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Toward climate resiliency in fisheries management

Kirstin K. Holsman, Elliott Lee Hazen, Alan Haynie, Sophie Gourguet, Anne Hollowed, Steven Bograd, Jameal F. Samhouri, and Kerim Aydin

Bering Sea case study

The Bering Sea and Aleutian Islands (US) have long supported large commercial fisheries, with regional commercial harvest representing more than 40% of national fishery landings annually (Fissel *et al*., 2016). Current Bering Sea fisheries management includes fixed ecosystem-based policies aimed at maintaining long-term productivity in the system, such as fishery closure areas (including a moratorium on bottom-trawl fisheries in the northern Bering Sea), fishery restrictions in marine mammal habitats, and a legislatively mandated 2 million t limit on total groundfish harvest. At the same time, adaptive measures such as Council-based annual harvest limits informed by annual scientific revaluation of population biomass and within-season cooperative industry–agency observer-based data on harvest and bycatch rates may allow fishery management to adapt to variable conditions and productivity regimes. These measures are central to successful management in the Bering Sea and Aleutian Islands to date *(*Livingston *et al*., 2011), and have helped maintain sustainability in this largest of US fisheries (Lawler *et al*., 2010; Lewison *et al*., 2015). These measures, however, may be challenged by rapid changes in species distributions and concomitant novel risks to species survival. Thus, despite a robust management system and process, the region's important fishery resources may be particularly vulnerable to climate change, especially given that productivity in the region is highly influenced by the extent and timing of annual winter sea ice formation and retreat, conditions that can change markedly over the course of a year (Sigler *et al*., 2016). For example, since 2014, summer bottom temperatures in the Bering Sea have been warmer than average (as measured during the annual National Marine Fisheries Service Alaska Fisheries Science Center summer groundfish survey) (NPFMC, 2018). In particular, in 2016 and 2018, the Bering Sea ecosystem experienced unprecedented warming, markedly reduced winter sea ice formation, and climate-driven declines in productivity that rapidly impacted key regional fisheries for pollock (*Gadus chalcogrammus*) and Pacific cod (*Gadus macrocephalus*) (Stevenson and Lauth, 2018). In 2017, during a special extended northern Bering Sea survey, a large proportion of the cod stock was observed north of the standard survey area for the first time (in contrast to the previous northern Bering Sea survey in 2010, a relatively "cold" year, which revealed few cod in the northern Bering Sea) (Stevenson and Lauth, 2018); at the same time, the biomass of cod in the southern Bering Sea "standard survey" was declining relative to previous years. In 2018, low catches and continued declines of cod in the standard survey initiated an additional "emergency" survey in the northern area, which revealed that 50% of the cod biomass was located in the northern Bering Sea (NPFMC, 2018). The rapid redistribution of cod biomass presented a challenge to management as survey biomass from the northern Bering Sea had not yet been used to estimate Bering Sea cod population dynamics. In 2018, after much review and debate, combined northern and southern survey biomass estimates were included for the first time in the assessment model used to set the 2019 harvest limit for cod. Yet, significant concern regarding "the future survival and contribution to the greater cod stock of the fish observed in the northern Bering Sea (over half of the total biomass) in 2018"led the

Scientific and Statistical Committee of the North Pacific Fisheries Management Council (NPFMC) to give a specific recommendation that "in-season reporting of fishery performance be used to track the presence and/or success of these fish into next spring."(Link: SSC draft minutes).

Dynamic tools like in-season catch reporting and near-term ecosystem forecasts may become increasingly important components of the management portfolio for this region as climate-driven extreme events are anticipated to increase in frequency and magnitude under climate change, yet remain difficult to predict more than a year in advance (Sigler *et al*., 2016). To address those emergent challenges, evaluating climate-change impacts on the region and the performance of climate-resilient dynamic-adaptive-fixed management tools is a priority of the NPFMC as part of their recently adopted Bering Sea Fishery Ecosystem Management Plan (Link: AP minutes on the FEP). Additionally, ensuring that effective fixed measures do not become obsolete under climate change, but also preserving their role in the portfolio of management approaches, is an identified step in developing "climate-resilient" policies in the region (Sigler *et al*., 2016). Collectively, these measures could address steps 1 and 2 of our step-wise approach, i.e. (1) consider future condition and risk of the socio-ecological system and (2) characterize existing management on the spectrum of dynamic to adaptive to fixed approaches. In this, a critical element will be identifying nodes of integration between management measures and key uncertainties in performance under both changing climate conditions, but also future socio-economic conditions and risk tolerance. For example, management strategy evaluations could explore fish population trajectories and changes in fishery value under future climate scenarios with and without dynamic management (e.g. in-season fishery performance reporting or emergent tools like seasonal ecosystem forecasts) coupled to adaptive measures and long-term fixed ecosystem-based measures (i.e. total cap on yield or minimum biomass thresholds). We further suggest that additional steps to explicitly evaluate and define an optimal portfolio of short-term dynamic, medium-term adaptive, and long-term fixed management tools and targets could help balance tradeoffs, clarify risk, and promote resilience to climate-driven change in Bering Sea fisheries.

Eastern Australian Southern Bluefin tuna case study

A well-documented example of climate-resilient fishery management is the dynamic management of Southern Bluefin tuna (*Thunnus maccoyii*; SBT) in eastern Australia (Hobday *et al*., 2011, 2016; Eveson *et al*., 2015). As a quota-limited species in a large multispecies longline fishery, SBT are a potential limiting (i.e. "choke") species for the harvest of other cocaptured species. The species is also highly migratory and seasonally spatially distributed according to distinct thermal conditions. In 2011–2012, SBT redistributed eastward of historical fishing grounds which impacted fishery harvest costs, effort, and methodology.

The decline in SBT and establishment of a conservative catch quota provided challenges that could not be overcome by traditional management approaches. Tagging data for bluefin tuna revealed the narrow temperature preferences of the species, which gave rise to the hypothesis that a dynamic approach would be better than a static one (Hobday *et al*., 2009). To minimize potential bycatch by non-quota holders, near real-time nowcasts are used to manage bycatch risk and short-term forecasts of climate-enhanced habitat models were used to develop risk-specific forecast maps (2–4 months; i.e. dynamic management) to aid in fishery planning. Combined with adaptive management limits on bycatch via species-specific quotas, these dynamic management tools enhanced fisheries agencies in avoiding bycatch areas and reducing costly impacts of climate-driven changes to SBT distribution (Hobday *et al*., 2011, 2016; Eveson *et al*., 2015). While quantifying the specific economic benefits of this approach is challenging, these tools have proven useful to industry in terms of improving marine management and advanced planning, and reducing climate-driven unpredictability and cost of fishing operations in the region (Hobday *et al*., 2011; Eveson *et al*., 2015). As such, Hobday and colleagues (2016) identified that short-term forecasts hold promise for management at longer time-scales as well. The utility of such an approach is also driven by the method in which it was developed, which included an iterative codevelopment with stakeholders and climate and biological modelers that was initiated first through discussions with users to identify industry needs and then followed by forecast tool development and evaluation. Such collaboration and codevelopment ensures that management tools are aligned with the needs of marine-dependent communities and is essential for efficient implementation to address rapid and increasingly extreme climate-driven changes to marine resources.

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