Progress in Oceanography 138 (2015) 348–380

Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

Demonstration of a fully-coupled end-to-end model for small pelagic fish using sardine and anchovy in the California Current

Kenneth A. Rose [a,*], Jerome Fiechter [b], Enrique N. Curchitser [c], Kate Hedstrom [d], Miguel Bernal [e], Sean Creekmore [a], Alan Haynie [f], Shin-ichi Ito [g], Salvador Lluch-Cota [h], Bernard A. Megrey [f,1], Chris A. Edwards [i], Dave Checkley [j], Tony Koslow [k], Sam McClatchie [l], Francisco Werner [l], Alec MacCall [m], Vera Agostini [n]

[a] Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA 70803, USA
[b] Institute of Marine Sciences, University of California, Santa Cruz, CA 95064, USA
[c] Department of Environmental Sciences, Institute of Marine and Coastal Sciences, Rutgers University, 14 College Farm Road, New Brunswick, NJ 08901, USA
[d] Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, AK 99775, USA
[e] General Fisheries Commission for the Mediterranean (GFCM), FAO of the United Nations, Fisheries and Aquaculture Department, Palazzo Blumenstihl, Via Vittoria Colonna 1, 00193 Rome, Italy
[f] Alaska Fisheries Science Center-NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, USA
[g] Atmosphere and Ocean Research Institute, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8564, Japan
[h] CIBNOR, Mar Bermejo # 195, Col. Playa Palo de Santa Rita, La Paz, B.C.S. 23090, Mexico
[i] Ocean Sciences Department, University of California, Santa Cruz, CA 95064, USA
[j] Scripps Institute of Oceanography, U.C. San Diego, 9500 Gilman Drive, La Jolla, CA 92093, USA
[k] Scripps Institution of Oceanography, CalCOFI, 9500 Gilman Drive, Department 0218, La Jolla, CA 92093, USA
[l] Southwest Fisheries Science Center-NOAA, 8604 La Jolla Shores Drive, La Jolla, CA 92037-1508, USA
[m] Southwest Fisheries Science Center-NOAA, 110 Shaffer Road, Santa Cruz, CA 95060, USA
[n] Global Marine Team, The Nature Conservancy, 255 Alhambra Circle, Miami, FL 33133, USA

ARTICLE INFO

Article history:
Available online 4 February 2015

ABSTRACT

We describe and document an end-to-end model of anchovy and sardine population dynamics in the California Current as a proof of principle that such coupled models can be developed and implemented. The end-to-end model is 3-dimensional, time-varying, and multispecies, and consists of four coupled submodels: hydrodynamics, Eulerian nutrient–phytoplankton–zooplankton (NPZ), an individual-based full life cycle anchovy and sardine submodel, and an agent-based fishing fleet submodel. A predator roughly mimicking albacore was included as individuals that consumed anchovy and sardine. All submodels were coded within the ROMS open-source community model, and used the same resolution spatial grid and were all solved simultaneously to allow for possible feedbacks among the submodels. We used a super-individual approach and solved the coupled models on a distributed memory parallel computer, both of which created challenging but resolvable bookkeeping challenges. The anchovy and sardine growth, mortality, reproduction, and movement, and the fishing fleet submodel, were each calibrated using simplified grids before being inserted into the full end-to-end model. An historical simulation of 1959–2008 was performed, and the latter 45 years analyzed. Sea surface height (SSH) and sea surface temperature (SST) for the historical simulation showed strong horizontal gradients and multi-year scale temporal oscillations related to various climate indices (PDO, NPGO), and both showed responses to ENSO variability. Simulated total phytoplankton was lower during strong El Nino events and higher for the strong 1999 La Nina event. The three zooplankton groups generally corresponded to the spatial and temporal variation in simulated total phytoplankton. Simulated biomasses of anchovy and sardine were within the historical range of observed biomasses but predicted biomasses showed much less inter-annual variation. Anomalies

* Corresponding author. Tel.: +1 225 578 6346; fax: +1 225 578 6513.
E-mail addresses: karose@lsu.edu (K.A. Rose), Fiechter@ucsc.edu (J. Fiechter), enrique@marine.rutgers.edu (E.N. Curchitser), kshedstrom@alaska.edu (K. Hedstrom), Miguel.Bernal@fao.org (M. Bernal), screek2@lsu.edu (S. Creekmore), Alan.Haynie@noaa.gov (A. Haynie), goito@aori.u-tokyo.ac.jp (S.-i. Ito), slluch@cibnor.mx (S. Lluch-Cota), cedwards@ucsc.edu (C.A. Edwards), dcheckley@ucsd.edu (D. Checkley), tkoslow@ucsd.edu (T. Koslow), Sam.McClatchie@noaa. gov (S. McClatchie), cisco.werner@noaa.gov (F. Werner), Alec.Maccall@noaa.gov (A. MacCall), vagostini@tnc.org (V. Agostini).
[1] Deceased.

http://dx.doi.org/10.1016/j.pocean.2015.01.012
0079-6611/© 2015 Elsevier Ltd. All rights reserved.

of annual biomasses of anchovy and sardine showed a switch in the mid-1990s from anchovy to sardine dominance. Simulated averaged weights- and lengths-at-age did not vary much across decades, and movement patterns showed anchovy located close to the coast while sardine were more dispersed and farther offshore. Albacore predation on anchovy and sardine was concentrated near the coast in two pockets near the Monterey Bay area and equatorward of Cape Mendocino. Predation mortality from fishing boats was concentrated where sardine age-1 and older individuals were located close to one of the five ports. We demonstrated that it is feasible to perform multi-decadal simulations of a fully-coupled end-to-end model, and that this can be done for a model that follows individual fish and boats on the same 3-dimensional grid as the hydrodynamics. Our focus here was on proof of principle and our results showed that we solved the major technical, bookkeeping, and computational issues. We discuss the next steps to increase computational speed and to include important biological differences between anchovy and sardine. In a companion paper (Fiechter et al., 2015), we further analyze the historical simulation in the context of the various hypotheses that have been proposed to explain the sardine and anchovy cycles.

© 2015 Elsevier Ltd. All rights reserved.

Introduction

End-to-end models are receiving increasing attention as a quantitative tool for investigating marine ecosystem responses to climate variation and fisheries management (Travers et al., 2007; Cury et al., 2008). End-to-end models typically combine submodels of physics (hydrodynamics), lower trophic levels (nutrient–phytoplankton–zooplankton, NPZ), and upper trophic levels (fish, birds, fishers) into a single modeling framework (Plagányi, 2007). Such models are conceptually and politically attractive because they can simulate ecosystem responses to single and simultaneous changes in multiple types of bottom-up (e.g., environmental) and top-down (e.g., harvest) perturbations and variation.

End-to-end models are possible now because of several developments. The traditional division between oceanography and fisheries is disappearing (Hollowed and Baily, 2009) and multidisciplinary studies that combine oceanography and fisheries are now common place (Megrey et al., 1996; Kendall and Duker, 1998). Furthermore, fishing, which was previously treated as a mortality rate specified externally to the population models, is now being considered as a dynamic member of the ecosystem (Liu et al., 2007; Perry et al., 2009; Fulton et al., 2011a,b; Marchal et al., 2013). For more than a decade, there also have been calls to develop tools for ecosystem-based fisheries management (e.g., Pikitch et al., 2004). Demand for new, comprehensive tools is due to uncertainty over the status of fish stocks worldwide (Hilborn, 2007; Worm et al., 2009), perceived deficiencies in the single-species approach (Latour et al., 2003; Rose and Cowan, 2003), and recognition of the complexity of ecosystem responses (Cury et al., 2000; Rose, 2000; Frank et al., 2005; Pine et al., 2009; Hunt et al., 2011). Models that permit the emergence of bottom-up, top-down, and wasp-waist controls (Cury et al., 2000; Bakun, 2006; Field et al., 2006), and how they operate simultaneously and vary in time, is vital for accurate projections of ecosystem responses (Cury et al., 2008). Finally, there have been advances in both the physics (e.g., meso-scale features, resolution of upwelling systems) and biological modeling (e.g., individual-based approach) that provide the needed ingredients for constructing end-to-end models. These advances have been partly possible due to ever increasing computing power (Rose et al., 2010), and due to the availability of new data acquired by remote sensing that permits broad-scale synoptic measurements, spatially-resolved field data, and movement information from acoustic and sonic tagging of animals (Nathan et al., 2008; Rutz and Hays, 2009).

Our approach presented here is an example of an end-to-end model that is 3-dimensional, time-varying, multispecies, and individual-based for fish, with all submodels using the same resolution spatial grid and all solved simultaneously to allow for feedbacks. Most of the end-to-end models to date, typified by Atlantis, OSMOSE, and Ecospace (see Plagányi, 2007), simplify one or more of these features. We developed our model within the Regional Ocean Modeling System (ROMS), a commonly used hydrodynamics model. Using the well-tested and open-access ROMS enables a regional model that resolves scales relevant to the biology, and lays the groundwork for the potential future distribution of an individual-based end-to-end capability within ROMS. We use a widely-used NPZ model (NEMURO; Kishi et al., 2007) as a balance between simplicity and allowing for multiple prey options for fish. An individual-based approach for fish, if computationally feasible and supportable with data, has advantages over the commonly used age and stage structured approaches typical of fisheries modeling (see Hilborn and Walters, 1992). The individual-based approach allows for conceptually straightforward linking of growth and mortality processes to the detailed spatial and temporal scales of the physical and NPZ submodels, and relatively easy representation of foodweb interactions on local scales and behavioral movement (DeAngelis and Rose, 1992; Breckling et al., 2006). Finally, we include fishing via an agent-based bioeconomic model to allow for harvest to dynamically respond to changing conditions. While each of these model types has been used before (either separately or coupled in various combinations), our approach was to combine them into a single end-to-end model.

We present our end-to-end model using northern anchovy (*Engraulis mordax*) and Pacific sardine (*Sardinops sagax caerulea*) in the California Current system (CCS). The CCS is a good test system because it is well studied (Bograd et al., 2003; Checkley and Barth, 2009), was included in several existing ROMS hydrodynamic models (Curchitser et al., 2005; Powell et al., 2006; Veneziani et al., 2009a), was included in other end-to-end modeling analyses (Field et al., 2006; Kaplan et al., 2010), and has been the focus of discussion about ecosystem-based fisheries management (Field and Francis, 2006). In addition, the CCS is one of the major upwelling systems in the world, which are important habitat for fish production (Rykaczewski and Checkley, 2008), and anchovy and sardine show decadal long cycles in multiple ecosystems, including the California Current (Schwartzlose et al., 1999). Sardine and anchovy are of interest because their dynamics have generated general theories about fish population dynamics (Chavez et al., 2003; MacCall, 2009), and because coastal pelagic species represent a large portion of the world's catch and play an important ecological role as grazers of zooplankton and forage for other harvested fish species (Cury et al., 2000; Fréon et al., 2005; Hannesson et al., 2009; Smith et al., 2011; Pikitch et al., 2014).

In this paper, we illustrate our end-to-end model using a 50 year (1959–2008) simulation of anchovy, sardine, and a predator species (albacore). Our objectives are to demonstrate a multi-species, individual-based end-to-end modeling approach

Download English Version:

https://daneshyari.com/en/article/4552977

Download Persian Version:

https://daneshyari.com/article/4552977

Daneshyari.com