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Distribution, diet, and energetic condition of age-0 walleye pollock (*Gadus chalcogrammus*) and pacific cod (*Gadus macrocephalus*) inhabiting the Gulf of Alaska

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ABSTRACT

Walleye pollock (*Gadus chalcogrammus*) and Pacific cod (*Gadus macrocephalus*) are commercially and ecologically important species in Alaska waters. Little is known about their ecology after transitioning from larvae to free swimming fish until settlement to nursery habitats in the eastern Gulf of Alaska. Differences in the distribution, diet, body size, and energetic status between the eastern and central Gulf of Alaska were investigated during summer months to better understand regional and interspecific differences in life history and ecology. The composition of zooplankton prey in the diets of walleye pollock and Pacific cod inhabiting shelf waters was more varied relative to those inhabiting the slope and basin. Body condition and total energy content of Pacific cod was greater than walleye pollock, however total energy content increased with length at a similar rate for both species. Walleye pollock inhabiting continental slope waters had higher energy stores relative to those inhabiting the continental shelf and basin, indicating an energetic advantage for individuals remaining off the shelf during summer months or potentially the advection of fish with higher energy reserves off of the shelf. Previous studies have documented the importance of energy stores for surviving winter and future studies should focus on understanding the mechanisms influencing lipid storage and somatic growth for walleye pollock and Pacific cod inhabiting the eastern and central Gulf of Alaska.

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1. Introduction

Walleye pollock (*Gadus chalcogrammus*) (hereafter "pollock") and Pacific cod (*Gadus macrocephalus*) (hereafter "cod") are ecologically and economically important species in the Gulf of Alaska (GOA) that rank first and second in terms of marine fish biomass landed from Alaskan waters (http://www.npfmc.org/wp-content/PDFdocuments/resources/Species_Profiles2011.pdf). Pollock are widely distributed across the GOA (Bailey, 2000) with the majority of spawning occurring within the vicinity of Shelikof Strait (Kendall et al., 1996). Cod are also widely distributed, but spawn in deep waters during late winter and have negatively buoyant eggs (Doyle et al., 2009). Positively buoyant larvae rise through the water column and are transported onshore by ocean currents after pollock and cod eggs hatch (Rugen and Matarese, 1998), where both species are known to utilize pelagic shelf habitats during early life in the Bering Sea (Moss et al., 2009; Hurst et al., 2012, 2014) and the GOA (Laurel et al., 2009; Doyle et al., 2009). In order to survive the first summer of life pollock and cod must successfully navigate a biophysical gauntlet described by the abundance of planktonic prey resources, larval transport, predation, and eventual settlement in suitable habitat. Years of high larval pollock and cod abundance in the GOA are associated with cooler winters and enhanced alongshore winds (Doyle et al., 2009). Biophysical conditions during the following spring, summer, and fall must result in favorable foraging conditions, optimum temperatures for growth, transport to summer nursery grounds, or a combination of all three. Coastal regions in the GOA are settlement grounds where cod may remain through the second year of life and utilize macrophytes and benthic structure as refuge from predators (Abookire et al., 2007; Laurel et al., 2007).

Recruitment estimates based on the latest stock assessments are highly variable and appear to not be related to spawning biomass for pollock (Dorn et al., 2008) or cod (Thompson et al., 2008). The influence of environment and climate on marine fish production is still poorly understood and traditional spawner-recruit models typically do not incorporate nonlinear effects caused by biophysical forces on growth and survival in an explicit manner (Bailey et al., 2005). Therefore, investigating the processes supporting somatic growth and energy storage for age-0 pollock and cod as they transition from offshore to nearshore habitats while navigating a

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gauntlet of predators and prey resources will provide insight into how biophysical conditions influence recruitment.

Larval supply and survival is critical to recruitment and prior to the mid-1980s pollock recruitment in the GOA was correlated with larval abundance, which was believed to be largely influenced by environmental conditions (Bailey et al., 2012). However, this relationship deteriorated following a major environmental shift in the mid-1970s known as the Pacific Decadal Oscillation which is a long-lived El Nino-like pattern of Pacific climate, and it appears that pollock recruitment is now largely dependent on conditions experienced during the post larval, juvenile life stage (Bailey, 2000). Recent investigations have identified the first autumn as a "critical period" in the life history of juvenile fishes and a time when an individual must exceed a threshold body size (Beamish and Mahnken, 2001) or acquire a minimum level of energy stores (Moss et al., 2009; Heintz et al., 2013) in order to survive winter. This minimum level of energy reserves is necessary to prevent starvation and to minimize foraging during winter months when prey is limited. Increased foraging activity elevates predation risk (Heintz and Vollenweider, 2010), whereas rapid growth during summer months increases the capacity for energy storage during fall. Length-specific weight of age-0 pollock inhabiting the western GOA decreased from autumn to winter by up to 17% and spatial heterogeneity in habitat quality was believed to influence size and condition (Bucheister et al., 2006).

Previous investigations into age-0 pollock growth, distribution, and feeding ecology focused on the western GOA, spanning an area from Kodiak Island to the Shumagin Islands (Wilson et al. 2013; Wilson et al., 2011; Wilson et al., 2006; Bucheister et al., 2006; Wilson, 2009; Wilson et al., 2009), and primarily sampled the progeny of pollock spawning in Shelikof Strait (Dougherty et al., 2012). This body of work has concluded that water temperature does not influence age-0 pollock growth rate (Dougherty et al., 2012; Mazur et al., 2007) as strongly as the abundance and availability of high quality prey (Wilson et al., 2009; Wilson et al. 2011; Wilson et al. 2013). Euphausiids are particularly important prey for age-0 pollock and high-quality feeding locations shift seasonally in response to their availability, which can influence growth, condition and potentially survival (Wilson et al., 2011).

The lipids contained in prey influences the composition and concentration of lipids in their predators (Morris and Culkin, 1989; Linko et al., 1985; St. John and Lund, 1996) with higher amounts of lipid ingested by the predator leading to greater accumulation of energy reserves (Heintz et al., 2004; Heintz et al., 2013). Larger copepods such as *Calanus marshallae* and *Neocalanus cristatus* generally contain higher lipid levels than their smaller bodied and younger congeners *Pseudocalanus* spp. and *Acartia* spp. (Tsuda et al., 1999) with *Calanus* spp. typically accumulating lipids at older copepodite stages (Hakanson, 1984; Kattner and Krause, 1987). Large copepods are more abundant during years when conditions are anomalously cool in the Bering Sea (Hunt et al., 2011) where a diet of large, lipid rich copepods enables age-0 pollock to acquire adequate energy reserves for surviving winter (Heintz et al., 2013). Temperature is also an important regulator of growth in juvenile pollock (Cianelli et al., 1998) and cod (Hurst et al., 2010), however, prey quality has been shown to have a greater effect on growth rate in pollock (Mazur et al., 2007).

Success of a particular cohort of marine fish is influenced by environmental conditions; specifically, the thermal experience, availability of suitable prey, and the successful eluding of predators (Peterman et al., 1988; Leggett and Deblouis, 1994). Areas in the GOA that exhibit high sustained productivity through summer months support an abundance of planktonic prey (Stabeno et al., 2016) and recruitment to a commercially viable age classes depends on the survival of juveniles, which is influenced by environmental conditions experienced during early life (Moss et al., 2009). This study examines differences in the distribution, feeding habits, body condition, and energetic status of age-0 pollock and cod inhabiting the GOA during July and August. Specific findings are used to understand life history strategies for these species in the eastern Gulf of Alaska (EGOA) and central Gulf of Alaska (CGOA).

1.1. Study region

The GOA is a predominantly downwelling system that is generally characterized as being a high-nutrient, low-chlorophyll environment (Ladd et al., 2005). Even though the coastal GOA is a predominantly downwelling system, it supports a productive ecosystem (Stabeno et al., 2004). This complex system is characteristic of high coastal freshwater input from drainages, rivers, and strong winds (Stabeno et al., 2004; Weingartner, 2007). A combination of cyclonic winds, freshwater input, and alongshore transport in conjunction with a narrow shelf contributes to the formation of mesoscale eddies that propagate from east to west (Ladd, 2007). These eddies transport coastal water over the shelf out to the deep basin of the GOA causing episodic upwelling from tidal mixing and complex bottom topography (Weingartner et al., 2005; Ladd et al., 2005). The three major currents in the GOA are the Alaska Coastal Current (ACC), Alaska Current (AC), and the Alaska Stream (AS). The ACC is a buoyancy driven current (Weingartner, 2007) located close to shore and is not a continuous feature in the EGOA (Stabeno et al., 2016). The AC and AS are continuous features that are located further offshore than the ACC. Mixing in Cross Sound is an important source of nutrients on the continental shelf in the EGOA (Stabeno et al., 2016) and localized hot-spots such as Cross Sound are presumably important for supporting the rich assemblage of fish and marine life in the region. Environmental conditions in the Northeast Pacific Ocean and GOA during the time of this study (July and August 2012) were neutral in terms of the El-Nino-Southern Oscillation and sea surface temperature and the Pacific Decadal Oscillation was negative/neutral (McKinnell, 2013).

2. Methods

2.1. Biological sampling, distribution, and abundance

The National Oceanographic and Atmospheric Administration conducted a large-scale surface trawl survey that collected pollock, cod, and other pelagic species. The survey sampled stations along transects west of the Alaska panhandle during 3 July–21 July, 2012 and transects to the east of Kodiak Island during 3 August–21 August, 2012 (Fig. 1). We collected fish using a 198- m long mid-water rope trawl with hexagonal mesh wings and body and a 1.2-cm mesh liner in the codend. The rope trawl was towed between 3.3 and 7.0 km h^{-1} at an average rate of 5.6 km h^{-1} at or near the surface, had an average horizontal spread of 40.3 m, and an average vertical spread of 36.0 m. All tows lasted 30 min and covered a distance of 1.7–3.5 km. Fishes collected by the trawl were sorted by species and age class, counted, and measured for standard length (tip of the snout to the hypural plate, mm). At each station we measured the lengths of up to 50 individuals for a given species; if there were fewer than 50 fish we measured them all. Pollock and cod measuring <120 mm in length were designated as age-0 (Csepp et al., 2011). Up to 10 fish were randomly selected from the catch at each station, individually bagged, and frozen whole at -80 °C for laboratory analyses. If fewer than 10 fish were collected at a station all of the fish sampled were brought back to the laboratory for analysis. We selected a small, mean, and large fish based on length to be composited for a representative sample for energetics during bioprocessing and all fish brought back to the laboratory were used in the diet analysis. Our procedure for preserving samples for laboratory analysis was designed to provide