Surfclams and Climate Change: Report of the National Science Foundation Study

Abstract

Overview: In 2009 the National Science Foundation (NSF) awarded a large research grant to us from its very competitive program on "Coupled Natural and Human Systems." We proposed to study Atlantic surfclams and the fishery and management system involved from this "coupled systems" perspective, which meant investigating everything from the workings of the ocean, settlement of larvae and the growth of clams to the workings of markets and the decisions made by clam harvesters and fishery managers. Our focus was how this complex "coupled" system is affected by and responds to climate change, which in this case is mainly the warming of waters. In the 4th year of this study, we report on three major modeling projects that came out of it, focusing on the topic of spatial distribution and variability . The models should be particularly useful in investigating trends in the surfclam stock and fishery of concern to the council, including continued poor recruitment inshore Delmarva, the influence of long-term recruitment trends off New Jersey, the declining trend in LPUE in the same region, and the declining trend in maximum size throughout the range of the stock. The lead scientists involved in the study are Eric Powell, Dale Haidvogel, Roger Mann, Eileen Hofmann, Bonnie McCay, and Sylvia Brandt. Others include John Klinck, Daphne Munroe, Peter Zhang, Diego Narváez, Paula Moreno, and Carolyn Creed. The institutions represented are Rutgers-New Brunswick, Virginia Institute of Marine Science, University of Massachusetts-Amherst, and Old Dominion University. The project has also benefited from industry, management, and scientific personnel who agreed to serve in an advisory capacity.

Larval Dispersal Model

Spatial distribution of a fish or shellfish population can change due to increased mortality of portions of the stock and the failure of larval dispersal to replenish those lost populations, and we hypothesized that this might be happening in the southern range of the Atlantic surfclam due to climate change, accounting for the observed decline of surfclam populations in the Delmarva (DMV) and New Jersey (NJ) areas from 1997 to 2008.

We used a coupled physical-biological larval dispersal model to identify the probable inter-population larval connectivity patterns of the Atlantic surfclam, *Spisula solidissima*, and to evaluate the seasonal and interannual variability in these patterns. The model uses the hydrodynamic model ROMS (Regional Ocean Modeling System) for the Mid-Atlantic and New England areas (Mid-Atlantic Bight, MAB) to simulate water flow and a Lagrangian particle tracking module coupled to a surfclam larval growth and behavior model to track the transport of larvae from birth to settlement.

Simulated surfclam larvae generally disperse over one hundred kilometers along the shelf, but the distance traveled is highly variable in space and over time. Simulations show a typical along-shore connectivity pattern from the northeast to the southwest among the surfclam populations distributed from Georges Bank west and south along the MAB shelf. Continuous surfclam larval input into regions off Delmarva (DMV) and New Jersey (NJ) suggests that insufficient larval supply is unlikely to be the factor causing the failure of the population to recover after the observed decline of the surfclam populations in DMV and NJ from 1997 to 2008. The Georges Bank (GBK) population is relatively isolated from populations to the west and south in the MAB; however, model results suggest substantial inter-population connectivity from southern New England to the Delmarva region. Seasonality in the timing of larval release (timing of spawning) tended to change larval dispersal particularly for northern regions like Long Island and New Jersey, where very early (May) and late (September/October) larval releases showed much shorter alongshore dispersal distances than larvae released between these times. Success of larval survival also varied, with larvae released in the summer tending to survive to settle more than those released very early (May) or very late (October).

These results provide important insight into the general mechanism of how the physical environment interacts with larval behavior to influence larval transport, connectivity and population dynamics in this system. The results also show that recruitment is dependent upon broodstock locally and immediately north. Recruitment off New Jersey is dependent upon spawning off New Jersey and off Long Island. Thus, populations are likely relatively resilient to local variations in abundance as recruitment is dependent on broodstock from a relatively large regional area.

Adult Clam Biology Model

Since 1997, populations from southern inshore regions of the clam's range have experienced significant mortality events, which have coincided with a general warming of bottom water temperatures (reaching 21-24˚C in September) along the MAB. Coincidentally, population size structure appears to have shifted to smaller maximum sizes. The potential linkages between warming bottom temperatures and increased surfclam mortality and/or reduced growth are being addressed using a hindcast model that simulates the growth of post-settlement surfclam populations at specific locations on the MAB shelf. External forcing for the growth model is provided by a 50-year simulation (1958-2007) of bottom water temperature obtained from an implementation of the Regional Ocean Modeling System (ROMS) for the MAB continental shelf.

The simulations show that surfclams experience high mortality (mortality > 0.20 per year) during years when bottom water temperatures remain 1-2°C above average conditions for an extended time at each location. Further, simulations show that the magnitude of mortality is moderated by the existing population structure such that older, larger populations experience higher mortality than smaller, younger populations. Simulation results demonstrate that the general increase in bottom temperatures, particularly in inshore regions, is capable of causing a small decrease in the maximum size of clams through changes in individual scope-for-growth and through mortality loss of large clams. These physical drivers generate only a portion of the observed changes in size; this suggests that additional processes must be present leading to a reduction in size. Possibilities include a reduction in food supply accompanying warmer bottom water and harvesting pressure. These results provide a basis for analyzing the mechanisms responsible for long-term changes in surfclam abundance distribution along the MAB.

Fishery Economics Model

The influence of climate-induced range compression on the surfclam stock of the Mid-Atlantic Bight (MAB) has engendered significant changes in fleet dispersion amongst ports and in the economics of the industry. A spatially-explicit fisheries economics model (SEFES) has been developed to evaluate how changes in stock distribution force responses in the fishery. This model is capable of carrying out a Management Strategy Evaluation (MSE) for the surfclam fishery.

Fishing location is determined by port location, vessel characteristics, Captain's behavior, and stock density. The model reproduces and explains known characteristics of the fishery, including the limitation of the fishery predominately to a few 10-minute squares and the half-decadal to decadal decline of LPUE within heavily-fished 10-minute squares. Some 10-minute squares remain productive for the fishery over decadal time periods, even with continuous targeted harvesting, while productivity in others rapidly declines, as also is observed in today's fishery. Vessel speed, hold capacity, and dredge size are important determinants of the degree of dispersion of fishing among 10-minute squares.

To examine the effects of a change in range, we performed 50-year simulations for 24 scenarios: three surfclam ranges (past, present, one possible future), four boat types, and two distinct captain behaviors (exploratory and conservative). As expected, vessel effort shifted northward and uncaught quota varied by port, increasing southward, and boat type, with larger vessels often showing better performance suggesting that the larger vessels can better cope with changes in surfclam range.

Future Uses of the Models

Future scenarios depending upon assumed rates of continued warming and degrees of surfclam range adaptability can now be investigated. Outcomes that might be investigated with these models--resulting from further warming of the Mid-Atlantic Bight--- which might impact management decisions include estimates of optimal vessel size and distribution, economic return, and stock status, including variation in recruitment pattern, size frequency, and mortality. The models should be particularly useful in investigating trends in the surfclam stock and fishery of concern to the council, including continued poor recruitment inshore Delmarva, the influence of long-term recruitment trends off New Jersey, the declining trend in LPUE in the same region, and the declining trend in maximum size throughout the range of the stock.