Journal of Sea Research 107 (2016) 31–42

Contents lists available at ScienceDirect

Journal of Sea Research

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

Distribution of early life Pacific halibut and comparison with Greenland halibut in the eastern Bering Sea

D. Sohn [a,*], L. Ciannelli [a], J.T. Duffy-Anderson [b]

[a] College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331, USA
[b] Recruitment Processes Program, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, NOAA Fisheries, 7600 Sand Point Way NE, Seattle, WA 98115, USA

A R T I C L E   I N F O

Article history:
Received 28 January 2015
Received in revised form 3 September 2015
Accepted 10 September 2015
Available online 14 September 2015

Keywords:
Pacific halibut
Greenland halibut
Eastern Bering Sea
Distribution
Settlement
Early life history

A B S T R A C T

Information about spatial distribution patterns during early life stages of fish is key to understanding dispersal trajectories and connectivity from spawning to nursery areas, as well as adult population dynamics. More than 30 years of historical field data were analyzed in order to describe the horizontal and vertical distributions of Pacific halibut early life stages (larvae to juveniles) in the eastern Bering Sea and to compare the distributions between Pacific halibut and Greenland halibut. Our results indicate that spawning for both species likely occurred in Bering and Pribilof canyons, along the slope between the two canyons, and on the eastern side of the Aleutian Islands during winter, but Pacific halibut spawning was protracted until early spring. Larvae of both species rose to shallower depths in the water column as they developed, but Pacific halibut larvae had an abrupt movement toward shallower depths. Geographically, larvae for both species either advected northwestward along the Bering Sea Slope or crossed onto the shelves from the slope regions, but the timing in Pacific halibut larval progression onto the shelf and along the slope was earlier than for Greenland halibut larvae. Pacific halibut juveniles (≤90 mm total length (TL)) were mostly found in the inner shelf between Bristol Bay and Nunivak Island, along the Alaskan Peninsula, and in the vicinity of the Pribilof Islands. The range of Greenland halibut juvenile (≤90 mm TL) distribution was expanded to south of the Pribilof Islands in the middle shelf and to the inner shelf. Although the two species share some attributes (i.e., spawning location) during early life stages, there were species-specific differences associated with spatial distribution (vertically and horizontally), timing differences in larval progression onto the shelves, pelagic larval duration, and juvenile nursery areas.

1. Introduction

Knowledge of the distribution and dispersal trajectories of marine fish during early life is critical for understanding recruitment and adult population dynamics. The early life stages of marine fishes are influenced by interactions between abiotic (i.e., currents, geographical feature, temperature, and dissolved oxygen) and biotic (i.e., food availability, predation, growth, body-length, and behaviors) factors. Changes in prevailing currents induced by variable atmospheric forcing play an important role in variations of dispersal trajectories and recruitment of marine fish (Van der Veer et al., 1998; Wilderbuer et al., 2002; Bailey et al., 2005; Cowen and Sponaugle, 2009). Currents may transport fish larvae to unsuitable areas resulting in high mortality rates and low recruitment (Houde, 2008). Flatfish may be particularly vulnerable to advective loss due to their long pelagic phases as larvae (Bailey et al., 2005) and their strict benthic habitat requirements as juveniles (Petitgas et al., 2013). It has been shown in several studies that slope-spawning flatfish may be vulnerable to changes in currents during their dispersal phases, when they rely on extensive drift to connect from spawning to settlement areas (Wilderbuer et al., 2002; Bailey et al., 2008; Duffy-Anderson et al., 2013; Vestfals et al., 2014; Duffy-Anderson et al., in press). Further, variations in connectivity between spawning and nursery habitats influence recruitment in flatfish populations (Hufnagl et al., 2013; Petitgas et al., 2013).

Pacific halibut (*Hippoglossus stenolepis*) and Greenland halibut (*Reinhardtius hippoglossoides*) are two ecologically and commercially important slope-spawning flatfish in the eastern Bering Sea (EBS). Both species are piscivorous and substantial predators — adults feed on abundant juvenile gadid species (e.g., walleye pollock (*Gadus chalcogrammus*), cod (*Gadus macrocephalus*)) and other flatfish species in the EBS (Aydin and Mueter, 2007). The abundances of Pacific halibut and Greenland halibut in the EBS have differentially fluctuated during the last three decades although they share many life history attributes. Pacific halibut had been stable prior to 2000, but over the last decade, biomass has continuously decreased because of poor recruitment and decreasing adult body-size at age (Stewart et al., 2013). Greenland halibut has decreased since late 1970s due to low recruitment and spawning biomass, however, there are signs of improved recruitment after 2006 (Barbeaux et al., 2013).

Distribution, dispersal trajectory, and population dynamics of Greenland halibut and Pacific halibut may be affected differently by

* Corresponding author.
E-mail address: dsohn@coas.oregonstate.edu (D. Sohn).

http://dx.doi.org/10.1016/j.seares.2015.09.001

changes in environmental conditions (e.g., changes in water temperature and currents) due to species-specific differences (i.e., vertical distribution, pelagic duration, and settlement location) during the early life stages. Greenland halibut is a circumpolar species while Pacific halibut is a subarctic species and comparing the two species may provide insight on how environmental variability affects the two species with contrasting ecological niches. The EBS has exhibited a prolonged cold period (2007–2012) after a prolonged warm period (2001–2005) with respect to variations in the timing of sea ice retreat and water temperature (Stabeno et al., 2012). The habitat occupied by Greenland halibut juveniles and adults has expanded to the south in the middle shelf with a series of cold periods in the EBS (Ianelli et al., 2011). Previous studies showed that differences in advective connectivity in flatfish are influenced by depth-discrete currents (Lanksbury et al., 2007; Duffy-Anderson et al., 2013). Therefore, it is important to understand the spatial distribution (vertically and horizontally), dispersal trajectories, and connectivity between spawning and nursery areas for the two species of halibut in order to understand their diverging population dynamics.

Little is known about Pacific halibut early life history in the EBS. From studies in the Gulf of Alaska (GOA) it is known that Pacific halibut spawn in relatively deep water (>400 m) along the continental slope during the winter, from December to March. Pacific halibut eggs have been found at depths between 100 and 400 m water, and newly hatched larvae below 425 m, along the continental slope (Thompson and Van Cleve, 1936; Skud, 1977). Pacific halibut hatching time was 20 days at 5 °C (Forrester and Alderdice, 1973). Larvae were reported to move to shallower depths as they developed, and 3 to 5 months after hatching were found at 100 m or shallower. The larvae are advected by currents from offshore to inshore and settle in shallow nursery habitat in May and June, 6 to 7 months after spawning (Skud, 1977; Norcross et al., 1997). In the EBS, Best (1981) mentioned that Pacific halibut spawn at depths between 250 and 550 m along the continental edge from Unimak Island and the Pribilof Islands and along the Aleutian Islands between December and January based on an International Pacific Halibut Commission (IPHC) cruise data. St-Pierre (1989), using 1985 and 1986 field survey data, reported that Pacific halibut postflexion larvae (16–25 mm) were found in Unimak Pass, along the eastern side of the Aleutian Islands, and along Unimak Island. Best (1974, 1977) and Best and Hardman (1982) showed that settled juveniles (<100 mm) and larger individuals were found in shallower water along the Alaskan Peninsula and in the inner shelf (<50 m isobaths) near Bristol Bay. Recently, Seitz et al. (2011) based on tagging data, found that localized spawning population may exist in the EBS. However, the horizontal and vertical distributions and dispersal trajectories of Pacific halibut larvae in the EBS are yet unknown. These knowledge gaps impede an understanding of whether and how dispersal and circulation differently affect Pacific halibut and Greenland halibut recruitment variability.

In contrast to Pacific halibut, there have been more studies about Greenland halibut ecology and biology during early life stages in the EBS, particularly in recent years. Alton et al. (1988) reported on the history of harvest and management for Greenland halibut and distribution of adult stages. Swartzman et al. (1992) showed that Greenland halibut adults moved to deeper water as they grew. McConnaughey and Smith (2000) found that the spatial distribution of Greenland halibut (>141 mm fork length (FL)) was related to sediment characteristics – a mixture of mud and fine sand. Distribution and dispersal trajectories of Greenland halibut during the early life stages have been studied based on observational data or/and passive modeling approaches (Sohn et al., 2010; Duffy-Anderson et al., 2013). Greenland halibut spawn along the slope near Bering Canyon and along the eastern Aleutian Islands during winter. Eggs have been found at depths between 200 and 600 m and larvae have been found between surface and 600 m (Sohn, 2009; Duffy-Anderson et al., 2013). After hatching, Greenland halibut larvae slowly move upward in the water column as they develop. Settlement areas are located over the middle shelf in the vicinity of St. Matthew Island (Sohn et al., 2010). Greenland halibut have a long pelagic larval duration of over six months from spawning to settling areas (Sohn et al., 2010).

The goals of this study are to (1) characterize the distribution and dispersal trajectories for Pacific halibut larvae by ontogenetic stage, (2) describe age-0 nursery habitats for Pacific halibut, and (3) compare the larval progression (horizontally and vertically) of Pacific halibut larvae to that of Greenland halibut. Using more than 30 years of historical data (1979 to 2012), we examined the spatial (horizontal and vertical) distributions of larval Pacific halibut (preflexion, flexion, and postflexion) abundance and body length, and then compared these results to a similar set of results for Greenland halibut. We also examined Pacific halibut age-0 distribution using historical field survey data. This study provides important fundamental early life history information about the ecology and biology of two commercial flatfish species in the EBS, especially for Pacific halibut. The comparison between the two species will be useful for studying habitat usages and predator–prey interactions, as well as conducting biophysical modeling, and climate impact projects for the two species and also other flatfish in the EBS.

2. Materials and methods

2.1. Study area

The EBS includes both the basin and the continental shelf that support one of the highly productive marine ecosystems from phytoplankton to mammals (Fig. 1). The shelf can be divided into three domains based on bathymetry: the inner shelf (<50 m isobaths), the middle shelf (50 m–100 m isobaths), and the outer shelf (100 m–200 m isobaths) (Fig. 1; Coachman, 1986). There are two dominant currents; the Aleutian North Slope Current (ANSC), flowing eastward along the Aleutian Islands, and the Bering Slope Current (BSC), flowing northwestward along the Bering Slope of the EBS (Fig. 1; Stabeno et al., 1999). In addition, part of the Alaska Coastal Current (ACC) flows from the GOA into the EBS through Unimak Pass and flows eastward parallel to the 50 m isobath along the Alaska Peninsula (Fig. 1; Stabeno et al., 2002). A portion of the ACC continues westward and enters into the Bering Sea through other passes including Samalga, and some of the Aleutian Stream flows through Amukta and Amchitka Passes along the Aleutian Islands (Stabeno et al., 1999; Ladd et al., 2005; Stabeno and Hristova, 2014). Submarine canyons, including Bering, Pribilof, and Zhemchug Canyons, are located on the continental margin edge along the Bering Slope and serve as spawning grounds for skates (Rajidae), Pacific halibut, Greenland halibut (Fig. 1; St-Pierre, 1984; Seitz et al., 2007; Hoff, 2010; Sohn et al., 2010; Duffy-Anderson et al., 2013) and nursery grounds for Pacific Ocean perch (*Sebastes alutus*) and skates (Brodeur, 2001; Hoff, 2008), as well as conduits for slope-shelf exchanges of nutrients and larvae (Stabeno et al., 1999; Mizobata et al., 2006).

2.2. Data sources

To characterize the horizontal and vertical distributions of Pacific halibut larvae and to compare the horizontal and vertical distributions between Pacific halibut and Greenland halibut larvae in the EBS, we obtained historical Pacific halibut larval abundance and body-length data including sampling date, sampling location (latitude and longitude), and bottom depth at each sampling location between 1979 and 2012 from the ichthyoplankton survey database (EcoDAAT) at the National Oceanic and Atmospheric Administration (NOAA)'s Alaska Fisheries Science Center (AFSC; Table 1). During the surveys, Pacific halibut larvae were collected by various gear types including 60 cm bongo (BON), 1 m^2 Tucker trawl (TUCK), modified beam trawl (MBT; used in midwater towing), 5 m^2 frame Methot trawl (METH; Methot, 1986), and 1 m^2 Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS; Wiebe et al., 1976). The gears including BON,