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Fisheries Management in a Changing Climate

Lessons From the 2012 Ocean Heat Wave in the Northwest Atlantic

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INTRODUCTION

Climate change became real for many Americans in 2012 when a record heat wave affected much of the United States, and Superstorm Sandy pounded the Northeast. At the same time, a less visible heat wave was occurring over a large portion of the Northwest Atlantic Ocean. Like the heat wave on land, the ocean heat wave affected coastal ecosystems and economies. Marine species responded to warmer temperatures by shifting their geographic distribution and seasonal cycles. Warm-water species moved northward, and some species undertook local migrations earlier in the season, both of which affected fisheries targeting those species. Extreme events are expected to become more common as climate change progresses (Tebaldi et al., 2006; Hansen et al., 2012). The 2012 Northwest Atlantic heat wave provides valuable insights into ways scientific information streams and fishery management frameworks may need to adapt to be effective as ocean temperatures warm and become more variable.

TEMPERATURE IN THE NORTHWEST ATLANTIC

Temperatures in the world ocean are rising rapidly, with some of the fastest warming occurring in the Northwest Atlantic, particularly in the Labrador Sea (Belkin, 2009; Taboada and Anadón, 2012). The 2012 ocean heat wave is notable as the largest, most intense warm event in the Northwest Atlantic in the last 30 years (Figure 1a). Over the region from Cape Hatteras to Iceland and northward into the Labrador Sea, sea surface temperature (SST) was 1–3°C warmer than the 1982–2011 average (Figure 1a), a level of warming that is on par with the mean SST change projected for the end of the century (Meehl et al., 2007).

A full analysis of the atmosphere-ocean interactions that produced this anomaly has not been conducted;

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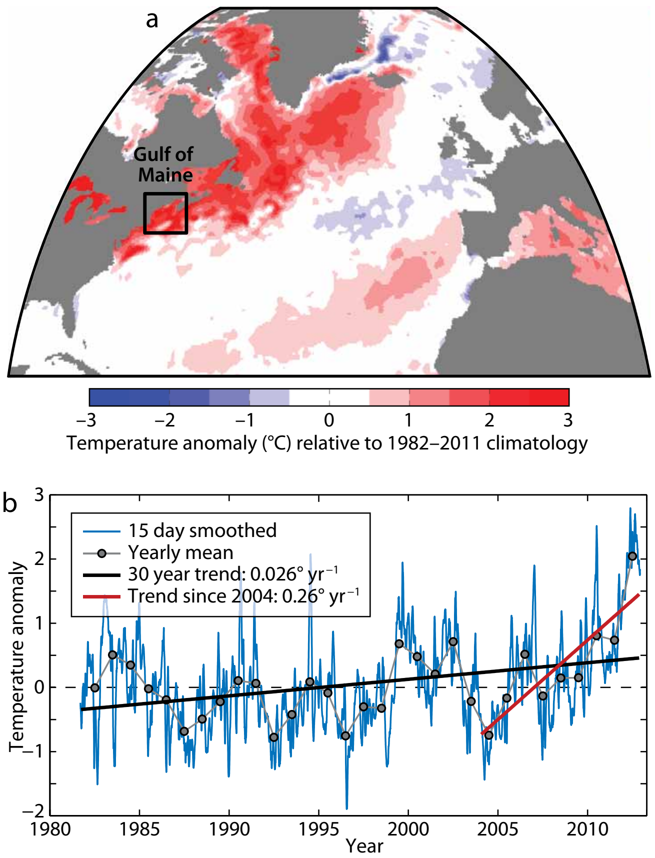

Figure 1. Sea surface temperature (SST) anomalies for the Northwest Atlantic and the Gulf of Maine. (a) Mean SST anomaly for June–August 2012. The anomaly values are relative to the 1982–2011 climatology, calculated using optimally interpolated daily 1/4° SST fields (data from Reynolds et al., 2007; http://data.nodc.noaa.gov/ghrsst/L4/GLOB/NCDC/AVHRR_OI). (b) SST record from the Gulf of Maine showing 15-day (blue line) and annual (gray circles) variability. The linear trend in the daily anomalies has a slope of 0.026°C yr^{-1} ($r^2 = 0.10$, $p < 0.01$, black line) for the entire record. After 2004, the rate increased to 0.26°C yr^{-1} ($r^2 = 0.51$, $p < 0.01$, red line).

however, there were several periods in late winter and also in summer of persistent atmospheric blocking that brought warm air into the region and contributed to ocean warming (Greene and Monger, 2012; Nghiem et al., 2012). The same atmospheric conditions that gave rise to the ocean heat wave likely contributed to an extreme melting event in Greenland (Nghiem et al., 2012), while the SST anomaly may have influenced the trajectory of Superstorm Sandy (Greene et al., 2013).

In addition to its large size and persistence, the 2012 heat wave was remarkable in its intensity on the continental shelf, and warming was especially pronounced the Gulf of Maine. Temperatures in the Gulf of Maine have increased by an average of 0.026°C yr^{-1} since 1982, but the pace of warming accelerated to 0.26°C yr^{-1} after 2004 (Figure 1b). The annual SST anomaly for 2012 was 2°C above the 1982–2011 climatology, more than a degree warmer than the next highest anomaly and 3.5 standard deviations above the mean. As we will show, the intense warming in the Gulf of Maine triggered rapid and unprecedented changes in the marine ecosystem, revealing complex interactions among physics, ecology, economics, and policy. Failure to anticipate these changes and incorporate them into management processes can exacerbate economic and social impacts.

ECOLOGICAL AND ECONOMIC IMPACTS

Gradual warming of the ocean is already affecting the distributions of marine fish and invertebrates (Perry et al., 2005; Cheung et al., 2013b). As mean temperatures on the Northeast Shelf have increased, the distributions of many fish species have also shifted northward or into deeper waters (Nye et al., 2009). Species exhibiting range shifts span diverse taxonomic groups and life histories, but some of the largest shifts have occurred among commercially valuable species such as silver hake, red hake, yellowtail flounder, and winter flounder, and among species at the southern extent of their ranges, including Atlantic cod. As species continue to move northward, fisheries will be affected by a redistribution of resources available to fishermen from different ports (Pinsky and Fogarty, 2012). One of the surprises in 2012 was how quickly species and their fisheries responded to the intense warming. During 2012, longfin squid—which are caught primarily in Rhode Island, New York, and New Jersey—were present in Maine waters throughout the summer, and local fisheries and markets for this species developed within the season (Frederick, 2012).

Warm events and warming trends can also affect abundance, mortality, growth, and phenology of commercially important species (Edwards and Richardson, 2004; Simpson et al., 2011; Cheung et al., 2013a). American lobsters provide a clear example of how these effects can impact fisheries through complex coupled ecological and economic pathways. Warming can directly increase the mortality of lobsters. For example, a warm event in 1999 contributed to a massive die-off of lobsters in Long Island Sound (Pearce and Balcom, 2005), and warming has been implicated in the spread of lobster shell disease, which has decimated populations south of Cape Cod (Wahle et al., 2009). In addition, as fish distributions change with warming waters, lobsters are likely to face a more diverse suite of predators, which may increase lobster mortality (Wahle et al., 2013).

The response of lobsters in the Gulf of Maine to the 2012 heat wave demonstrates how phenological changes can have major fishery impacts. As waters warm each spring, lobsters move from deep offshore waters into shallower coastal areas, and catch rates rise rapidly as they become accessible to the large inshore fleet (Holland, 2011). Temperatures in late spring of 2012 were typical of those normally encountered three weeks later (Figure 2a). Lobsters moved inshore earlier, and landings rose sharply during June and peaked in July, whereas the season typically begins in earnest during July and peaks in August or September (Figure 2b). The temporal shift in the landings matches the shift in temperatures.

The lobster fishery in the northeastern United States is essentially a recruitment fishery, with more than 75% of annual landings from animals that molted into legal sizes during the season (Atlantic States Marine Fisheries Commission, 2009). The record temperatures in 2012 increased molting rates and enhanced the number of legal-sized lobsters, extending the fishing season and supporting record landings (Figure 2b). Over the long term, warmer temperatures will hasten molting and reduce growth variability among individuals, which will decrease the number of year classes contributing to annual recruitment, increase the interannual catch variability, and make the population more susceptible to overfishing.

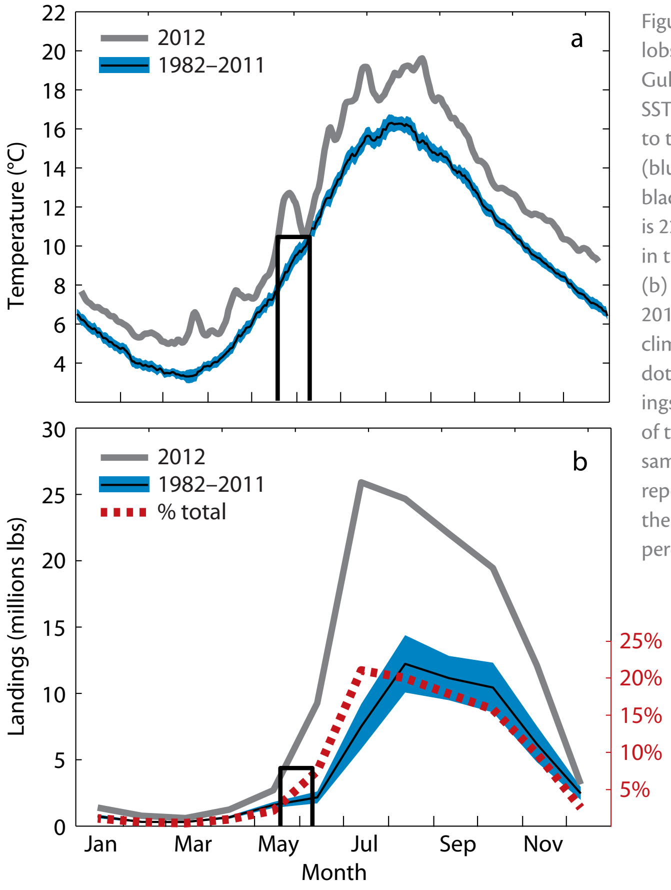

Figure 2. Temperature and lobster phenology from the Gulf of Maine. (a) Gulf of Maine SST in 2012 (gray) referenced to the 1982–2011 climatology (blue region is +/– 2SE). The black bar centered at day 150 is 22 days wide, the mean shift in the temperature phenology. (b) Maine lobster landings for 2012 (gray) and the 1992–2011 climatology (blue, +/– 2SE). The dotted red line is the 2012 landings expressed as a percentage of the total. The black bar is the same as in (a). The 22-day shift reported for SST is similar to the shift in both the total and percentage of landings.

During 2012, the extended fishing season and high landings paradoxically led to an economic crisis in the lobster fishery. Record landings outstripped the processing capacity and market demand for the product, which contributed to a price collapse. Ex-vessel prices (price received by fishermen at the dock) for lobster dropped as low as $1.25 per pound in some areas of Maine, 70% below normal (Dicolo and Friedman, 2012). Low prices threatened the economic viability of both US and Canadian lobstermen. With an influx of US lobsters, prices offered to Canadian fishermen also plummeted, leading to demonstrations against Canadian plants processing US lobster (Woodard, 2012). The 2012 experience highlighted how complex relationships among physical, biological, and economic processes can rapidly affect fisheries, and it called attention to the need for policies that enable fisheries management to rapidly adapt to circumstances created by such abrupt events.

POLICY INSIGHTS AND RECOMMENDATIONS

The ecological and economic impacts of the 2012 ocean heat wave reveal the need for climate adaptation planning within fisheries management. Based on the 2012 experience, we identify several directions that may help sustain fisheries and fishing communities in a warming and more variable climate. Both improved capacities to detect and predict ecosystem impacts of climate change and nimble fishery management systems that can adapt to ecosystem changes will be critical for achieving these outcomes. Specific recommendations include the following.

1. Develop Climate-Ecosystem Models

Much progress has been made over recent decades in refining models of the climate system, following the dedication of substantial funding streams from national and international institutions (Randall et al., 2007). However, advances have been considerably slower in modeling the impacts of climate change—including gradual warming and warm events—on marine ecosystems, fishery resources, and human communities. Coupled models that link physical changes to biological outcomes and economic impacts at a variety of spatial and temporal scales would help fishery managers identify and evaluate climate adaptation strategies.

2. Enhance Management-Relevant Predictive Capacities

In addition to the general models described above, targeted predictive models will be valuable for supporting fishery management decisions in the context of climate change. Many biological responses to the warmer 2012 conditions could have been predicted using data that are routinely collected by ocean observing systems. For example, the timing of lobster inshore migration and molting is closely related to temperature, and observing systems routinely monitor coastal temperatures. However, models that integrate multiple data streams to anticipate species distributions, migrations, or other biological conditions in near-real time are rare. Developing management-relevant predictive capacity requires: (1) maintaining and enhancing observing programs that track changes in physical conditions, biological attributes, and fisheries activities, and (2) integrating these individual data streams into operational models of biological and fishery responses to physical changes.

3. Identify Adaptation Needs Within Fisheries Management

Beyond improving information about how climate-driven physical changes will affect marine ecosystems, it is also imperative to (1) proactively identify ways in which fishery management structures and processes will need to adapt to future climate conditions, and (2) ensure that fishery policies facilitate these changes. We identify three adaptation needs that became apparent as a result of events that took place during 2012.

a. *Evaluate permit structures to facilitate access to new target species.* As species distributions shift, resources will be lost to fisheries in certain areas but will become available in new areas (Link et al., 2011); these losses and gains may happen suddenly, as was the case with squid in the Gulf of Maine during 2012. In turn, fishermen may attempt to target different species, either in an effort to sustain a livelihood that was once dependent on a declining species or to take advantage of a species that has previously not been available (Pinsky and Fogarty, 2012). Switching target species is not easily accommodated by the current permit structure of most commercial fisheries but may be critical for supporting fishing communities and sustaining fisheries under climate change.

b. *Prepare for shifting management boundaries.* The start up of new fisheries poses challenges to management agencies, which may not immediately have authority over or be prepared to monitor or regulate a stock in a new area. Existing policies and governance arrangements (including both domestic jurisdictions and international agreements on transboundary stocks) will need to be modified to facilitate permitting, monitoring, and regulation of fisheries as species distributions shift.

c. *Decrease reliance on stationary baselines.* Finally, many fishery management frameworks are designed around previously observed biological patterns: the status of commercially fished stocks is assessed against biomass levels over the past 20 to 30 years; stock boundaries and protected areas are established based on the distribution of species when they were originally designated; temporal spawning closures are timed to historical spawning periods; and fishing seasons are set to open after a certain reproductive threshold is likely to be met or when product quality is expected to be high. These baseline biological patterns and events are not stationary and are expected to change in response to climate conditions. Moving forward, adapting fisheries management to climate change will require that management tools and reference points appropriately incorporate nonstationarity due to climate-driven physical variability and biological changes.

CONCLUSION

The 2012 ocean heat wave serves as a preview of the types of changes that are likely to occur in marine ecosystems as ocean temperatures warm and become more variable. The events associated with this heat wave brought both unanticipated challenges and opportunities to fisheries in the Gulf of Maine and likely in other areas that were affected by the extremely warm temperatures. The 2012 experience also provides a rare case study that can be used to develop a deeper understanding of how ecosystems respond to warming and to identify ways in which management can prepare for changes that will occur under future climate conditions. Drawing lessons from events like the 2012 heat wave is critical for developing adaptation strategies that will enhance existing capacities to sustain marine ecosystems and fisheries in the context of climate change.

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