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Modeling connectivity of walleye pollock in the Gulf of Alaska: Are there any linkages to the Bering Sea and Aleutian Islands?

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ABSTRACT

We investigated the connectivity of walleye pollock in the Gulf of Alaska (GOA) and linkages to the Bering Sea (BS) and Aleutian Island (AL) regions. We used a spatially-explicit Individual-based model (IBM) coupled to 6 years of a hydrodynamic model that simulates the early life history of walleye pollock in the GOA (eggs to age-0 juveniles). The processes modeled included growth, movement, mortality, feeding and the bioenergetics component for larvae and juveniles. Simulations were set to release particles on the 1st of the month (February to May) in fourteen historical spawning areas in the GOA up to the 1st of September each year. Model results reproduced the link between the Shelikof Strait spawning area and the Shumagin nursery region for March and April spawners, besides other Potential Nursery Areas (PNAs) found in the GOA. A prominent finding of this study was the appearance of the BS as important PNAs for several GOA spawning grounds, which is supported by a consistent flow into the BS through Unimak Pass. The simulations showed the highest density of simulated surviving pollock in the western Bering Sea (WBS) region with the lowest coefficients of variation of the whole domain. Three spawning sectors were defined, which aggregate multiple spawning areas in the eastern (EGOA), central (CGOA) and western Gulf of Alaska (WGOA). A connectivity matrix showed strong retention within the CGOA (25.9%) and EGOA (23.8%), but not in the WGOA (7.2%). Within the GOA, the highest connectivity is observed from EGOA to CGOA (57.8%) followed by the connection from CGOA to WGOA (24.3%). Overall, one of the most prominent connections was from WGOA to WBS (62.8%), followed by a connection from CGOA to WBS (29.2%). In addition, scenarios of shifting spawning locations and nursery sectors of GOA, BS and AL are explored and implications for walleye pollock stock structure hypotheses are discussed.

1. Introduction

Walleye pollock (*Gadus chalcogrammus*) is a dominant component of the Gulf of Alaska (GOA) ecosystem, but knowledge of the biological and physical mechanisms that create variability in its recruitment is incomplete. Peak spawning at the major spawning areas in GOA occurs at different times. Adult walleye pollock are known to spawn from late March to early April at the southwestern end of Shelikof Strait, between Kodiak Island and mainland Alaska (Kendall et al., 1987). Eggs are fertilized at depths between 150 and 200 m, and hatch after a period of about two weeks (Yoklavich and Bailey, 1990). These larvae rise to the upper 50 m of the water column and drift in prevailing currents for the next several weeks (late April through mid-May) (Yoklavich and Bailey, 1990). Larger larvae undergo diel migrations between 15 and 50 m (Kendall et al., 1994). Currents transport larvae southwest along the Alaska Peninsula (Fig. 1), or offshore along the shoreward edge of the Shelikof sea valley southwest of Shelikof Strait (Yoklavich and Bailey, 1990; Hinckley et al., 2001). By midsummer, many of the survivors (juvenile stage) have been

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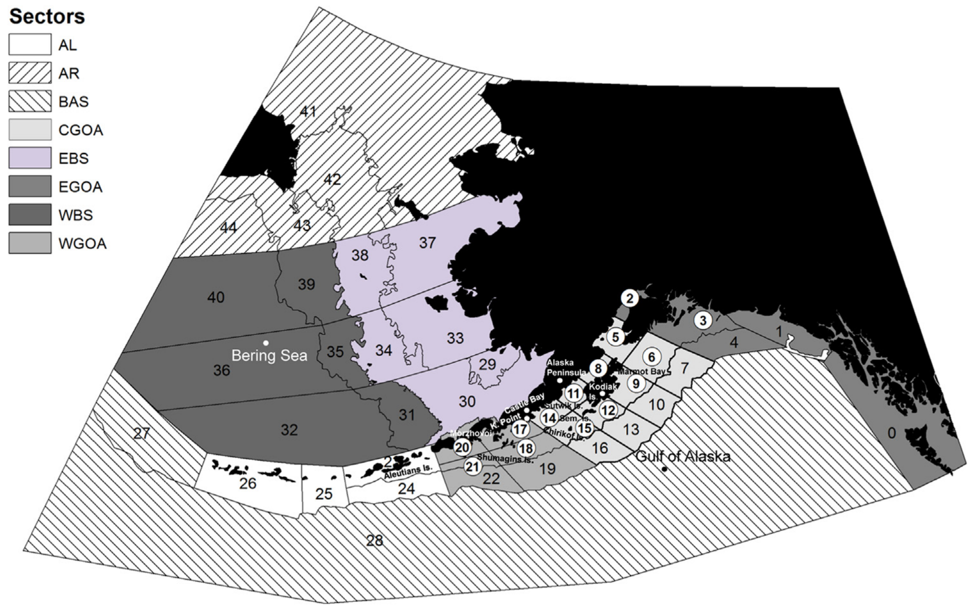

Fig. 1. Map of the names of the areas used to set the spawning and nursery areas in eastern (EGOA), central (CGOA) and western the Gulf of Alaska (WGOA), the Aleutians (AL), the western (WBS) and eastern Bering Sea (EBS), the Arctic (AR) and the Basin (BAS) sectors. The spawning grounds corresponded (white circle) to the areas: 2: Inner Cook Inlet (InC), 3: Prince William Sound Inner (PWSin), 5: Outer Cook Inlet (OC), 6: Seward Inner (Sin), 8: Shelikof Strait North (SSN), 9: Kodiak Island North (KIN), 11: Shelikof Strait Exit (SSE), 12: Kodiak Island South (KIS), 14: Sutwik (Sut), 15: Semidi Islands (SemI), 17: Shumagin Islands Inner (SIin), 18: Shumagin Islands Outer (SIo), 20: Unimak Pass (UP), 21: Unimak Pass Outer (UPo). The potential nursery areas explored with the model were the same as the spawning areas (above) plus the following areas: 0: South East Alaska (SEA), 1: Yakutat (Yak), 4: Prince William Sound Outer (PWSo), 7: Seward Offshore (So), 10: Kodiak Island North Offshore (KINof), 13: Kodiak Island South Offshore (KISof), 16: Semidi Islands Offshore (SemIo), 19: Shumagin Islands Offshore (Siof), 22: Unimak Pass Offshore (UPof), 23: Unalaska Island (UI), 24: Unalaska Island offshore (UIof), 25: Chagulak Island (CI), 26: Adak (Ad), 27: Cobra Dane (CD), 28: Offshore (Off), 29: Bering Sea South Inner domain (BSSin), 30: Bering Sea South Middle domain (BSSm), 31: Bering Sea South Outer domain (BSSo), 32: Bering Sea South Basin (BSSb), 33: Bering Sea Central Inner domain (BSCin), 34: Bering Sea Central Middle domain (BSCm), 35: Bering Sea Central Outer domain (BSCo), 36: Bering Sea Central Basin (BSCb), 37: Bering Sea North Inner domain (BSNin), 38: Bering Sea North Middle domain (BSNm), 39: Bering Sea North Outer domain (BSNo), 40: Bering Sea North Basin (BSNb), 41: Arctic Inner domain (Arin), 42: Arctic Middle domain (Arm), 43: Arctic Outer domain (Aro), and 44: Arctic Basin (Arb).

advected to the Shumagin Islands, about 300 km southwest of the Shelikof spawning site (Hinckley et al., 1991). The prevailing hypothesis is that Shelikof Strait is the primary spawning area, and that the Shumagin Islands provide the main nursery area in the GOA (Hinckley et al., 2001). Another apparent spawning peak occurs between February 15 to March 1 in the Shumagin Islands area and surrounding areas, (Dorn et al., 2012). These secondary walleye pollock spawning areas have been observed in the GOA during acoustic surveys. The shelf break near Chirikof Island, the Shumagin area, Sanak Gully, Morzhovoi Bay and Marmot Bay (Fig. 1) satisfy the criterion of appearing in the acoustic surveys at least three times to be considered secondary spawning regions (Dorn et al., 2014). In addition, egg distribution data from ichthyoplankton surveys conducted by the Alaska Fisheries Science Center (AFSC, Ciannelli et al., 2007) have shown non-Shelikof spawning locations (Unimak Pass, Semidis and Shumagin Islands, Fig. 1; Ciannelli et al., 2007). However, the role of these non-Shelikof spawning areas and their contribution to the GOA pollock stock remains uncertain.

GOA walleye pollock is currently managed as a single stock, independent of Bering Sea (BS) and Aleutian Islands (AL) walleye pollock. Within the GOA, there is evidence that distinguish (e.g. allozyme frequency and mtDNA) the Shelikof Strait spawning population from spawning populations in the northern GOA (Prince William Sound and Middleton Island), although some interannual genetic variability has been observed (Olsen et al., 2002). Despite this variability, evidence provided from the assessment of the stock structure following the template developed by the North Pacific Fishery Management Council) stock structure working group (Dorn et al., 2012) supports treating pollock in the eastern portion of the GOA separately from pollock in the central and western portions. Separation of walleye pollock in the GOA from those in the Eastern Bering Sea (EBS) is based on studies of larval drift from spawning locations (Bailey et al., 1997) and genetic studies based on allozyme frequencies (Grant and Utter 1980; Olsen et al. 2002), mtDNA variability (Mulligan et al., 1992; Shields and Gust 1995; Kim et al., 2000), and microsatellite allele variability (O'Reilly et al., 2004). Dorn et al. (2012) claim that results supporting the current separation of walleye pollock stocks in the GOA are equivocal, since the data used for the larval transport study (Bailey et al., 1997) did not encompass the entire range of the GOA, and genetic analyses have not provided definitive results on the separation or mixing of population components. However, examining how distributions of fish evolve between adult spawning locations and juvenile retention areas, may contribute to the understanding of early stage growth and survival, the connection between spawning and nursery areas, and population structure.

Population connectivity is inherently a coupled bio-physical research topic, involving physical processes such as jets, eddies, meanders, fronts, tides, island wakes and lateral intrusions (Cowen and Spounagle, 2009). However, physical processes alone do not determine connectivity, because larval behavior such as vertical migration also plays a relevant role (Cowen et al., 2002). A connectivity matrix describes the spatial distribution of settlement destinations or nursery grounds of individuals that originate from a given source, as well as the links between both regions (Largier, 2003). The quantification of the probability of larvae reaching nursery areas, through transport, given specific spawning grounds determines the strength of the connectivity. Almost all fish have planktonic life stages that can spend days, weeks, or months drifting, eating, and growing in the pelagic zone (Gaines et al., 2007). Scales of dispersal can vary by more than six orders of magnitude, ranging from meters to hundreds of kilometers