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Environmental covariates of sablefish (*Anoplopoma fimbria*) and Pacific ocean perch (*Sebastes alutus*) recruitment in the Gulf of Alaska

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ABSTRACT

The sablefish (*Anoplopoma fimbria*) and Pacific ocean perch (POP; *Sebastes alutus*) fisheries in the Gulf of Alaska (GOA) are both highly lucrative and variable. Determining environmental factors that drive variability in their recruitment may improve our understanding of forces affecting their early life survival, which may be helpful when evaluating management strategies. Here we examine relationships between sablefish and POP recruitment and multiple environmental indices associated with circulation in the GOA. We used hierarchical cluster analysis to determine spatially and seasonally relevant scales for analyzing these relationships. We then used structural equation modeling to examine sequential relationships between large-scale climate variables, regional (eastern and western GOA) environmental variables, and recruitment using both hypothesis-testing and exploratory approaches. Exploratory analyses revealed that sablefish recruitment was positively related to July upwelling-favorable winds and negatively related to late winter freshwater discharge in the eastern GOA during age 1. POP recruitment was negatively related to June upwelling-favorable winds in both regions during ages 0 and 1 and positively related to late spring freshwater discharge throughout the GOA during age 1. These results suggest that upwelling-favorable winds and freshwater discharge may affect recruitment of both species through productivity-related mechanisms, and may additionally affect POP recruitment through advection-related mechanisms. Targeted studies at the appropriate scales are needed to provide greater certainty in the potential mechanisms behind these relationships.

1. Introduction

Sablefish (*Anoplopoma fimbria*) and Pacific ocean perch (POP, *Sebastes alutus*) both support highly lucrative commercial fisheries in the Gulf of Alaska (GOA). Identifying environmental drivers of recruitment may lead to a greater understanding of mechanistic processes affecting early life survival of these species (e.g., McFarlane and Beamish, 1992; Vestfals et al., 2014; Shotwell et al., 2014). Furthermore, robust relationships between recruitment and environmental variables, if well understood, may be incorporated into simulations used for management strategy evaluations (MSEs) in order to inform potential management measures under varying environmental conditions (e.g., A'Mar et al., 2009; Ianelli et al., 2011). This study seeks to determine the biological relevance of several specific climate and regional-scale environmental processes (as revealed by derived indices) to sablefish and POP recruitment in the GOA, as well as to identify the specific regions within the GOA that exhibit the strongest recruitment–environment relationships.

1.1. *Sablefish*

Sablefish are a deep-sea fish inhabiting waters throughout the North Pacific, with a southern range limit extending from Sagami Bay, Japan in the western Pacific to Baja California, Mexico in the eastern Pacific (Sasaki, 1985; Wolotira et al., 1993). The Alaskan population ranges from the Bering Sea to northern British Columbia; some mixing between the two stocks occurs near southern Vancouver Island (McDevitt, 1990; Kimura et al., 1998; Hanselman et al., 2011a). Alaskan sablefish are managed as a single population due to their widespread migration within this region (Heifetz and Fujioka, 1991; Kimura et al., 1998; Hanselman et al., 2011a). Sablefish spawn offshore at depths up to 500 m, with an approximate peak spawning date during February–March in Alaska (Mason et al., 1983; Wing and Kamikawa, 1995; Wing, 1997) and a peak abundance of eggs occurring during late February (Doyle and Mier, 2016). While there is little information on the incubation time and depth of Alaskan sablefish eggs, studies on other stocks indicate that their eggs incubate for several weeks, during which time they increase in density and sink to depths of 400–1000 m

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before hatching (Mason et al., 1983; Kendall and Matarese, 1987). Newly hatched larvae move to the surface and remain neustonic as they drift toward nearshore waters, which serve as important nursery habitat for Alaskan sablefish (Sasaki, 1985; Kendall and Matarese, 1987; Rutecki and Varosi, 1997b; Wing, 1997). Alaskan young-of-year sablefish peak in abundance during late May (Doyle and Mier, 2016) and are believed to reach nearshore settlement areas during summer and fall (Rutecki and Varosi, 1997a,b). Juveniles remain in these nearshore nursery sites until roughly age 2, at which point they migrate back offshore (Rutecki and Varosi, 1997b; Maloney and Sigler, 2008). They reach their adult habitat and recruit to the fishery at around age 4 (Maloney and Sigler, 2008).

1.2. Pacific ocean perch

POP inhabit demersal shelf and slope habitat throughout the North Pacific, but catches are most abundant in the GOA and Aleutian Islands (Carlson and Haight, 1976; Allen and Smith, 1988). POP in the GOA consist of genetically distinct subpopulations that occur at small geographic scales, indicating that larval dispersal is limited (Palof et al., 2011; Kamin et al., 2013). Female POP are ovoviviparous, maintaining fertilized eggs internally until hatching and larval parturition (Gunderson, 1971). Parturition occurs during April and May in gullies, canyons, and along the slope at depths of 500–700 m (Paraketsov, 1963). POP larvae are pelagic, remaining primarily within the upper 100 m of the water column before settling in their demersal nearshore nursery habitat, which they likely reach within a year and may reach by their first autumn (Carlson and Haight, 1976; Doyle and Mier, 2016). Their preferred nearshore habitat consists of rough substrata and complex structure comprised of boulders, corals, and sponges (Carlson and Haight, 1976; Rooper et al., 2007). They remain in their nursery habitat until roughly age 3, at which point they begin to migrate offshore toward their adult habitat (Carlson and Haight, 1976; Carlson and Straty, 1981). They reach their adult habitat in gullies and along the continental slope by age 6 (Carlson and Haight, 1976; Gunderson, 1977).

1.3. Study area

The GOA continental shelf varies in width from 5 km to 200 km; it is generally narrower in the eastern GOA and broader to the west (Weingartner, 2007). Depth on the shelf predominantly ranges over 150–200 m, and the shelf-break occurs at a depth of 200–300 m (Weingartner, 2007).

Ocean circulation in the GOA is primarily influenced by two main current systems: the Subarctic Gyre over the slope and basin and the Alaska Coastal Current (ACC) along the coast (Fig. 1; Stabeno et al., 2004). The Subarctic Gyre system is comprised of three currents that combine to create a cyclonic circulation pattern: the North Pacific Current, the Alaska Current, and the Alaskan Stream (Stabeno et al., 2004). Transport of water in this current system is mostly driven by cyclonic winds, which are associated with downwelling-favorable conditions along Alaska's southern coastline (Stabeno et al., 2004). During spring and summer months, these downwelling conditions weaken and are accompanied by intermittent, variable upwelling episodes (Stabeno et al., 2004).

The ACC flows counter-clockwise along the GOA coastline before flowing into the Bering Sea through the Aleutian passes, and is driven by a combination of alongshore winds and freshwater discharge into the GOA (Royer, 1982; Stabeno et al., 2004; Weingartner et al., 2005). The prominence of its freshwater core is reduced during spring and summer as water spreads offshore due to relaxed downwelling or upwelling (Stabeno et al., 2004).

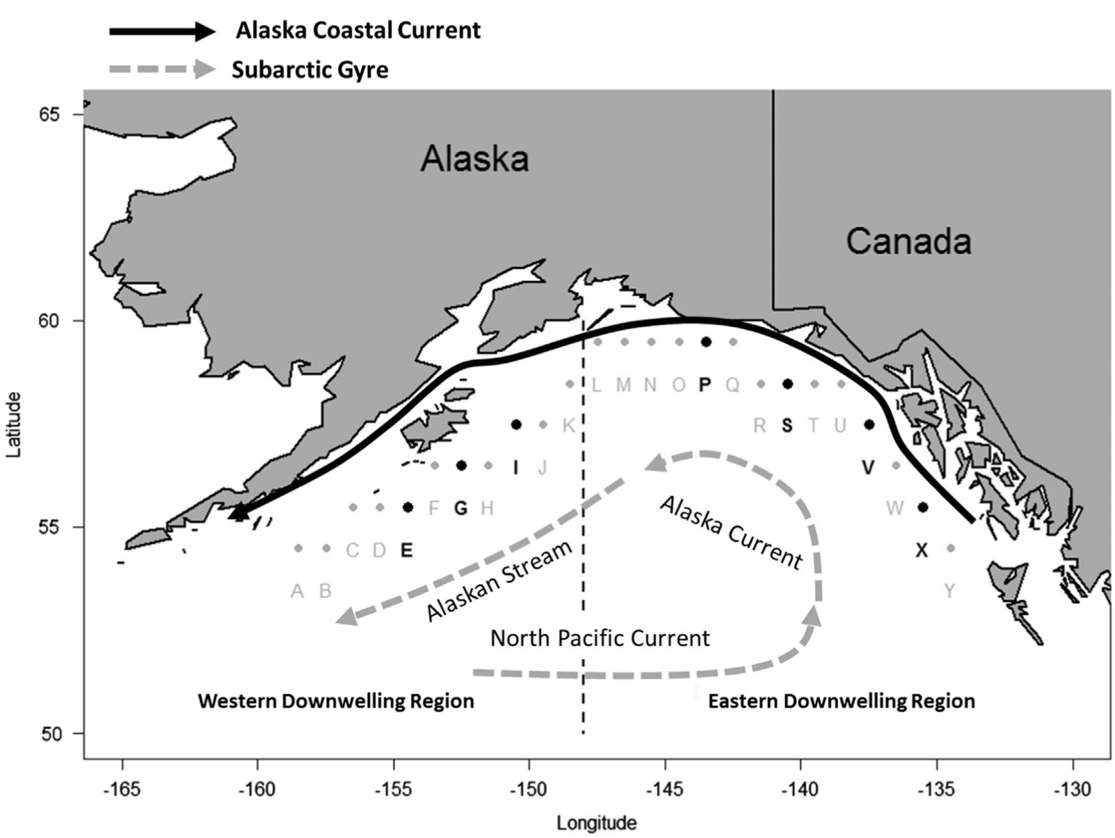

Fig. 1. Map showing GOA current systems (arrows), downwelling index locations used in analysis (points), and downwelling regions. The dotted line marks the division between eastern and western downwelling regions identified in this study (see Fig. 4). Black points (labeled in bold) denote locations used as subsamples to represent regional downwelling variability.