HOW DOES EXPLICIT TREATMENT OF SPATIAL VARIABILITY IN ENVIRONMENTAL CONDITIONS AFFECT SIMULATED ANCHOVY RECRUITMENT?

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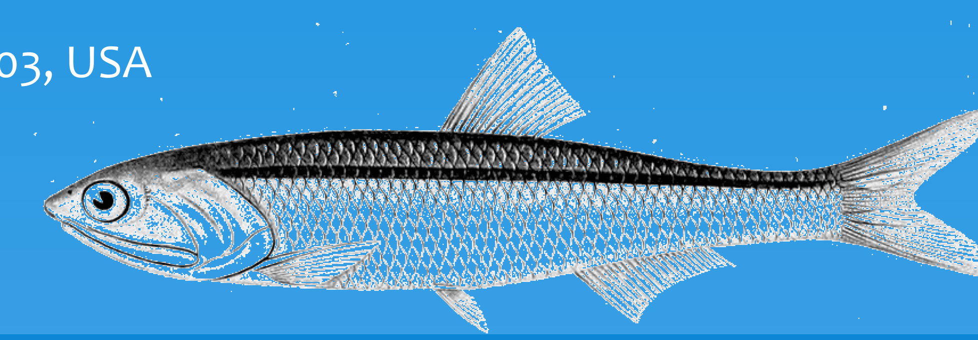
*** Presenter for PICES 2015 Annual Meeting, Oct 14~25, Qingdao, China**



Introduction

Spatial variation in environmental conditions such as temperature and food availability can greatly affect larval and juvenile fish growth and survival, and therefore ultimately affect recruitment to the population. In this study, we use a 3-dimensional (3-D) individual-based model (IBM) of Peruvian anchovy to examine how explicit representation of spatial variation in environmental conditions can affect recruitment. Peruvian anchovy is a good test case because it is well-studied, it is an important ecological and commercial species, and inhabits a coastal upwelling system that is highly spatially and temporally dynamic.

Fig. 1 Peruvian anchovy large schools close to the coasts of Peru.

Methods

Our IBM model uses temperature, velocity, and phytoplankton and zooplankton concentrations generated from a coupled hydrodynamic and NPZD model, mapped to the three dimensional rectangular grid used in the anchovy IBM. Our IBM model domain is focused on the Peruvian upwelling area (0-20°S and 70-85°W, Fig. 2).

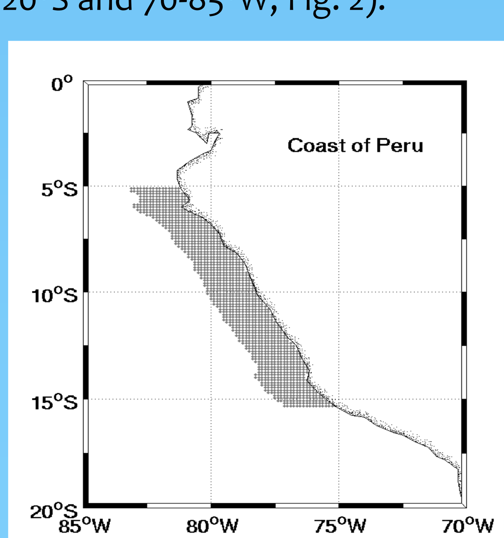


Fig. 2 The portion of the ROMS model grid (45° S to 65° N) used for the IBM grid (entire box), and the shaded area used to start super-individuals for the 3-D version and to average results for input to the 0-D version.

We compare predicted recruitment for cohorts that start each month between 1990 and 2004 between a fully 3-D IBM and point model (0-D) that used spatially-averaged environmental conditions. The IBM simulated individuals as they progressed from eggs to recruitment at 10 cm. Eggs and yolk-sac larvae were followed hourly through the processes of development, mortality, and movement, and larvae and juveniles were followed daily through the processes of growth, mortality, and movement (advection plus behavior). A bioenergetics model was used to grow larvae and juveniles. The NPZD model provided prey fields which influence both food consumption rate as well as behavior mediated movement with individuals going to grids cells having optimal growth conditions. We conduct three sensitivity simulations to demonstrate how recruitment was affected by the importance of spatial variation in temperature and food.

Results

Recruitment

The 3-D and 0-D versions generally produced similar interannual patterns in recruitment (to 10cm) for individuals or cohorts starting monthly from 1991 to 2004, with the 3-D results yielding consistently higher survivorship (Fig. 3). They both captured the very poor recruitment observed during the 1997-1998 El Niño event. While both versions generated very low recruitment during the El Niño period, the recruitment predicted by the 3-D version was substantially higher (but still low) compared to the 0-D version.

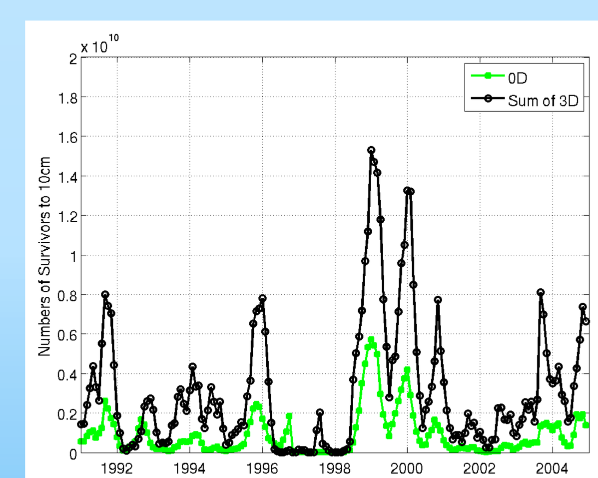


Fig. 3 Recruitment of anchovy (numbers of 10 cm) for each year-month simulation for the 3-D and 0-D versions of the model.

Spatial distribution of growth rates

We recorded the growth rates of all larvae each day for the October 1991, 1997, and 2004 cohorts and averaged them each day over super-individuals for those that occurred in the surface layer or 50 m layer (Fig. 4). The October 1997 cohort was during the El-Nino period, and larval growth was uniformly low. The October 1991 and 2004 cohorts resulted in average to high recruitment, but showed different local hot spots for larval growth between surface and 50 m within a cohort and between cohorts.

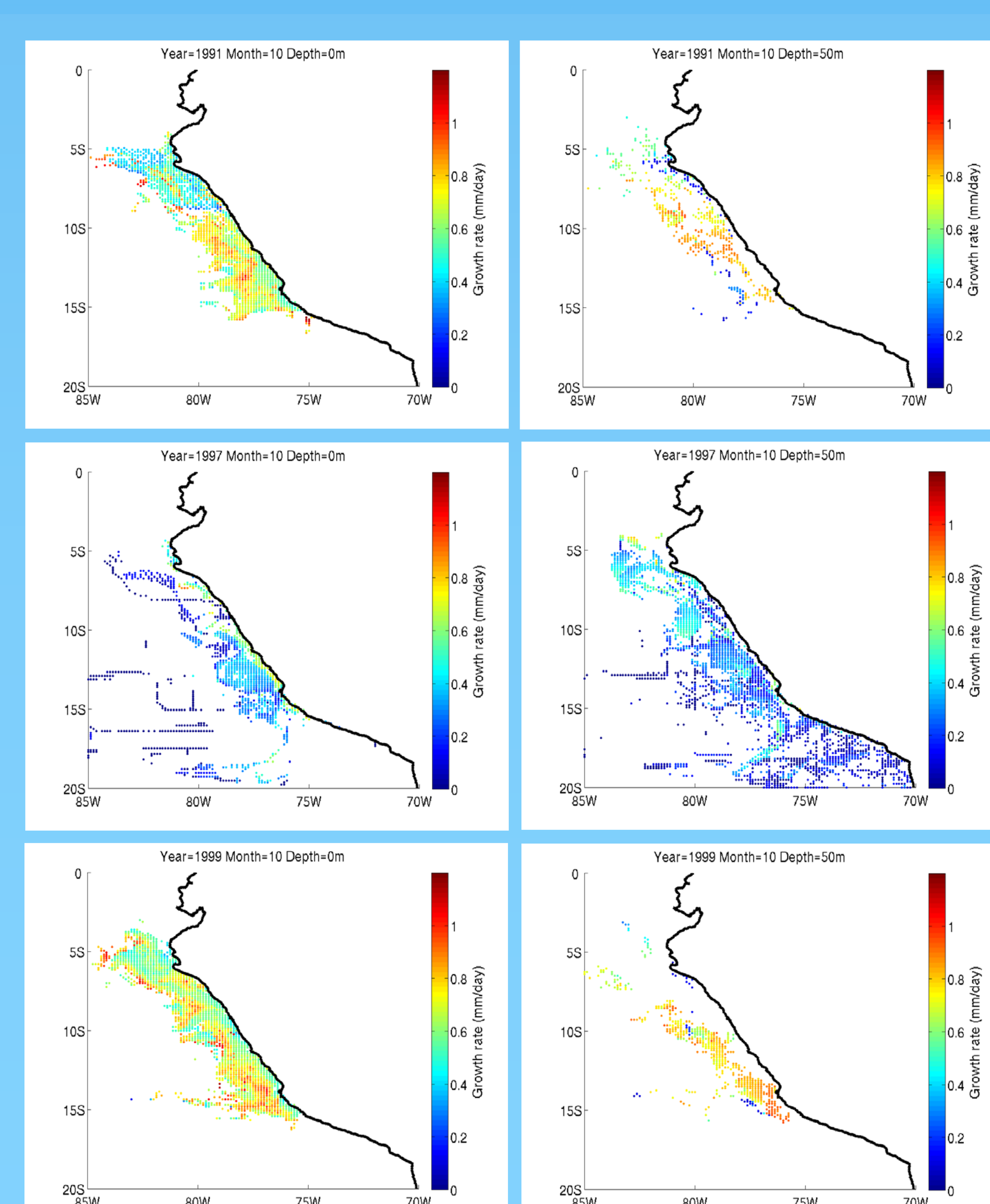


Fig. 4 Average daily larval anchovy growth rates in the surface and 50 m layers, by horizontal gird cell, for the 3-D simulations of the October 1991, 1997, and 1999 cohorts.

Stage-specific survivals

Higher recruitment in the 3-D simulations was mostly due to consistently higher survival during the larval stage and some increase in survival in the juvenile stage during certain month-year combinations coincident with the La Niña period (1999-2001 in Fig. 5).

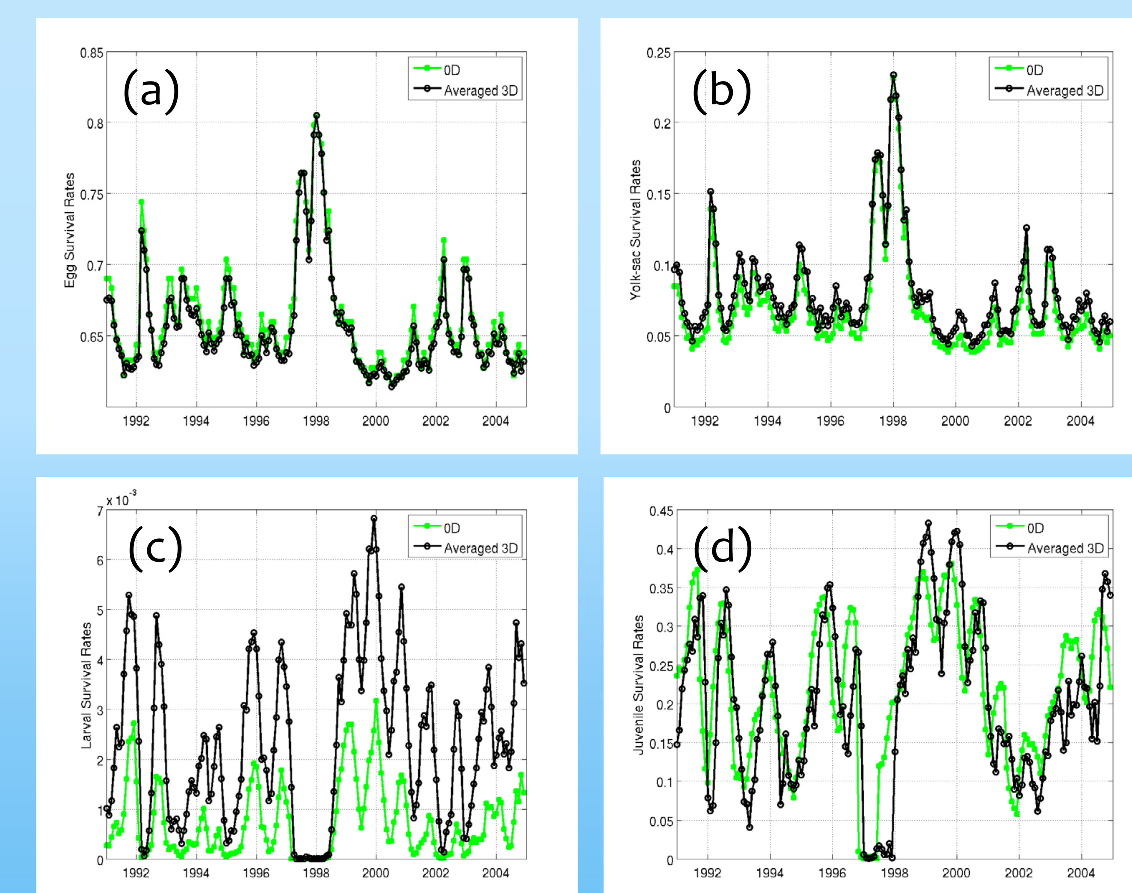


Fig. 5 Stage-specific fractions surviving of anchovy for each year-month simulation for the 3-D and 0-D versions of the model. (a) eggs, (b) yolk-sac larvae, (c) larvae, and (d) juveniles.

Sensitivity Studies

Three sensitivity simulations were conducted: passive moving for all stages (drift only), constant averaged temperature, and constant averaged food. Not allowing for super-individuals to move towards cells with high growth rates resulted in very low recruitment, especially during 1992 to 1998 and after 2002, when baseline recruitment was relatively average or higher. Eliminating the spatial variability in temperature resulted in mostly higher recruitment than baseline (green versus red lines), while eliminating spatial variation in food resulted in lower recruitment than baseline (black versus red lines).

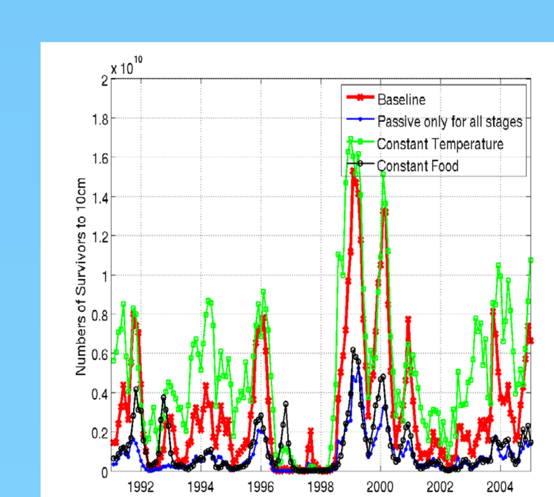


Fig. 6 Recruitment (numbers of anchovy surviving to 10 cm) of for each year-month simulation for baseline, passive transport only for all stages, and spatially-averaged temperature or food.

Conclusion

We compared predicted Peruvian anchovy recruitment between the full 3-D IBM and 0-D model that used spatially-averaged environmental conditions. The 3-D and 0-D versions generated similar interannual patterns in monthly recruitment for 1991 to 2004, with the 3-D results yielding consistently higher survivorship. Both model versions successfully captured the very poor recruitment during the 1997-1998 El Niño event. Higher recruitment in the 3-D simulations was due to higher survival during the larval stage resulting from individuals searching for more favorable temperatures that lead to faster growth rates. The strong effect of temperature was because both model versions provided saturating food conditions for larval and juvenile anchovies.

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Acknowledgements

This research was initially funded by NASA grants (NNG04GM64G and NNX09AU39G) to Dr. F. Chai and Dr. F. Chavez. The major analyses were done during the lead author's working time supported by NOAA Fisheries through the Fisheries And The Environment (FATE) program. We acknowledge National Science Foundation (granted to Dr. Enrique Curchister, US delegate to the PICES Governing Council) who kindly provided partial financial support to Y. Xu to travel to Qingdao, China to present this research. We acknowledge Ian Liu and Jenny Zhang's assistance with the poster design ideas.