Harvest Strategies and Climate Change: A Review of the Literature

Author: Ellen Ward, Ph.D., The Pew Charitable Trusts | Date: November 13, 2024

The goal of this literature review is to evaluate the findings of relevant work in the field of fisheries science and management driving our understanding of the intersection of climate change with harvest strategies/management procedures, in order to evaluate and summarize the state of knowledge in the field. A preliminary review of the literature shows that there are a range of considerations at play when seeking to design climate-informed harvest strategies, as well as a diversity of options available to managers seeking to develop them (for more on the literature included in this review, please see *Annex 1* below). Five major themes emerged in the review of the selected literature:

(i) Harvest strategies as an effective adaptation tool for managing stocks under conditions of a changing climate

Since harvest strategies allow for adjustments in response to impacts on stocks from environmental change, including those due to climate change, they can serve as an adaptive tool for managers to use in the face of climate change (Ortega-Cisneros et al. 2021). Researchers evaluating the performance of harvest strategies have found that they support the climate resilience of managed species, with studies finding harvest control rules (HCRs) robust to climate-driven changes in productivity and recruitment variability (e.g., a 2017 HCR adopted for North Atlantic albacore, evaluated by Merino et al. 2019); and biomass-responsive HCRs providing climate resilience benefits compared to HCRs with fixed fishing mortality (Kritzer et al. 2019; Yin et al. 2023). Harvest strategies can thereby serve as a reliable approach for managers looking to improve the climate resilience of their management regimes (Kritzer et al. 2019).

(ii) Opportunities and limitations to the explicit incorporation of climate-related environmental factors into HCRs and MSE

Going beyond the climate resilience benefits of harvest strategies as management tools, researchers have sought to integrate climate change into the design of harvest strategies, especially focusing on HCRs and MSE, through the incorporation of mechanistic links between environmental variables and stock dynamics. Here, 'mechanistic link' refers to a quantitative relationship represented between two variables—such as: (i) an environmental variable affected by climate change, and (ii) a variable reflecting the biology of the species in question—in this case a process by which (i) drives variability in (ii) (e.g., Haltuch et al. 2019). For instance, Haltuch et al. (2019) employ a mechanistic framework linking climate variability, sea level, zooplankton community structure, and sablefish recruitment, in using MSE to assess robustness of HCRs to climate-driven effects to sablefish recruitment.

For researchers working in other ecosystems, however, a lack of suitable data and scientific understanding of environmental factors driving species population dynamics can limit opportunities to take a mechanistic approach (Bell et al. 2020). For instance, Blamey et al. (2022) use MSE to evaluate the robustness of HS to extreme events for large prawn stocks in Australia, and find that HS incorporating the environmental variable do not provide substantive advantages, which the researchers attribute to a lack of scientific understanding of the environmental relationship to a stock. Faced with modeling limitations from this data scarcity, researchers looking to mechanistically incorporate climate-driven environmental change into HS development have flagged the advantages that improved monitoring and data collection could offer in this regard (Blamey et al. 2022; Bryndum-Buchholz, Tittensor, and Lotze 2021), while others have recommended deprioritizing the mechanistic approach in favor of other climate planning approaches for HS, such as widening the adoption of threshold F harvest control rules, which allow fishing at a target level until a specified limit is reached (Free et al. 2023). Collie et al. (2021) argue that the priority for managing fish stocks influenced by climate change should remain the application of a dynamic HCR based on current productivity and abundance, rather than focusing on defining a mechanistic cause for species change and using forecasts.

Noting the difficulties of a mechanistic understanding of environment-stock relationships, researchers looking to consider potential future conditions under a changing climate in developing HS have also considered the implications of broadly "plausible" scenarios in harvest strategy development (Punt et al. 2014). These studies typically construct scenarios in which changes to a stock are assumed to play out in relation with an environmental variable, and then use MSE to test the robustness of a HS to those conditions, such as: different degrees of future northward movement of a species associated with increases in water temperature (Jacobsen et al. 2022); the impacts of extreme events (e.g. cyclone) assumed to result in a specific change in the availability of simulated species groups, and longer-term climatic change assumed to result in a given percent migration southward and decrease in abundance of the modeled species (Dowling et al. 2020); or scenarios of differing levels of plankton productivity, with plankton productivity serving as an indicator for climate and ocean changes (Guo et al. 2019). Through such analyses, researchers have tested HS robustness to potential future conditions without the use of a mechanistic environment-stock relationship.

(iii) "Climate-informed" harvest strategies as those designed to include extreme events as 'Exceptional Circumstances'

An aspect of climate-informed harvest strategy development may also include accounting for climate-driven extreme weather and ocean events. For instance, a harvest strategy may be designed at the outset to feature "environmental overrides" by which Total Allowable Catch (TAC) may be adjusted "in response to a spatially or temporally isolated weather event (e.g. a tropical cyclone or coral bleaching)" (Dichmont et al. 2021). Through ocean and ecosystem monitoring, conditions that fall outside those through which a harvest strategy was tested (during the design phase) may further be detected, signaling an 'exceptional circumstance' that could in turn trigger re-examination of the harvest strategy if so agreed (Goodman et al. 2022).

(iv) "Climate-informed" harvest strategies as those that account for shifts in geographic distribution across management regimes

For cases in which climate-driven shifts in the geographic distribution of a stock may affect multiple fisheries jurisdictions, a climate-informed harvest strategy may also mean coordination across management regimes in the design of harvest strategies that would otherwise be siloed. For instance, in regional fisheries management organization (RFMO) planning for the climate-driven redistribution of tropical tuna resources in the Pacific Ocean, researchers have highlighted the potential for coordination between the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC) to develop harvest strategies for tuna species that are expected to experience an overall shift eastward across the Convention Areas of these RFMOs, as well as a move from Exclusive Economic Zones of Contracting Parties to the high seas, in the coming decades (Lam et al. 2020; Goodman et al. 2022).

(v) Management options for data-rich and data-poor fisheries

In addition to the data considerations flagged in section *(ii)* above on the explicit incorporation of climate-related environmental factors into HCRs and MSE, researchers flagged several other data considerations in the context of climate-informed harvest strategies. For cases of data-rich fisheries, near real-time climate, environment or socioeconomic data could be applied to increase the responsiveness of management procedures (Karp et al. 2019). In data-limited fisheries, on the other hand, a "multi-indicator framework" approach may be developed taking into account indicators, or proxies, for environmental and stock changes in combination with one another to inform management decisions (Harford et al. 2021).

Annex 1. Literature included in the review

Google Scholar search: The search used the Advanced Search Feature in Google Scholar. There are a range of Operators available to inform the search; here, the AND operator was used to include several phrases, and quotation marks were used to ensure that exact phrases were returned in the search. Advanced search results excluded patents and citations and were sorted by relevance over the time period of 2019 to present. The search was conducted in March 2024.
Search terms: To address the use of both "harvest strategies" and "management procedures" as common terms in the literature, two separate searches were performed (Searches A and B, below).

Search A

With all of the words: “harvest strategies” AND “fisheries” AND “climate change” *(anywhere in the article)*
Article date: 2019 – 2024

Search B
With all of the words: “management procedures” AND “fisheries” AND “climate change” *(anywhere in the article)*
Article date: 2019 – 2024

Sources reviewed for the Literature Review:
Drawing on the results of the Google Scholar search, for each of Groups A and B, the top 20 sources considered most relevant were evaluated for inclusion in the literature review, with those deemed relevant to the goal of the review then included. In addition, two additional sources were included that were (1) referenced by one of the reviewed articles (Punt et al. 2014), and (2) recommended for inclusion by an expert in the field (Free et al. 2023).

References

Bell, Richard J., Jay Odell, Gway Kirchner, and Serena Lomonico. 2020. “Actions to Promote and Achieve Climate-Ready Fisheries: Summary of Current Practice.” *Marine and Coastal Fisheries* 12 (3): 166–90. https://doi.org/10.1002/mcf2.10112.

Blamey, Laura K., Éva E. Plagányi, Trevor Hutton, Roy A. Deng, Judy Upston, and Annie Jarrett. 2022. “Redesigning Harvest Strategies for Sustainable Fishery Management in the Face of Extreme Environmental Variability.” *Conservation Biology* 36 (3): e13864. https://doi.org/10.1111/cobi.13864.

Bryndum-Buchholz, Andrea, Derek P. Tittensor, and Heike K. Lotze. 2021. “The Status of Climate Change Adaptation in Fisheries Management: Policy, Legislation and Implementation.” *Fish and Fisheries* 22 (6): 1248–73. https://doi.org/10.1111/faf.12586.

Collie, Jeremy S, Richard J Bell, Samuel B Collie, and Cóilín Minto. 2021. “Harvest Strategies for Climate-Resilient Fisheries.” Edited by Jan Jaap Poos. *ICES Journal of Marine Science* 78 (8): 2774–83. https://doi.org/10.1093/icesjms/fsab152.

Dichmont, Catherine M, Natalie A Dowling, Sean Pascoe, Toni Cannard, Rachel J Pears, Sian Breen, Tom Roberts, George M Leigh, and Marc Mangel. 2021. “Operationalizing Triple Bottom Line Harvest Strategies.” Edited by Raúl Prellezo. *ICES Journal of Marine Science* 78 (2): 731–42. https://doi.org/10.1093/icesjms/fsaa033.

Dowling, Natalie A., Catherine M. Dichmont, George M. Leigh, Sean Pascoe, Rachel J. Pears, Tom Roberts, Sian Breen, Toni Cannard, Aaron Mamula, and Marc Mangel. 2020. “Optimising Harvest Strategies over Multiple Objectives and Stakeholder Preferences.”

Ecological Modelling 435 (November):109243. https://doi.org/10.1016/j.ecolmodel.2020.109243.

Free, Christopher M., Tracey Mangin, John Wiedenmann, Conner Smith, Halley McVeigh, and Steven D. Gaines. 2023. "Harvest Control Rules Used in US Federal Fisheries Management and Implications for Climate Resilience." *Fish and Fisheries* 24 (2): 248–62. https://doi.org/10.1111/faf.12724.

Goodman, Camille, Ruth Davis, Kamal Azmi, Johann Bell, Grantly R. Galland, Eric Gilman, Bianca Haas, et al. 2022. "Enhancing Cooperative Responses by Regional Fisheries Management Organisations to Climate-Driven Redistribution of Tropical Pacific Tuna Stocks." *Frontiers in Marine Science* 9 (December):1046018. https://doi.org/10.3389/fmars.2022.1046018.

Guo, Chuanbo, Caihong Fu, Robyn E Forrest, Norm Olsen, Huizhu Liu, Philippe Verley, and Yunne-Jai Shin. 2019. "Ecosystem-Based Reference Points under Varying Plankton Productivity States and Fisheries Management Strategies." Edited by Jason Link. *ICES Journal of Marine Science* 76 (7): 2045–59. https://doi.org/10.1093/icesjms/fsz120.

Haltuch, Melissa A, Z Teresa A'mar, Nicholas A Bond, and Juan L Valero. 2019. "Assessing the Effects of Climate Change on US West Coast Sablefish Productivity and on the Performance of Alternative Management Strategies." Edited by Jörn Schmidt. *ICES Journal of Marine Science* 76 (6): 1524–42. https://doi.org/10.1093/icesjms/fsz029.

Harford, William J., Ricardo Amoroso, Richard J. Bell, Matias Caillaux, Jason Marc Cope, Dawn Dougherty, Natalie Anne Dowling, et al. 2021. "Multi-Indicator Harvest Strategies for Data-Limited Fisheries: A Practitioner Guide to Learning and Design." *Frontiers in Marine Science* 8 (December):757877. https://doi.org/10.3389/fmars.2021.757877.

Jacobsen, Nis S, Kristin N Marshall, Aaron M Berger, Chris Grandin, and Ian G Taylor. 2022. "Climate-Mediated Stock Redistribution Causes Increased Risk and Challenges for Fisheries Management." Edited by Jan Jaap Poos. *ICES Journal of Marine Science* 79 (4): 1120–32. https://doi.org/10.1093/icesjms/fsac029.

Karp, Melissa A, Jay O Peterson, Patrick D Lynch, Roger B Griffis, Charles F Adams, William S Arnold, Lewis A K Barnett, et al. 2019. "Accounting for Shifting Distributions and Changing Productivity in the Development of Scientific Advice for Fishery Management." Edited by Christos Maravelias. *ICES Journal of Marine Science*, April, fsz048. https://doi.org/10.1093/icesjms/fsz048.

Kritzer, J P, C Costello, T Mangin, and S L Smith. 2019. "Responsive Harvest Control Rules Provide Inherent Resilience to Adverse Effects of Climate Change and Scientific Uncertainty." Edited by Raúl Prellezo. *ICES Journal of Marine Science* 76 (6): 1424–35. https://doi.org/10.1093/icesjms/fsz038.

Lam, Vicky W. Y., Edward H. Allison, Johann D. Bell, Jessica Blythe, William W. L. Cheung, Thomas L. Frölicher, Maria A. Gasalla, and U. Rashid Sumaila. 2020. "Climate Change, Tropical Fisheries and Prospects for Sustainable Development." *Nature Reviews Earth & Environment* 1 (9): 440–54. https://doi.org/10.1038/s43017-020-0071-9.

Merino, Gorka, Haritz Arrizabalaga, Igor Arregui, Josu Santiago, Hilario Murua, Agurtzane Urtizberea, Eider Andonegi, Paul De Bruyn, and Laurence T. Kell. 2019. "Adaptation of North Atlantic Albacore Fishery to Climate Change: Yet Another Potential Benefit of Harvest Control Rules." *Frontiers in Marine Science* 6 (October):620. https://doi.org/10.3389/fmars.2019.00620.

Ortega-Cisneros, Kelly, Kevern L. Cochrane, Nina Rivers, and Warwick H. H. Sauer. 2021. "Assessing South Africa's Potential to Address Climate Change Impacts and Adaptation in the Fisheries Sector." *Frontiers in Marine Science* 8 (June):652955. https://doi.org/10.3389/fmars.2021.652955.

Punt, André E., Teresa A'mar, Nicholas A. Bond, Douglas S. Butterworth, Carryn L. De Moor, José A. A. De Oliveira, Melissa A. Haltuch, Anne B. Hollowed, and Cody Szuwalski. 2014. "Fisheries Management under Climate and Environmental Uncertainty: Control Rules and Performance Simulation." *ICES Journal of Marine Science* 71 (8): 2208–20. https://doi.org/10.1093/icesjms/fst057.

Yin, Jie, Ying Xue, Yunzhou Li, Chongliang Zhang, Binduo Xu, Yiwen Liu, Yiping Ren, and Yong Chen. 2023. "Evaluating the Efficacy of Fisheries Management Strategies in China for Achieving Multiple Objectives under Climate Change." *Ocean & Coastal Management* 245 (November):106870. https://doi.org/10.1016/j.ocecoaman.2023.106870.