Scenario Planning

Overview
Even the best predictions often turn out to be off. Scenario planning is a tool that, rather than predicting a specific future, allows participants to create and explore a set of plausible future scenarios that could happen. It can identify uncertainties and help to find solutions and approaches that can be useful in multiple possible futures.[1] Perhaps the most famous example of scenario planning is by Shell Oil, who successfully anticipated and navigated price shocks in the oil market using the tool.[2] Scenario planning can be driven by researchers or by a participatory process[3]; the focus here is on the latter type. Typically, a participatory scenario planning process engages people from different perspectives to enrich the exploration of these plausible futures.

Why it is relevant to climate-ready fisheries
Climate change is creating unprecedented challenges for fisheries and for fishery managers and affects every part of the management system. Scenario planning is helpful when considering an uncertain future and how to move forward. Many natural resource managers have used scenario planning to enable stronger decision-making in uncertain contexts, like climate change. When done in an inclusive and effective manner, scenario planning can also increase buy-in of stakeholders and encourage broader participation from groups that tend to be less active in the management process.

Quick Facts

Overview: Scenario planning is a process that engages stakeholders to explore plausible future scenarios and consider potential actions to respond

Key characteristics: Stakeholder engagement, long-term planning, qualitative

Limitations: Takes 2-3 years to complete; does not necessarily result in recommendations for changes to management

Outcome: A set of scenarios that describe possible futures and strategies and actions that can work in multiple scenarios

How Councils can use it
A few Councils are currently using scenario planning to explore resilience to climate change in a regionally relevant context. Through an initiative or process, a Council could engage in scenario planning to identify how to move forward given the uncertainties of climate change for fishery management. Scenario planning could also be used to inform a management strategy evaluation process. NOAA Fisheries has worked on scenario planning in several contexts and would be a useful partner for any Council embarking in a scenario planning effort.

Finally, a Council could revisit the scenario planning process over time. In doing so, a Council could consider how different possible futures could influence a management decision on the table and evaluate whether a proposed change in management would make the system more or less responsive to changes in the future.[4]

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[1] Frens, Kathryn M., and Wendy E. Morrison. 2020. Scenario Planning: An Introduction for Fishery Managers. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OSF-9, at 1.
[2] National Park Service, 2013. Using Scenarios to Explore Climate Change: A Handbook for Practitioners. National Park Service Climate Change Response Program. Fort Collins, Colorado at 6.
[3] Star, J. et al. 2016. Supporting adaptation decisions through scenario planning: Enabling the effective use of multiple methods. *Climate Risk Management* 13: 88–94.
[4] Frens, Kathryn M., and Wendy E. Morrison. 2020. Scenario Planning: An Introduction for Fishery Managers. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OSF-9, at 6.

Strengths and limitations
Scenario planning is especially helpful for planning for unexpected changes that would be unlikely to be part of predictive models and in cases where much is out of the control of managers. The process can make management more adaptive. However, if current uncertainties are too overwhelming, it can hinder the value of the tool because the future can seem irrelevant to those involved.[5] One limitation is that managers still must find ways to translate the solutions identified by the scenario planning process into tangible management actions. Finally, the benefits around stakeholder buy-in and collaboration will only materialize if the process is carefully considered and run.

Outcomes
At the end of a scenario planning effort, Councils can expect to have a set of plausible future scenarios that can be used to think about possible management actions or changes. In addition, the process can also include identification of a set of tools or strategies that are robust across scenarios. Arguably, scenario planning is as much about the process as the end results, and one central outcome should be increased trust and engagement of resources users in the management process.

Considerations (e.g., funding, time, data needed)
Scenario planning is a significant investment of effort and time. Costs will vary, but many groups have found it helpful to have an experienced facilitator to guide the process, as well as a core team who can help with logistics and structure of the process. While there are a commonly followed set of steps that scenario planning processes tend to use, these should be modified as needed to meet the goals of a specific project or group.

Example
The Pacific Fishery Management Council (PFMC) recently completed the Climate and Communities Initiative under its Fishery Ecosystem Plan (FEP). This initiative relied heavily on scenario planning. The goal of the initiative was to identify actions the Council could take in the near term to be more prepared for future climate change-driven events and impacts on West Coast fisheries and communities. The Council initiated its scenario planning process in early 2019, and the process completed in 2021.

There were several steps for the scenario planning process: First, the Council established the project and researched drivers of change that could inform the work. The Council formed a core team to manage the process and decided to focus on the topic of shifting stock availability (including shifting distribution) across species, fishery management plans, and communities. The Council set a goal of defining tools, products, and processes necessary to react to potential future ecosystem states resulting from climate variability and climate change in the next 20 years.

Then, the Council held a workshop with scientists, fishery experts and stakeholders to develop four alternative scenarios about what West Coast fishing communities might look like in 2040. The core team added more detail to those scenarios in partnership with the Council and its advisory bodies. These "deepened" scenarios were presented to stakeholders in a series of virtual workshops in late 2020 and early 2021. Using the scenarios, workshop participants considered the implications of possible changes described and identified actions the Council and stakeholders could take in response. The Council is currently adopting management actions and next steps based on what was identified by stakeholders.

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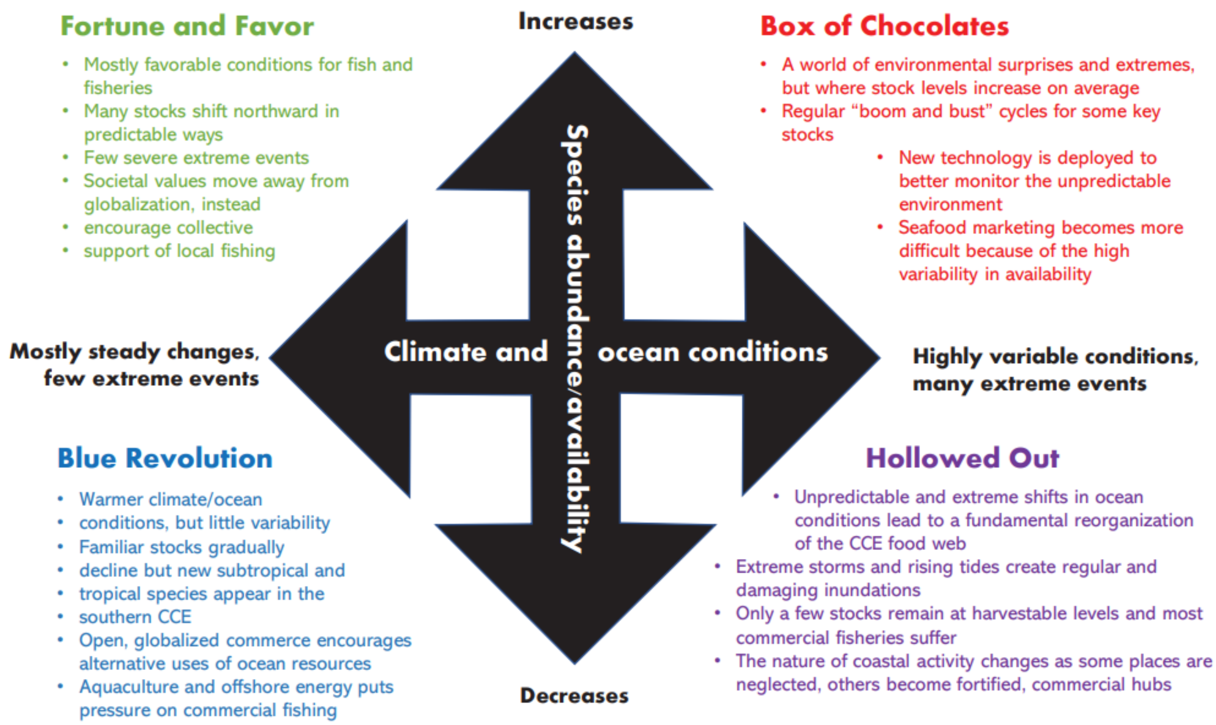
[5] Frens, Kathryn M., and Wendy E. Morrison. 2020. Scenario Planning: An Introduction for Fishery Managers. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OSF-9, at 5.



Four scenarios identified by the Pacific Council's Scenario Planning process. The scenarios are determined by two axes: species abundance and availability and climate and ocean conditions. Graphic available at: https://www.pcouncil.org/documents/2020/11/scenarios-for-west-coast-fisheries-climate-and-communities-initiative.pdf/

The process at the Pacific Council was improved by bringing a scenario planning expert on board to facilitate and guide the process. One challenge for the Council was meeting its goal of bringing a diverse set of stakeholders to the table to provide input; it tended to be that the stakeholders involved were those already very engaged in management and the Council process.

Resources

Scenario Planning: An Introduction for Fishery Managers (National Marine Fisheries Service, 2020)
https://www.fisheries.noaa.gov/resource/document/scenario-planning-introduction-fishery-managers

Using Scenarios to Explore Climate Change: A Handbook for Practitioners (National Parks Service, 2013)
https://www.nps.gov/parkhistory/online_books/climate/CCScenariosHandbookJuly2013.pdf

Climate and Communities Initiative webpage (Pacific Fishery Management Council):
https://www.pcouncil.org/actions/climate-and-communities-initiative/

East Coast Climate Change Scenario Planning webpage (Mid-Atlantic Fishery Management Council):
https://www.mafmc.org/climate-change-scenario-planning

Four Possible Climate Futures for West Coast Fisheries (Ocean Conservancy):
https://oceanconservancy.org/sustainable-fisheries/take-deep-dive/four-possible-climate-futures-west-coast-fisheries/

Management Strategy Evaluation

Quick Facts

Overview: Management strategy evaluation can be used for many purposes, but it primarily helps managers understand trade-offs and performance of different management strategies using a set of models

Key characteristics: Adaptable, modeling, collaborative, and iterative

Limitations: Depends on data availability and usefulness of management objectives being tested; can be a lengthy process; not always transparent to stakeholders

Outcome: Results that describe performance of different strategies relative to objectives

Overview

Management Strategy Evaluation (MSE) is an analytical technique that uses simulation to compare different strategies under a range of possible future realities and identify performance in relation to management objectives.[1] It accomplishes this by simulating the entire management system from data collection to management action. It can clarify how to make decisions that are most likely to achieve management objectives given uncertainty. It was developed to implement adaptive management of natural resources and has been used for a wide variety of applications in fisheries.[2]

Why it is relevant to climate-ready fisheries

MSE can identify trade-offs, explore the impacts of uncertainty or management assumptions, and allow managers to understand the performance of different possible management strategies. In a nutshell, it allows managers identify approaches that are likely to work and eliminate those that will not.

MSEs were originally used for management of single species and with limited inclusion of ecological processes in the analysis. More recently, however, MSE has been used to evaluate strategies to meet multi-species or ecosystem objectives as part of ecosystem-based fisheries management (EBFM). With these advances in MSE, it is possible to use the tool to address several questions around the impacts of climate change. MSEs can integrate ecosystem and climate information to answer questions regarding climate impacts on stocks and stock assessments, evaluate the performance of climate-informed reference points and harvest control rules, assess spatial management options, and explore how surveys and monitoring could be improved in response to climate change.[3]

How Councils can use it

Councils can use MSE for answering many questions of interest, so a first step is identifying the question and scope for the process. For example, one consideration may be whether the underlying model requires a single-species stock assessment or more complicated ecosystem models. This step could be conducted in partnership with a Council's relevant NOAA Fisheries' Science Center. NOAA Fisheries is a key partner for Councils in the MSE process, and the agency and its Integrated Ecosystem Assessment program have identified MSE as a critical tool for climate-ready and ecosystem-based management. The agency is developing a shared set of resources (e.g., model code and lessons learned) from previous MSEs, which holds potential to facilitate faster and easier implementation of new MSEs.[4]

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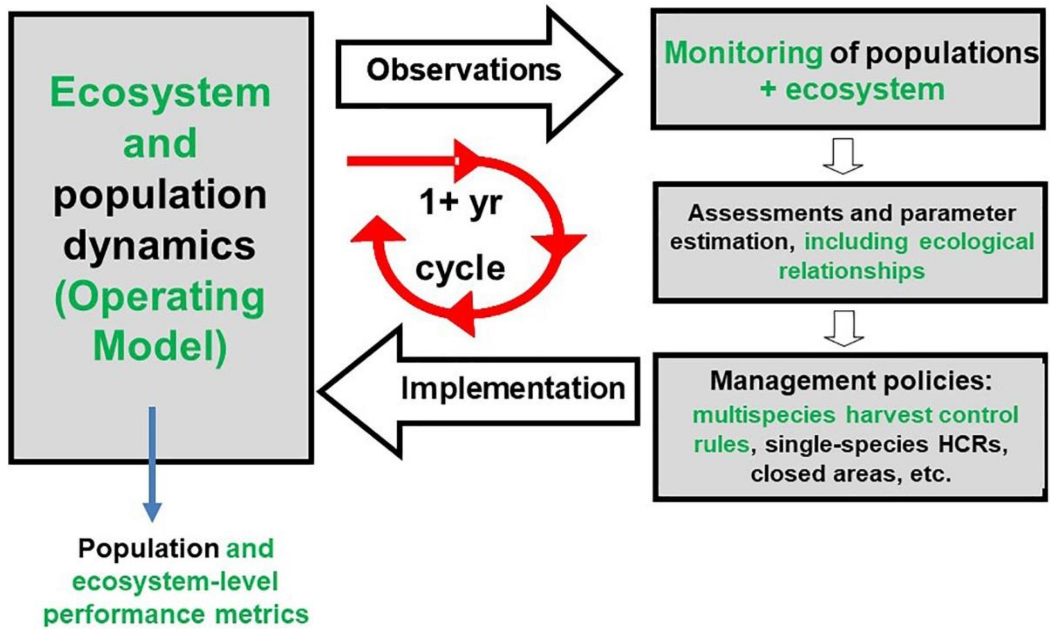
[1] Punt, A. E., et al. 2016. Management strategy evaluation: Best practices. *Fish and Fisheries* 17(2):303–334.
[2] Kaplan, I.C., et al. 2021. Management Strategy Evaluation: Allowing the Light on the Hill to Illuminate More Than One Species. *Front. Mar. Sci.* https://doi.org/10.3389/fmars.2021.624355
[3] *Id.*
[4] *Id.*



The "MSE loop" from Kaplan et al. 2021. MSE iteratively tests performance of monitoring, assessment and policies (right side) within the simulated 'virtual world' of the operating model (left side). Text in green highlights some of the ecosystem aspects that can be incorporated into each step of the MSE loop.

Once an MSE has been initiated, there is a general series of steps in the process.[5]

1. Identify management objectives and ways to quantify them. Decision-makers, like Councils, must identify the outcomes they are trying to achieve and how they can be measured. This can be done through workshops in partnership with managers and analysts.
2. Identify uncertainties (e.g., biological, environmental, in the fishery, in management). The key uncertainties considered in MSE can be consequential for the performance of different strategies, and the best strategies in the MSE should be robust to these uncertainties. Managers should be a part of determining uncertainties based on their fishery knowledge.
3. Develop a set of models and select parameters. Scientists develop operating models, which represent the system (the fish population, the fishery, etc.), and an implementation model, which reflects how management regulations are applied in practice. Models are then conditioned, where performance is compared to available data and parameters are adjusted as needed.
4. Identify candidate management strategies. These strategies should be ones that can realistically be implemented in the fishery. Managers should be involved in selecting these strategies. Often, some strategies will reflect current management practice, such as a current harvest control rule for the fishery, while others are novel and can be evaluated for their efficacy in achieving the stated goals.
5. Run simulations. Simulations include the application of each strategy to each operating model over a set number of years and for repeated runs. These simulations generate the data on how the strategies perform.
6. Summary and interpretation of the performance statistics. The results of the simulations and the performance of the candidate strategies relative to the predetermined management

[5] Adapted from Punt, A.E., et al. 2016.

objectives should be communicated and poorly performing strategies can be eliminated. The trade-offs in the remaining strategies can be explored by managers and the Council. The results may lead to refinement of the MSE in an iterative process.

Strengths and limitations

MSE is increasingly becoming a tool of choice for those looking to evaluate management in relation to management objectives and is well-suited to enable managers to consider adaptive options for management in response to climate change.[6] While the quantitative requirements of MSE used to be a hurdle for use, the tool has become much more accessible in recent years.

One strength of MSE is that it works iteratively to take the reaction of management into account as things change in the operating model. It is also highly adjustable and is capable of handling uncertainty and data limitations. However, an MSE is only as good as what goes into it. If the management strategies evaluated are not carefully selected and uncertainty is not adequately captured, the results will not be as useful as other approaches.

Outcomes

At the most basic level, MSE offers a clear sense of how different management strategies perform, including which perform poorly. In the MSE, managers and stakeholders also undergo a process to clarify management objectives, which can build shared understanding. It is also worth noting that MSE can be used as an exercise to inform a traditional assessment and management approach or can be used as an approach implemented on its own as part of managing a fishery.

Considerations (e.g., funding, time, data needed)

To be successful, MSE takes ongoing and close collaboration between managers and scientists and a clear sense of the responsibilities and outputs of each group. Strong facilitation (ideally by a trained facilitator) is valuable throughout the process. Stakeholders must be a part of the process, particularly if the MSE seeks to address complex ecosystem-level questions, and they are critical for the development of management objectives.[7] Engagement must be fostered by efforts to educate stakeholders on the process and the terminology used to ensure the MSE results are transparent for all. Overall, MSEs tend to require a substantial time investment on the part of all involved. As an iterative process, stakeholders and decision-makers must engage multiple times.[8] For analysts, MSEs tend to require considerable quantitative expertise. Depending on the complexity of the operating model, MSE can be also be quite data intensive.

Example

There are a range of examples of how MSE has been used to incorporate climate and ecosystem information. One example is in the Pacific hake fishery. Pacific hake, or whiting, is the largest groundfish fishery on the West Coast, and it is partly managed by the Joint Management Committee (JMC) under an international treaty between the United States and Canada. Scientists from both nations have used MSE as a tool to understand various aspects of the fishery and inform management.

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[6] Link, J.S., Griffis, R. and S. Busch (Eds.). 2015. NOAA Fisheries Climate Science Strategy. U.S. Dept. Commer. NOAA. NOAA Technical Memorandum NMFS-F/SPO-155.

[7] Kaplan, I.C., et al. 2021.

[8] Gaichas, S.K., et al. 2016. A Framework for Incorporating Species, Fleet, Habitat, and Climate Interactions into Fishery Management. *Front. Mar. Sci.* https://doi.org/10.3389/fmars.2016.00105

A recent MSE effort on Pacific hake was to evaluate the performance of the current management procedure in the fishery under hypotheses about current and future environmental conditions.[9] Scientists at NOAA Fisheries and the Fisheries and Oceans Canada worked with the JMC, which appointed an MSE Working Group as the primary way to engage on the effort. The group worked collaboratively to develop management objectives and performance metrics that were focused on stock status, coastwide catch, catch variability, and spatially explicit exploitation rates.[10] They next created a model that allowed for spatial movement of hake across areas.

To understand how climate change might influence future performance of management, the group developed and tested a few scenarios, including looking at the potential implications of more fish shifting northward as a result of climate change (and fewer fish moving southward). The MSE results indicated that scenarios with larger increases in movement rates meant more variable catch and a lower median long-term catch.[11] The changes were relatively small, and the results suggested the current harvest control rule was fairly robust to the climate scenarios, but more extreme movement could make it more difficult to reach full attainment of quotas in the future.[12]

The project took a few years and was able to build on a previous MSE developed for the fishery. During the process, model output from the MSE was presented multiple times to the management bodies, allowing for input and feedback.[13] The project provided managers with an understanding of how influential climate scenarios might be on stock management and indicated places to explore future adaptation. The next iteration of work on the MSE will aim to capture more realistic movement shifts in the stock.

Resources

Sixth National SCS Workshop: The Use of Management Strategy Evaluation (MSE) to Inform Management Decisions Made by the Regional Fishery Management Councils (Scientific Coordination Subcommittee):
http://www.fisherycouncils.org/ssc-workshops/sixth-national-ssc-workshop-2018

California Marine Life Management Act (MLMA) Master Plan. Appendix L, Guidance for Conducting Management Strategy Evaluation:
https://wildlife.ca.gov/Conservation/Marine/MLMA/Master-Plan/Mgmt-Strategy-Eval

Evaluate Management Strategies, NOAA Integrated Ecosystem Assessment Step 5 (NOAA Integrated Ecosystem Assessment):
https://www.integratedecosystemassessment.noaa.gov/national/management-strategy-evaluations

[9] Kaplan, I.C., et al. 2021.
[10] Jacobsen, N. S., et al. 2021. Management Strategy Evaluation of Pacific Hake: Exploring the Robustness of the Current Harvest Policy to Spatial Stock Structure, Shifts in Fishery Selectivity, and Climate-Driven Distribution Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-NWFSC-168.
[11] *Id.*
[12] Kaplan, I.C., et al. 2021.
[13] *Id.*

Risk Assessment

Overview

Risk assessment is a general and widely used tool that is intended to identify the probability of undesirable events and their potential consequences.[1] Used in the business context, it has been covered by the International Standards Organization (ISO) standard 31000, which bases the assessment process on identification, analysis, and evaluation to determine if intervention is needed to meet management objectives given risk.[2]

Risk assessments have been used in fisheries, particularly within ecosystem-based management frameworks, by characterizing the likelihood and consequences of multiple different pressures on an ecosystem and the cumulative impacts. While the tool has traditionally been a quantitative one, it can also be done more qualitatively.

> ***Quick Facts***
>
> *Overview:* A tool that enables managers to understand risks of undesirable events and prioritize actions to minimize or mitigate risk
>
> *Key characteristics:* Flexible, prioritizing, and conceptually intuitive
>
> *Limitations:* Few limitations, but generally risk assessment does not identify specific management actions to address risks
>
> *Outcomes:* Understanding of risks and vulnerability to those risks, way to prioritize action, can identify data gaps and research needs

Why it is relevant to climate-ready fisheries

Risk assessment can be used to better understand the risks posed to fisheries (and to the ecosystem and participants) by climate impacts, as well as understand interactions between climate and the ecosystem and fishery. Understanding of risks and their consequences can be used to prioritize management. By linking risks with indicators, managers can also identify where there are interventions needed and data gaps to be addressed.

How Councils can use it

There are many different types of risk assessment. Ecological Risk Assessments are a type of assessment that is focused on potential unintended impacts from fishing or other pressures.[3] Ecosystem Risk Assessments evaluate the cumulative impacts of multiple pressures on multiple ecosystem components, including the risk to both biological and human communities. Climate vulnerability assessments are a specific type of risk assessment that are focused on sensitivity and exposure to climate impacts.[4]

Councils can undertake a risk assessment process to understand the threats to a fishery, fishing community or even the ecosystem, and use that information to prioritize management action.

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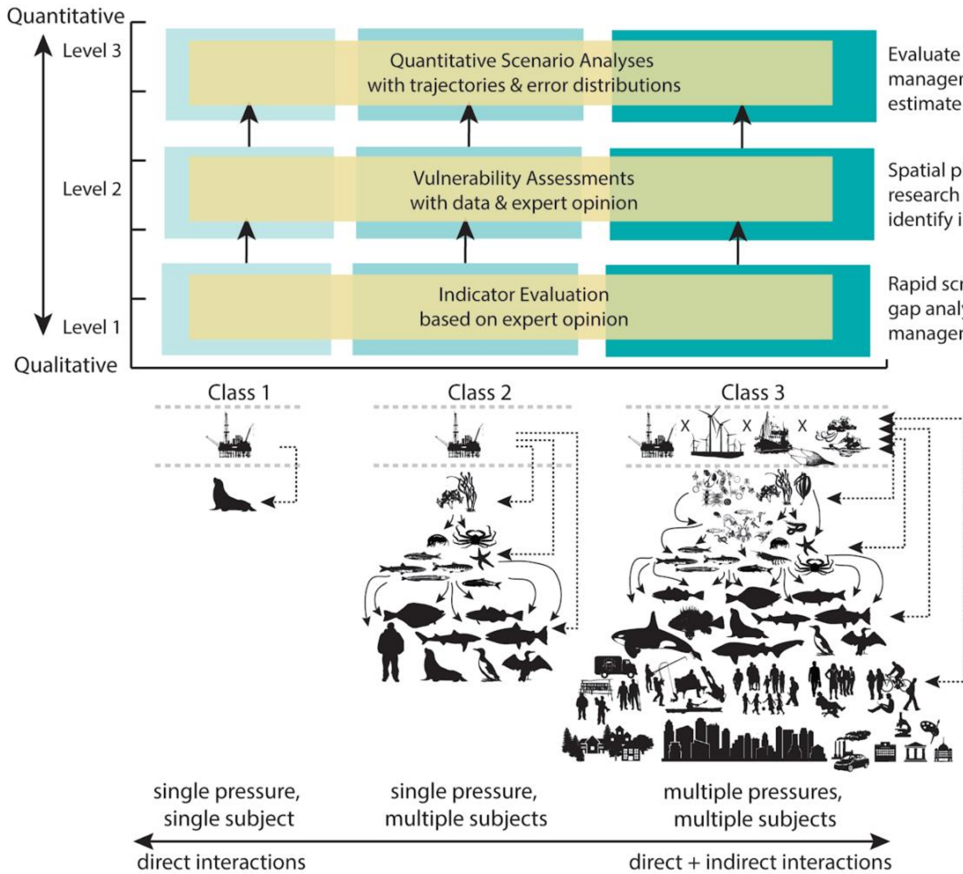
[1] Holsman, K., et al. 2017. An ecosystem-based approach to marine risk assessment. *Ecosystem Health and Sustainability*. 3(1):e01256. 10.1002/ehs2.1256

[2] Gaichas, S.K., et al. 2016. A Framework for Incorporating Species, Fleet, Habitat, and Climate Interactions into Fishery Management. *Front. Mar. Sci.* https://doi.org/10.3389/fmars.2016.00105

[3] Samhouri, J., et al. 2017. An ecosystem-based risk assessment for California fisheries co-developed by scientists, managers, and stakeholders. *Biological Conservation* 231: 103-121.

[4] Karp, M. A., J. Peterson, P. D. Lynch, and R. Griffis (editors). Accounting for Shifting Distributions and Changing Productivity in the Fishery Management Process: From Detection to Management Action. 2018. U.S. Dept. of Commer. NOAA. NOAA Technical Memorandum NMFS-F/SPO-188, 37 p.

As a first step, a Council should decide on the focus of the assessment. Given that Councils often have limited time and resources, one possible approach is to assess risk in a sequential or tiered fashion (see schematic below). A first analysis (level 1) identifies the risk of different species (or other subjects such as fishing communities or habitats). From there, the at-risk group would be considered for further analysis (level 2), and the species (or other subjects) found to be of the highest risk would be prioritized for more quantitative assessments and modeling (level 3).[5]



This schematic can be used to help identify the type of risk assessment desired. The levels range from qualitative (level 1) to quantitative (level 3). The class refers to the number of pressures and subjects considered in the assessment. The classes range from a single pressure on a single subject (e.g., the impact of fishing on a marine mammal species) to multiple pressures on multiple subjects (e.g., the impacts of multiple climate factors on an ecosystem). Graphic from (Holsman et al. 2017).

A risk assessment process can easily be coordinated with the general format of Council meetings and engage the Council, advisory bodies, and stakeholders. In addition, risk assessment can use existing data that the Council is familiar with, such indicators from an Ecosystem Status Report, and the results of the assessment can be updated as new information is available.

Strengths and limitations

Risk assessment is a flexible tool with few limitations. Risk assessment can be rapid, can be applied to various levels of interest—from species and community through ecosystem—and tends to be a

[5] After Holsman, K. et al., in Karp, M.A., et al. 2018.

relatively straightforward approach for managers and stakeholders to understand.[6] An effective process can strengthen stakeholder engagement and trust.

Outcomes

The increased understanding of risks to achieving management objectives is the primary outcome, but risk assessment also produces a strategic framework with which to make management decisions. The understanding of risks and tradeoffs can be used to inform a management strategy evaluation process.

Considerations (e.g., funding, time, data needed)

Risk assessment is likely to be most effective and efficient when it follows existing standards and protocols. There are many potential approaches under risk and vulnerability assessment, and it may be beneficial to seek expert input when selecting an approach. NOAA Fisheries would be a valuable partner for a Council; in particular, NOAA's Integrated Ecosystem Assessment program has extensive experience conducting risk assessments and is a conceptual leader in this area.

While risks from climate change impacts could be a central component of a risk assessment, Councils may want to consider risks from other factors in conjunction with climate for a more complete picture.

Example

The Mid-Atlantic Fishery Management Council completed an ecosystem-level risk assessment as part of its ecosystem approach to fisheries management (EAFM). The Council was interested in understanding and incorporating species, fleet, habitat and climate interactions into its management and science programs as part this approach.[7] To this end, the Council finalized its EAFM guidance in 2016, and embarked on developing the risk assessment from 2016-2017.[8]

Through review of existing policies and in discussions with the Council members, advisory bodies, stakeholders, and experts, Council staff identified several relevant "risk elements" that were binned as being ecological, economic, social, or related to food production or management. These groups of risk elements roughly aligned with different management objectives of the Council. For each risk element, a definition was developed describing what was at risk (e.g., failing to achieve optimum yield due to climate variability). Managers also had to decide *what* was going to be assessed for risk (e.g., species, sector, or ecosystem).[9] The Council ultimately selected 25 risk elements and indicators, and assessed risk for managed species, species/sector, and the whole ecosystem. Climate was included as its own risk element, but was also reflected in other elements, like system productivity and species distribution shifts. The climate indicator was based on NOAA Fisheries' Northeast Climate Vulnerability Assessment.

Each risk element was connected to an indicator that made it measurable; many of these indicators were already included in the annual Ecosystem Status Report produced by the regional Integrated Ecosystem Assessment program or in other available sources.[10] For each indicator, the group established

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[6] Gaichas, S.K., et al. 2018. Implementing Ecosystem Approaches to Fishery Management: Risk Assessment in the US Mid-Atlantic. *Front. Mar. Sci*. https://doi.org/10.3389/fmars.2018.00442.

[7] Mid-Atlantic Fishery Management Council. 2021. Mid-Atlantic EAFM Risk Assessment: 2021 Update. Available at: https://www.mafmc.org/eafm

[8] Gaichas, S.K., et al. 2018. Implementing Ecosystem Approaches to Fishery Management: Risk Assessment in the US Mid-Atlantic. *Front. Mar. Sci*. https://doi.org/10.3389/fmars.2018.00442.

[9] *Id.*

[10] *Id.*

criteria that could be used to judge the level of risk, from low to high. Applying these criteria gave the Council a score for each risk element and allowed the elements to be ranked.

A final outcome from the effort was the development of a ranked list of risk elements. The Council has used the ranked list to prioritize key interactions of interest in the ecosystem for further research, analysis, and management attention. This prioritization is important given the number of interactions the Council could consider and limited resources to explore the interactions. Specific questions of interest were identified for high priority interactions, and those questions will be answered using more quantitative analysis (including management strategy evaluation) with the idea to implement changes to management.

Each year, the status of the various risk elements is updated if there is new information (see tables below for the latest update). In addition, the entire approach is intended to be dynamic, and the risk elements may change over time, as could the indicators or the levels set for the risk criteria.[11]

Table 3: Species level risk analysis results; l=low risk (green), lm= low-moderate risk (yellow), mh=moderate to high risk (orange), h=high risk (red)

Species	Assess	Fstatus	Bstatus	FW1Pred	FW1Prey	FW2Prey	Climate	DistShift	EstHabitat
Ocean Quahog	l	l	l	l	l	l	h	mh	l
Surfclam	l	l	l	l	l	l	mh	mh	l
Summer flounder	l	l	lm	l	l	l	lm	mh	h
Scup	l	l	l	l	l	l	lm	mh	h
Black sea bass	l	l	l	l	l	l	mh	mh	h
Atl. mackerel	l	h	h	l	l	l	lm	mh	l
Butterfish	l	l	lm	l	l	l	l	h	l
Longfin squid	lm	lm	lm	l	l	lm	l	mh	l
Shortfin squid	lm	lm	lm	l	l	lm	l	h	l
Golden tilefish	l	l	lm	l	l	l	mh	l	l
Blueline tilefish	h	h	mh	l	l	l	mh	l	l
Bluefish	l	l	h	l	l	l	l	mh	h
Spiny dogfish	lm	l	lm	l	l	l	l	h	l
Monkfish	h	lm	lm	l	l	l	l	mh	l
Unmanaged forage	na	na	na	l	lm	lm	na	na	na
Deepsea corals	na	na	na	l	l	l	na	na	na

Table 4: Ecosystem level risk analysis results; l=low risk (green), lm= low-moderate risk (yellow), mh=moderate to high risk (orange), h=high risk (red)

System	EcoProd	CommRev	RecVal	FishRes1	FishRes4	FleetDiv	Social	ComFood	RecFood
Mid-Atlantic	lm	mh	h	l	mh	l	lm	h	mh

The Mid-Atlantic Council's updated risk tables for 2021, including for species (Table 3) and for the ecosystem (Table 4).

Resources

Ecosystem Approach to Fisheries Management (Mid-Atlantic Fishery Management Council): https://www.mafmc.org/eafm

Assess Risk, NOAA Integrated Ecosystem Assessment Step 4 (NOAA Integrated Ecosystem Assessment): https://www.integratedecosystemassessment.noaa.gov/national/risk-analysis

[11] *Id.*

Climate-ready or Climate-smart Harvest Control Rules

Overview

Harvest control rules (HCRs) describe pre-set fishery management actions that occur in response to designated triggers, conditions, indicators, or reference points. These rules are already common and important in fishery management as a way to deal with uncertainty in setting catch limits and connect science to management decisions.[1] Climate-ready or climate-smart harvest control rules take this framework and bring ecological and climate information into consideration. HCRs can promote stock resilience, react to current conditions, and incorporate long-term climate conditions into management decisions.

NOAA's 2015 Climate Science Strategy defines climate-smart harvest control rules as "a set of well-defined pre-agreed rules or actions used for determining a management action in response to changes in indicators of stock status…based on reference points that incorporate climate considerations in their estimation, and/or account for climate impacts in adjustments to their rules, policy or actions."[2] Climate-ready HCRs can be either mechanistic or empirical.[3]

> ***Quick Facts***
>
> *Overview:* HCRs are a central part of management. If chosen effectively, HCRs can promote stock resilience and/or reflect climate information in management decisions
>
> *Key characteristics:* adaptable, familiar, precautionary, responsive
>
> *Limitations:* Need to periodically reassess underlying assumptions. Climate-smart HCRs may be difficult to implement unless a strong link between stock and environment is known
>
> *Outcomes:* Set of pre-agreed on rules for management that are reflective of environmental conditions and stock status and are intended to meet management objectives

Why it is relevant to climate-ready fisheries

In general, HCRs fit well into a precautionary management framework and are helpful for making management more responsive to changes, which is valuable in a climate context. HCRs are a key point where scientific information is translated into policy decisions for fisheries. They can also be used to reduce political pressure around management decisions in an uncertain context. There are three ways in which harvest control rules are relevant for climate-ready fisheries:

- First, managers can develop and implement "traditional" HCRs that are precautionary and expected to perform well under predicted climate change impacts (e.g., by improving stock resilience to disruptions or rebuilding to higher biomass targets).
- Second, existing HCRs can be coupled with climate-informed stock assessments.
- Finally, climate-informed HCRs can be developed to explicitly include and act on environmental information. These are the least common but most direct in the link between environmental and stock status and catch advice.

How Councils can use it

HCRs are a framework, there are many ways they are applied across fisheries, and the Councils already broadly use HCRs in management. HCRs may already reflect ecological considerations to some degree if

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[1] Kvamsdal, S.F. et al. 2016. Harvest control rules in modern fisheries management. *Elementa: Science of the Anthropocene.* 4: 000114 doi: 10.12952/journal.elementa.000114

[2] Link, J.S., Griffis, R. and S. Busch (Eds.). 2015. NOAA Fisheries Climate Science Strategy. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-F/SPO-155, 70p.

[3] Punt, A.E., et al. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. *ICES Journal of Marine Science* 71(8): 2208–2220

they are responsive to estimates of stock status from assessments that include ecological and environmental information. Assessments that directly observe recruitment, rather than back-calculate recruitment from older fish, will also be responsive to environmental change using existing HCRs.

Responsive and precautionary HCRs can be used by Councils as a climate tool. In a study by Kritzer and co-authors, a responsive and precautionary HCR where fishing mortality changed based on stock biomass (rather than a fixed fishing mortality approach) could support stock resilience to adverse climate impacts and address high scientific uncertainty.[4] In particular, the authors found these approaches performed better than fixed-rate F approaches in cases where there was directional variability in environmental conditions and the stock was expected to experience adverse impacts of climate change. Another option is an HCR that changes fishing mortality rate or catch based on an environmental or climate indicator, but these climate-informed HCRs can be challenging to implement.

A Council could use information from climate vulnerability assessments to inform selection of HCRs or evaluate HCRs under highly variable and/or directional assumptions of recruitment, natural mortality, and growth. HCRs can be further tested using management strategy evaluation.

Strengths and limitations

Since HCRs are a tool that Councils already use, existing management processes can be used to adapt current HCRs to be more “climate-ready.” HCRs are also a clear step in the science-based management process where information about the status of the stock and the environment can readily be used to inform management action. Because HCRs do not dictate what specific management measures to use (e.g., bag limits) as things change, they can be used as part of a broader suite of climate-ready tools.

Another benefit of HCRs generally is that they can reduce political pressure for management decisions by setting agreed-upon rules ahead of time; this pre-agreement can be especially useful to deal with increased uncertainty and rapidly changing conditions associated with climate change. Even though rules are agreed-upon ahead of time, however, there can be pressure during management decisions to deviate from rules to avoid difficult choices.

One challenge for climate-informed HCRs that use an environmental indicator is that they are most relevant in cases where there is an established and relatively consistent link between environmental conditions and stock response, which is unlikely to be the case for most managed stocks at present.

Outcomes

The development and implementation of a climate-informed HCR should result in management that is responsive to changes in stock availability that are relevant in a climate change context and can maintain stock resilience and prevent overfishing. These HCRs should be evaluated in order to determine whether they are effectively meeting conservation and management objectives.

Considerations (e.g., funding, time, data needed)

HCRs should ideally be well-tested while being developed and may consider a range of different objectives. In particular, management strategy evaluation, or MSE, is a valuable tool for developing HCRs. To include an environmental variable or indicator directly in the HCR, there should be data

[4] Kritzer, J.P. et al. 2019. Responsive harvest control rules provide inherent resilience to adverse effects of climate change and scientific uncertainty. *ICES Journal of Marine Science*. 76(6): 1424-1435. doi:10.1093/icesjms/fsz038

available, and the variable should be periodically revisited. To be successful and part of a transparent management process, HCRs must be developed with and communicated effectively to stakeholders.[5]

Example

Perhaps the most prominent example of an explicit climate-informed HCR is used in the Pacific Sardine fishery off the U.S. West Coast, and it illustrates some of the challenges with the approach. The northern subpopulation of Pacific sardine are managed in U.S. federal waters by the Pacific Fishery Management Council (PFMC) as part of the Coastal Pelagic Species Fishery Management Plan (CPS FMP). Sardine have cyclical fluctuations in population abundance that have been related to water temperature and the longer-term Pacific Decadal Oscillation, or PDO. Given the particularly strong link between temperature and sardine recruitment, the PFMC has implemented an HCR that used 3-year average sea-surface temperature (SST) to modulate fishing pressure. In its current form, the HCR provides the harvest guidance (HG), or U.S. directed harvest, and is calculated as follows:

*Harvest Guideline = (Biomass – Cutoff) * Fraction above* E_{MSY} ** Distribution*

Where *Biomass* is the projected stock biomass, the *Cutoff* is the lowest level of biomass for which directed harvest is allowed (set at 150,000 metric tons), *Fraction* is the percentage of biomass above the cutoff that can be harvested and is set as bounded range of MSY based on prevailing environmental conditions (E_{MSY}), and *Distribution* is the average portion of the biomass in U.S. waters. The E_{MSY} is calculated using T, which is a three-year running average of the SST. The value of E_{MSY} is bounded for the OFL and ABC between 0 and 0.25.

E_{MSY} only comes into play in the harvest guideline if biomass is greater than the cutoff. Since the most recent rule was instituted, biomass has been below the cutoff, and directed fishing has been prohibited since 2015 for the U.S. fishery. However, E_{MSY} is still used to calculate an OFL and ABC.[6]

The sardine HCR also illustrates the challenges incorporating an environmental link, such as an environmental stock-recruit relationship, into an HCR within in the context of continually updated scientific understanding and a complex ecosystem. The initial temperature relationship was based on a study which used sea surface temperature at the Scripps Institution of Oceanography pier and its correlation to recruitment. However, a 2010 study found that the existing relationship no longer held for the stock, and in 2011 the PFMC temporarily removed the temperature component from the rule.[7] Later research supported a different temperature-dependent correlation, and 2014 the PFMC reinstated the rule but used a different source of sea-surface temperature data (from CalCOFI) for specifying the environmentally dependent E_{MSY} each year.[8] More recently, scientists reexamined these relationships using data from recent stock assessment; the results suggest the relationship between annual SST and sardine recruitment currently in use may be invalid, in part due to shifts in the stock distribution.[9] That

[5]Berger, A.M. et al.. 2012. Introduction to Harvest Control Rules for WCPO Tuna Fisheries. Available at: https://www.researchgate.net/publication/264544407_Introduction_to_harvest_control_rules_for_WCPO_tuna_fisheries

[6] Kuriyama, P.T. et al. 2020. Assessment of the Pacific sardine resource in 2020 for U.S. management in 2020-2021. Pacific Fishery Management Council, Portland, OR. Available from https://www.pcouncil.org/coastal-pelagic-species/stock-assessmentand-fishery-evaluation-safe-documents/

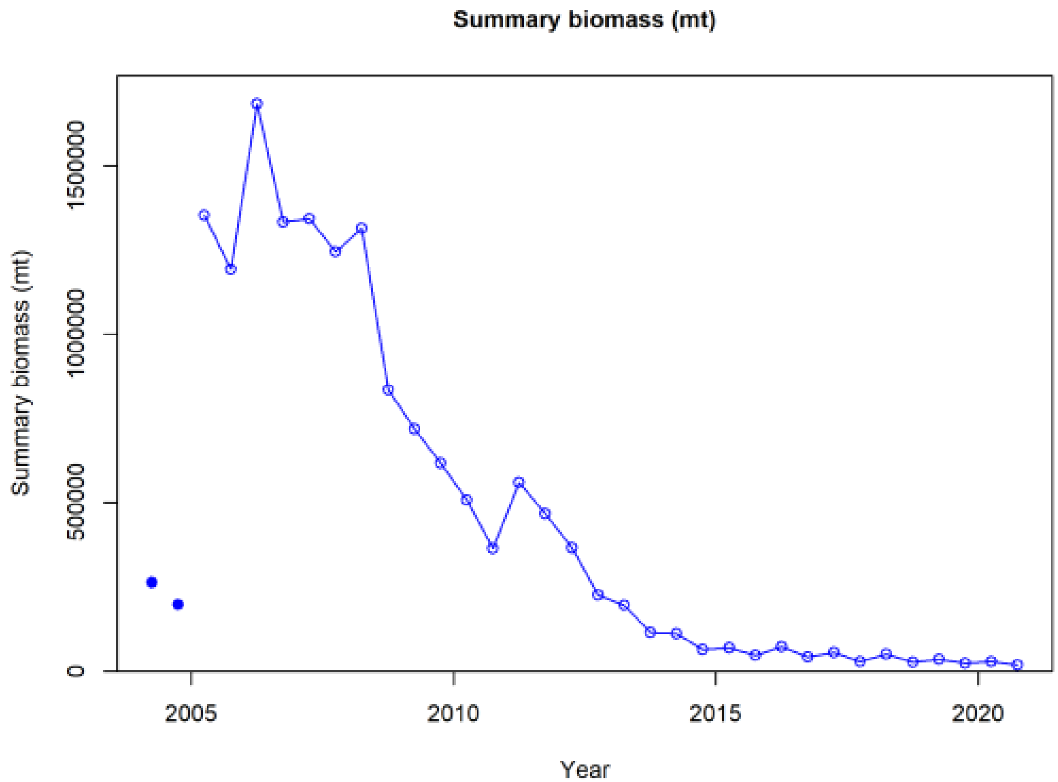
[7] Kvamsdal, S.F. et al. 2016.

[8] Kvamsdal, S.F. et al. 2016.

[9] Zwolinksi, J.P. and D.A. Dremer. 2019. Re-evaluation of the environmental dependence of Pacific sardine Recruitment. *Fisheries Research* 216: 120-125.

research suggested a different environmental variable, a PDO index, may be a better predictor of sardine recruitment than SST.

Pacific sardine is currently overfished, with biomass at very low levels (see figure below).[10] Given the condition the stock and the recent science, the use of the temperature-dependent relationship to determine E_{MSY}, as well as other components of the HCR, have been the subject of concern.[11]



Estimated stock biomass (age 1+ fish; mt) time series for 2020 stock assessment base model (Kuriyama, P.T. et al. 2020). The cutoff value for which directed commercial fishing is prohibited is 150,000 mt.

Resources

What is a Harvest Control Rule? (Interactive App from Pacific Community): https://ofp-sam.shinyapps.io/amped-intro-hcr/

California Marine Life Management Act (MLMA) Master Plan. Appendix J. Harvest Control Rules: https://wildlife.ca.gov/Conservation/Marine/MLMA/Master-Plan/Harvest-Control-Rules

Harvest Control Rules: Approaches to effective long-term fisheries management (Pew Charitable Trusts): https://www.pewtrusts.org/en/research-and-analysis/fact-sheets/2016/07/harvest-control-rules

[10] Kuriyama, P.T. et al. 2020.

[11] E.g. Oceana and Earthjustice. April 2021 Letter to the Pacific Fishery Management Council, RE: Agenda Item E.4: 2021-22 Pacific Sardine Assessment, Harvest Specifications, and Management Measures. Available at: https://pfmc.psmfc.org/CommentReview/DownloadFile?p=398a32ba-9c0a-4c09-9287-1ac8cfcc855b.pdf&fileName=E4sardine_EJ-Oceana_PFMC-4-5-21.pdf

Climate Vulnerability Assessment

Overview

Vulnerability assessment is a framework that has been commonly used in conservation to understand which species are vulnerable to a certain risk and why they are vulnerable, with the goal of informing adaptation planning.[1] Climate vulnerability assessments (CVAs) focus on vulnerability to climate-related factors. Traditionally, vulnerability assessments are based on both *sensitivity* to climate-related factors or conditions and *exposure* to those conditions, but they can also address the adaptive capacity of a species in the analysis.[2] In CVAs, vulnerability can be defined as a reduction in productivity and abundance of a species in response to climate variability and multidecadal change.[3] Broadly, vulnerability assessment is a type of risk assessment.

Quick Facts

Overview: CVAs use information on the exposure and sensitivity of species or other entities to climate change and of factors to qualitatively understand vulnerability

Key characteristics: cross-species, prioritizing, rapid, informational

Limitations: Risk assessment can be a good tool to frame and organize adaptation actions and identify research needs, but it does not offer direct management information.

Outcomes: Ranked vulnerability of species with explanation of ranking and other information

Why it is relevant to climate-ready fisheries

Climate change is unlikely to affect all species equally, yet our understanding of how all species will respond to change is not complete. In this context—and given limited time and capacity—managers must make decisions for how to adapt fisheries for change in the near term. Vulnerability assessments are a way to look across species, understand differences in vulnerability, and prioritize action.

NOAA Fisheries has produced or is in the process of completing climate vulnerability assessments for fish and marine mammals in several regions and has also completed one assessment of vulnerability of fishing communities and one of habitats to climate change.[4] In this document, reference to CVAs is to these NOAA efforts, with a focus on the fish and shellfish climate vulnerability assessments. However, there are many other CVAs that have been completed and can be useful to managers.

How Councils can use it

In short, CVAs use scientific research and expert opinion to determine the vulnerability of different fish (or habitats, marine mammals, fishing communities, etc.) to climate change. Councils can use this information in several ways. In general, a Council may want to assess the vulnerability of a stock and determine whether additional action or precaution should be considered in a management decision. There are several different ways that scientists and others have proposed CVAs could be integrated into management, including informing management and regulatory documents such as FMPs, informing spatial management, and even linking studies to risk policies or control rules.[5]

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[1] Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

[2] Bell, R.J. et al. 2020. Actions to Promote and Achieve Climate-Ready Fisheries: Summary of Current Practice. *Marine and Coastal Fisheries* 12(3): 166-190.

[3] Morrison, W.E., et al. 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OSF-3.

[4] As of 12/2021. For more information, see: https://www.fisheries.noaa.gov/national/climate/climate-vulnerability-assessments

[5] See Hare, J.A. et al. 2016 as cited in Bell, R.J. et al. 2020

Across stocks, Councils can use CVAs to help prioritize research and scientific decisions. Councils can use vulnerability of stocks as a factor when determining their research and data needs under 302(h)(7) of the Magnuson-Stevens Act. As recommended by NOAA in 2018, the CVAs can be used as part of the stock assessment prioritization process.[6] CVAs could also be used to determine whether climate variables should be included in a stock assessment.

Strengths and limitations

Given the many stocks that most Councils manage or have under their authority, CVAs are a flexible and useful framework to identify the most vulnerable stocks in order to give them greater management attention or consideration. CVAs are an efficient way to provide information on vulnerability across species, including data-poor species, by using existing knowledge and expert opinion. They can be readily updated as new information is available.

The NOAA Fisheries CVAs for fish and shellfish use a methodology developed by experts that is specific to the life history of fish and shellfish.[7] For these CVAs, vulnerability is assessed is through identification of different sensitivity attributes and exposure factors; a species is then scored on each of these attributes and factors by experts and based on research. For each species, there is also information on uncertainty and data quality. These components are used to calculate an overall vulnerability rank for each species, which allows for comparison across species.

However, the methodology has a few limitations. First, the CVAs often do not include indirect impacts, like ecosystem changes, into vulnerability. The method also makes assumption that current biological parameters and expected exposure can be used to assess vulnerability, and they do not directly account for possible genetic adaptation or changes to biological parameters.[8] While the CVAs are not reliant on having the most current and accurate projection of climate impacts, the analysis does depend on some climate data for determining the exposure component of vulnerability. Therefore, it would be best if the CVAs for stocks were updated periodically.

Different vulnerability assessment approaches will have their own strengths and limitations, and new methods are still emerging. For example, one recently proposed framework includes feedbacks between the ecological and fisheries social system and identifying risks.[9]

Outcomes

The CVA itself provides a structured ranking of how vulnerable fish are to climate change in a region, along with information about factors most important for determining the vulnerability of each species in terms of sensitivity and exposure. It offers information on data gaps and rank for potential for shifts in distribution.[10] The results tend to be accompanied by graphics (such as a species vulnerability matrix). Each species also has a narrative about its vulnerability, which can inform thinking about its resilience

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[6] Lynch, P. D., R. D. Methot, and J. S. Link (eds.). 2018. Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-183, 127 p.

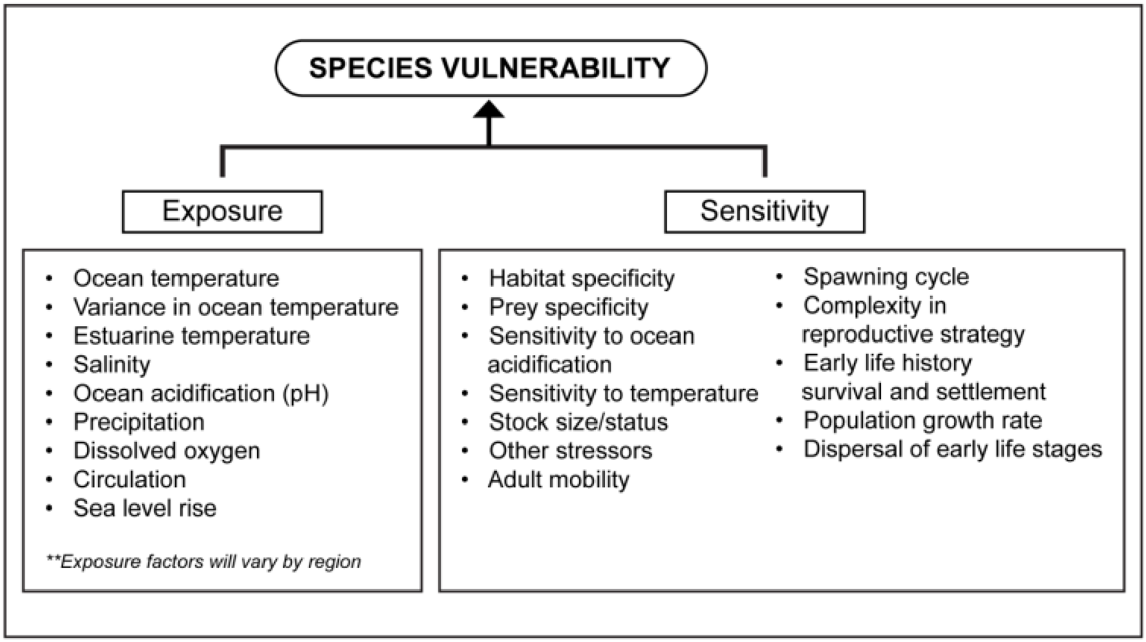
[7] Morrison et al. 2015

[8] Morrison et al. 2015

[9] Dudley, P.N. et al. 2021. A More Comprehensive Climate Vulnerability Assessment Framework for Fisheries Social-Ecological Systems. *Frontiers in Marine Science* https://doi.org/10.3389/fmars.2021.678099

[10] Morrison et al. 2015

and potential for needed management changes. CVAs that focus on fishing communities could also be used to better understand interventions in the fishery to make it more adaptable.



A species' vulnerability is based on a combination of its sensitivity and exposure. Exposure is determined by the overlap of the species' current distribution and the magnitude of the expected climate change. Twelve sensitivity attributes characterize life history characteristics believed to be indicative of how much a species may be affected by a changing climate. From Morrison et al. 2015.

Considerations (e.g., funding, time, data needed)
In most cases, a Council would want to work closely with fisheries scientists and NOAA Fisheries in either using an available CVA and/or directing development of a new targeted assessment to address a specific set of management questions. Developing a new CVA with new species-specific information and environmental information can be a time-consuming process, and there are important considerations on method and process.[11] Engaging stakeholders and managers in new CVA development can be important in shaping the focal species and attributes considered in the analysis.

Example
The first implementation of the NOAA Fisheries CVA for fish and shellfish was for the Northeast region. The Northeast Vulnerability Assessment (NEVA) included 82 species of fish and invertebrates in the Northeast.[12] This region, which supports valuable commercial and recreational fisheries, is already experiencing rapid climate change. The study used climate projections from 2005-2055 to look at vulnerability of species to changes in distribution and productivity.

[11] Morrison et al. 2015
[12] Hare, J.A. et al. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS ONE 11(2): e0146756. doi:10.1371/journal.pone.0146756

The CVA found that of the species included, almost half were ranked as having either high or very high vulnerability.[13] In particular, diadromous and benthic invertebrate species were the most vulnerable. Many species had high potential for distributional shifts in response to climate change. When assessing vulnerability, roughly half the species were expected to be negatively impacted by climate change—the remaining half of species were expected to see neutral or even positive effects.

In developing the CVA, the NMFS Northeast Fisheries Science Center took a lead role. At various points, it engaged the New England Fishery Management and Mid-Atlantic Fishery Management Councils, including having representatives from both councils provide input on the species selected at an expert workshop.[14] However, given the objective of the study was to implement the methodology developed by NMFS for the first time, there was less stakeholder engagement than there could have been.

For an example of how this information was used by a Council, see the section on “Risk Assessment,” where the Mid-Atlantic Fishery Management Council and the NOAA Northeast IEA team used the NEVA as a climate indicator in a risk assessment. The goal of that risk assessment was for the Council to understand and incorporate species, fleet, habitat and climate interactions into its management and science programs.[15]

Resources

Climate Vulnerability Assessments (NOAA Fisheries):
https://www.fisheries.noaa.gov/national/climate/climate-vulnerability-assessments

Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate (NOAA Fisheries)
https://www.st.nmfs.noaa.gov/Assets/ecosystems/climate/documents/TM%20OSF3.pdf

Scanning the conservation horizon: A guide to climate change vulnerability assessment (National Wildlife Federation)
https://www.fs.usda.gov/treesearch/pubs/37406

Report of the ICES/PICES Workshop on Regional climate change vulnerability assessment for the large marine ecosystems of the northern hemisphere (WKSICCME-CVA) (International Councils for the Exploration of the Sea):
https://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGEPD/2017/WKSICCME%202017_Full%20report.pdf

[13] Hare, J.A. et al. 2016
[14] Hare, J.A. et al. 2016
[15] Gaichas, S.K., et al. 2018. Implementing Ecosystem Approaches to Fishery Management: Risk Assessment in the US Mid-Atlantic. *Front. Mar. Sci*. https://doi.org/10.3389/fmars.2018.00442