No Replication Without Process Documentation: An Assessment of Management Strategy Evaluations

#### Jonathan W. Cummingsa, Amanda Harta, Gavin Faya

aSchool for Marine Science and Technology, University of Massachusetts – Dartmouth  
836 South Rodney French Blvd. New Bedford, MA 02744 United States

Corresponding author: Jonathan Cummings, jcummings@umassd.edu

Highlights

* Documentation of management strategy evaluation processes is incomplete
* Scientists often led the process and filled the role of stakeholders
* Facilitators and decision analysts were rarely participants in MSE processes
* We provide a repository for reviews and summaries of previous management strategy evaluations to aid learning

Abstract

The aim and vision for fisheries management that comes from management strategy evaluation and adaptive management is a noble and aspirational vision. We review MSE documentation in the published literature to appraise the achievement of this vision, finding that reality doesn’t fully reflect this vision. The steps taken to complete the management strategy evaluation process often are not documented. Scientists often filled the role of fishery stakeholders, seemingly selecting the objectives and alternatives to evaluate in most management strategy evaluations. Facilitators and decision analysts – participants focused on the decision making process rather than making the decision – were rarely participants in MSE processes. Conservation, Economic, and Yield focused objectives were commonly considered in MSE processes, while broader social objectives were rarely considered. The picture painted by MSE documentation is primarily one of scientist driven simulation studies rather than management driven decision processes, with limited process documentation occurring. We hope providing a repository for reviews of previous management strategy evaluations will aid and speed learning among practitioners of management strategy evaluation.

Keywords

Management strategy evaluation, structured decision making, climate change, adaptive management

# Introduction

The calls for fisheries management to utilize management strategy evaluation and adaptive management have been both aspirational and estimable in their aim and vision. For example, management strategy evaluation (MSE) is “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” (Punt et al., 2016). The positive aspects of MSE that have been listed include that it is “A tool that scientists and managers can use to simulate the workings of a fisheries system and allow them to test whether potential harvest strategies — or management procedures — can achieve pre-agreed management objectives.” (Nickson, 2016), that it “can be used to identify a ‘best’ management strategy among a set of candidate strategies” (Punt, 2014) and “MSE has the advantage of being able to reveal the trade-offs among a range of possible management decisions, and should assist our Commissioners in determining whether the objectives should be weighted differently. Specifically, to provide the information on which to base a rational decision, given objectives, preferences, and attitudes to risk.” (International Pacific Halibut Commission, 2017). Based on these descriptions MSE is a compelling tool to support and improve fisheries management decisions.

Are the results of MSE living up to their descriptions? Are MSEs evaluating trade-offs and the consequences of uncertainty? Do they test potential harvest strategies? Were the management objectives used to evaluate management procedures established and agreed to? Was a 'best' management strategy identified? Was consideration given to the weights on objectives, preferences, and attitudes to risk?

In the descriptions of the MSE process, the process itself is described as being “at the interface between science and policy.” (Punt, 2014) and being an “Undertaking [that] requires scientists, managers, and stakeholders to be involved throughout the process.” (International Pacific Halibut Commission, 2017). The International Pacific Halibut Commission (2017) also states, “While the scientists do the modelling, managers must offer extensive input. Because of the many steps and the iterative process, communication among parties is critical for achieving buy-in on the results of the management strategy evaluation.”

Are MSE processes being conducted in the manner described? Do MSE processes consider and account for the interface between science and policy? Are scientists, managers and stakeholders involved and communicating through and iterative process that creates buy-in?

Adaptive management developed in fisheries management as a means to improve the achievement of objectives through time, when learning can aid achieving those objectives (Walters, 1986). For example, the Millennium Ecosystem Assessment (*Ecosystems and human well-being*, 2005) defines adaptive management as “A systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices. In active adaptive management, management is treated as a deliberate experiment for purposes of learning.” We contend that scientific publication is essentially a process intended to support adaptive management, in that researchers gain knowledge from the decisions made and outcomes produced by previous work to inform their decisions. In the case of fisheries management, are scientific publications of management strategy evaluations supporting adaptive management?

### Objectives

Our overall objective is to determine the extent that MSE achieves the aspirational aims outlined above, and whether MSE documentation supports learning within the MSE practitioner community. Given that scientific publication is the primary means of communicating the results of MSE, we review the scientific literature to assess the extent to which the process and aims of MSE, and adaptive management are being achieved and supported by the scientific literature. To assess this, we determine how MSEs utilize standard components of decision making processes. We use the structured decision making (SDM) process (United States Geological Survey, 2020)– the decision making framework in which adaptive management occurs – as our framework for evaluation. Using this framework, we review published MSEs to:

* Determine what questions MSE processes are addressing
* Identify the objectives and alternatives considered in MSE
* Determine the prevalence of a) explicit documentation and b) use of decision making steps in the MSE process, and
* Identify participants in MSE processes.

An increasingly recognized challenge in fisheries management is responding to changes in the productivity of fisheries stocks as a result of climate change (Brander, 2007; Busch et al., 2016). We also conduct a focused analysis of MSE processes that address the influence of climate change on fisheries management, highlighting aspects of MSE processes that model climate change as a driver of system status.

# Methods

## 2.1 Finding and Sampling the MSE Literature

We conducted our search for MSEs in the SCI-EXPANDED index from Web of Science, searching for “management strategy evaluation” by topic across all years on January 8th, 2019 (Table 1). This search returned 264 results. We reviewed a random sample of 30 articles that document a MSE (Appendix A), removing articles that were reviews, meta-analyses, or simply cited other MSE articles from our sample. After removing other articles from the original set of 264 articles, 154 articles document a MSE. The number of MSEs published each year is trending higher (Figure 1), with the ICES Journal of Marine Science and Fisheries Research as the leading publication outlets (Figure 2).

Table 1: January 8, 2019 Web of Science ‘management strategy evaluation’ search results

|  |  |
| --- | --- |
| MSE Type | Count |
| Published | 154 |
| Random Sample | 30 |
| Climate Change | 12\* |

\* We also reviewed 4 additional climate change MSE articles published in 2019 for a total of 16

Figure 1: Management strategy evaluations published per year for those selected and not selected in our random sample

Figure 2: Count of management strategy evaluations published by journal for those journal that have published at least two management strategy evaluations

We reviewed 16 climate change MSE articles (Appendix A). Twelve of these articles came from our original January 8th, 2019 Web of Science search. To give as full a picture of the climate change MSE articles to date as possible we also reviewed the 4 climate change MSE articles published in 2019.

## 2.2 Reviewing MSE documentation

We used the structured decision making framework (Conroy and Peterson 2013; Gregory et al. 2012) as our framework for evaluating management strategy evaluation documents (Figure 3). The structured decision making process is composed of the six process stages: problem definition, objective elicitation, alternative development, consequence prediction, trade-off analysis, and decision implementation.

Figure 3: Review framework - structured decision making process

We present the review methodology and results in four groups: consequences - which focuses on what was considered during the prediction stage, objectives - which focuses on what categories of objectives were considered, stages - which focuses on whether and how the stages of the process were completed, and participants - which focuses on how participation in the process was structured. These results were entered into a relational database for storage and evaluation, and is available via our shiny application (<https://jonathancummings.shinyapps.io/MSEreview/>).

The consequence group addresses what question the MSE was designed to address, and how it was addressed. We report the drivers included as the primary factors influencing the predictions produced by the MSE model, listing each driver a MSE included. We also report how the consequence predictions were made, with possible values of simulation modeling, dynamic programming, expert elicitation, and mental models, or unknown when it is unclear what methodology was used to predict the status of the system for management evaluation.

In the objectives group we address what the concerns, or goals of the MSE were. We record each objective considered, and report the type and category of objectives included in each MSE. Natural resource management problems typically include four types of objectives: conservation, resource use, i.e., yield in the fisheries context, as well as economic, and social objectives (Runge, Grand, and Mitchell 2013). We sort objectives into four types: strategic objectives - which are concerned with the overall mission of the system in which the decision evaluated by the MSE falls, process objectives - which are concerned with how the management decision addressed by the MSE would be made, fundamental objectives - which address the goals of the management decision, and means objectives - which address means to achieving the fundamental objectives of the management decision.

In the stages group we address how the MSE stages were completed. We report whether the stages of the structured decision making framework, i.e., problem, objectives, alternatives, tradeoffs, were explicitly completed and the methods used to complete them were documented. We also report whether the MSE results were adopted in subsequent management.

In the participant group we address how participation in the MSE process was structured and who participated. We report who lead the MSE process, who participated in it, and if the roles of participants were established and documented. In many cases the process used to elicit objectives and alternatives was not explicit. In these cases, we used what information was provided to glean who participated in the production of those components of the MSE. We record and report who those participants were, referring to them as subjective participants in the objectives or alternatives process. In other cases where there was not enough information to glean who participated we report the participants as unknown.

We collected additional information about the MSEs we reviewed beyond what is reported here. For a full description of the information recorded in the relational database see our appendix (Appendix B), and for the full data set and results see our shiny application (<https://jonathancummings.shinyapps.io/MSEreview/>).

# Results

### 3.1 What questions and management objectives do MSEs address?

We found that uncertainty was the main driver of the system state included in management strategy evaluations, with uncertainty included in 21 of the 30 evaluations we reviewed in our random sample (Table 2). In addition to uncertainty about the system model itself, monitoring methodology, how and what data is collected, was the most prevalent driver in MSE models, but a variety of drivers were considered across the random sample of MSEs.

Table 2: Drivers included in management strategy evaluations

|  |  |  |
| --- | --- | --- |
| Driver | Percent | Frequency |
| Uncertainty | 70 | 21 |
| Monitoring methodology | 20 | 6 |
| Spatial structure | 13 | 4 |
| Allowable catch adjustment | 10 | 3 |
| Environmental conditions | 10 | 3 |
| Fishing behavior | 10 | 3 |
| Implementation uncertainty | 10 | 3 |
| Ecosystem based management | 7 | 2 |
| Species interactions | 7 | 2 |
| Climate change | 3 | 1 |
| Landing regulations | 3 | 1 |
| Management timeline | 3 | 1 |
| Migration | 3 | 1 |
| Multiple sectors in fishery | 3 | 1 |
| Stock status | 3 | 1 |

Conservation objectives were present in nearly all of the MSEs we sampled (Table 3). Yield and economic objectives were present in about three quarters of the MSEs, while social objectives were only included in 2 of the sampled MSEs.

Table 3: Consideration of objective categories in management strategy evaluation

|  |  |  |
| --- | --- | --- |
| Objective category | Percent | Frequency |
| Conservation | 93 | 28 |
| Economic | 73 | 22 |
| Yield | 73 | 22 |
| Social | 7 | 2 |
| Utility | 3 | 1 |

No strategic or process objectives were documented in the MSEs. There were roughly the same number of fundamental and means objectives included in the MSEs (Table 4). An average of 6 objectives were evaluated by each management strategy evaluation.

Table 4: Objective Types

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Percent | Number | Per MSE |
| Fundamental | 53 | 94 | 3.13 |
| Means | 47 | 85 | 2.83 |

## 3.2 Are structured decision making steps explicit in MSEs?

The majority of MSEs did not explicitly document how the stages of the MSE process – defined using the SDM framework – were completed (Table 5). Apart from the consequence stage, which is the primary focus of MSE publication and therefore was always addressed, the most documented stage was the alternative stage with 6 MSEs documenting this stage of the process. The MSE process, problem, and objectives methodology were each documented in 5 of the MSEs. Three of the 30 MSEs explicitly documented a trade-off analysis and 2 of the 30 documented a management decision. One MSE documented that the results of the MSE were adopted.

Table 5: Prevalence of explicit documentation of stages in the MSE process

|  |  |  |
| --- | --- | --- |
| Explicit | Percent | Number |
| Process | 17 | 5 |
| Problem | 17 | 5 |
| Objectives | 17 | 5 |
| Alternatives | 20 | 6 |
| Tradeoffs | 10 | 3 |
| Decision | 7 | 2 |
| Results adopted | 3 | 1 |

### 3.3 Who is involved in MSEs?

MSEs were rarely explicit about the roles participants played in MSE processes, as only one MSE documented the roles participants played in the process (Table 6). None of the MSEs noted whether or not public meetings were held in which the public was invited to participate.

Table 6: Prevalence of explicit roles for MSE participants and meetings that were open to the public during the MSE process

|  |  |  |
| --- | --- | --- |
| Explicit | Percent | Number |
| Roles | 3 | 1 |
| Open meetings | 0 | 0 |

The primary participants and leaders of the MSE processes were scientists, while some MSE process were led by governments and management agencies (Figure 4 Process). Scientists were explicitly the leaders – or the sole participants and therefore seemingly the leaders – in 73 percent of the MSE processes, while 27 percent of processes lacked enough documentation of participants and leadership such that we were unable to identify a presumed leader of the process.

Scientists were participants in nearly all of the reviewed MSE processes (Figure 4 Participants). Other stakeholders in MSE processes were less frequent participants. Members of the fishery participated in 30 percent, management and government representatives in 23 percent, representatives of independent institutions in 7 percent, and the members of the public in 3 percent of reviewed MSEs. Decision makers – those responsible for selecting the management plan to implement – were participants in 13 percent of MSEs. Experts – a possible source of data or predictions – participated in 3 percent of the MSEs reviewed. Participants involved to the assist the MSE process itself, i.e., facilitators and decision analysts, participated in 10 and 3 percent of MSE processes respectively.

Objectives and alternatives were elicited from a variety of participants. Management, government, or fishery participants explicitly provided objectives and alternatives in about 10 percent of the MSE processes (Figure 4 Explicit). However, in most cases the source of the objectives and alternatives was not explicit. The source of objectives and alternatives was not explicit in more than 80% of the MSE processes, 25 of 30 objective sources were not explicit and 24 of 30 alternative sources. In those subjective cases scientists – being the only or primary participants – seemingly selected these components most frequently (Figure 4 Subjective).

Figure 4: Who guided (Process), participated in (Participants), or provided explicitly documented input (Explicit), or seemingly provided input (Subjective) during the specified steps of the MSE process

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Climate Change in MSE Fisheries management has mostly focused on fishing impacts with ecosystem status viewed as a background constant. The increasing rate of climate change and its influence on fisheries is changing this dynamic, bringing ecosystem status to the forefront of fisheries management.  Here we review published MSEs the include climate change as a driver of the fisheries model using the stages in a SDM process to highlight unique aspects of these MSEs. We filtered the original set of MSEs published by as of December 31st, 2019 searching for the term “climate change” within the set that resulted from searching for “management strategy evaluation”. This resulted in our reviewing 16 published MSEs that included climate change as a driver. We reviewed the climate change MSEs using the same methodology described above. These MSEs have been concentrated in North America and Australia (Figure 5).  Figure 5: Map of MSE study locations.  As with the random sample of reviewed MSEs, uncertainty was the most common driver, apart from climate change, included climate change MSEs (Table 7), while other biological drivers were also included in some of the climate change MSEs. Overall climate change MSEs considered fewer drivers on average, 1.4, than the random sample of MSEs, which included 1.8.  Table 7: Drivers included in climate change management strategy evaluations   |  |  |  | | --- | --- | --- | | Driver | Percent | Frequency | | Climate change | 100 | 11 | | Uncertainty | 12 | 2 | | Environmental conditions | 6 | 1 | | Habitat change | 6 | 1 | | Migration | 6 | 1 | | Monitoring methodology | 6 | 1 | | Spatial structure | 6 | 1 |   Climate change MSEs averaged the same number of objectives per MSE. The categories of the objectives differed however, with more frequent inclusion of yield objectives, but less frequent consideration of economic objectives and no consideration of social objectives (Table 8) in the climate change MSEs.  Table 8: Objective categories considered in management strategy evaluations   |  |  |  |  | | --- | --- | --- | --- | | Analysis | Objective category | Percent | Frequency | | Random sample | Conservation | 93 | 28 | | *Climate change* | *Conservation* | *94* | *15* | | Random sample | Yield | 73 | 22 | | *Climate change* | *Yield* | *88* | *14* | | Random sample | Economic | 73 | 22 | | *Climate change* | *Economic* | *50* | *8* | | Random sample | Social | 7 | 2 |   Climate change MSEs were more likely to explicitly document the trade-off analysis stage, equally likely to document the alternatives stages, but were less likely to document the other stages in the decision process.  Table 9: Prevalence of explicit documentation of stages in climate change MSE processes   |  |  |  | | --- | --- | --- | | Explicit | Percent | Number | | Process | 6 | 1 | | Problem | 6 | 1 | | Objectives | 6 | 1 | | Alternatives | 19 | 3 | | Tradeoffs | 19 | 3 | | Decision | 0 | 0 | | Results adopted | 0 | 0 |   Including climate change in a MSE appears to reduce the complexity of other stages in the MSE process, in particular those stages that utilize input from additional participants. On average climate change MSEs consider fewer drivers, consider less diverse objectives, and explicitly document fewer stages of the MSE process. If the MSE process is time, effort, or participant limited, the inclusion of climate change may be utilizing time, effort, or outside participants to focus on climate change rather than other aspects of the MSE process. |

# Discussion

The primary picture painted by MSE documentation is one of scientist driven simulation studies rather than management driven decision processes. While documentation about the modeling conducted in a MSE was explicit, documentation about the MSE process itself was often limited.

We found that management strategy evaluations do typically assess the consequences of uncertainty for achieving management goals, but other factors influencing the consequences of management strategies get more sporadic treatment. Data limitation is a frequent concern in fisheries management, and contributes to the degree of uncertainty present in fisheries management. Next to accounting for uncertainty, accessing the influence of data quality and availability, i.e., monitoring methodology was the most prevalent driver included in MSEs. This likely points to a desire for the design and use of cost-effective fisheries monitoring plans, suggesting future MSEs may be able to learn from the set including monitoring methodology as a driver. Additionally, the use of value of information analyses could expand upon the benefits of MSE as a tool to direct scientific resources (Moore and Runge, 2012; Runge et al., 2011). While discussions of fisheries research and management seem to be moving toward ecosystem effects, spatial models, and multiple species models, these characteristics were rarely considered in the set of MSEs we reviewed.

Managing natural resources entails achieving the objectives of people interacting with a natural resource, so decision processes are likely to produce more desirable results when they include objectives that reflect stakeholders’ and society’s values. These objectives are likely to include conservation, yield, economic, and social concerns. As noted, MSEs are described as a tool to evaluate what management strategy best achieves objectives, however the MSEs we reviewed don’t cover all categories of objectives. Yield and economic objectives were not included in about one quarter of MSEs, and broader social objectives were absent from all but 2 of the 30 evaluations. While we are unable to know the cause for this without more explicit documentation of MSE processes, our results may provide some clues.

Scientists led, and participated in most of the MSEs, while decision-makers, decision making institutions, and stakeholders were relatively infrequent leaders or participants in the process. The lack of participation by stakeholders may result in less frequent inclusion of social objectives, as well as yield and economic objectives specific to a particular fishery. Another factor may be that MSE models are likely constructed mainly by ecosystem modelers, who are likely to be more comfortable modeling the consequences of conservation and yield objectives than economic or social objectives. Given that scientists seem to be providing the objectives in many MSE processes, they may be selecting objectives that they are more comfortable evaluating. There also appears to be some degree of borrowing occurring in which scientists use a set of generic fishery objectives when conducting a MSE. Perhaps because their were few social objectives included in these MSEs, there was little inclusion of experts to aid in the prediction of consequences, or consequence prediction techniques other than simulation modeling.

Participants that would be likely to expand the set of objectives considered in a MSE rarely participated in the MSEs we reviewed. That is, facilitators and decision analysts were rarely participants in MSE processes. The inclusion of facilitators in decision processes aid information gain and conflict resolution, increase trust between participants, and lead to more beneficial environmental and social outcomes (Vente et al. 2016). The additional structure and focus on the decision process would likely result in more explicit documentation when facilitators and decision analysts participate in MSE, as resulted in some of the MSEs reviewed here (Williams, Little, and Begg 2011; Smith et al. 2013; Kolody et al. 2008). Facilitators and decision analysts can also aid decision processes by helping to diagnose the problem, which can result in selecting more appropriate analysis techniques for the problem type, elicit a more complete and representative set of objectives, and select analysis tools to best address decision impediments to identify the optimal management strategy (Cummings, In prep).

The MSE process may be aided by utilizing the techniques from the structured decision making approach to decision analysis, such as expanding the focus on problem framing at the outset of MSEs, eliciting fully representative sets of objectives, and utilizing multiple attribute utility theory to evaluate tradeoffs between objectives (Cummings, In prep). Utilizing the structured decision making approach also eases the documentation process by breaking decision making into more discrete stages. However, there may be practical considerations, such as time or budgetary constraints that limit how complex the stages of a MSE are, and the degree of documentation that occurs. Where the expertise and budget are available, the use of facilitators and scribes may aid in addressing and documenting MSE processes.

The relative dearth of explicit documentation we found in our review of MSE publications may hinder learning by MSE practitioners. While the modeling was clearly documented, the MSE process steps were often inexplicit. Without explicit documentation it is unclear why the analysis was structured as it was, why a particular set of drivers was selected, and why a set of objectives or alternatives were chosen. Perhaps the most crucial stage to enable understanding a replication of a decision resulting from a MSE is a clear presentation of how trade-offs between the multiple objectives were evaluated, and what the optimal or chosen alternative was that resulted from the MSE process. Different decision makers can rationally look at the same prediction of consequences and select a different preferred alternative if they treat the importance of the objectives differently. Therefore, MSE documentation often is not fully supporting replication or learning due to the frequent absence of trade-off and decision documentation.

### 5.1 Explore and expand upon this review

To aid learning from the documentation that has occurred, and provide ready access to future MSE documentation we produced a shiny application to enable an interactive means to explore the MSE literature (<https://jonathancummings.shinyapps.io/MSEreview/>). The MSE review shiny application enables users to interactively explore the results presented in this article. The application includes additional analyses that may be of interest, such as an analysis of what journals MSEs have been published in, who is authoring MSEs, and more. Users may also filter by driver, location, species, or other characteristics of MSEs to explore a set of MSEs of interest and relevance to aid learning in the MSE practitioner community. We hope that as MSE are conducted they are entered here so that MSE practitioners can further learn from each other in the future.

# References

Brander, K.M., 2007. Global fish production and climate change. Proceedings of the National Academy of Sciences 104, 19709–19714. <https://doi.org/10.1073/pnas.0702059104>

Busch, D.S., Griffis, R., Link, J., Abrams, K., Baker, J., Brainard, R.E., Ford, M., Hare, J.A., Himes-Cornell, A., Hollowed, A., Mantua, N.J., McClatchie, S., McClure, M., Nelson, M.W., Osgood, K., Peterson, J.O., Rust, M., Saba, V., Sigler, M.F., Sykora-Bodie, S., Toole, C., Thunberg, E., Waples, R.S., Merrick, R., 2016. Climate science strategy of the US National Marine Fisheries Service. Marine Policy 74, 58–67. <https://doi.org/10.1016/j.marpol.2016.09.001>

Change, W., Chang, J., Allaire, J., Xie, yihui, 2018. shiny: Web Application Framework for R.

Conroy, M.J., Peterson, J.T., 2013. Decision Making in Natural Resource Management: A Structured, Adaptive Approach. John Wiley & Sons.

Cummings, J.W., In prep. Overlooked steps: Using structured decision making to guide management strategy evaluation processes.

de Vente, J., Reed, M.S., Stringer, L.C., Valente, S., Newig, J., 2016. How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. E&S 21, art24. <https://doi.org/10.5751/ES-08053-210224>

Ecosystems and human well-being, 2005. . Millennium Ecosystem Assessment.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., Ohlson, D., 2012. Structured Decision Making: A Practical Guide to Environmental Management Choices. John Wiley & Sons.

International Pacific Halibut Commission, 2017. Management Strategy Evaluation [WWW Document]. International Pacific Halibut Commission. URL <https://iphc.int/management/science-and-research/management-strategy-evaluation> (accessed 3.26.20).

Kolody, D., Polacheck, T., Basson, M., Davies, C., 2008. Salvaged pearls: lessons learned from a floundering attempt to develop a management procedure for Southern Bluefin Tuna. Fisheries Research 94, 339–350. <https://doi.org/10.1016/j.fishres.2008.08.016>

Moore, J.L., Runge, M.C., 2012. Combining Structured Decision Making and Value-of-Information Analyses to Identify Robust Management Strategies: Identifying Robust Management Strategies. Conservation Biology 26, 810–820. <https://doi.org/10.1111/j.1523-1739.2012.01907.x>

Nickson, A., 2016. Management Strategy Evaluation for Fisheries, Informing the Selection of Harvest Strategies [WWW Document]. URL <https://www.pewtrusts.org/-/media/assets/2019/07/harvest-strategies/hs_mse_update.pdf> (accessed 3.26.20).

Punt, A.E., 2014. Management Strategy Evaluation [WWW Document]. The Punt Lab. URL <http://puntlab.washington.edu/management-strategy-evaluation/> (accessed 3.26.20).

Punt, A.E., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A., Haddon, M., 2016. Management strategy evaluation: best practices. Fish Fish 17, 303–334. <https://doi.org/10.1111/faf.12104>

Runge, M.C., Converse, S.J., Lyons, J.E., 2011. Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biological Conservation 144, 1214–1223. <https://doi.org/10.1016/j.biocon.2010.12.020>

Runge, M.C., Grand, J., Mitchell, M., 2013. Structured decision making, in: Wildlife Management and Conservation:  Contemporary Principles and Practices. Johns Hopkins University Press, Baltimore, Maryland, pp. 51–72.

Smith, D.R., McGowan, C.P., Daily, J.P., Nichols, J.D., Sweka, J.A., Lyons, J.E., 2013. Evaluating a multispecies adaptive management framework: must uncertainty impede effective decision-making? J Appl Ecol 50, 1431–1440. <https://doi.org/10.1111/1365-2664.12145>

United States Geological Survey, 2020. . Structured Decision Making. URL <https://www.usgs.gov/centers/pwrc/science/structured-decision-making> (accessed 3.27.20).

Walters, C.J., 1986. Adaptive Management of Renewable Resources. Macmillan.

Williams, A.J., Little, L.R., Begg, G.A., 2011. Balancing indigenous and non-indigenous commercial objectives in a coral reef finfish fishery. ICES J Mar Sci 68, 834–847. <https://doi.org/10.1093/icesjms/fsr034>

# Appendix A: Articles reviewed

### Random Sample

Bastardie, F., Nielsen, J.R., Kraus, G., 2010. The eastern Baltic cod fishery: a fleet-based management strategy evaluation framework to assess the cod recovery plan of 2008. ICES Journal of Marine Science 67, 71–86. <https://doi.org/10.1093/icesjms/fsp228>

Bischof, R., Nilsen, E.B., Brøseth, H., Männil, P., Ozoliņš, J., Linnell, J.D.C., 2012. Implementation uncertainty when using recreational hunting to manage carnivores: *Carnivore hunting quotas*. Journal of Applied Ecology 49, 824–832. <https://doi.org/10.1111/j.1365-2664.2012.02167.x>

Chen, N., Zhang, C., Sun, M., Xu, B., Xue, Y., Ren, Y., Chen, Y., 2018. The impact of natural mortality variations on the performance of management procedures for Spanish mackerel (Scomberomorus niphonius) in the Yellow Sea, China. Acta Oceanol. Sin. 37, 21–30. <https://doi.org/10.1007/s13131-018-1234-0>

Cox, S.P., Kronlund, A.R., Benson, A.J., 2013. The roles of biological reference points and operational control points in management procedures for the sablefish ( *Anoplopoma fimbria* ) fishery in British Columbia, Canada. Envir. Conserv. 40, 318–328. <https://doi.org/10.1017/S0376892913000271>

Curtis, K.A., Moore, J.E., Benson, S.R., 2015. Estimating Limit Reference Points for Western Pacific Leatherback Turtles (Dermochelys coriacea) in the U.S. West Coast EEZ. PLoS ONE 10, e0136452. <https://doi.org/10.1371/journal.pone.0136452>

Dawson, H.A., Jones, M.L., Irwin, B.J., Johnson, N.S., Wagner, M.C., Szymanski, M.D., 2016. Management Strategy Evaluation of Pheromone-baited Trapping Techniques to Improve Management of Invasive Sea Lamprey. Natural Resource Modeling 29, 448–469. <https://doi.org/10.1111/nrm.12096>

Dichmont, C.M., Ellis, N., Bustamante, R.H., Deng, R., Tickell, S., Pascual, R., Lozano-Montes, H., Griffiths, S., 2013. Evaluating marine spatial closures with conflicting fisheries and conservation objectives. J Appl Ecol 50, 1060–1070. <https://doi.org/10.1111/1365-2664.12110>

Dichmont, C.M., Punt, A.E., Venables, W., Haddon, M., 2006. Management strategies for short lived species: The case of Australia’s Northern Prawn Fishery 3. Factors affecting management and estimation performance. Fisheries Research 11.

Ellis, N., Pantus, F., Welna, A., Butler, A., 2008. Evaluating ecosystem-based management options: Effects of trawling in Torres Strait, Australia. Continental Shelf Research 28, 2324–2338. <https://doi.org/10.1016/j.csr.2008.03.031>

Froehlich, H.E., Essington, T.E., McDonald, P.S., 2017. When does hypoxia affect management performance of a fishery? A management strategy evaluation of Dungeness crab ( *Metacarcinus magister* ) fisheries in Hood Canal, Washington, USA. Can. J. Fish. Aquat. Sci. 74, 922–932. <https://doi.org/10.1139/cjfas-2016-0269>

Fulton, E.A., Smith, A.D.M., Smith, D.C., Johnson, P., 2014. An Integrated Approach Is Needed for Ecosystem Based Fisheries Management: Insights from Ecosystem-Level Management Strategy Evaluation. PLoS ONE 9, e84242. <https://doi.org/10.1371/journal.pone.0084242>

Haddon, M., Helidoniotis, F., 2013. Legal Minimum Lengths and the Management of Abalone Fisheries. Journal of Shellfish Research 32, 197–208. <https://doi.org/10.2983/035.032.0126>

Harford, W.J., Grüss, A., Schirripa, M.J., Sagarese, S.R., Bryan, M., Karnauskas, M., 2018. Handle with Care: Establishing Catch Limits for Fish Stocks Experiencing Episodic Natural Mortality Events. Fisheries 43, 463–471. <https://doi.org/10.1002/fsh.10131>

Horbowy, J., 2011. Comparison of stock management with production, difference, and age-structured models using operating models. Fisheries Research 108, 153–162. <https://doi.org/10.1016/j.fishres.2010.12.015>

Irwin, B.J., Wilberg, M.J., Bence, J.R., Jones, M.L., 2008. Evaluating alternative harvest policies for yellow perch in southern Lake Michigan. Fisheries Research 94, 267–281. <https://doi.org/10.1016/j.fishres.2008.05.009>

Kell, L.T., Pilling, G.M., Kirkwood, G.P., Pastoors, M., Mesnil, B., Korsbrekke, K., Abaunza, P., Aps, R., Biseau, A., Kunzlik, P., Needle, C., Roel, B.A., Ulrich-Rescan, C., 2005. An evaluation of the implicit management procedure used for some ICES roundfish stocks. ICES Journal of Marine Science 62, 750–759. <https://doi.org/10.1016/j.icesjms.2005.01.001>

Klaer, N.L., Wayte, S.E., Fay, G., 2012. An evaluation of the performance of a harvest strategy that uses an average-length-based assessment method. Fisheries Research 134–136, 42–51. <https://doi.org/10.1016/j.fishres.2012.08.010>

Kolody, D., Polacheck, T., Basson, M., Davies, C., 2008. Salvaged pearls: lessons learned from a floundering attempt to develop a management procedure for Southern Bluefin Tuna. Fisheries Research 94, 339–350. <https://doi.org/10.1016/j.fishres.2008.08.016>

Kuykendall, K.M., Powell, E.N., Klinck, J.M., Moreno, P.T., Leaf, R.T., 2017. Management strategy evaluation for the Atlantic surfclam (Spisula solidissima) using a spatially explicit, vessel-based fisheries model. FB 115, 300–325. <https://doi.org/10.7755/FB.115.3.3>

Little, L.R., Grafton, R.Q., Kompas, T., Smith, A.D.M., Punt, A.E., Mapstone, B.D., 2010. Complementarity of No-Take Marine Reserves and Individual Transferable Catch Quotas for Managing the Line Fishery of the Great Barrier Reef: Marine Reserves and Catch Shares. Conservation Biology no-no. <https://doi.org/10.1111/j.1523-1739.2010.01590.x>

Little, L.R., Punt, A.E., Mapstone, B.D., Begg, G.A., Goldman, B., Ellis, N., 2009. Different responses to area closures and effort controls for sedentary and migratory harvested species in a multispecies coral reef linefishery. ICES Journal of Marine Science 66, 1931–1941. <https://doi.org/10.1093/icesjms/fsp164>

Plagányi, É.E., Skewes, T.D., Dowling, N.A., Haddon, M., 2013. Risk management tools for sustainable fisheries management under changing climate: a sea cucumber example. Climatic Change 119, 181–197. <https://doi.org/10.1007/s10584-012-0596-0>

Prellezo, R., Carmona, I., García, D., 2016. The bad, the good and the very good of the landing obligation implementation in the Bay of Biscay: A case study of Basque trawlers. Fisheries Research 181, 172–185. <https://doi.org/10.1016/j.fishres.2016.04.016>

Punt, A.E., Hobday, D., 2009. Management strategy evaluation for rock lobster, *Jasus edwardsii* , off Victoria, Australia: Accounting for uncertainty in stock structure. New Zealand Journal of Marine and Freshwater Research 43, 485–509. <https://doi.org/10.1080/00288330909510017>

Punt, A.E., McGarvey, R., Linnane, A., Phillips, J., Triantafillos, L., Feenstra, J., 2012a. Evaluating empirical decision rules for southern rock lobster fisheries: A South Australian example. Fisheries Research 115–116, 60–71. <https://doi.org/10.1016/j.fishres.2011.11.010>

Punt, A.E., Siddeek, M.S.M., Garber-Yonts, B., Dalton, M., Rugolo, L., Stram, D., Turnock, B.J., Zheng, J., 2012b. Evaluating the impact of buffers to account for scientific uncertainty when setting TACs: application to red king crab in Bristol Bay, Alaska. ICES Journal of Marine Science 69, 624–634. <https://doi.org/10.1093/icesjms/fss047>

Smith, D.R., McGowan, C.P., Daily, J.P., Nichols, J.D., Sweka, J.A., Lyons, J.E., 2013. Evaluating a multispecies adaptive management framework: must uncertainty impede effective decision-making? J Appl Ecol 50, 1431–1440. <https://doi.org/10.1111/1365-2664.12145>

Wetzel, C.R., Punt, A.E., 2015. Evaluating the performance of data-moderate and catch-only assessment methods for U.S. west coast groundfish. Fisheries Research 171, 170–187. <https://doi.org/10.1016/j.fishres.2015.06.005>

Wiedenmann, J., Wilberg, M., Sylvia, A., Miller, T., 2017. An evaluation of acceptable biological catch (ABC) harvest control rules designed to limit overfishing. Can. J. Fish. Aquat. Sci. 74, 1028–1040. <https://doi.org/10.1139/cjfas-2016-0381>

Williams, A.J., Little, L.R., Begg, G.A., 2011. Balancing indigenous and non-indigenous commercial objectives in a coral reef finfish fishery. ICES J Mar Sci 68, 834–847. <https://doi.org/10.1093/icesjms/fsr034>

### Climate Change

A’mar, Z.T., Punt, A.E., Dorn, M.W., 2009a. The evaluation of two management strategies for the Gulf of Alaska walleye pollock fishery under climate change. ICES Journal of Marine Science 66, 1614–1632. <https://doi.org/10.1093/icesjms/fsp044>

A’mar, Z.T., Punt, A.E., Dorn, M.W., 2009b. The impact of regime shifts on the performance of management strategies for the Gulf of Alaska walleye pollock (Theragra chalcogramma) fishery. Can. J. Fish. Aquat. Sci. 66, 2222–2242. <https://doi.org/10.1139/F09-142>

Brunel, T., Piet, G.J., van Hal, R., Röckmann, C., 2010. Performance of harvest control rules in a variable environment. ICES Journal of Marine Science 67, 1051–1062. <https://doi.org/10.1093/icesjms/fsp297>

Castillo-Jordán, C., Wayte, S.E., Tuck, G.N., Tracey, S., Frusher, S.D., Punt, A.E., 2019. Implications of a climate-induced recruitment shift in the stock assessment of Patagonian grenadier (Macruronus magellanicus) in Chile. Fisheries Research 212, 114–122. <https://doi.org/10.1016/j.fishres.2018.12.019>

Dorner, B., Peterman, R.M., Su, Z., 2009. Evaluation of performance of alternative management models of Pacific salmon (Oncorhynchus spp.) in the presence of climatic change and outcome uncertainty using Monte Carlo simulations. Can. J. Fish. Aquat. Sci. 66, 2199–2221. <https://doi.org/10.1139/F09-144>

Haltuch, M.A., A’mar, Z.T., Bond, N.A., Valero, J.L., 2019. Assessing the effects of climate change on US West Coast sablefish productivity and on the performance of alternative management strategies. ICES Journal of Marine Science 76, 1524–1542. <https://doi.org/10.1093/icesjms/fsz029>

Hofmann, E.E., Powell, E.N., Klinck, J.M., Munroe, D.M., Mann, R., Haidvogel, D.B., NarvÁEz, D.A., Zhang, X., Kuykendall, K.M., 2018. An Overview of Factors Affecting Distribution of the Atlantic Surfclam (Spisula solidissima), a Continental Shelf Biomass Dominant, During a Period of Climate Change. shre 37, 821–831. <https://doi.org/10.2983/035.037.0412>

Ianelli, J.N., Hollowed, A.B., Haynie, A.C., Mueter, F.J., Bond, N.A., 2011. Evaluating management strategies for eastern Bering Sea walleye pollock (Theragra chalcogramma) in a changing environment. ICES Journal of Marine Science 68, 1297–1304. <https://doi.org/10.1093/icesjms/fsr010>

Ives, M.C., Scandol, J.P., Montgomery, S.S., Suthers, I.M., 2009. Modelling the possible effects of climate change on an Australian multi-fleet prawn fishery. Mar. Freshwater Res. 60, 1211. <https://doi.org/10.1071/MF07110>

Kuykendall, K.M., Powell, E.N., Klinck, J.M., Moreno, P.T., Leaf, R.T., 2019. The effect of abundance changes on a management strategy evaluation for the Atlantic surfclam (Spisula solidissima) using a spatially explicit, vessel-based fisheries model. Ocean & Coastal Management 169, 68–85. <https://doi.org/10.1016/j.ocecoaman.2018.11.008>

Little, L.R., Lin, B.B., 2017. A decision analysis approach to climate adaptation: a structured method to consider multiple options. Mitig Adapt Strateg Glob Change 22, 15–28. <https://doi.org/10.1007/s11027-015-9658-8>

Merino, G., Arrizabalaga, H., Arregui, I., Santiago, J., Murua, H., Urtizberea, A., Andonegi, E., De Bruyn, P., Kell, L.T., 2019. Adaptation of North Atlantic Albacore Fishery to Climate Change: Yet Another Potential Benefit of Harvest Control Rules. Front. Mar. Sci. 6, 620. <https://doi.org/10.3389/fmars.2019.00620>

Plagányi, É.E., Skewes, T.D., Dowling, N.A., Haddon, M., 2013. Risk management tools for sustainable fisheries management under changing climate: a sea cucumber example. Climatic Change 119, 181–197. <https://doi.org/10.1007/s10584-012-0596-0>

Punt, A.E., 2011. The impact of climate change on the performance of rebuilding strategies for overfished groundfish species of the U.S. west coast. Fisheries Research 109, 320–329. <https://doi.org/10.1016/j.fishres.2011.02.019>

Wayte, S.E., 2013. Management implications of including a climate-induced recruitment shift in the stock assessment for jackass morwong (Nemadactylus macropterus) in south-eastern Australia. Fisheries Research 142, 47–55. <https://doi.org/10.1016/j.fishres.2012.07.009>

Weijerman, M., Fulton, E.A., Brainard, R.E., 2016. Management Strategy Evaluation Applied to Coral Reef Ecosystems in Support of Ecosystem-Based Management. PLoS ONE 11, e0152577. <https://doi.org/10.1371/journal.pone.0152577>

# Appendix B. MSE Review Data Collection

Data was collected and entered into database fields in the relation database containing three tables, tblStudy, tlbStudyObjectives, and tblStudyManagementTools (Table A.1).

We recorded information about who conducted the study, when and where, and what was studied in the ‘Documentation’ and ‘System’ field categories. The ‘Decision Analysis’ and ‘Decision Process’ fields recorded how the MSE process occurred and was documented. To be deemed explicit, at a minimum the MSE needed to report the results for that stage of the process. The problem definition, tradeoff, decision, and optimal alternatives – if reported – were deemed to be explicitly documented. What objectives and alternatives are evaluated in a decision analysis will depend on who the objectives and alternatives are elicited from. Therefore, the objectives and alternative stages were deemed to be explicitly documented if both the results of those stages, and the process used to elicit them, were reported in the MSE article.

We recorded how the tradeoff analysis occurred and who the objectives and alternatives (aka management procedures) were elicited from. These three fields were split into cases where the documentation was explicit, and where our subjective judgement was necessary to enter a value in the database. The …Exp fields hold the results of explicit document, while the …Sub fields hold the results for cases where our judgement was necessary.

The fields in tblStudyObjectives hold information related to objective documentation. In addition to having a clear category and type, a fully fleshed out objective will have a desired state or direction, scale, and metric of measurement. Wherever possible even if it was not explicit we provided these values.

The fields in tbleStudyManagementTools record the type of management tool considered, such as catch limits, effort limits, and a more detailed description of the management actions considered.

Table A.1 Relational Database Field Descriptions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Field Name | Field Category | Field Type | Table | Description |
| Authors | Documentation | Description | tblStudy | Abbreviated names of the authors of the study |
| YearPub | Documentation | Description | tblStudy | The year of publication from WOS citation |
| Species | System | Description | tblStudy | Common name and (*scientific name*) of target species |
| Location | System | Description | tblStudy | Name of the geographic area where the fishery is located |
| Latitude | Documentation | Lat. | tblStudy | Center point of the geographic area the MSE applies to (latitude) per Google Maps |
| Longitude | Documentation | Long. | tblStudy | Center point of the geographic area the MSE applies to (longitude) per Google Maps |
| System | System | Description | tblStudy | A short description of the study system. For example, the common name of the fishery or a combination of the target species and the fishery location |
| Drivers | System | List | tblStudy | System drivers included in the operating model, e.g., climate change, environmental conditions, predation, species interactions, etc. |
| ProcessExplicit | Decision Analysis | Yes/No | tblStudy | Was the decision process methodology documented clearly? |
| ProblemDefinitionExplicit | Decision Analysis | Yes/No | tblStudy | Was a problem definition completed and documented? |
| ObjectivesExplicit | Decision Analysis | Yes/No | tblStudy | Were objectives elicited and documented clearly? |
| AlternativesExplicit | Decision Analysis | Yes/No | tblStudy | Were alternatives elicited and documented clearly? |
| TradeOffsExplicit | Decision Analysis | Yes/No | tblStudy | Was a tradeoff analysis conducted and documented? |
| DecisionExplicit | Decision Analysis | Yes/No | tblStudy | Was the decision of the process documented? |
| OptimalAltExplicit | Decision Analysis | Yes/No | tblStudy | Was the best management procedure, aka optimal alternative, documented? |
| RoleSpecification | Decision Process | Yes/No | tblStudy | Were roles assigned and documented? |
| OpenMeetings | Decision Process | Yes/No | tblStudy | Were open meetings held? |
| ResultsAdopted | Decision Process | Yes/No | tblStudy | Did the MSE influence subsequent management? |
| ProblemDefinition | Decision Analysis | Description | tblStudy | A problem definition taken from the documentation (Often requiring extrapolation by the reviewer) |
| ObjElicitationMethod | Decision Analysis | Description | tblStudy | If documented, how were objectives elicited? |
| TradeOffMethod\_Exp | Decision Analysis | Description | tblStudy | If explicitly documented, what form of tradeoff analysis occurred? |
| TradeOffMethod\_Sub | Decision Analysis | Description | tblStudy | If not explicitly documented, what form of tradeoff analysis seemingly occurred? |
| Decision | Result | Description | tblStudy | If documented, the management procedure that was selected for implementation |
| Leader | Decision Process | List | tblStudy | What organization initiated and directed the MSE process? |
| Participants | Decision Process | List | tblStudy | Who, or what organizations, participated in the MSE process? |
| ObjElicitationSource\_Exp | Decision Process | List | tblStudy | If explicitly documented, who were objectives elicited from? |
| ObjElicitationSource\_Sub | Decision Process | List | tblStudy | If not explicitly documented, who were objectives seemingly elicited from? |
| ProcedureElicitation\_Exp | Decision Process | List | tblStudy | If explicitly documented, who were alternative management procedures elicited from? |
| ProcedureElicitation\_Sub | Decision Process | List | tblStudy | If not explicitly documented, who were alternative management procedures elicited from? |
| ConsequencePrediction | Decision Process | List | tblStudy | What method was used to predict the consequences, (e.g., simulation modelling, expert elicitation, etc.)? |
| FullCitation | Documentation | Description | tblStudy | The full citation for the study |
| DOI | Documentation | ID | tblStudy | The Digital Object Identifier for the study |
| Comments | Comments | Description | tblStudy | Additional notes and comments about the study |
| ObjName | Objectives | Description | tblStudyObjectives | Text description of the objective |
| ObjCategory | Objectives | List | tblStudyObjectives | The objective category (conservation, yield, economic, social, utility) |
| ObjDescription | Objectives | Description | tblStudyObjectives | Description of the objective |
| ObjDirection | Objectives | List | tblStudyObjectives | The desired state of the objective |
| ObjType | Objectives | List | tblStudyObjectives | The type of objective. E.g., strategic, process, fundamental, or means |
| ObjScale | Objectives | Description | tblStudyObjectives | The scale on which the objective is measures (natural, proxy, or constructed) |
| ObjMetric | Objectives | Description | tblStudyObjectives | The units used to measure the objective |
| MPManagementTool | Alternatives | List | tblStudyManagementTools | Types of alternatives evaluated. E.g., catch limit, effort limit, closure, size limit, access control |
| MPAlternativesEvaluated | Alternatives | Description | tblStudyManagementTools | More detailed text description of the alternatives considered |