Modeling climate effects on the dispersal and distribution of early life stages of walleye pollock over the eastern Bering Sea Shelf

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Summary

We developed a coupled biological-physical model (ROMS-TRACMASS) to examine how variable atmospheric and oceanographic forcing affects the spawning, transport, and distribution of walleye pollock early life stages (ELS) in the eastern Bering Sea. The eastern Bering Sea recently experienced a prolonged warm period followed by a prolonged cold period. Analyses of observational data indicated that spatial distributions of walleye pollock (*Theragra chalcogramma*; hereafter pollock) ELS are influenced by broad-scale and fine-scale variables, with temperature explaining more of the variation in abundance than wind, spawning stock biomass, and zooplankton biomass. Under warmer-than-average thermal conditions over the Bering Sea shelf distributions were shifted to the east, suggesting a relationship with the predominant wind patterns in these years. Additionally, adult fishery data indicate a change in the time of peak spawning between warm and cold years. The individual-based biophysical model was used to test the effects of atmospheric, oceanographic, and biological conditions on the transport, growth, and distribution of walleye pollock eggs and larvae. Model results will help elucidate the dominant physical mechanisms responsible for observed changes. We are currently examining historical pathways of dispersal with the intention of forecasting how pathways and distributions might vary in the future under changing climate conditions.

Introduction

The eastern Bering Sea recently underwent a prolonged warm period (2001-2005), followed by a prolonged cold period (2007-2012; Stabeno et al. 2012). During cold years, winter ice extends farther south and offshore, creating a cold pool of bottom water <2°C, which could influence the movements and spawning of demersal fishes (Mueter and Litzow 2008). The water circulation also differs between these periods with weaker westward flow over the middle shelf during warm years (Stabeno et al. 2012), which could affect the dispersal of pelagic ELS. Recent studies on the distributions of pollock ELS indicate that stages are found further inshore in warm years than in cold years (Smart et al. 2012). Analyses indicated that temperature explained the greatest amount of variation in abundance. The variations in distribution could be the result of differences in physical transport associated with temperature, or the result of biological responses to the differing physical environments. The shift in distributions to the east in warm years suggests a relationship with enhanced onshelf transport in those years. Additionally, preliminary analyses of fishery data suggest that spawning extends further inshore in warm years (Barbeaux unpub. data). Differences in water temperature could also impact the development rates of ELS, and thus their distributions. Mechanisms behind the distribution divergences have not been identified, and effects of climate variation on the dispersal of pollock ELS have not been investigated. To do so, we developed an individual-based model of pollock biology and behavior coupled to a hydrodynamics model. Our objective was to test the effects of atmospheric (wind), oceanographic (ice, water column temperature), and biological (time and location of spawning) conditions on the distribution, growth, and transport of pollock eggs and larvae.

Materials and Methods

Observational data from the Fisheries Oceanographic Coordinated Investigations (FOCI) surveys and Bering Sea Ecosystem Study (BEST)/Bering Sea Integrated Ecosystem Research Project (BSIERP) cruises were used to estimate horizontal distributions of pollock ELS for model-data comparisons. A version of ROMS for the Northeast Pacific (NEP6) was used as the physical forcing. Daily averages of the physical variable fields (velocity, temperature, depth of mixed layer) from hindcasts for 1995-2012 were stored and used by the offline particle-tracking model TRACMASS. The TRACMASS code was modified to include a biological subroutine that simulated the development, growth, and vertical behavior of pollock ELS, parameterized from the literature for the Bering Sea population. Spawning polygons were created from fishery-based observations of adult pollock in spawning condition using only the dominant spawning regions on the shelf. Polygons were created for 2-week periods from the middle of January to the end of April for a total of 7 release dates. Spawning was initialized at all ROMS grid points within each spawning polygon. Ten particles were released as eggs every 10 m from surface to bottom at each grid point. This yielded a total number of particles that produced stable results in particle number sensitivity analyses. Model runs for two years with the most spatially and temporally resolved observations (1995, 2007; both cold years) were used to choose the growth and vertical behavior routines that were most consistent with the data. After selecting the best routines, the model was run for the warm (1996, 2002, 2003, 2005) and cold (1997, 1999, 2000, 2006, 2008-2012) years. The centers of gravity of modeled ELS in warm and cold years were calculated, contrasted, and related to physical forcing.

Results and Discussion

When spawning time and location were held constant, and growth was temperature-independent, the centers of gravity of pollock ELS differed in warm and cold years. In warm years, yolksac and preflexion larvae were more inshore, while late larvae were slightly more northward. The modeled distributions of the earliest larval stages qualitatively matched those of observations, though differences between warm and cold years were not as large. Thus, physical transport alone, as affected by differences in atmospheric and oceanographic forcing, was able to account for some of the variability in pollock ELS distributions. Further simulations are underway to assess the effect of spawning timing, spawning location, and temperature-dependent growth on the remaining variability.

References

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