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Modeled connectivity between northern rock sole (*Lepidopsetta polyxystra*) spawning and nursery areas in the eastern Bering Sea

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ABSTRACT

Connectivity between spawning and potential nursery areas of northern rock sole, *Lepidopsetta polyxystra*, in the eastern Bering Sea was examined using an individual-based biophysical-coupled model. Presumed spawning areas were identified using historical field-collected ichthyoplankton data, and nursery habitats were characterized based on previously described settlement areas. Simulated larvae were released from spawning areas near the Pribilof Islands, south of the Pribilof Islands along the outer continental shelf, on the north side of the Alaska Peninsula, and in the Gulf of Alaska south of Unimak Island. Simulated larvae were transported along two general pathways: 1) northwards along the outer continental shelf from Unimak Island towards the Pribilof Islands and further north offshore of mainland Alaska, and 2) eastward along the Alaska Peninsula. At the end of the 2-month simulation, drift pathways placed pre-settlement stage larvae offshore of known nursery areas of older juveniles near mainland Alaska, consistent with a hypothesis that initial settlement may be followed by substantial post-settlement redistribution.

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1. Introduction

Connectivity in marine populations has been the focus of intense interest, both among invertebrate and vertebrate marine populations, due to its ecological (biogeographic structuring, population dynamics, climate change) and management (stock structure, essential fish habitat, marine protected areas) implications. Considerable work on the topic has been done in tropical systems where locating, orienting toward, and settling to coral reef habitat is of critical importance to recruitment success (Cowen and Sponaugle, 2009; Sale, 2004). Complementary work in high-latitude systems has centered on flatfishes, as these forms face similar constraints as reef-associated species, in particular the requirement of delivery to suitable nursery habitats prior to assuming a settled existence. For these and other substrate-reliant fishes, locations of spawning areas may be highly evolved such that they are located in areas where prevailing hydrodynamic patterns transport eggs and larvae to juvenile nursery habitat (Bailey et al., 2005; Hinckley et al., 2001). Such a strategy may be critical for flatfishes as it maximizes the likelihood that settlement-ready stages are in close proximity to appropriate benthic habitat, which may be decisive if a species cannot delay metamorphosis until suitable habitat can be found. Accordingly, studies that examine the transport and timing of dispersal of pelagic flatfish stages are of importance to the study of flatfish advection, survival, and recruitment.

Northern rock sole is commercially fished in the Bering Sea (BS) and Gulf of Alaska (GOA). The species has a large biomass (estimated at over 1.8 million tons in the eastern BS; Wilderbuer and Nichol, 2011) and is an important component of the BS ecosystem (Zador, 2011). Annual differences in wind direction and resulting larval transport variations are hypothesized to explain northern rock sole recruitment variability in the eastern BS (Wilderbuer et al., 2002), and disruptions in connectivity between spawning and nursery areas are one postulated mechanism for variable recruitment. However, links between spawning and nursery habitat have not been directly investigated, and transport trajectories and source-sink relationships remain unknown.

Northern rock sole spawn in December through March (Wilderbuer and Nichol, 2011). Eggs are demersal and "semi-adhesive," and incubation ranges from about 15 days at 9 °C to about 36 days at 2 °C (Laurel and Blood, 2011). Larvae hatch between 3.0 and 5.4 millimeters (mm) standard length (SL) (Laurel and Blood, 2011). Larvae are most abundant in Alaskan waters in April (Matarese et al., 2003) and have been reported in the eastern BS and the GOA near Unimak Island, along the north side of the Alaska Peninsula in May (Lanksbury et al., 2007), and near the Pribilof Islands in July and August (Duffy-Anderson et al., 2006). Lanksbury et al. (2007) have hypothesized several unique larval dispersal pathways for northern rock sole larvae in the southeast BS (Fig. 1), but to date there have been no directed studies evaluating trajectory variations in time and space.

Compared to what is known about larvae, less is known about the distribution of juvenile northern rock sole in the BS. Recent work

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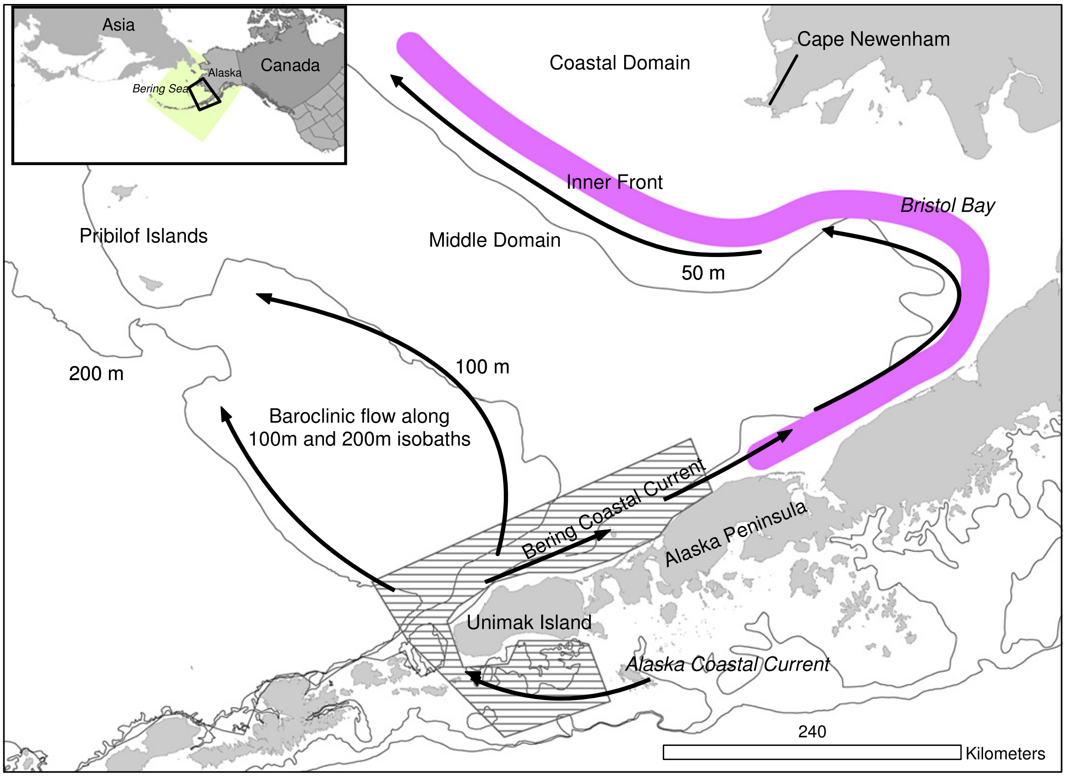

Fig. 1. Area (gray cross hatch) with reported concentrations of northern rock sole larvae in May. Arrows show hypothesized larval transport following the Bering Coastal Current to the northeast along the Alaska Peninsula, and baroclinic flow to the north towards the Pribilof Islands. The approximate location of the Inner Front is depicted in purple. The inset map shows the study area (black polygon) and the area of the regional ocean modeling system (ROMS; green shading) used in this study.
From Lanksbury et al., 2007.

over a relatively small geographic area has found age-0 northern rock sole off of mainland Alaska from Nunivak Island to Cape Newenham, and along the north side of Unimak Island and the Alaska Peninsula (Fig. 2). Age-0 northern rock sole have highest densities offshore of the coast (Fig. 2), in the vicinity of a seasonal front (Inner Front, IF) near the 50-m isobath and the Bering Coastal Current (BCC), which separates the thermally-mixed coastal domain from the thermally-stratified middle domain (Kachel et al., 2002; Fig. 1). Interestingly, in the absence of the IF along the north side of Unimak Island and the Alaska Peninsula, age-0s are readily collected inshore (Fig. 2). No other distributional information is available for the eastern BS. More data on settlement locations and juvenile habitat are available for the GOA, and from that, additional settlement areas in the BS can be inferred. In the GOA, age-0 post-settlement juveniles spend the first summer on sand and mixed sand sediment, primarily at <50 meters (m) depth (Norcross et al., 1999; Stoner et al., 2007); however, age-0 northern rock sole have been observed at lower densities on sand and mixed sand sediment to 80 m depth (Norcross et al., 1999). Based on the depth and sediment in the eastern BS shelf (McConnaughey and Smith, 2000), presence of settled juveniles in the BS might be expected in other geographic areas such as around the Pribilof Islands, in Bristol Bay, or in the vicinity of Cape Newenham (Fig. 1).

Our objectives are to examine connectivity of northern rock sole from spawning to nursery areas in the eastern BS using field data and biophysical modeling to determine the relative contributions of various source areas to corresponding settlement areas, and to examine temporal and spatial variations in larval dispersal. This research will refine our understanding of the scales over which larvae may be transported and the potential degree of connectivity between spawning and suitable nursery grounds.

2. Methods

2.1. Spawning areas

Spawning areas, and thus larval source areas for the individual-based biophysical-coupled model, were determined from locations where small larvae (≤4 mm SL) were collected in the eastern BS and south of Unimak Island from historical data obtained from surveys conducted by the Alaska Fisheries Science Center (AFSC) Recruitment Processes Program. Data for cruises were found in the AFSC ichthyoplankton cruise database.[1] Ichthyoplankton data are accessible in the AFSC larval fish database (ICHBASE). For the eastern BS, data from 1592 oblique plankton tows (60 cm bongo nets and 1 m Tucker trawls) from 17 years of sampling from 1988 to 2008 were used. In the GOA, data from 105 plankton tows from 14 years of sampling from 1982 to 2007 in the vicinity of Unimak Island were used. Matarese et al. (2003) contains detailed sampling protocols. Northern rock sole eggs are demersal (Laurel and Blood, 2011; Orr and Matarese, 2000), so eggs were not present in historical plankton records. Small (≤4 mm SL) planktonic larvae are considered to be suitable proxy data for spawning grounds since transport of demersal and semi-adhesive eggs is likely to be minimal and emergent larvae would be observed in proximity to egg deposition areas. Mean densities of newly-hatched (≤4 mm SL) northern rock sole larvae collected in plankton tows in April and May were averaged by 20×20 kilometer (km) grid squares and mapped. Areas with high densities were delineated, and subsets of these areas based on reported spawning depth

[1] Ichthyoplankton Cruise Database, NOAA-NMFS, Alaska Fisheries Science Center. Available from: http://access.afsc.noaa.gov/icc/index.cfm, accessed Feb. 2010.