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Marine species distribution shifts on the U.S. Northeast Continental Shelf under continued ocean warming

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ABSTRACT

The U.S. Northeast Continental Shelf marine ecosystem has warmed much faster than the global ocean and it is expected that this enhanced warming will continue through this century. Complex bathymetry and ocean circulation in this region have contributed to biases in global climate model simulations of the Shelf waters. Increasing the resolution of these models results in reductions in the bias of future climate change projections and indicates greater warming than suggested by coarse resolution climate projections. Here, we used a high-resolution global climate model and historical observations of species distributions from a trawl survey to examine changes in the future distribution of suitable thermal habitat for various demersal and pelagic species on the Shelf. Along the southern portion of the shelf (Mid-Atlantic Bight and Georges Bank), a projected 4.1 °C (surface) to 5.0 °C (bottom) warming of ocean temperature from current conditions results in a northward shift of the thermal habitat for the majority of species. While some southern species like butterfish and black sea bass are projected to have moderate losses in suitable thermal habitat, there are potentially significant increases for many species including summer flounder, striped bass, and Atlantic croaker. In the north, in the Gulf of Maine, a projected 3.7 °C (surface) to 3.9 °C (bottom) warming from current conditions results in substantial reductions in suitable thermal habitat such that species currently inhabiting this region may not remain in these waters under continued warming. We project a loss in suitable thermal habitat for key northern species including Acadian redfish, American plaice, Atlantic cod, haddock, and thorney skate, but potential gains for some species including spiny dogfish and American lobster. We illustrate how changes in suitable thermal habitat of important commercially fished species may impact local fishing communities and potentially impact major fishing ports along the U.S. Northeast Shelf. Given the complications of multiple drivers including species interactions and fishing pressure, it is difficult to predict exactly how species will shift. However, observations of species distribution shifts in the historical record under ocean warming suggest that temperature will play a primary role in influencing how species fare. Our results provide critical information on the potential for suitable thermal habitat on the U.S. Northeast Shelf for demersal species in the region, and may contribute to the development of ecosystem-based fisheries management strategies in response to climate change.

1. Introduction

At a range of spatial scales, marine species worldwide are already experiencing the effects of global climate change due to increasing temperatures, altered weather patterns, changes in sea level, circulation patterns, nutrient loads, and the acidity of the oceans (Stock et al., 2011; Walther et al., 2002). Some species may respond to climate change by shifting their distributions to regions with more favorable conditions or by changes in productivity in response to the new conditions in a given region.

Within the Northwest Atlantic Ocean, the U.S. Northeast Continental Shelf (U.S. NES, Fig. 1) is a region where ocean warming has been identified as a major driver of changes in the distribution of marine species (Hare et al., 2010, 2016; Lynch et al., 2015; Nye et al., 2009; Pinsky and Fogarty, 2012; Pinsky et al., 2013;

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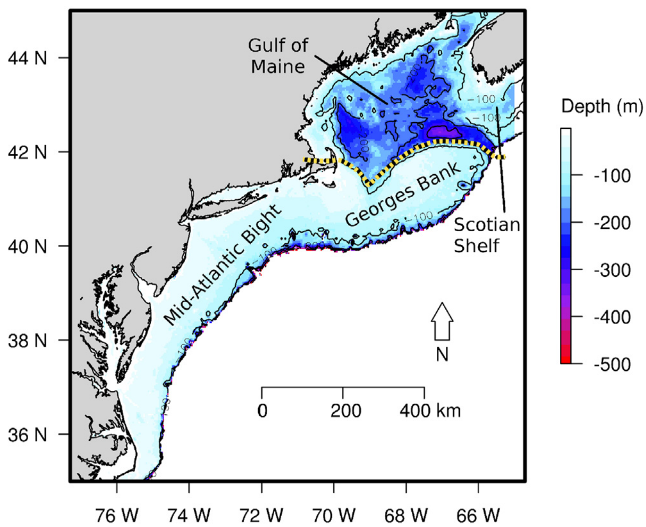

Fig. 1. The Northeast U.S. Shelf illustrating the southern region: the Mid-Atlantic Bight and Georges Bank, and northern region: the Gulf of Maine with shaded bathymetry (meters depth). Dashed line indicates the split between the northern and southern regions.

Rijnsdorp et al., 2009). Observations of sea surface temperature (SST), particularly within the Gulf of Maine, show a warming rate faster than 99% of the global ocean over the past decade (Pershing et al., 2015). Climate change projections from a high-resolution global climate model also suggest a U.S. NES warming rate that will be two to three times faster than the global average (Saba et al., 2016). Ocean temperature in the Northwest Atlantic has been linked to the relationship between the Atlantic Meridional Overturning Circulation (AMOC) and the position of the Gulf Stream (Zhang, 2008). The AMOC is a major component of the Earth's climate system and can be characterized by a northward flow of warm, salty water in the upper layers of the Atlantic Ocean, and a southward flow of colder water in the deep Atlantic Ocean. A weaker AMOC correlates with a more northerly position of the Gulf Stream, which is associated with warmer ocean temperatures (Zhang, 2008) and more Gulf Stream-associated slope water entering the Gulf of Maine (Saba et al., 2016). The enhanced warming of the U.S. NES in both observations and modeled climate change projections are thought to be due to the combined effects of global warming, a weakening AMOC, and changes in regional ocean circulation (Saba et al., 2016).

The U.S. NES is a highly productive, temperate system that is influenced by tides, wind-driven mixing, a strong seasonal cycle, and two major oceanic current systems: the Labrador Current (colder and fresher water from the north) and the Gulf Stream (warmer and saltier water from the south). The high primary productivity in the region combined with its location between warm and cold temperate regions results in a diverse array of fish and invertebrates, many of which are commercially important. With complex biotic, environmental, and anthropogenic forces at play, it is critical to gain a better understanding of the interactions between species, the effects of fishing pressure, and to understand the role of climate change in shifting species and community distributions.

There is consensus among researchers that climate change is going to affect marine taxa, but it is not clear that all species will be negatively impacted. There has recently been a focus on climate change 'winners and losers' (Glantz, 1995) and the idea that the abundance and distribution of some species or species groups may remain stable or expand with changes in climate whereas others may decline in abundance and distribution (Hare et al., 2016; Hoelzel, 2010). While it is appreciated that some species may do better while others worse under climate change, the complex interplay of changing species interactions and fishing patterns make understanding the intricacies of these changes difficult. Despite this complexity, understanding changes in thermal habitat availability will help clarify general patterns of change in species distributions. Using bottom trawl survey data collected within the U.S. NES, we estimated realized bathy-thermal niches for 58 demersal and pelagic species. A high-resolution global climate model developed by the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) was used to generate future projections of bottom and surface ocean temperature across the U.S. NES region. We then used these future temperatures to project the distributions of marine species on the Shelf and explore the hypothesis that some species will be more impacted than others by changes in ocean temperature.

Kleisner et al. (2016) illustrated historical differences in regional oceanographic and environmental characteristics and bathymetry along the U.S. NES responsible for variability in the response of individual species and species assemblages to warming ocean temperatures over the past four decades. In particular, the Gulf of Maine is a semi-enclosed continental shelf sea with deep and variable topography that is strongly influenced by the mixing of water masses from the North and South, while Georges Bank and the Mid-Atlantic Bight have comparatively more uniformly shallow bathymetry and less mixing. Between the northern and southern U.S. NES, there were differential shifts in species and assemblage distributions over the 1968–2013 time period. In general, species on Georges Bank and the Mid-Atlantic Bight exhibited stronger pole-ward shifts, while species in the Gulf of Maine exhibited stronger shifts in depth rather than latitude. We expect that these strong regional patterns on the U.S. NES will carry forward under future climate change scenarios. Therefore, we hypothesize that species that are currently distributed in the southern U.S. NES will continue to have adequate levels of suitable thermal habitat within the survey region in the future because they can potentially shift northward following the movement of temperature isotherms. Conversely, species that are currently concentrated on the northern U.S. NES will ultimately experience a decline in suitable thermal habitat within the survey region. Here we present an analysis of historical and potential future species distribution change on the U.S. NES.

2. Materials and methods

2.1. Global climate model projection

The most recent Intergovernmental Panel on Climate Change (IPCC) assessment of projected global and regional ocean temperature change is based on global climate models that have relatively coarse ($\sim$100 km) ocean resolutions (IPCC, 2013). At this coarse resolution, the Gulf Stream position is misrepresented in the models, separating from the U.S. coast too far to the north, and therefore resulting in a warm bias in sea surface temperature (Saba et al., 2016).

Recently, a high-resolution global climate model was developed by NOAA GFDL, which has a 0.1° (10-km global) resolution ocean component and a 0.5° (50-km global) resolution atmosphere component (CM2.6). This model has been shown to resolve regional ocean circulation and bathymetry within the U.S. NES, including the position of the Gulf Stream, Georges Bank, and the Gulf of Maine's Northeast Channel, much more accurately than lower resolution models assessed by the IPCC (Saba et al., 2016). Consequently, CM2.6 has the lowest bias in SST and bottom temperature in the U.S. NES relative to coarser models (Saba