi (CSIRO), Huihua Lee (SWFSC), Owen Hamel (NWFSC), Marlowe Sabater (WPFMC)

WHAT IS AN MSE?

Management strategies are combinations of data collection schemes, the specific analyses applied to those data, and the harvest control rules used to determine management actions based on the results of those analyses. MSEs simulate alternative management strategies and evaluate their performance. They are widely considered to be the most appropriate way to evaluate the trade-offs achieved by alternative management strategies and to assess the consequences of uncertainty for achieving management goals.

An MSE is more a process than an analysis, where scientists from diverse fields engage with managers and stakeholders to identify alternative management strategies designed to accomplish a specific objective. While it is important to clarify the objectives and consider the need for a full MSE before initiating the process, management objectives do not need to be fully defined at the outset of an MSE.

MSEs are best viewed as iterative processes where management objectives can be clarified as the process evolves. In some cases, a simpler analytical approach will suffice to accomplish a management objective. An MSE may better inform the trade-offs associated with alternative management strategies when there is a diverse set of stakeholders with differing objectives, or when the predicted outcomes of management strategies are highly uncertain due to a dynamic physical or socioeconomic environment. It is important to understand that MSEs do not generally attempt to identify optimal strategies for accomplishing management objectives; however, they do tend to identify poor management strategies.

STAKEHOLDER ENGAGEMENT AND DIVERSITY OF MSE LEADERSHIP

Stakeholder engagement is critical in an MSE process. Stakeholders can help clarify management objectives and define performance metrics against which simulation results are compared. Stakeholders are diverse, and the type of stakeholders involved depends on the scope and extent of the MSE. It is important to clarify stakeholder roles and responsibilities in an MSE process before it begins. Some will be fully engaged and others will be less engaged, but will still be affected by management decisions. Stakeholders should be aware of the need to be engaged, and should be encouraged to stay involved in the often long and iterative MSE process. Social scientists and economists can help identify and bring less engaged stakeholders into the process, directly or indirectly, by collecting data from or about them.

Scientists may not be best placed to lead an MSE process. It may be more productive to have independent and skilled facilitators lead the process. If appropriate, stakeholders can choose chairpersons and help design the engagement process. How best to run an MSE will vary depending on circumstance.

Analysts conducting an MSE should not be perfectionists and should avoid complex analyses where possible. In many cases economic and social data

André Punt (University of Washington) addresses the SCS are scarce, making quantitative economic and social analyses challenging. Some trade-offs can be effectively characterized qualitatively. Social scientists and economists should be engaged in an MSE process at conception, bringing perspective as well as expertise.

ECOSYSTEM MSES

Ecosystem MSEs are especially challenging. Because the dynamics of ecosystems are complex and poorly understood, predicting the results of any management action in an ecosystem context is very uncertain. There are several types of ecosystem MSEs, including climate-related MSEs, which examine how climate-linked harvest control rules inform management; MSEs focused on spatial management (e.g., addressing behavioral responses to area closures); MSEs that consider multiple objectives (e.g., biophysical, economic, social) using integrated approaches such as the Atlantis ecosystem model; and MSEs that account for predation. There is also what has been termed a "bolt-on" MSE, which is a single-species MSE that calculates ecosystem metrics.

The complexity of ecosystem MSEs makes it important to involve experts in different fields. Multiple operating models, such as Models of Intermediate Complexity for Ecosystem assessments (MICE), empirical models, production models, and age-structured models, are used in ecosystem MSEs. Ecosystem modeling may require extensive data mining from various institutions. It is important to determine the types of information decision-makers need when conducting an ecosystem MSE to avoid overwhelming them with too much detail. One useful approach is to make conservative assumptions in a data-limited situation and attempt to provide support for revising these assumptions through an MSE modeling exercise.

When developing an ecosystem MSE, it is helpful to have diet information for relevant species, as well as data on abundance at lower trophic levels. Well-informed behavioral models are also useful.

COMMUNICATING RESULTS

Effectively communicating the results of an MSE is a particular challenge. Analysts are not always skilled at communicating the science, uncertainty, and risk to stakeholders and decision-makers, and may want to consult others who are better equipped for this task. For example, the International Pacific Halibut Commission consulted with the Psychology Department at the University of Washington to improve their communication of MSE results. Alternatively, others who are good at communication can be tasked with presenting MSE results.

The best practices for communicating science, uncertainty, and risk portray MSE results clearly to stakeholders who may not have the technical expertise to understand model outputs and statistical analyses. Analysts' writing should be edited to make sure it is straightforward and does not contain language that will confuse, or that is too informal or too technical. Frequency or proportional occurrence is more easily interpretable than probability. "One in eight" is more easily interpretable than 12.5 percent. "Fifty year flood" is helpful even if the result is more complex than once every 50 years. Tell a story and have a conversation; describe what we do not know rather than just using "uncertainty." Start simply, then extrapolate.

Simplicity is also better when presenting MSE results using graphs, tables, and pictures. Complex graphs may be appropriate for colleagues and pub-

Will Satterthwaite (SWFSC) and John DeVore (PFMC staff) lications, but they are not as effective for communicating results to stakeholders and decision-makers. The challenge is how to present results for more complex analyses, such as MICE and ecosystem models, in which the optimal fishing rate for one species can depend upon the fishing rate for other species. Consistency in presentation over time and across analyses and species may be limiting, but greatly improves understanding as the audience is able to draw relational contrast in analytical results. Getting advice on presentation, colors, etc. can be helpful in developing more effective graphics.

Different audiences (such as Council members and other stakeholders) require different communication approaches and skills and often have different agendas. An iterative MSE process allows analysts and communication experts to better engage with stakeholders. Listening to their questions and being receptive to their input builds trust and facilitates better communication and understanding.

COMMUNICATING UNCERTAINTY

It is important for scientists and stakeholders to understand how uncertainty should be used in making management decisions. Consider reporting uncertainty first, before reporting the point estimate, as uncertainty intervals in parentheses are often ignored. Eighty percent confidence intervals tend to work best for interpretation; 95 or 99 percent confidence intervals are not nearly as intuitive. Use metrics that are meaningful to stakeholders and Council members when presenting MSE results. Present performance of a management strategy by answering questions such as, "how often/how likely will fishing have to be shut down?" and "how often/how likely will inseason actions/actions between Council meetings be needed?"

Howard Townsend (NMFS OST) and Marcel Reichert (South Carolina Dept. of Natural Resources)

Explain the mechanisms underlying uncertainty. This helps open up dialogue; stakeholders appreciate when scientists admit that they don't know something.

Describe not just scenarios but, to some extent, why they differ. List research that could address some of the mechanisms underlying the uncertainty. Communicate research needs that might resolve critical uncertainties if funding were available to conduct such research.

In conclusion, a well done MSE results in better understanding of the science, the uncertainty associated with the analyses, and the risk involved in making complicated management decisions by those making the decisions and those affected by the action. A successful MSE process results in better stakeholder trust and buy-in in the science informing management decisions. ●

1. Use of Management Strategy Evaluations in Evaluating and Modifying Harvest Control Rules

KEYNOTE PRESENTATION

Experience from a Stakeholder-Engaged MSE Process for Walleye Fishery Management in Lake Erie

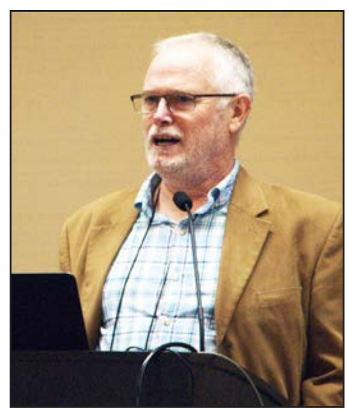
Michael L. Jones

Peter A. Larkin Professor of Quantitative Fisheries, Co-Director
Quantitative Fisheries Center, Michigan State University

Dr. Jones' presentation is available online at http://tinyurl.com/SCS2018jones.

The Laurentian Great Lakes, shared by the United States and Canada, include some of the most valuable recreational and freshwater commercial fisheries in the world. Among the most important of these are the walleye and yellow perch fisheries of Lake Erie. Since a substantial recreational fishery for these species developed in the late 1970s, these fisheries have been negatively affected by conflict among recreational and commercial fishery stakeholders, and between stakeholders and managers. From 2005-2009 this conflict reached peak levels, resulting in legal action by the Ontario Commercial Fisheries Association and a near breach of the consensus management process that has been a hallmark of Great Lakes interjurisdictional fisheries management since the 1980s.

In fall 2010 the Lake Erie Committee, the bi-national management body for these fisheries, established a working group comprising managers, fishery stakeholders, and a team of modeler/facilitators, to develop a transparent process for collaboration on analysis of fishery data and development of harvest policies for both species. The working group is known as the Lake Erie Percid Management Advisory Group (LEPMAG). Prior to this process beginning, harvest control rules (HCRs) for walleye and yellow perch were in place, and had been informed by quantitative analysis of stock assessment data, but the process of developing the HCR was opaque to stakeholder groups. As well, no forum had existed for recreational and commercial stakeholders to have a common conversation about management goals and fishery concerns.



Michael Jones (Michigan State University)

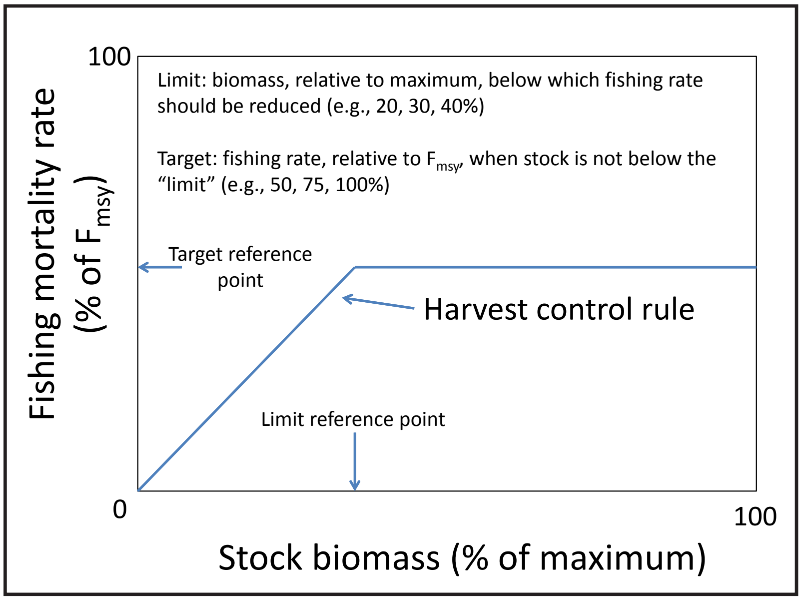


Figure 1. Biomass-based harvest control rule evaluated in the LEPMAG MSE process.

Between 2010 and 2014 the LEPMAG met on twelve occasions, using a Structured Decision Making approach to guide discussions of future policy for the walleye fishery. Early on, the process focused on developing "rules for engagement," resulting in terms of reference that described the (advisory) relationship between LEPMAG and actual decision makers (the Lake Erie Committee), how participation in the group would be determined, how recommendations would be formulated (including the option for minority opinions to be recorded, etc., and on defining a set management objectives and options to guide the analytical phase of the process). Subsequent meetings provided opportunities for the stakeholders to develop an understanding of and provide feedback on the analysis, which included refinements to the existing stock assessment models and development of an MSE simulation model to evaluate alternative HCRs.

Since 1978 the walleye fishery has been assessed using a combination of fishery-dependent (recreational and commercial catch and effort data) and fishery-independent (trawl and gillnet surveys) data sets. From the 1990s these data have been used to inform a statistical catch-at-age model. During the LEPMAG process this model was refined to improve estimation of fishery and survey catchabilities (random walk model) and selectivities (estimating age-specific selectivities as free parameters). To develop the operating model for the MSE, the retrospective assessment results were used to estimate a stock-recruitment relationship (Ricker model), and the analysis indicated a shift in productivity (Ricker alpha) after Lake Erie was invaded by dreissenid mussels. Post-dreissenid productivities were used for the forward simulations.

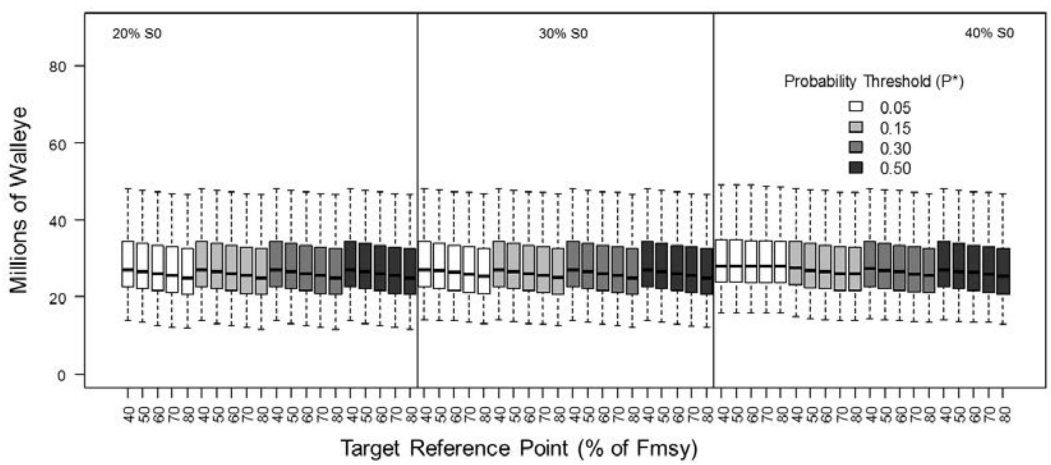


Figure 2. Box plot showing the results of the MSE for mean total abundance. Panels represent different limit reference points (% of unfished spawning stock biomass). Shading of the bars represents different probability thresholds (P). Individual bars with the same shading represent a range of F_{targ} values, as indicated on the x-axis. (Jones et al. 2016)*

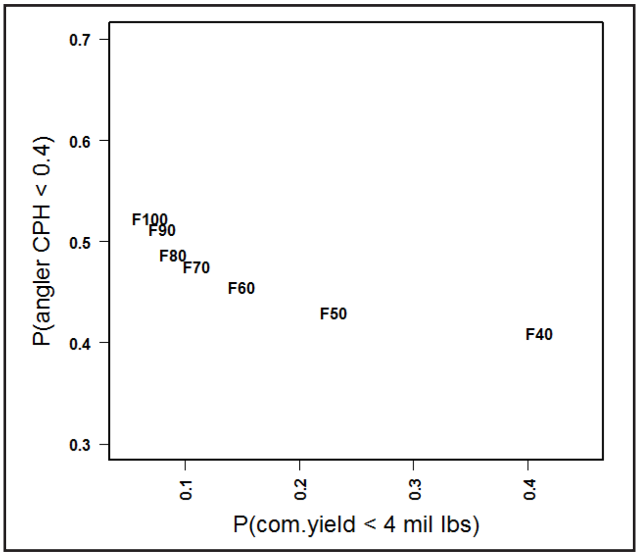


Figure 3. Trade-off analysis of two risk-related performance measures: probability of recreational catch per hour falling below 0.4 (y-axis) and probability of commercial yield falling below four million pounds of walleye (x-axis). Each point represents a different F_{targ} with the number representing the target as a % of F_{MSY}. All HCR results presented here used a P of 0.05 and a limit reference point of 20% B_0. (Jones et al. 2016)*

The MSE focused on comparing the performance of a range of biomass-based HCRs, defined by a target fishing mortality when stock biomass is high and a biomass limit below which fishing mortality rates would be reduced (Figure 1). The HCR accounted for uncertainty in assessed stock status by including a probabilistic component: fishing mortality would be reduced from the target level if the forecasted spawning stock biomass after fishing was estimated to be lower than the limit reference point with a probability greater than P*, where this quantity is a component of the control rule.

The technical complexity of the MSE analysis presented a communication challenge for our engaged process. Many stakeholders found it difficult to interpret the large volume of graphical output we presented of model results, representing the range of possible outcomes for each candidate HCR, quantified in terms of performance measures linked to management objectives (Figure 2). Despite this challenge, stakeholders maintain a strong level of interest in and support for the process, largely because it was seen as a genuine effort to make transparent the analysis that would ultimately inform policy. In the end, a synthetic trade-off plot (Figure 3) provided a key visualization of MSE results that allowed the group to arrive at a consensus on a management recommendation to the Lake Erie Committee. In January 2014 the Lake Erie announced that it would adopt a new HCR based on the LEPMAG recommendation.

We surveyed the LEPMAG at three points during the Structure Decision Making process to evaluate changes in attitude regarding the fisheries and their management. Our experience and the evidence from the survey suggest that the interspersion of analysis and deliberation has been very successful in increasing stakeholder trust and stakeholders' views of the transparency of Lake Erie percid management. Since 2014 the process has continued with the objective of developing a similar HCR recommendation for yellow perch fisheries. ●

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Post-Speaker Discussion

In this case, the full MSE process coupled population dynamics analyses with stakeholder engagement. Estimation uncertainty was portrayed in the estimate of effects in box and whisker plots which characterized the uncertainty. It is important to characterize outcomes in terms of risk.

When asked if there were plans to conduct a follow-up to evaluate the performance of the new harvest policy, Mike Jones said there is a similar MSE underway for other important Lake Erie species. However, it is important to do follow-up evaluations since natural variation is part of the system. In this case, there were two of the strongest walleye recruitments observed. There are plans to conduct more walleye research; further evaluations are planned in the next five years. There is evidence that warmer environments result in poorer walleye recruitment. Evaluation of this hypothesis is planned in the next step.

When asked if multiple models were evaluated in the MSE and how lack of understanding of operating models was handled, Mike Jones acknowledged that more could be done with respect to model structural uncertainty. Bringing stakeholders along in an MSE process requires building trust through patient explanation of model results and the MSE process. ●

Will Satterthwaite (SWFSC)

Matthew Reimer, University of Alaska Anchorage, and Anne Hollowed (AFSC)

Subtheme 1.1

Regional Examples and Lessons Learned

Discussion led by Galen Johnson and Teresa Tsou; John Budrick, rapporteur

The **Caribbean Fishery Management Council** has used the management strategy evaluation (MSE) approach integrated in the DLMToolKit (https://www.datalimitedtoolkit.org/) to evaluate the suitability of various approaches for a range of selected data-limited stocks. This was primarily an exploratory analysis, but the Council is encouraged that these data-limited tools may aid in moving away from catch-only models.

The **Gulf of Mexico Fishery Management Council** uses MSEs for spatial management considerations and to investigate how red tide events affect management decisions, to investigate alternative data-limited models (DLMToolKit), and to investigate spatial management by mapping coral distribution with fishing effort to optimize fishing strategies while protecting corals. The MSE is exploring optimization objectives by evaluating alternative performance measures. In addition, the International Commission for the Conservation of Atlantic Tunas developed MSEs informed by Gulf of Mexico ecosystem modeling.

The **Mid-Atlantic Fishery Management Council** (MAFMC) has made extensive use of MSEs to explore management strategies for summer flounder, to conduct risk assessments, and to develop more effective harvest control rules. An Atlantic mackerel MSE was developed in 2015 that showed the acceptable biological catch (ABC) control rule was no longer valid. As a result, the ABC control rule was changed. The MAFMC uses the DLMToolKit to determine best methods for determining data-limited overfishing limits. They are using MSE to evaluate their current harvest control rules for all stocks.

Gerard DiNardo (NMFS SWFSC), Peter Flournoy (International Law Offices of San Diego), Erin Schnettler (NMFS)

The **New England Fishery Management Council** (NEFMC) has used MSE for management of Atlantic herring and is starting an MSE process for ecosystem-based fishery management of a Georges Bank Ecosystem Production Unit. The NEFMC is exploring when a more time-intensive, rigorous MSE should be done vs. a quicker retrospective evaluation.

The **North Pacific Fishery Management Council** has 10 ongoing MSE projects, including a sablefish MSE to evaluate alternative apportionment strategies for the different management areas, and a Pacific halibut MSE to better utilize allocations as part of the Alaska Climate Integrated Modeling project.

The **Pacific Fishery Management Council** has used MSEs to develop policies on rockfish rebuilding plan revisions, groundfish rebuilding strategies, Pacific hake harvest control rules in the international U.S.-Canada management forum, sablefish (effects of climate change to explore resiliency of current harvest control rules), performance of flatfish harvest control rules, sardine harvest control rules, alternative salmon harvest control rules for Sacramento River winter Chinook, and evaluation of alternative harvest control rules for North Pacific albacore in the international forums where they are managed (the Western and Central Pacific Fisheries Commission and the Inter-American Tropical Tuna Commission).

Don Hansen (PFMC) and Cisco Werner (NMFS)

The **South Atlantic Fishery Management Council** has not yet used MSEs, other than modeling management of king mackerel and red porgy.

The **Western Pacific Fishery Management Council** uses MSE for managing insular fisheries and exploring area strategies for the multispecies bottomfish fishery. The Council has conducted Atlantis modeling for managing bottomfish off Guam and the Hawaiian Islands. They are developing an MSE framework for managing highly migratory species (skipjack and albacore) in the international forums, and to reduce fishery interactions with false killer whales.

The **National Marine Fisheries Service** (NMFS) is developing a national MSE capability through complementary expertise at science centers. NMFS has created an MSE working group and established an MSE scientist at each science center. They have underway or completed 82 MSE projects, with more planned.

Discussion

The discussion focused on how the NMFS Science Center MSE experts will evaluate national technical issues, and when MSE is the best approach for addressing a management challenge. Participants went on to discuss the importance of engaging stakeholders, defining management objectives, developing performance measures, accounting for uncertainty, and communicating with both stakeholders and decision-makers. ●

KEYNOTE PRESENTATION

Realizing the Full Potential of Management Strategy Evaluation

Dan Holland
Senior Scientist, Northwest Fisheries Science Center

Dr. Holland's presentation is available online at https://tinyurl.com/SCS2018Holland.

Management strategy evaluation (MSE) is a general methodology for designing and testing decision rules (heuristics) or broader management strategies that meet objectives of decision makers and stakeholders, and are robust to diverse sources of uncertainty. MSE is a process that integrates science and management.

The steps in the process should ideally include the following:

1. Stakeholders, decision makers and analysts agree on "operational" fishery management objectives and a set of performance metrics to evaluate management strategies and identify uncertainties to which the management strategy should be robust.
2. Analysts develop "operating models" to represent biology, assessment uncertainty, and implementation in closed loop system (feedback loop).
3. Analysts identify candidate decision rules (often testing a large number to find a small set for in-depth consideration).
4. Stakeholders, decision makers and analysts agree on and test decision rule(s) and broader management strategies that determine what actions will be taken, dependent on pre-specified indicators (e.g., survey index or fishery catch per unit effort (CPUE)).
5. Analysts communicate results to stakeholders and decision makers—explain and discuss trade-offs and uncertainty.
6. Stakeholders and decision makers agree on strategy to adopt, when it will be re-evaluated, and what to do when things go wrong.
7. Decision rule is implemented, monitored, and evaluated.
8. Go back to step 1 after agreed period of operation or if problems arise.

Dan Holland (NWFSC)

MSEs can help identify and facilitate effective implementation of management strategies that balance a variety of conflicting stakeholder objectives that stakeholders may find difficult to put explicit weights on. Examples include: higher yields vs. higher CPUE and lower cost; short term gains vs. long-run performance; higher average profit vs. robust (less risky) performance; alternative distributions of benefits among user (and non-user) groups. The goal of an MSE is generally not to identify a harvest control rule (HCR) that optimizes a single objective or objective function. It is often as important to focus on eliminating scenarios with significant probability of very poor performance (or unacceptable outcomes) than to find the best performing rule. Negatively affected stakeholders can often block options that increase overall value, so distributional outcomes can be important to model, and options for compensating losers should sometimes be explored.

MSE can generate stakeholder support for management approaches that can sometimes deliver both higher value to stakeholders and lower risk than traditional harvest control rules. This is a primary benefit of MSE, but one that is not always realized because insufficient attention is given to involving stakeholders in determining objectives and in the design, evaluation, and selection of the management strategy. Many MSEs could also be improved with inclusion of integrated economic models that track economic performance indicators, such as costs and revenues and their variability, along with biological outcomes. Adding economic performance indicators can help clarify trade-offs and better inform decision makers. In addition, few MSEs do a good job of modeling implementation error which can be facilitated by modeling human behavior in response to the economic incentives. Modeling fisher behavior can improve upon simplistic implementation assumptions (e.g., total allowable catches (TACs) will be fully taken) and better clarify risks and benefits of decision rules.

Some examples from South Africa, New Zealand and Australia help to illustrate the potential of MSE to stabilize catches, increase fishery benefits, reduce conflicts, and decrease the cost of fishery management. These case studies illustrate how the MSE approach has been applied and some of its advantages and limitations, and they reveal factors that enable or constrain development and implementation of MSEs.

SOUTH AFRICA

Management procedures (MPs), which are rules for setting harvest levels or other management controls that have been tested with an MSE, have been used in South African hake, anchovy, and sardine fisheries for over 20 years and are used in several other fisheries now (Holland 2010). The MP process creates transparency and confidence in how policy will be applied. Not everyone is happy with outcomes all the time, but the process has endured. The South African Marine Living Resources Act recognizes MPs as the preferred management approach. The planning process for MPs is facilitated by having an identifiable set of quota holders represented by

Owen Hamel (NWFSC), John Budrick (CDFW), and Dan Holland (NWFSC)

industry organizations that have the legally recognized right to make management recommendations and have the resources to participate in the management process. The need for changes to the MP is expected and planned for with agreed schedules for re-evaluation and agreed upon procedures, “meta rules,” to identify and act on exceptional circumstances that indicate the need to deviate from the MP’s recommendations. MPs in South Africa are designed to reduce financial risk by limiting changes in TACs. They have also been used to address conflicts between fisheries (e.g., enabling the anchovy fishery to take advantage of booms in recruitment while limiting bycatch of sardines) (De Moor and Butterworth 2016).

AUSTRALIA

An MSE was used for the multispecies Northern Prawn fishery in Australia to identify an effort control rule to achieve maximum economic yield (Dichmont et al. 2016). A maximum economic yield strategy was identified that leads to higher profits and also lower ecosystem impacts than a maximum sustainable yield strategy. Use of a bioeconomic model as the basis for the HCR has increased transparency into how decisions are made, and the industry has become more involved in providing economic data and validating assumptions. The MSE has provided effort-setting advice since 2008 that has always been followed.

NEW ZEALAND

Management procedures tested with MSEs have been used in New Zealand rock lobster for over 20 years, and all but one New Zealand rock lobster stock are now managed with MPs. MPs have produced both increases and decreases in TACs that were accompanied by very little debate and controversy (Breen et al. 2009). Many MPs are designed explicitly to reduce variability in TACs (e.g., by not allowing changes every year or by creating HCRs where changes in CPUE—and presumably biomass—do not result in TAC changes). An MSE for the NSS Otago and Southland rock lobster fisheries in New Zealand evaluated different rules for setting and adjusting TACs for two quota areas with a probabilistic meta population structure (Holland et al 2005). In addition to rules for setting TACs, the MSE looked at alternatives for separate and joint management and for amalgamation of the two areas and associated quota. The performance metrics included average and minimum TACs levels, but also profit and quota value.

Understanding distributional outcomes was very important for this MSE. Althoug the MSE suggested amalgamation would yield the highest overall value from the fishery, the stakeholders instead opted for separate management, in part because quota holders from one stock saw little gain and potential risk from more catch being taken from their area and voted against amalgamation.

PACIFIC COAST GROUNDFISH

There are a number MSEs that could be useful for the Pacific groundfish trawl fishery. An MSE might evaluate carry-over or multi-year ABCs and quota allocations that could help reduce risk for fishers. An MSE might be used to evaluate risks and benefits of basket quotas (one annual catch limit and quota for a group of related species) and whether/when to manage species individually (e.g., minor slope rockfish, other flatfish). A MSE for the sablefish and Dover sole-thornyheads-sablefish components of the fishery might look at management questions

Doug Butterworth (University of Cape Town)

such as combining north and south areas or combining trawl and fixed gear fisheries. ●

Conclusions

MSE should be considered a process that integrates science and management rather than a modeling exercise to inform managers. Up-front costs of MSE can be high, but can reduce assessment costs in the long run with fewer regular assessments. The process should lead to explicit definition of objectives, and creates a formal (though potentially subjective) process where objective information is used to evaluate trade-offs. All participants in the fishery can become involved in the choice of rule, a long-term view is forced, and buy-in is generated by stakeholder participation and agreement on the final rule. The result is improved fishery governance and legitimacy, reduced management cost, lower risk, and higher overall benefits.

MSE can enable safe implementation of complex rules that address multiple objectives and avoid ad-hoc resolution of conflicts and crises. It can help stabilize harvests across years safely and avoid erratic swings in TAC due to noisy assessments. MSE has often resulted in selection of strategies that trade-off lower catch for stability and lower costs, which may yield higher profitability in the long run. More attention should be paid to the process of MSE, and involving stakeholders at all stages. It is important to have social scientists involved at all stages including developing objectives and performance measures and developing implementation models that account for behavior. ●

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Post-Speaker Discussion

MSE integrates science and management. Explaining trade-offs and uncertainty of analyses to stakeholders can be difficult. Stakeholder engagement can be especially challenging when there is a large number of diverse stakeholders, for example with the recreational sector. The best MSEs have been done on rationalized fisheries with catch shares, since stakeholders are easily identified.

One of the most important aspects of effective communication with stakeholders is listening to them rather than explaining results of analyses. If stakeholders know you are listening to them, they will be more willing to listen to you. It may be unrealistic to fully educate stakeholders on the technical details of analytical models, but trust is built by continual engagement. Transparency is critical. Also, getting stakeholders to agree on management objectives can be a frustrating aspect of the MSE process. Patience is required and is part of building trust.

A well-done MSE inspires confidence in the management system.

Participants discussed how natural environmental variation and fleet behavior (i.e., illegal fishing or poaching) can confound evaluation of management performance, and the fact that economic uncertainty is generally lower than biological uncertainty.

Participants agreed that management strategies should be evaluated after implementation. Performance needs to be monitored and re-evaluated. ●

Subtheme 1.2

Clarifying Objectives, Incorporating Stakeholder Input, and Social/Economic Evaluation

Discussion led by Rishi Sharma and Cameron Speir; Michael Harte, rapporteur

This session focused on how to make management strategy evaluations (MSEs) more efficient and how to best solicit stakeholder input.

Rishi Sharma (NWFSC) and Cameron Speir (SWFSC)

Stakeholders include "traditional" stakeholders as well as managers. They also include consumers, businesses associated with fishing, and cultural and indigenous fishers. These groups often differ in their level of engagement. Different regions may define stakeholders differently. Sometimes it is necessary to broaden the spectrum of participants in order to find success.

Roles and responsibilities need to be quickly identified in an MSE process. The vision for the management system should be solicited early on, with an understanding of which impacts are measureable or can be modeled and which cannot. This builds trust and engagement. Determining specific objectives is an evolutionary process in an MSE.

The International Pacific Halibut Commission (IPHC) MSE process has robust stakeholder engagement. The IPHC formed a stakeholder group with representatives from a wide variety of perspectives. They have learned not to have scientists run the meeting, but to have a facilitator who is not a stakeholder run the process. One participant noted that "independent facilitation is critical for success."

Identifying stakeholders is an art. In some MSEs, known and trusted constituents are first identified and then asked to recommend others. It is important to obtain a commitment from stakeholders to ensure consistent engagement.

Lack of traction in MSE processes can be blamed on scientists who tend to get too far into technical detail and are less effective at communication. There needs to be some independence, with a facilitator asking stakeholders what science was most helpful and listening to stakeholder input.

Operational objectives need to be well-developed, and performance measures need to have quantifiable metrics. A well-done MSE clarifies objectives and communicates trade-offs (see Punt et al. 2016 for background).

Analyses that seek to gain input from recreational stakeholders need to focus on socioeconomics, since those are areas where these stakeholders get the most traction. Recreational value tends to center on "happiness" of anglers. Focusing on maximizing biomass of the catch may not be helpful in conducting a good MSE of fisheries with high involvement of recreational anglers.

Economists may have a better understanding of data needs in an MSE process than biologists. A model of what drives fishermen's behavior is critical, and that requires a lot of data gathered through surveys, etc.

Stakeholder input should also come from people who have left the fishery, possibly to embark on other careers.

Engaging stakeholders who tend not to trust scientists is a major challenge. However, initial negative perspectives often become more positive after the process.

Stakeholders tend to posture and not "put their cards on the table." Engaging in a neutral, informal setting (such as over dinner and drinks) may help build relationships and increase trust.

Create a strong association of biologists, social scientists, and economists early in the process. Their alternative perspectives may be more important than expertise. Industry advisory panels can also help highlight those alternative perspectives.

Some stakeholders who are most affected by a management decision may not be included in the largest sectors, and may have the quietest voices in the process.

The presence of social scientists and economists is critical on Scientific and Statistical Committees, and can help identify the types of information needed for an MSE. Better socioeconomic information may help mitigate impacts or spread impacts more equitably. There is a need for data that can better predict the distribution of impacts.

Finally, be careful in deciding what questions can benefit from an MSE approach. ●

Éva Plagányi (CSIRO), Lisa Kerr (Gulf of Maine Research Institute), and Steve Martell (Sea State, Inc.)

Subtheme 1.3

Role of MSEs in Informing and Advancing Ecosystem-Based Fisheries Management

Discussion led by Galen Johnson and Michael Harte; Cameron Speir, rapporteur

Bringing ecosystem considerations into management strategy evaluation (MSE) represents the "cutting edge of MSE." André Punt proposed four categories of ecosystem-based fishery management (EBFM)-related MSE projects:

1. **Climate-related MSEs**. These have often been desktop exercises that incorporate the impact of climate on various biological parameters, with the goal of determining whether a climate-linked harvest control rule improves performance. One example is the Pacific sardine MSE, which had recruitment as a function of sea surface temperature.

2. **MSEs with a focus in spatial management**, which often relates to behavioral responses to closing areas to fishing (e.g., MSEs evaluating spatial management on the Great Barrier Reef).

3. **MSEs that focus on diverse objectives** (i.e., biophysical, economic, and social), based on operating models such as Atlantis, an ecosystem model that considers all parts of marine ecosystems.

4. **MSEs that account for predation**. Examples include Beth Fulton's work in Southeast Australia; Pacific sardine linked to predator dynamics; South African sardine and anchovy linked to the declining African Antarctic penguin population.

Punt coined the term "bolt-on" EBFM, which means a single-species MSE that adds a sub-model allowing ecosystem metrics to be computed. An alternative is an MSE that uses an integrated ecosystem model; however, this is difficult to do, and there are few examples. The application of non-fishery issues in these types of MSEs can be challenging.

Galen Johnson (Northwest Indian Fisheries Commission)

Stakeholder Involvement

There are two opposing approaches to deciding the amount of stakeholder involvement in an MSE. In the case of an MSE of Chesapeake Bay oysters, a broad set of stakeholders was considered, but analysts chose to frame the problem in terms of fishery management to keep the stakeholder process manageable.

Ecosystem models such as the Atlantis model were developed to support analysis of multi-sector impacts such as the Puget Sound ecosystem assessment. In this case, stakeholder involvement has been both broad and successful.

Communication to Councils

One way to communicate MSEs and EBFM to Councils is to work them into the Council's existing review processes, like the Pacific Council does with ecosystem issues each March. In the future, annual Integrated Ecosystem Assessment reports to the Pacific Council are anticipated to include MSE results. Complex model results can be communicated through simpler video simulations and graphics to portray results.

The North Pacific Council has begun appending multi-species models to single-species assessments. This allows multi-species models that could be used in a fully integrated ecosystem model and MSEs to be reviewed by the Scientific and Statistical Committee (SSC) as they are developed.

Timelines for conducting EBFM MSEs should be communicated to Councils early to set expectations. If the complexity is too great to meet the timeline, simpler modeling approaches can then be considered.

Communication is a challenge whether or not you are portraying MSE results in an EBFM framework. Try winnowing down the detail communicated to the Council. SSCs need more detail than Councils.

Regional Lessons from Developing Ecosystem-Based MSEs

Once a multi-species MSE approach is chosen, expertise from multiple disciplines needs to be included. NMFS hired MSE experts across multiple disciplines in order to have a collective knowledge base. A similar approach was used in the Atlantic herring MSE, with experts in seabird ecology added to the analytical team and stakeholder group. However, securing funding to set up integrated teams to do an ecosystem-based MSE can be a challenge.

Model uncertainty increases dramatically as more species interactions are added to the operating model. The analysis should be kept as simple as possible to achieve the stated objective. It is also important not to promise too much when contemplating an EBFM MSE. Time and effort expands exponentially in such MSEs.

In order to verify simulation results, MSEs should reviewed by an SSC/methodology review panel. Models need to fit the data as a first validation. They need to predict exceptional circumstances that arise.

Finally, consider "Models of Intermediate Complexity for Ecosystem Assessments" (MICE) and their application. MICE have a tactical focus, including use as ecosystem assessment tools. MICE are context- and question-driven, and limit complexity by restricting the focus to those components of the ecosystem that are needed to address the main effects of the management question under consideration.

In the Northeast, simulations are conducted to see if they can predict the scale of catch and other fishery interactions. Such models do not necessarily fit to data quantitatively.

The North Pacific uses an ensemble of simpler models to conduct single-species simulations. Each of these models can undergo SSC review and be integrated later to simulate predator-prey interactions. These simpler models can be tailored to simulate more complex ecological relationships.

Many of the MSEs in the Great Lakes use an ecosystem approach and may be a good example of how to approach such complex analyses.

There are also many examples of well-done analyses in a data-limited system. Flexible approaches may be warranted when data are limited.

Participants discussed recommended data collections and intermediate steps to an ecosystem approach. It isn't obvious which data are important until the approach and challenge are thought out. Some early modeling can help determine what data are key; a multi-front approach is recommended. Further, more data are available to inform fishery interactions than you might expect. Some examples of key data, models and information: abundance of lower trophic levels (e.g., krill, forage fish), diet information, and fishery behavioral data.

Data on abundance of low trophic levels is key. These data are hugely influential in ecosystem models, regardless of model complexity. There is also a need for good diet data to improve ecosystem models. Before attempting ecosystem modeling, think hard about where data can be obtained.

There are intermediate steps between an initial modeling approach for an EBFM analysis and developing an EBFM MSE. Data are necessary, but if informative data are unavailable, one can make conservative assumptions and then provide support later for relaxing them. This approach is illustrated by the Australian experience with integrated ecosystem MSEs, which are data-poor and analyst-rich. EBFM MSEs evolved because Australia didn't have the resources and data to do everything they wanted. MSEs were built without much data and with data of lower quality than one might expect, yet they still proved useful in analyzing ecosystem effects.

Participants discussed whether and to what extent to operate without data. The general strategy in fisheries management has shifted to collect data to estimate absolute abundance rather than investing in long-term surveys to estimate relative abundance.

Participants discussed reference points in the context of MSE and EBFM, and the use of trade-offs and trigger points instead of reference points.

The North Pacific Council's "Global cap on production" in the Bering Sea is an example of an ecosystem-based reference point. It's an overall cap on the amount of groundfish that can be removed, and has been in place for about 30 years. It has served the North Pacific well. The cap is fixed (doesn't change with biomass) and is useful in maintaining system sustainability over time. ●


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Subtheme 1.4

Multi-Year Status Determinations, Assessment Frequency, Setting Acceptable Biological Catches (ABCs) Between or Without Assessments, and Phase-In of ABC Changes

Discussion led by John Budrick and Owen Hamel; Dan Holland, rapporteur

This session began with some examples of the role management strategy evaluation (MSE) can play in multi-year status determinations, assessment frequency, setting acceptable biological catches (ABCs), and phase-in of ABC changes.

Regular assessment of all stocks is not possible, so there is a trade-off between how many stocks are assessed and with which methods, and how often they can be fully assessed or updated. The risks and trade-offs associated with forestalling assessments and alternative methods of setting ABCs between assessments or without assessments can be evaluated using MSE.

FOCUS QUESTIONS

- What uncertainties should be included in setting ABCs based on assessment projections?
- How can survey/fishery data inform ABCs in years between assessments?
- What are trade-offs and benefits of phasing-in ABC changes based upon new assessments?
- What factors should be taken into account in evaluating the minimum assessment frequency both in terms of the life history of the species and the nature of the assessment methods?
- What are the trade-offs associated with allowing multi-year overfishing determinations, and how should that metric be calculated?

The National Standard 1 guidelines allow overfishing status determinations to be based on up to three consecutive years of past data. These multi-year overfishing determinations may allow for more flexibility in management. Trade-offs associated with such multi-year status determinations can also be evaluated through MSE.

Participants discussed the role of MSE in allowing more flexibility in management. MSE has often been used to answer questions such as the effect of varying assessment frequency, phasing in ABC changes, etc. Councils have not always been clear about what they mean by flexibility, and are not always ready to consider the trade-offs that flexibility may require. In some cases, Councils may want to take ad hoc actions when control rules produce unwelcome advice. MSE may be able to enable flexibility (e.g., phased-in changes in ABC), but not ad hoc actions, since the MSE has to explicitly evaluate how the flexibility is used.

There was an extended discussion of the merits and feasibility of using MSE to evaluate the effects associated with constraining the amount by which a total allowable catch (TAC) can be changed each year or the frequency of changes. Such management procedures can result in a more stable management regime at the expense of taking the largest amount of yield available in the short term. There has been general support from industry stakeholders on such management procedures.

Owen Hamel (NWFSC)

Participants discussed whether MSE could be used to create flexibility in setting ABCs for choke stocks taken as bycatch. The mixed stock exception could potentially be applied to enable some level of fishing that would result in a stock being below B_{MSY}, as long as it did not drive the stock below the overfished limit. However, this is not allowed if the choke stock is already overfished, which is generally when the problem arises. MSE can be used to explore the options for adequate protection of an individual stock when it is managed in a stock complex, and can be helpful and for evaluating setting TACs for low information stocks without full assessments. ●

Synthesis Findings for Focus 1

- An MSE is better characterized as a process rather than an analysis.
- MSEs tend to identify poor management strategies. MSEs do not identify optimal strategies.
- MSEs need to analyze the relevant aspects of the management system and account for uncertainty in analyses.
- It is important to clarify objectives and consider the need for a full MSE before starting the process.
- Management objectives do not need to be fully defined at the outset of an MSE. They can be clarified as the MSE process evolves. An MSE is best viewed as an iterative process.
- Clarify stakeholder roles and responsibilities in an MSE process before it begins.
- Stakeholders are diverse, and the type of stakeholders involved depends on the scope and extent of the MSE. Some stakeholders will be fully engaged and others will be less engaged, but still affected by management decisions.
- Social scientists and economists can help identify and bring less engaged stakeholders into an MSE process either directly or indirectly through collecting data about or from them.
- Stakeholders should be aware of the need to be engaged and encouraged to stay engaged in an often long and iterative MSE process.
- Scientists may not be best placed to lead an MSE process. It can be productive to have independent and skilled facilitators lead an MSE process. If appropriate, stakeholders can choose chairs and help design the engagement process. How best to run an MSE process will vary depending on circumstance.
- Analysts conducting an MSE should not be perfectionists and avoid complex analyses where possible.
- In many cases economic and social data are scarce, making quantitative economic and social analyses challenging. Some trade-offs can be effectively characterized qualitatively.
- Social scientists and economists should be engaged in an MSE process at conception, bringing perspective as well as expertise. ●

2. Estimating and Accommodating Uncertainty

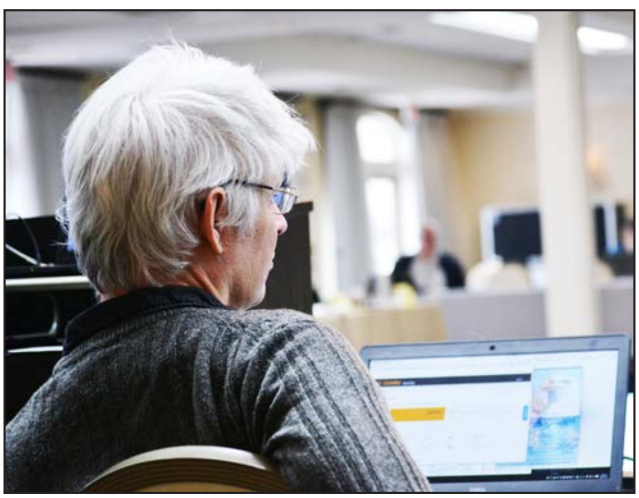
KEYNOTE PRESENTATION

Estimating and Accommodating Uncertainty in MSE: Challenges and Best Practices

André E. Punt

Professor and director, School of Aquatic and Fishery Sciences, University of Washington, Seattle

Dr. Punt's presentation is available online at http://tinyurl.com/SCS2018punt.



André Punt (University of Washington/PFMC)

Management strategy evaluation (MSE) aims to identify management strategies (combinations of data collection schemes, analysis methods and harvest control rules) that are robust to uncertainty. MSE can be used to develop a management strategy for a particular fishery (often referred to as a management procedure), evaluate generic management strategies, and identify management strategies that will not work and should be eliminated from consideration.

MSE involves many steps, one of which is to specify an operating model that represents the system to be managed and generates the data used by the candidate management strategies. Multiple operating models are often used to capture uncertainty. Operating models are parameterized to represent various scenarios, which then form the trials on which simulations are based.

The types of uncertainties represented in operating models can be divided into five categories: (a) process uncertainty, (b) estimation uncertainty, (c) model uncertainty, (d) observation uncertainty, and (e) implementation uncertainty. The aim of an MSE is to focus on the key uncertainties. MSEs often divide the trials into a reference set and a robustness set, with most of the focus being on the reference set, which is used to select a management strategy for actual implementation.

Estimating and Accommodating Uncertainty

It is best practice to (a) consider a range of uncertainties, which is sufficiently broad that new information collected after the management strategy is implemented should reduce rather than increase this range, (b) include trials for each potential source of uncertainty, (c) consider the need for spatial structure, multiple stocks, predator-prey interactions and environmental drivers on system dynamics, and (d) use Bayesian posterior distributions to capture the parameter uncertainty for each trial, if possible.

A few key sources of uncertainty impact the ability of management strategies to achieve their objectives. These include the productivity of the resource, uncertainty in the data available for stock assessments, spatial structure, and non-stationarity in the parameters of the operating model, perhaps due to climate-related factors. Implementation uncertainty, which results in fishers not behaving as expected given the management strategy, can be the largest source of uncertainty in some cases, although this can be hard to model.

Most MSEs account for process uncertainty (e.g., variation in recruitment about an assumed stock-recruitment relationship) and observation uncertainty (i.e., uncertainty regarding stock status).

Factors, whose uncertainty commonly has a large impact on management strategy performance, which should be considered for inclusion in any MSE (Punt et al., 2016: F&F 17:303-334).	
Productivity	Data-related issues
• Form and parameters of the stock-recruitment relationship • Presence of depensation • Extent of variation and correlations in recruitment about the stock-recruitment relationship • Occasional catastrophic mortality or recruitment events	• Coefficients of variation and effective samples sizes of data • Changes in the relationship between catchability and abundance • Changes in survey bias (fishery-independent data) • Survey and sampling frequency • Ageing error • Historical catch inaccuracy (bias)
Non-stationarity	Outcome (Implementation) uncertainty
• Changes in the stock-recruitment relationship • Time-varying natural mortality (potentially a multispecies operating model) • Time-varying carrying capacity (regime-shift; linked to environmental variables or multispecies effects) • Time-varying growth and selectivity	• Decision makers adjust or ignore management advice • Realized catches differ from TACs due to misreporting, black market catches, discards, etc.
Other factors	
• Spatial and stock structure • Technical interactions • Time-varying selectivity, movement and growth • Initial stock size (unless it is estimated reliably when conditioning the operating model)	

Estimating and Accommodating Uncertainty

Model uncertainty is seldom fully represented in MSEs, although identification of alternative operating models can be a substantial exercise, and coding of many alternative operating models can be very time-consuming. This is particularly the case when the MSE includes ecosystem and social objectives.

Nevertheless, MSEs are increasingly including technical interactions due to multiple fleets fishing a single stock, as well as one or more fleets having bycatch of a non-target species. Biological interactions can be included in MSEs, but this can be more complex because multi-species models often have many parameters. This has led to operating models based on MICE (Models of Intermediate Complexity for Ecosystem Assessment), which can be fitted to data, and for which it is possible to conduct many sensitivity tests.

Other substantial challenges to MSE related to the design of the operating models and the selection of trials include an over-focus on estimating uncertainty for a single operating model, parameterizing unlikely but plausible operating models, and how to weight alternative operating models when presenting outcomes to decision makers. ●

Entrance to the Kona Kai Resort

Subtheme 2.1

Model Selection and Multi-Model Inference

Discussion led by Aaron Berger and John Budrick; John Field, rapporteur

Model selection and multi-model inference were discussed in terms of management strategy evaluations (MSEs) and non-MSE processes. There are many tools for model selection; for multi-model inference, Ianelli's background treatise (Ianelli et al. 2016) recommends several methods.

Akaike Information Criterion (AIC) weighting and other model fitting weighting schemes are generally not recommended for MSEs since they are used for balancing model fit and parsimony. However, over-parameterized models can be useful in an MSE since they enable an evaluation of a broader set of uncertainties.

Ensemble model averaging may capture more variation. However, this is complicated when some models are not independent and some are. Decision tables may be useful since the uncertainty in model selection is better understood.

It is important to differentiate stock assessment models and MSE models. Implications of model selection in stock assessments are well understood, but MSE models are different and should be selected differently. Qualitative weights of ensemble models in an MSE are a better way to go, as is hypothesis selection rated by plausibility. Model selection in ensemble modeling is one of the most difficult aspects in using multiple models.

The International Pacific Halibut Commission has been conducting ensemble modeling for six years, generally using nested models and information theoretic approaches.

AIC can be problematic since it depends on data weighting. Sensitivity analyses are often used to select independent models. The decision table risk assessment in model selection is only useful when one is selecting a point estimate. Integrating models in a Bayesian approach is a better approach to weight independent models using posterior probabilities.

FOCUS QUESTIONS

- Assigning model weights can be difficult and arbitrary. Are there recommended methods for weighting plausible operating models?
- Does data quality influence model selection?

An objective approach for weighting ensemble models to avoid renegotiation of model weighting/selection is recommended.

It is also possible to weight models based on parameter estimation distributions (when estimated), and assign less weight to fixed or profiled parameters. It may be more useful to select major axes of uncertainty and use the statistical results of estimation of those parameters to weight ensemble models. A trade-off of risks associated with performance measures can be used when weighting models. Model averaging using this approach has been shown to be more robust.

There has been some use of averaging ensemble models from the DLMToolKit in the mid-Atlantic. The struggle is determining the axes of uncertainty.

Model averaging has less context within an MSE as opposed to model selection, which is best handled with a risk assessment of multiple models. However, there is always some model averaging in an MSE, since one needs to integrate alternative model uncertainties. For instance, different assessments may handle steepness in different ways. Therefore, the uncertainty is characterized differently in each of these models, and affects the risk analysis used to assess the robustness of ensemble models to the performance measures in an MSE.

Some of the most interesting ensemble model selection processes in an MSE used models that could not be averaged but that were fundamentally different. When you can't differentiate between hypotheses, the useful approach is to judge performance across each operating model, positing different hypotheses to determine robustness of the MSE given uncertainty of key results.

MSEs have value in providing feedback, given new data, or when modeling new hypotheses. A better debate is at what level MSE results will offer practical advice. In moving from the technical group building the operating models, to the scientific review groups, to stakeholders and decision-makers, enormous simplification is required. One cannot overwhelm decisionmakers with technical details.

Participants discussed how to use a grid of outputs from multiple operating models to summarize the results across multiple axes of uncertainty. One step is to ensure these models capture the range of pertinent uncertainties. Another aspect is triage of management strategies. One needs enough to understand a range of strategies to model trade-offs given uncertainty in outcomes or states of nature, but not so many that they contribute to information pollution.

There are three levels of models: empirical, production, and age-structured models. The problem with using only production models in operating models is that the estimation of uncertainty of a key parameter be wide enough. In these cases, there needs to be an expansion of operating models to better characterize key uncertainties. ●

Farron Wallace (AFSC)

Subtheme 2.2

Quantitative and Qualitative Risk Assessment Methods for Evaluating Uncertainty in Overfishing Limits, Stock Biomass, and F

Discussion led by John Field and Owen Hamel; Dan Holland, rapporteur Aaron Berger

This discussion began with an example management strategy evaluation (MSE) conducted for the Pacific Council on rockfish rebuilding guidelines/plans. This MSE looked at the trade-off between volatility in alternative rebuilding trajectories and stability in management and management advice, and found that there were more volatile catches when assessments changed a lot from cycle to cycle, and poor performance when the assessment didn't change at all. The sweet spot was somewhere in between.

Owen Hamel (NWFSC) and John Field (SWFSC)

Use of MSEs to Inform Council Decisions

The **Mid-Atlantic Council** evaluated acceptable biological catch (ABC) control rules using MSE, with different operating models across life history types and assessment errors, to elicit how risk and uncertainty informs the performance of alternative rules. They found that the current rule was performing well, and identified some specific control rules for data-poor species that should not be used. Performance metrics that described both short-term and long-term metrics showed that in general, long-term performance was fairly stable across candidate rules, but there were important short-term differences. Hockey-stick ramp-type harvest control rules showed good performance. The Council didn't have a full understanding of risk level decisions and how those decisions affect policy evaluations, so this was a good learning experience. These analyses informed Council decisions about selecting P* and the trade-offs associated with that decision. The Scientific and Statistical Committee (SSC) also benefited from going through the MSE processes.

The **North Pacific Council** has been and is currently conducting extensive analysis of the P* approach for crab stocks. These stocks are managed by the state of Alaska, but the Council sets the overfishing limits (OFLs). The Council process currently applies a tier system, so species with less information have a larger acceptable biological catch (ABC) buffer.

The **South Atlantic Council** is currently considering changing P* rules, but not a formal MSE, to address rebuilding and changes in national standards. Preliminary evaluations showed the ABC control rules may need to be changed. There were concerns about using outdated or lower quality indices in control rules, and about having risk metrics as part of the ABC control rule, since risk is a Council decision and should be outside of the explicit control rule procedure. Trade-offs can change seasonally and spatially, so spatio-temporal performance metrics and management options (seasonal quotas or spatial management) may need to be considered for certain fisheries.

The **Gulf Council** is currently reviewing and revising ABC control rules and buffers, but has not conducted a formal MSE. Analyses are being done to address concerns that the current range of P* (0.3 to 0.5) for data-rich stocks is not flexible enough, given changes in stock status, and that control rules for data-poor stocks that use mean catch over a period of time need revising.

In **New England**, an Atlantic herring MSE is underway, but the SSC has not yet been involved other than conducting initial reviews. The MSE process went through a suite of candidate control rules and was able to reduce the large set of candidate control rules to a workable set.

Probability Distributions and Risk

Outcomes using probabilities are perhaps better than relying on point estimates for communication and for capturing risk. However, careful consideration of uncertainty is critical as it relates to risk. Probability statements should be put in context, because specified probability distributions are a function of the models evaluated. Median values will be more robust than absolute values. Probabilistic control rules that adequately meet objectives can only work if there is a good estimate of the OFL, which is uncertain itself because it uses the limited fishing mortality rate and uncertain biomass estimates.

Buffers

Most fishery management plans use a fixed buffer approach to lessen the probability of overfishing. One common question posed is related to the trade-off between survey quality/quantity and the translation to alternative buffer specifications. Can the buffer be reduced with better or more frequent surveys? There is active research on survey and age data quality/quantity going on in the North Pacific and Pacific regions.

Conclusions

MSE is a good way to demonstrate risk trade-offs to industry/stakeholders. In general, MSE works well for multi-objective comparisons, such as risk of overfishing and stakeholder risk profiles. ●

Subtheme 2.3

SSC Communication of Uncertainty and Risk Management in Management Decision-Making

Discussion led by Galen Johnson and Michael Harte; Owen Hamel, rapporteur

The South Atlantic Scientific and Statistical Committee (SSC) has established standard practices for reporting uncertainties associated with acceptable biological catches (ABCs) to the Council. In general, reports are focused on the information the Council needs, rather than detailed treatment of uncertainty.

The International Pacific Halibut Commission (IPHC) has also invested a lot of time on how to communicate uncertainty. Communicating weather and medical decision-making elements are way ahead of fisheries in this regard. The IPHC consulted with the Psychology Department at the University of Washington, which recommended simplifying the graphics and reports. Uncertainty does not tend to gain traction until it gets to about twenty percent; one percent differences are ignored. The University also recommended communicating uncertainty up front and giving it as much importance as point estimates used in management. The IPHC hired a professional writer to communicate assessment results.

Analysts are not the best ones to communicate results to decision-makers; seek people with good communication skills to give the message.

The South Atlantic Council uses a communication template that decision-makers are familiar with. The New England Council, in collaboration with the Atlantic States Marine Fisheries Commission, has used a decision tree matrix to provide MSE results.

Michael Harte (Oregon State University) and Galen Johnson (Northwest Indian Fisheries Commission)

The Mid-Atlantic Council communicates uncertainty by providing coefficients of variation (CVs) for estimating overfishing limits (OFLs) that go beyond the CV in an assessment. They are working on developing a checklist used to assign a CV to an OFL as a communication device for decision makers. They also state how long an ABC should be specified. When the CV is large or when natural variation in the stock is large, they only recommend a one-year ABC. A standardized approach for communicating advice on specifications and uncertainty is recommended.

The Gulf Council's SSC also recommends consistency in communication to the Council. Think broadly about the audience you are communicating to and design your communication accordingly.

FOCUS QUESTIONS

- What means of communicating uncertainty are best for you (as an SSC in evaluating an MSE)?
- What means of communicating uncertainty and risk are best for stakeholders and to decision-makers?
- What tools have you used to communicate uncertainty and risk that have been particularly effective?
- What unsolved challenges have you had in communicating uncertainty and risk?

Often, the New England Council receives assessment results with point estimates and narrow CVs. The SSC tends to increase the CV on OFL estimates, which can cause angst from assessment scientists who may take that as criticism of the assessment.

It is important to communicate risk and uncertainty in terms of probabilistic outcomes. What is the likelihood of fishery closures? What is the likelihood of inseason action to stay within a harvest limit? Those types of communication are most effective for stakeholders and decision-makers.

It is also important to communicate what is not known. Develop trust with Council staff, Council members, and stakeholders in order to communicate effectively. Scientists need to spend time talking with stakeholders and decision-makers and listening as much as reporting science.

Iterative communication is important. National Marine Fisheries Service adapted its communication approach from the National Weather Service.

Report what is meaningful to stakeholders and decision-makers; tell a story about what the risk entails rather than simply reporting statistics. For example, report outcomes rather than percentage of risk (e.g., bad outcome in 1 in 50 years rather than a 2 percent risk). Simply saying there is uncertainty is not sufficient; one needs to communicate what is not known, and recommend strategies for reducing that uncertainty through research activities, etc.

Communicating uncertainty also depends on the type of analysis results being reported and the audience. The Mid-Atlantic SSC attempts to build these communications into the analysis. Admitting uncertainty is not an admission of failure, but builds trust.

An interactive web site that allow stakeholders to see how changes in CVs affect management advice on harvest control rules (HCRs) is a useful tool. Although the IPHC found this tool too labor-intensive, it could be handed off to someone else. It does help stakeholders to visually see how changes in uncertainty affect changes to HCRs. Cornell University has invested in similar interactive tools, which are labor-intensive but helpful in communicating science.

Communication is more about why decisions are being made than simply about providing analytical results. It is important to consult with good storytellers and experts in communication methods.

Communicating why there is an evolution from single-species assessment models to multi-species models is also important. ●

Synthesis Findings for Subtheme 2

- There are several types of ecosystem MSEs, including climate-related MSEs (how do climate-linked HCRs inform management?), MSEs focused on spatial management (addressing behavioral responses to area closures), MSEs that consider multiple objectives (biophysical, economic, social) using integrated approaches such as Atlantis, MSEs that account for predation, and bolt-on (i.e., a single species MSE that incorporates ecosystem metrics) vs. integrated ecosystem MSEs.

- MSEs have been incorporated into Integrated Ecosystem Assessments (e.g., Bering Sea, California Current).
- Multiple models have been used in MSEs examining wave energy and effects on different sectors and resources (e.g., Atlantic herring).
- It is important to bring experts in different fields into an ecosystem MSE.
- Multiple operating models, such as MICE, empirical models, production models, age-structured models, etc. are used in ecosystem MSEs.
- Determine the types of information decision-makers need to avoid overwhelming them with too much detail.
- One useful approach is to make conservative assumptions in a data-limited situation and attempt to provide support for relaxing these assumptions through an MSE modeling exercise.
- If possible, include diet information and data on abundance at lower trophic levels when developing an ecosystem MSE.
- Strive for well-informed behavioral models.
- Ecosystem modeling may require extensive data mining from different institutions.
- MSEs are useful in analyzing trade-offs of alternative management reference points to enable decision-makers to decide what are important performance measures.
- One example of an ecosystem approach is the 2 million mt harvest cap in the Bering Sea. This policy creates fishing constraints and management trade-offs. ●

The Yokohama Friendship Bell by Masahiko Katori, near the Kona Kai Hotel, connects the two port cities of Yokohama, Japan, and San Diego.

3. Adjusting Harvest Control Rules in Changing Environments/Non-Static Maximum Sustainable Yield

KEYNOTE PRESENTATION

Adjusting Harvest Control Rules in Changing Environments/Non-Static Maximum Sustainable Yield

Éva Plagányi
Principle Research Scientist, CSIRO Oceans & Atmosphere, Queensland BioSciences Precinct, Brisbane, Australia

Dr. Plagányi's PowerPoint presentation is available at http://tinyurl.com/plaganyi.

Management Strategy Evaluation (MSE) involves evaluating and modifying harvest control rules (HCRs) to adjust management responses in such a way as to meet pre-specified objectives (which may include ecological, economic, social and/or broader ecosystem objectives). This is particularly challenging when considering changing environments and hence changing maximum sustainable yield (MSY) in marine systems. In this talk I provide a number of examples of approaches that have been used to design and implement MSEs to deal with these challenges, under the following categories: (a) highly variable stocks—examples from forage fisheries, the Torres Strait tropical rock lobster fishery, prawn, and bêche de mer fisheries; (b) impacts and approaches for dealing with changing climate; and (c) ecosystem and socio-economic interactions altering sustainable yield reference levels.

The dynamics of highly variable stocks are often driven strongly by environmental influences, driving fluctuations in recruitment (e.g., inter-annual variations due to changing ocean circulation and conditions), stock survival, growth and productivity (which lead to changes in the carrying capacity that in turn influence MSY), or both. However, there are very few examples of stocks where the underlying causative mechanisms are sufficiently well understood to enable reliable prediction of short- to medium-term population fluctuations, and hence associated recommended catch controls. Fisheries-independent

Éva Plagányi (CSIRO)

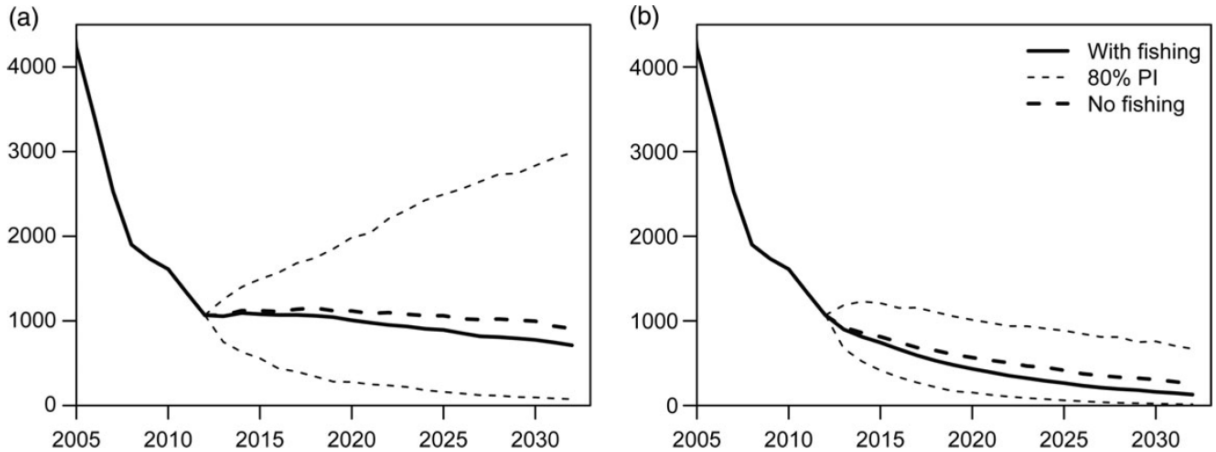


Fig. 1. Example of the use of MSE to simulation test the projected impact of the South African sardine fishery under interim OMP-13 on a declining penguin colony (median projected penguin numbers shown with 80% probability intervals), compared with a no-fishing control scenario and under two alternative plausible future sardine spatial distribution scenarios. The approach highlights that the additional mortality due to fishing is small compared with the role of the changing environment impacting the penguins. Source: (Robinson et al. 2015)

recruitment surveys conducted prior to the fishing season for such highly variable stocks can provide reliable estimates of the strength of a recruiting year class. If these data are input to a stock assessment model to inform on the setting of a catch limit or other control measures, there can be an unacceptably long delay in providing management advice given the time needed to update and review an assessment. This is particularly problematic because the most reliable pre-season survey information is often obtained as close to the start of the fishing season as possible. An alternative approach is to use pre-tested HCRs that use the survey information directly as an input, such that management advice can be obtained rapidly and in a transparent fashion. An example is provided of an empirical harvest control rule that uses survey inputs together with other data as part of a balanced portfolio that accounts for short-term inter-annual variability as well as medium-term trends. To fully capitalize on boom fishery years that cannot readily be predicted in advance, highly adaptive approaches such as the operational management procedure (OMP) for the South African sardine and anchovy utilize in-season adjustments based on mid-season survey information. In this case increases in the total allowable catch can be rapidly implemented mid-season, whereas decreases are capped (de Moor et al. 2011).

These empirical approaches typically require extensive stakeholder engagement to ensure buy-in to the approach, as well as to ensure that the final choice of HCR satisfies all of the major stakeholder objectives for the fishery. Moreover, the HCR needs to be tested to ensure it is robust to a range of uncertainties, and stakeholders can also inform choice of a range of robustness tests that should be conducted before a rule is adopted. Examples are provided of use of reference sets of alternative operating models to bound uncertainty, including to changing environmental drivers, as well as inclusion of implementation uncertainty. For many of these stocks, the carrying capacity, B_0, may not be static, and hence it is preferable to use a dynamic B_0 approach to evaluate the performance of alternative candidate HCRs, as well as in setting targets (target reference point) for which management should aim. For example, the performance of HCRs is often evaluated relative to the comparable no-fishing biomass level or distribution (Fig. 1) at the end of the projection period (us-

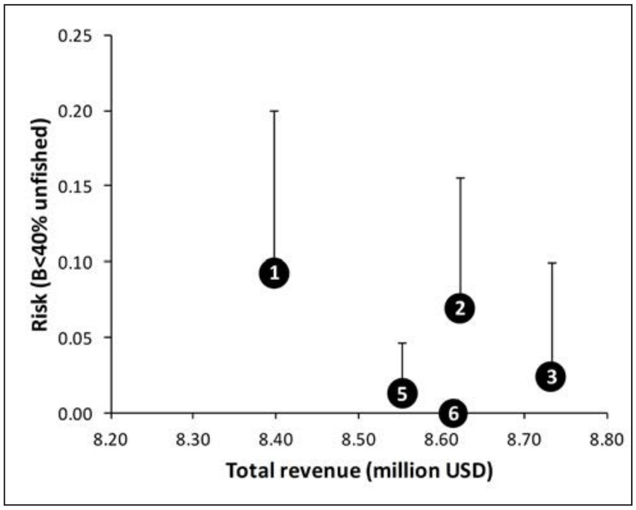


Fig. 2. Trade-off relationship obtained from a MSE applied to a multispecies bêche de mer fishery, showing median risk performance (defined as probability of biomass being reduced below 40% of the comparable no-fishing scenario) (+ 1 standard deviation encompassing variation across nine species) and total revenue (million USD) for Rotational Zone Strategies with different cycle times (year) as indicated on the symbols. MSE testing permitted distinguishing between alternative harvest strategy options even given uncertainty in the biology and non-static MSY (Source: (Plagányi et al. 2015)

ing the same random number sequence), or relative to a dynamic B_0 that accounts for regime shifts or other climate change that is known to be occurring. On the other hand, straightforward implementation of limit reference points can also be problematic for highly variable stocks which may naturally fluctuate to low levels periodically without the need to trigger the same level of precaution as for more stable stocks. An example is provided of a set of HCRs whereby a warning system triggers actions, but not immediate closure unless the decline persists into the second year.

Given the challenges of reliably establishing environmental correlations, the Pacific sardine fishery is one of the few fisheries to explicitly include an environmental correlate in a control rule. It is generally considered more pragmatic than simply using a stock assessment model with an environmental correlate, to include potential environmental variables in HCRs and/or pre-test the robustness of candidate HCRs to potential future variability and non-static system dynamics. An example is provided of a prawn harvest strategy currently being reviewed to account for predicted system responses under

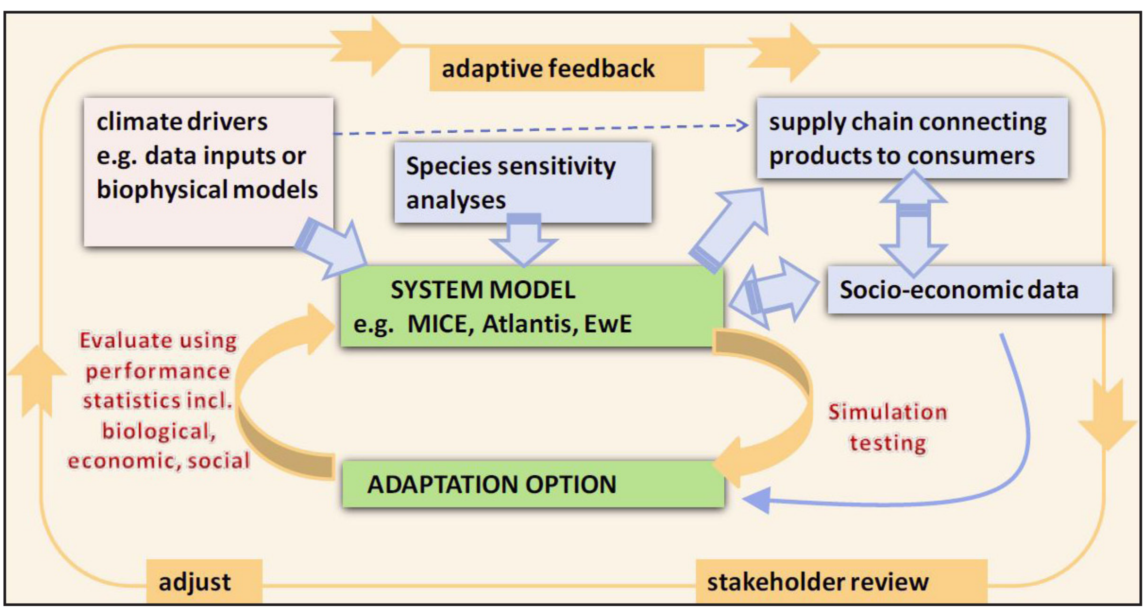


Fig. 3. Schematic framework showing how complexity (such as climate drivers, multispecies trophic interactions and socio-economic drivers), can be added to an operating model used to test and compare the performance of alternative harvest control rules and adaptation options for a fishery under non-static conditions. Source: (Plagányi 2016)

extreme negative environmental scenarios. HCRs can include environmental, economic and ecosystem considerations. Importantly, performance depends on life history characteristics—for example, the frequency of changes in recruitment patterns of different forage species yields different results (Siple et al. 2019). MSE can be used to understand and visualize trade-offs across a broad range of scenarios.

For stocks with unknown or non-static maximum sustainable yield, MSE can also be used to simulation test approaches that reduce risk whilst optimizing economic gains, even given considerable uncertainty around stock status (Fig. 2). For example, MSE testing showed a Rotational Zone Strategy applied to sea cucumbers in a multispecies fishery on Australia's Great Barrier Reef significantly reduces the risk of overall and localized species depletion in the fishery. MSE testing has provided examples showing it is possible to distinguish between the performances of alternative strategies even when there is considerable uncertainty in population dynamics.

Changing environments amplify the uncertainties in prediction and hence more conservative rules may be needed to achieve the same overall risk performance compared with a less uncertain scenario. The risk-cost-catch frontier refers to the trade-offs between managing a fishery in a biologically and economically optimal way whilst minimizing management costs. MSE testing is being used in several examples to inform establishment of tier systems that achieve risk equivalency by reducing quota if there are few data or increasing it if there are more data or monitoring.

Under a changing climate, there is a need to pretest harvest strategies to ensure they are climate-smart: robust and sufficiently adaptable to respond adequately and appropriately to future predicted environmental changes and shocks that may impact the system. They also need to account for multiple objectives and complexities, such as sustainable catches whilst ensuring maintenance of system resilience. An example is provided of using a reference set that integrates across both biological uncertainty and uncertainty regarding potential climate change influences. Spatial management approaches based on adaptive feedback performed best overall in the example presented.

MSE testing that included broader socio-cultural considerations showed that it is possible to use both qualitative and quantitative social information, and that trade-offs between social and economic considerations can be complex. Moreover drivers for fishing can be non-static also, and MSE can be used to evaluate sensitivity of results to changing drivers of participation and economic value of a fishery (Fig. 3). Brief mention is made of ongoing work to incorporate dynamic feedbacks in social-ecological models that take into account hard-to-quantify aspects such as the combination of characteristics or activities that make a place or activity special—Sense of Place Index. A stretch objective is to account in MSE testing for the sometimes influential role of non-static social and psychological drivers of changes in participation in a fishery, in turn influencing fishing effort.

In summary, some of the approaches used under (a) highly variable stocks include designing highly adaptive empirical HCRs, allowing within-season adjustments, simulation testing the robustness of HCRs across a broad range of plausible scenarios to bound the uncertainty, simulation testing less conventional management strategies such as spatial rotation strategies, using tiered approaches, and aligning choice of HCRs with life history and recruitment characteristics. A range of strategies are being used as part of (b) dealing with climate change, principally to road-test climate-smart adaptation options and some examples are presented. Finally, less work has been conducted to inform (c) ecosystem and socio-economic interactions, but HCRs should ideally take into account broader ecosystem targets and changes, as well as changes due to socio-cultural drivers, and this aspect is briefly discussed. ●

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San Diego harbor beach near the Kona Kai

Subtheme 3.1

Modifying Harvest Control Rules and Maximum Sustainable Yield to Adapt to Regime Shifts and Long-Term Drift in Stock Productivity

Discussion led by Cameron Speir and Rishi Sharma; Aaron Berger, rapporteur

This discussion focused on factors that influence productivity, including spatio-temporal variation in recruitment, growth, natural mortality, maturity, and on the various factors influencing environmental change (e.g., climate variability and directional change, biophysical relationships, and biochemical relationships).

Stationarity in population dynamic parameters and a global maximum sustainable yield (MSY) is usually the default assumption in many stock assessments, despite the growing appreciation of the spatio-temporal complexities for many stocks. Non-stationarity within dynamic models has historically led to very large retrospective problems. Real-world examples of detecting non-stationarity are rare.

Szuwalski and Punt (2016) suggested that unless there is a very good mechanistic relationship to the productivity dynamics in the system, incorrect assumptions about productivity changes can lead to poorly performing management procedures. The relationship between recruitment and the environment needs to explain roughly 50 percent or more of the total variation in recruitment before management procedures start showing benefits in terms of the summary performance statistics for risk and average catch (De Oliveira and Butterworth 1995).

Management strategy evaluations (MSEs) can be used to evaluate climate variability; the harvest control rule feedback process allows for management to adjust for changes in conditions. However, the feedback process can be slow and/or occur with only partial success in certain situations (e.g., short-lived species). Directional climate change is a different problem, because future climate/productivity relationships are much harder to predict. The best one can do is to evaluate the realm (analytical space) of possibilities using best available information and use the extremes to bound predicted management performance. This often (though not always) ends with more conservative options being selected that are robust to the uncertainty. Ultimately, scenarios that bound the distribution of realistic possibilities should be used in simulation-based operating models.

Scott Crosson (SEFSC), Cameron Speir (SWFSC)

Rick Methot (NMFS), Toby Garfield (SWFSC)

Changes in productivity can be dealt with by changing one or more management procedures. For example in New England, changes in cod productivity led to changes in the population dynamics model, not the harvest control rules, although both could be considered. The changes in productivity were characterized by the inclusion of time-varying natural mortality, which helped with the retrospective pattern problem, but it remained difficult to specify how natural mortality would continue to change through the projection time period. When adjusting harvest control rules based on environmental conditions, the assessment model needs to be correctly specified because biological processes such as natural mortality, recruitment, and growth impact reference points and resulting relationships are often nonlinear.

There are two main ways to incorporate changing productivity: first, be honest about climate change, bound the plausible range and try to adjust accordingly, and second, use some form of dynamic reference point (e.g., dynamic B_0) to explicitly evaluate the additional contribution to mortality from fishing. Economics can often provide a more natural way to evaluate how hard to fish the stock under different productivity regimes.

One critical question to understanding recruitment-driven productivity changes is the limits of compensation (e.g., the cod stock-recruitment relationship). Does the population have some ability to compensate beyond the additional pressure put on it? MSEs have been used to evaluate management procedures that are likely to be robust to climate change, but they often need to take different approaches than, for example, the use of more traditional harvest control rules that aim to rebuild back to some rigid number.

Research is needed to better understand how to make changes that reflect prevailing environmental variation and how to adjust reference points to adequately respond to these changes. An MSE on North Sea cod suggested that it depended on what variables climate change was acting upon, and whether alternative reference points were robust to different climate regimes.

Work by the International Pacific Halibut Commission has identified a harvest policy that is robust to two alternative recruitment regimes, but overall there are limited examples to date where harvest policies that are robust to environmental change have been identified or where broader ecosystem perspectives have been incorporated into reference points. Harvest control rules that used on/off switches (e.g., snow crab in Alaska) have been difficult for fishers and onshore processors. New rules are being evaluated for snow crab.

Biomass-based reference points can be cumbersome under regime shifts, so in those cases reference points that are primarily fishing mortality-based may work better. Nonetheless, there are biomass-based equivalents to harvest-based reference points, so the difficulty of identifying biomass limits and targets under new regimes remains. For North Atlantic bluefin tuna, a debate over the possibility of a regime shift led to changes in target reference points as a result of productivity change, where a F_{10}% policy was used as the basis for the total allowable catch.

Ideally, an MSE could be used to better understand how best to identify both fishing mortality and biomass-based reference points that reflect new regimes. There is flexibility within the National Standard guidelines to adjust biological reference points. The underlying conundrum with changing biological reference points (e.g., such as that with X% dynamic SB0) is if the stock can sustain the same level of harvest at a lower productivity regime as with a higher productivity regime.

One potential issue when changing assessment models to account for changes in productivity is that different assumptions within assessments (e.g., related to growth and natural mortality patterns) can have different implied reference points (based on model assumptions) that can be different or disconnected from those used for management. Spatial aspects of population dynamics (in addition to temporal aspects) can also have influence on productivity parameters, which if incorrect, can mask or create presumed productivity changes. Social and economic indicators can be useful indicators in addition to traditional reference points.

An outstanding question is how best to incorporate ecosystem models to evaluate and test operating model conditioning/performance. In the Bering Sea, multi-species models that incorporate bioenergetics that affect the biology of fish (such as time-varying growth) or predator-prey interactions are being explored as candidate operating models, but changes in productivity from recruitment are still difficult to assess.

The MSE process is beneficial in a management sense to improve decision-making, but it is also useful to identify where future research should be conducted. ●

San Diego sailboats

Subtheme 3.2

Incorporating Short-Term Perturbations in Stock Productivity into Harvest Control Rules and Rebuilding Plans

Discussion led by Aaron Berger and John Field; Galen Johnson, rapporteur

This section began with a discussion of tuna, salmon, and squid management, since these species exhibit high turn-over.

In the South Atlantic region, shrimp is an annual crop managed on the basis of a temperature trigger.

In the mid-Atlantic region, catch limits for squid are set for the long term. There are few conservation concerns, but there are management concerns.

In the Pacific region, a management strategy evaluation (MSE) was conducted for Sacramento River winter Chinook salmon. However, a similar MSE would be difficult for other salmon stocks managed by the Pacific Council. Since Sacramento River winter Chinook is listed under the Endangered Species Act and other co-occurring salmon stocks are generally not, the allowable harvest rate for this stock is almost always the strongest constraint on ocean salmon fisheries where it occurs.

In contrast, the target stocks supporting the fishery cover broader geographic ranges and overlap spatially with multiple constraining stocks. This makes modeling implementation error very challenging, as one cannot assume that the exploitation rate allowed by the stock-specific control rules for abundant stocks will actually be achievable without exceeding the allowable impacts on constraining stocks. Thus, while it was possible to build environmental drivers into an MSE for Sacramento River winter Chinook salmon, such an analysis would be very challenging for the main stocks in the fishery.

In South Africa, catch limits for sardine and anchovy are dependent on estimates of B_0 within the operating model, which are affected by the stock-recruitment (S-R) relationship. Since S-R relationships vary by environmental regimes, there are multiple S-R curves. They determine F based on setting F

John Field (SWFSC)

~20% to the left of the biomass distribution. When alternate S-R curves are used, they maintain that shift to the left in a relative sense. The slope of the ascending limb effectively determines the F.

Many control rules for tropical tunas are based on abundance of bigeye and yellowfin tuna. There is a need to better evaluate harvest control rules for these tuna stocks that also account for changes in fleet size. Environmental drivers are not part of the control rules.

Past discussions have focused on environmental drivers to recruitment and productivity; now the discussion focuses on F strategies. The only place where an environmental driver is part of the control rule is Pacific sardine. How do environmental drivers affect the rate of harvest? In the Pacific region, the allowable exploitation rate for some Oregon coho salmon stocks is a function of environmental conditions.

At what point are environmental perturbations noise in an assessment? How can short-term perturbations affect control rules when this could be statistical noise? Is an MSE the best way to consider this issue? Some perturbations can be accounted for in control rules to conserve the stock. It still comes down to using a constant F strategy and tracking changes in abundance as a better way to respond to short-term perturbations. An MSE is a good way to test the performance of control rules by understanding how assessment frequency, process error, and implementation error affect stocks subject to these perturbations.

Is the timing of implementation of scientific advice considered for stocks subject to short-term perturbations? There are some gains in performance when the time lag is shortened.

Anchovy management requires a fast response to surveys, since the fish are only available for catch for four months. After the survey, the response needs to be in play right away to get two months of fishing. Using trend analysis in control rules, which are based on recent year averages of abundance, is problematic because you are subject to greater variance in estimating current biomass. Surveys in as close to real time to the fishery perform best.

Steven Atran (GMFMC)

Pre-testing HCRs before implementing HCRs is important to determine the best management response and HCR. The interval between estimating biomass or relative biomass in an index can easily be tested in an MSE. In addition, data delivery needs to be quick to shorten response times.

It may be helpful to test secondary indicators of environmental conditions such as seabird abundance, but this is difficult to translate into fishery management advice. To react to short-term perturbations requires predicting both fish abundance and the weather. If the control rule has an environmental driver as with Pacific sardine, then one can attempt to forecast the environmental condition to project biomass. We need better understanding of the mechanism for potential environmental drivers to recruitment and production.

Stakeholders often have insight on environmental drivers to production. Such hypotheses can be collected and, when stakeholders collect data to support their hypotheses, they can then be tested through simulation. ●

Subtheme 3.3

Using MSE to Evaluate Harvest Control Rules that are either Robust to, or Adaptive to, Changes in Stock Productivity

Discussion led by Aaron Berger and John Field; Rishi Sharma, rapporteur

Cameron Speir (SWFSC) and Rishi Sharma (NWFSC)

Why has there been limited success incorporating regime shifts into management procedure frameworks, and what can be done to improve success? In particular, obstacles to including regime shifts and states into fisheries management include the following (refer to Section 3 in King et al. 2015):

- Linkages between environmental variables and recruitment time series often eventually break down.
- Typically, the length of the time series for recruitment data is shorter than the span of at least one regime shift and state of nature.
- The environmental and recruitment time series typically have high within-regime variability.
- Without a reliable way to anticipate a regime shift, even short-term predictions are not possible. How can we overcome these impediments?

Without information on environmental linkages and the ability to predict regime shifts, managers are left with lower, precautionary harvest limits. An aggressive harvest policy is only possible if we can follow all shifts. However, if you have a good abundance estimate and reasonably good trend information for the stock, one could potentially determine a robust and responsive control rule to environmental shifts.

An index of abundance, and a way to know whether it is increasing or decreasing, can fit into a harvest control rule.

If possible, detect indicators of regime shift retrospectively. Such indicators increase in variance when there is a regime shift; use that to detect a regime shift change. Management stategy evaluation (MSE) has a strategic role in testing such scenarios. A control rule would need to be elaborate to account for these changes.

If a stock becomes depleted in a certain area due to climate change, one might have to give up on trying to rebuild that species in that area. This is an extreme scenario, but we want to anticipate such cases and make appropriate management changes. There is a desire to react to climate change without fishing down a stock. We need good tools to address such a situation. It is possible that before a stock is extirpated in a certain area, the fishery will be extirpated because the fishery won't be economically sustainable. However, fishing could continue for other stocks and bycatch could cause a fishing-down effect.

How do we analyze this kind of situation in an MSE? Elaborate control rules would need to be analyzed.

What is the best way to develop operating models for MSEs to test control rules that are robust to environmental change? How can this be done when there is no known mechanistic link to productivity and regime shift? Mechanistic models are used more in a strategic process. Statistical models are more often used in this case. The evolution is to use both types of models in an MSE to explore a range of alternatives more thoroughly than can be done in an assessment.

One strategy is to mimic the empirical changes in abundance by changing the productivity parameters in assessment models. These are used more as robustness models than for operating models in MSEs. This approach is helpful in deciding bounds in MSE simulations.

In Australia, there is a mandate to try to protect resources affected by climate change. Active management strategies can be somewhat extreme to try to manipulate the environment. These are high-level decisions that are not always science-based.

There is also an effort to make long-term forecasts in the Bering Sea that predict the effects of climate change. And in the Great Lakes they are modeling large-scale ecosystem changes. Some lessons there may be useful.

Is maximum sustainable yield (MSY) an appropriate target? Maintaining MSY may not be the best reference point since it is hard or impossible to estimate with significant climate change. A better approach is to work with stakeholders on management strategies that are shown to be risk-averse at creating stock declines or stock extirpation. However, in the United States, we are currently managing under the legislative mandate of MSY.

Should we accept climate change or actively manage it? In many cases, we have to make a substantial decision, possibly working outside the box, combining management strategies, and using ecosystem approaches and adaptation options. Do we use fans to cool reefs? Do we try to mitigate climate change, or manage things as they are? ●

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Synthesis Findings for Subtheme 3

Who should communicate uncertainty and risk to stakeholders and Councils?

- Analysts are not always the best at communicating to stakeholders and Councils.
- Consult others who are better equipped in this task (e.g., International Pacific Halibut Commission consulted with the Psychology Department at the University of Washington).
- Alternatively, have others who are good at this present MSE results.
- Best practices for communicating science, uncertainty, and risk:
    - Analysts' writing should be edited to make sure it is straightforward and does not contain confusing language or language that is too informal or technical.
    - Frequency/proportional occurrence is more

  easily interpretable than probability. "One in eight" is more easily interpretable than 12.5 percent. "Fifty year flood" is helpful even if more complex than once every 50 years.
  - Tell a story and have a conversation. Describe what we do not know rather than just using "uncertainty." Start simply, then extrapolate.
  - When presenting MSE results using graphs, tables, and pictures, simpler is better.
  - Complex graphs may be fine for colleagues, but are not as effective for communication to the public and Councils.
  - The challenge is how to present results for more complex analyses, such as MICE, in which the optimal fishing rate for one species can depend upon the fishing rate for other species.
  - Analogies to things that are familiar can be helpful. For example, the Atlantic States Marine Fisheries Commission uses an analogy to "Plinko" for decision trees with a "bounce" left or right at each decision point.
  - Consistency in presentation over time and across analyses and species may be slightly limiting, but greatly improves understanding.
  - Getting advice on presentation, colors, etc. can be helpful in developing more effective graphics.
  - Consider reporting uncertainty first and then the point estimate, as the uncertainty intervals in parentheses are often ignored. Eighty-percent confidence intervals tend to work best for interpretation; 95 or 99 percent confidence intervals are not nearly as intuitive.
- Different audiences require different communication approaches and skills (e.g., Councils vs. stakeholders), and have different agendas. Council members are politically astute and, for example, ask questions they know the answer to in order to get the answers they want, or the perception of your support, on the record.

Tips to better engage an audience:

- Take time to listen and understand what Council members or stakeholders do not fully understand. This can lead to better communication and understanding.
- Develop relationships with Councils and stakeholders to develop better understanding and trust.
- It is important for scientists and stakeholders to understand how uncertainty should be used in making management decisions.

Use metrics that are meaningful to stakeholders and Council members when presenting MSE results. Presenting performance of a management strategy by answering questions such as, "how often/likely will fishing have to be shut down?" and "how often/likely will inseason actions/actions between Council meetings be needed?" can be an informative way to present results.

Mechanisms underlying uncertainty:

- Describe not just scenarios but, to some extent, why they differ.
- List research that could address uncertainty in some of the mechanisms underlying some of the uncertainty. Communicate research needs that might resolve critical uncertainties if funding was available to do such research.
- Stakeholders appreciate when scientists admit that they don't know something.
- Discussing underlying uncertainties helps open up dialogue.
- Communicating why a particular analysis was used and/or accepted is informative. More complicated methods are not always better.
- Consider using interactive methods such as Shiny apps, which can allow stakeholders to play around with assumptions and/or rules and see the outcomes. Such methods can lead to lots of questions. Does this improve understanding and buy-in? ●

The Tunamen's Memorial at Shelter Island. The bronze sculpture, dedicated in 1988, was created by Franco Vianello.

Poster Abstracts

Testing harvest control rules within end-to-end ecosystem models: A stepping stone toward management strategy evaluation

Kaplan, I.C. (1), Hansen, C. (2), Morzaria-Luna, H. (3), Girardin, R. (4), Marshall, K.N. (5).

Management strategy evaluation (MSE) provides a simulation framework to test the performance of living marine resource management. MSE has now been adopted broadly for use in single-species fishery management, often using a relatively simple "operating model" that projects population dynamics of one species forward in time. On the other hand, many challenges in ecosystem-based management involve trade-offs between multiple species and interactions of multiple stressors. Efforts are underway to include these dynamics in more complex "end-to-end" ecosystem models that can serve as operating models for MSE, but to date the most fruitful ecosystem-based MSE approach has often been to strip the ecosystem model (operating model) down to intermediate levels of complexity (often 3-5 species). Here we take a different tack, retaining the complexity of end-to-end ecosystem models (for the California Current and Nordic/Barents Sea), stripping down the simulated assessment in the MSE, and testing harvest control rules that explicitly address the linkage between predators and prey, and between forage needs of predators and fisheries.

We test harvest control rules that:
1) Explicitly include potential for prey-driven shifts in predator productivity. We vary the intensity of fishing on a predator (Pacific hake) dependent on the availability of prey (*euphausiids*) that may drive productivity shifts in the predator.

2) Provide a threshold of forage biomass, below which fishing on forage is eliminated and forage is reserved for predators. In Norway, a fishery targets the copepod (zooplankton) *Calanus finmarchicus*. We test threshold levels of prey (copepod) abundance below which copepod fisheries are closed.

These ecosystem-based harvest control rules that address shifting productivity or threshold forage biomass are not novel, but here we explore their implications for different trophic levels and the structure, function, and catches at the ecosystem level. We adopt lessons learned from other (mostly single-species) MSE efforts in terms of how to score, plot, and summarize model performance.

Affiliations:
1. Conservation Biology Division, NOAA NMFS Northwest Fisheries Science Center
2. Institute of Marine Research, Norway
3. Long Live the Kings, Seattle
4. IFREMER, France
5. Fishery Resource Analysis and Monitoring Division, NOAA NMFS Northwest Fisheries Science Center

Pacific whiting MSE: Testing the robustness of management procedures to environmental variability

Aaron Berger, Ian Taylor, and Michelle McClure, NOAA Fisheries, Northwest Fisheries Science Center

Pacific hake is the most abundant groundfish in the California Current Large Marine Ecosystem. Since 2011, it has been managed as a single stock through an international treaty between the U.S. and Canada. Growing recognition that environmentally-driven processes may act on hake of different ages has led to concerns that spatial population structure could affect harvest rates in both countries. Because the international boundary and the allocation between countries are fixed, there are potential management implications of variable spatial distributions of the hake stock under current and future ocean conditions. We have begun a management strategy evaluation (MSE), in close collaboration with the

Mike Burner (PFMC), John Hall, and John Field (SWFSC)

hake management bodies, to test the robustness of current management procedures (data collection, assessment, harvest control rule) to uncertainties in the environment and in our knowledge of hake biology. Our goals are to (1) investigate how robust the current hake management procedures are to alternative hypotheses about environmentally-driven spatial population structure; (2) explore potential trade-offs of harvest in the U.S. vs Canada; and (3) explore the performance of a spatially-explicit assessment model compared with a single stock model. The MSE will use a closed-loop simulation framework, where data collection, assessment methodology, and harvest control rules will be evaluated against known population dynamics specified in a spatial operating model. Simulations will include scenarios of environmental forcing on age-based spatial distribution, including recruitment of hake, and the impact of these scenarios on the performance of management procedures. Scenarios will span warm and cool El Nino Southern Oscillation conditions (interannual variability) and increasing trends in ocean temperatures. We will also evaluate how errors stemming from incorrect assumptions propagate to management advice across different hypotheses about the timing and duration of hake migrations (alternative operating models). We are working with the hake management bodies to co-create a work plan, conceptual models describing how hake interact with their environment, and objectives and performance indicators to evaluate alternative management procedures. Overall, this MSE lays the groundwork for addressing an important issue in the hake management process (age-based availability, stability, and equity of catch among fishing sectors).

Challenges and lessons learned implementing management strategy evaluation

Aaron Berger (1), Melissa Karp (2), Daniel Goethel (3), Sean Lucey (4), Sarah Gaichas (4), John Walter (3), and Patrick Lynch (2)

Management strategy evaluation (MSE) is a stakeholder-driven process involving closed-loop simulation tools, which allow testing the efficacy of various management options and identification of those that are likely to achieve prespecified biological and socioeconomic objectives. We summarize salient points and overarching themes from a two part MSE symposium (2017 American Fisheries Society, Tampa Bay, FL) focused on new analytical methods in MSE development along with best practices for improving stakeholder involvement in the MSE process. The symposium included a keynote address by Dr. Sean Cox, 28 presentations, and a discussion panel that included representatives from the local fishing community, non-governmental organizations, academia, regional management councils, and government scientists. The first set of presentations highlighted the advancements and challenges involved in developing and implementing MSEs and covered a range of species and issues including: environmental covariates, time-varying mortality events, spatial structure, optimizing data collection, developing management procedures, and evaluating harvest control rule performance. The second set of presentations highlighted the benefits of including stakeholders and lessons learned on how to improve stakeholder involvement in the MSE process. MSEs are not a one-size-fits-all process and tools must be custom made for each application, thereby allowing for the vagaries of the situation including the needs and wants of stakeholders involved. No matter the context, communication and education is critical to implementing a successful MSE. An important component of communication involves clearly laying out the goals and objectives before modeling is begun along with continued repetition and reminders of these goals throughout the MSE process.

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1. Fisheries Resource and Monitoring Division, Northwest Fisheries Science Center, NOAA-NMFS, Newport, Oregon

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4. Ecosystem Dynamics and Assessment Branch, Northeast Fisheries Science Center, NOAA-NMFS, Woods Hole, Massachusetts

Facing camera: Sandra Krause (PFMC), Ian Stewart (IPHC) Michael Harte (Oregon State University), Patrick Sullivan (Cornell University)

Which MSE should you do first? Prioritizing MSE investments using risk assessment under an ecosystem approach to fishery management

Sarah Gaichas and Geret DePiper (NMFS Northeast Fisheries Science Center), Richard Seagraves, Andrew Loftus, Brandon Muffley, and Mary Sabo (Mid-Atlantic Fishery Management Council).

Ecosystem approaches to fisheries management (EAFM) potentially expand the scope of interactions and uncertainties to consider in evaluating harvest control rules and other fishery management procedures. Management strategy evaluation (MSE) is generally recognized as a core component of EAFM, but can be a resource-intensive process when applied even to relatively simple single species harvest control rules. Involving stakeholders to establish a range of objectives and performance measures for MSE is critically important for developing management procedures that balance social, economic, and ecological needs, but requires even more resources in the form of organizers, facilitators, and technical experts. So how can managers ensure that the most important MSE gets done first? Risk assessment provides a systematic framework to ensure that limited MSE resources address the highest priority ecosystem interactions and risks. The Mid-Atlantic Fishery Management Council recently adopted EAFM policy guidance that outlines a framework involving risk assessment as the first step towards addressing species, climate, habitat and fishery interactions. Over the past year, the Council has defined a range of ecological, economic, social, and management related elements that track risk to achieving Council management goals and objectives. The risk was then evaluated as low, moderate, or high according to defined ranking criteria and measured by one or more ecosystem indicators assessed at multiple levels, ranging from single-species to system-wide. The resulting risk matrix can be used to quickly evaluate where further integrated analysis and MSE should be focused—which fishery management plans, which species, and which risk elements need to be included in the analysis. The ecosystem indicators are updated and reviewed regularly, so that the Council can update the EAFM risk assessment as needed.

Getting on the same page, or at least in the same library: Lessons in communication from a stakeholder driven MSE for Northeast US Atlantic herring

Jonathan J. Deroba, Sarah Gaichas, and Min-Yang Lee (NMFS Northeast Fisheries Science Center), Rachel Gallant Feeney and Deirdre Boelke (New England Fishery Management Council), and Brian Irwin (USGS University of Georgia Cooperative Institute).

Management strategy evaluation (MSE) should include stakeholder input, but such a process can have communication challenges. Atlantic herring in the northeast U.S. has diverse and engaged stakeholders. An MSE was recently conducted to evaluate harvest control rules for Atlantic herring that consider herring's role as forage within the ecosystem. This MSE was possibly the first in the U.S. to use open, public workshops for development. Two, two-day workshops were each attended by about 65 members of the public, with about 30 attending both. Participants had diverse backgrounds with differing levels of interest and preparedness. This diversity of participation was generally positive, but led to frequent misunderstandings about terminology and intentions for the MSE. The process overcame some of these communication problems by providing a forum for repeated interactions and presenting information using a range of methods (e.g., verbally and graphically). Improved understanding of MSE and technical methods was also achieved through informal lines of dialogue that opened through the MSE process. MSEs more broadly would benefit from repeated opportunities for interactions among stakeholders, scientists, and managers. Conducting stakeholder driven MSEs will require investment in organizers, facilitators, and technical experts, preferably with expertise in a particular system, and such investments can improve communication and understanding of MSE, to the betterment of fisheries management.

Kris Kleinschmidt and Mike Burner (PFMC staff)

The performance and trade-offs of alternative harvest control rules to meet management goals for U.S. West Coast flatfish stocks

Chantel Wetzel (NMFS Northwest Fisheries Science Center) and André Punt (University of Washington)

U.S. Federal fisheries managers are mandated to obtain optimum yield while preventing overfishing. The concept of maximum sustainable yield (MSY) has often been applied to provide an upper bound for the optimum yield value, but determining the MSY, identifying the relative biomass that produces MSY and the associated fishing rate required (F_{MSY}) is difficult. The Pacific Fishery Management Council has employed proxy targets in lieu of species-specific estimates of MSY, B_{MSY}, and F_{MSY}. The proxy targets are life history specific, with flatfish stocks managed using a target B_{PROXY} of 0.25 of unfished biomass and a harvest control rule that applies an exploitation rate equal to a spawner-per-recruit harvest rate of F30%, with a linear reduction of catch to zero if the stock falls below 5% of unfished biomass (B_{LIMIT}). A management strategy evaluation was performed to explore the performance of the current harvest control rule applied to flatfish stocks to meet management goals, along with alternative harvest control rules that explore varying the values for B_{PROXY}, B_{LIMIT}, and F_{SPR}. Each of the harvest control rules explored maintained stocks at or near B_{PROXY} when stock-recruit steepness was 0.85 or greater, with very low probabilities of reducing relative biomass below a minimum stock size threshold (set at 0.50 B_{PROXY} of each harvest control rule). The most aggressive harvest control rule, which applied a B_{PROXY} of 0.20 and a target harvest rate of F25%, led to fishing rates that exceeded the operating model F_{MSY} values for low steepness (0.75), reducing the stock below B_{PROXY} with catches exceeding MSY. Trade-offs exist among alternative harvest control rules where the more aggressive harvest control rules resulted in higher average catches, but with an increase in the average annual variation in catches and a decrease probability of the relative biomass being with 10% of the B_{PROXY}. The trade-offs among the performance metrics and alternative harvest control rules coupled with the risk to the resource across a range of life histories should be carefully considered by fishery managers when selecting a harvest control rule that will meet the goals of management. ●

Appendices

SCS 2018: Simplified Meeting Agenda

TUESDAY, JANUARY 16, 2018

Welcome Reception

WEDNESDAY, JANUARY 17, 2018

Welcome, Introductions, Meeting Logistics

Discussion: Meeting Expectations and Over-Arching Questions

Topic 1: Use of Management Strategy Evaluations (MSEs) in Evaluating and Modifying Harvest Control Rules

1.1: Example Applications from Each Region: Recent Past, Ongoing, and Foreseen in the Near Future; Lessons Learned

Invited Speakers: Mike Jones, Dan Holland

1.2: Clarifying Objectives, Incorporating Stakeholder Input, and Social/Economic Evaluation

Public Comment Period

Day 1 Synthesis: Findings, Recommendations, and Outstanding Questions

Poster Session Reception

THURSDAY, JANUARY 18, 2018

Recap of Day 1

1.3: Role of MSEs in Informing and Advancing Ecosystem-Based Fisheries Management

*1.4: Multi-Year Status Determinations, Assessment Frequency, Setting Acceptable Biological Catches (ABCs)
Between or Without Assessments, and Phase-in of ABC Changes*

Topic 2: Estimating and Accommodating Uncertainty

Invited Speaker: André Punt

2.1: Model Selection and Multi-Model Inference

Public Comment Period

Day 2 Synthesis: Findings, Recommendations, and Outstanding Questions

FRIDAY, JANUARY 19, 2018

2.2: Risk Assessment Methods (Quantitative and Qualitative) for Evaluating Uncertainty in Overfishing Limits, Stock Biomass, and F

2.3: Scientific and Statistical Committee (SSC) Communication of Uncertainty and Risk in Management Decision-Making

Topic 3: Adjusting Harvest Control Rules in Changing Environments/Non-Static Maximum Sustainable Yield

Invited Speaker: Éva Plagányi

3.1: Modifying Harvest Control Rules (HCRs) and Maximum Sustainable Yield to Adapt to Regime Shifts and Long-Term Drift in Stock Productivity

3.2: Incorporating Short-Term Perturbations in Stock Productivity into HCRs and Rebuilding Plans

3.3: Using MSE to evaluate HCRs That are Either Robust to or Adaptive to Changes in Stock Productivity

Public Comment Period

Day 3 Synthesis: Findings, Recommendations, Outstanding Questions, Report Writing Duties, and Suggestions for Next Meeting ●

Next Meeting of the SCS

The meeting concluded with a discussion of potential themes for the Seventh Annual SCS meeting. Participants agreed on the following higher and lower priority topics:

HIGHER PRIORITY TOPICS:

- Integrated biological, social and economic assessments
- Effective communication and coordination among SSCs, Councils, and stakeholders (it would be helpful to invite communication experts to such a meeting)
- Representative approaches for climate and fishery impacts analyses
- Recreational fisheries surveys, assessment, and modeling
- Alternatives to maximum sustainable yield
- Defining optimum yield in ways that consider ecosystem and economics
- Multi-model inference

LOWER PRIORITY TOPICS:

- Improved processes for setting harvest specifications
- Lessons learned in the evolution of regional SSC processes (rate process steps)
- Ways to implement flexible arrangements (include data-poor species)
- Technical interactions with "choke" species
- Ways to incorporate impacts on protected species in models ●

Meeting Attendees by Region

Caribbean Council

Richard Appeldoorn, University of Puerto Rico (SSC)
Graciela García-Moliner, Council Staff
Todd Gedamke, MER Consultants LLC (SSC)
Walter Keithly, Louisiana State University (SSC)
Kevin McCarthy, Southeast Fisheries Science Center (SSC)

Gulf of Mexico Council

Steven Atran, Council Staff
Bob Gill (SSC)
David Griffith, East Carolina University (SSC)
Jeff Isely, Southeast Fisheries Science Center (SSC)
Joseph Powers, Louisiana State University (SSC)

Mid-Atlantic Council

Lee Anderson, University of Delaware (SSC)
John Boreman, North Carolina State University (SSC)
Thomas Miller, Chesapeake Biological Laboratory (SSC)
Brandon Muffley, Council Staff
Richard Seagraves, Council Staff
Michael Wilberg, Chesapeake Biological Laboratory (SSC)

New England Council

Chris Kellogg Council Staff
Lisa Kerr Gulf of Maine Research Institute (SSC)
Jason McNamee, Rhode Island Dept. of Environmental Management (SSC)
Patrick Sullivan, Cornell University (Council Member)
John Wiedenmann, State University of New Jersey (SSC)

National Marine Fisheries Service

Gerard DiNardo, Southwest Fisheries Science Center
Toby Garfield, Southwest Fisheries Science Center
James Hilger, Southwest Fisheries Science Center
Dan Holland, Northwest Fisheries Science Center
Isaac Kaplan, Northwest Fisheries Science Center
Kristin Koch, Southwest Fisheries Science Center
Huihua Lee, Southwest Fisheries Science Center
Patrick Lynch, Office of Science & Technology
Kristin Marshall, Northwest Fisheries Science Center
Richard Methot, Office of Administrative Appeals
Barbara Muhling, NOAA Cooperative Institute
Erin Schnettler, Office of Sustainable Fisheries

Sarah Shoffler, Southwest Fisheries Science Center
Stephen Stohs, Southwest Fisheries Science Center
Desiree Tommasi, Southwest Fisheries Science Center
Howard Townsend, Office of Science & Technology
Cisco Werner, Chief Science Advisor

North Pacific Council

Sara Cleaver, Council Staff
Anne Hollowed, Alaska Fisheries Science Center (SSC)
Matthew Reimer, University of Alaska Anchorage (SSC)
Ian Stewart, International Pacific Halibut Commission (SSC)
Diana Stram, Council Staff
Farron Wallace, Southeast Fisheries Science Center (SSC)

Pacific Council SSC Members

Aaron Berger, Northwest Fisheries Science Center
John Budrick, California Dept. of Fish and Wildlife
John Field, Southwest Fisheries Science Center
Owen Hamel, Northwest Fisheries Science Center
Michael Harte, Oregon State University
Galen Johnson, Northwest Indian Fisheries Commission
André Punt, University of Washington
William Satterthwaite, Southwest Fisheries Science Center
Rishi Sharma, Northwest Fisheries Science Center
Cameron Speir, Southwest Fisheries Science Center
Theresa Tsou, Washington Dept. of Fish and Wildlife

Pacific Council Staff

Kimberly Ambert
Mike Burner
Patricia Crouse
John DeVore
Renee Dorval
Kris Kleinschmidt
Sandra Krause
Chuck Tracy

Other Pacific Council Attendees

Briana Brady, California Dept. of Fish and Wildlife (Council Member)
Charles Farwell, Monterey Bay Aquarium (Highly Migratory Species Advisory Subpanel)
Peter Flournoy, International Law Offices of San Diego
John Hall, Coastal & Offshore Pacific Corp.
Donald Hansen, Dana Wharf Sportfishing
Craig Hess, Martin Enterprises
Frank Lockhart, NOAA West Coast Region (Council member)

Corey Niles, Washington Department of Fish and Wildlife (Council Member)
Dave Rudie, Catalina Offshore Products

South Atlantic Council

John Carmichael, Council Staff
Scott Crosson, Southeast Fisheries Science Center (SSC)
Marcel Reichert, South Carolina Dept. of Natural Resources (SSC)
George Sedberry, NOAA Office of National Marine Sanctuaries (SSC)
Alexei Sharov, Maryland Department of Natural Resources (SSC)

Western Pacific Council

Debra Marie Cabrera, University of Guam (SSC)
Shelton Harley, New Zealand Ministry for Primary Industries (SSC)
Justin Hospital, Pacific Islands Fishery Science Center (SSC)
Steve Martell, Sea State (SSC)
Graham Pilling, The Pacific Community (SPC) (SSC)
Marlowe Sabater, Council Staff

Invited Speakers

Dan Holland, Northwest Fisheries Science Center
Michael Jones, Michigan State University
Éva Plagányi-Lloyd, Commonwealth Scientific and Industrial Research Organisation (Australia)
André Punt, Pacific Council SSC

Other Attendees

Doug Butterworth, University of Cape Town
Michael Drexler, Ocean Conservancy
William Koh, William Koh Environmental Strategies
Carolina Minte-Vera, Inter-American Tropical Tuna Commission ●

Acronyms

ABC	acceptable biological catch
AFSC	Alaska Fisheries Science Center (NMFS)
AIC	Akaike Information Criterion
B_{MSY}	The biomass that allows maximum sustainable yield to be taken. A
B_0	"B sub zero." Unfished biomass; the estimated size of a fish stock in the absence of fishing.
CDFW	California Dept. of Fish and Wildlife
CPUE	catch per unit of effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	coefficient of variation
DTS	dover-thorynhead-sole
EAFM	ecosystem approaches to fishery management
EBFM	ecosystem-based fishery management
F	The instantaneous rate of fishing mortality.
F_{MSY}	The fishing mortality rate that maximizes catch biomass in the long term.
GMFMC	Gulf of Mexico Fishery Management Council
HCR	harvest control rule
IEA	integrated ecosystem assessment
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea)
IPHC	International Pacific Halibut Commission
LEPMAG	Lake Erie Percid Management Advisory Group
LRP	Limit reference point
MAFMC	Mid-Atlantic Fishery Management Council
MEY	maximum economic yield
MICE	Models of Intermediate Complexity for Ecosystem Assessment
MP	management procedure
MSE	management strategy evaluation
mt	metric tons
NEFSC	New England Fishery Management Council
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWFSC	Northwest Fisheries Science Center (NMFS)
OFL	overfishing limit
OMP	operational management procedure
PFMC	Pacific Fishery Management Council
SB_0	unfished spawning biomass
SCS	Scientific Coordination Subcommittee (of the Council Coordination Committee)
SDM	Structured Decision Making
S-R	stock-recruitment
SSB	spawning stock biomass
SSC	Scientific and Statistical Committee
SWFSC	Southwest Fisheries Science Center (NMFS)
TAC	total allowable catch
USD	U.S. dollars
USGS	U.S. Geological Survey
WPFMC	Western Pacific Fishery Management Council

U.S. Regional Fishery Management Councils