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Sandy beach surf zones: An alternative nursery habitat for 0-age Chinook salmon

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ABSTRACT

The role of each habitat fish use is of great importance to the dynamics of populations. During their early marine residence, Chinook salmon (*Oncorhynchus tshawytscha*), an anadromous fish species, mostly inhabit estuaries but also use sandy beach surf zones and the coastal ocean. However, the role of surf zones in the early life history of Chinook salmon is unclear. We hypothesized that surf zones serve as an alternative nursery habitat, defined as a habitat that consistently provides a proportion of a population with foraging and growth rates similar to those experienced in the primary nursery. First, we confirmed that juvenile Chinook salmon cohorts are simultaneously using both habitats by combining field collections with otolith chemical and structural analysis to directly compare size and migration patterns of juveniles collected in two Oregon (USA) estuaries and surf zones during three years. We then compared juvenile catch, diet and growth in estuaries and surf zones. Juveniles were consistently caught in both habitats throughout summer. Catches were significantly higher in estuaries (average ± SD = 34.3 ± 19.7 ind. 100 m^{-2}) than surf zones (1.0 ± 1.5 ind. 100 m^{-2}) and were positively correlated ($r = 0.92$). Size at capture (103 ± 15 mm fork length, FL), size at marine entry (76 ± 13 mm FL), stomach fullness (2 ± 2% body weight) and growth rates (0.4 ± 0.0 mm day^{-1}) were similar between habitats. Our results suggest that when large numbers of 0-age Chinook salmon inhabit estuaries, juveniles concurrently use surf zones, which serve as an alternative nursery habitat. Therefore, surf zones expand the available rearing habitat for Chinook salmon during early marine residence, a critical period in the life history.

1. Introduction

Anadromous fish use a diversity of habitats throughout their life (Dadswell et al., 1987; McDowall, 1988). Using multiple environments can increase access to resources, reduce the risk of a catastrophic event (e.g. floods, droughts, predation pulse) eliminating a cohort (Hilborn et al., 2003; Secor, 2007; Schindler et al., 2010), and has been hypothesized to confer resilience to populations in the face of climate change and other anthropogenic impacts (Secor, 2007; Waples et al., 2009; Katz et al., 2012).

Heterogeneity in habitat use can occur within a life stage, with individuals of a cohort concurrently using multiple environments (Dadswell et al., 1987; McDowall, 1988; Bertness et al., 2001). When individuals within a cohort simultaneously use multiple habitats, the cohort is often defined as spatially-split (Skúlason and Smith, 1995). In anadromous fish, reliance on multiple habitats can occur when individuals follow different migratory pathways. Variability in migratory paths among individuals of a cohort has been hypothesized to be a consequence of the prey availability and predation risk fish encountered during previous life stages (Secor, 2007).

Chinook salmon (*Oncorhynchus tshawytscha*) is an anadromous species naturally distributed throughout the North Pacific Ocean that spawns in most coastal rivers of western North America north of San Francisco, California (Quinn, 2004). For fall-run populations, the majority of juveniles initiate their migration to the ocean at age-0 (sub-yearlings) or age-1 (yearlings). On the west coast of the continental USA, most fall Chinook salmon migrate to the ocean as subyearlings (Rich, 1920; Reimers, 1973; Nicholas and Hankin, 1988). Subyearling fall Chinook salmon reside in streams and rivers for several months before migrating to the estuary during the spring, summer or fall of their first year of life (Reimers, 1973; Healey, 1991; Bottom et al., 2005a). Estuaries are considered a nursery for Chinook salmon due to the potential for enhanced growth, refugia from predation, and physiological acclimation to

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marine waters (Reimers, 1973; Healey, 1980; Simenstad et al., 1982). Subyearlings may inhabit estuaries for an extended period (≥6 months) before continuing their migration to the ocean (Hering et al., 2010; Volk et al., 2010). This initial residence in estuaries and coastal waters is considered a critical period for juvenile salmon due to high and variable levels of mortality (for review see Pearcy, 1992).

During this important early marine residence period, a small number of sub-yearling Chinook salmon (<10% of a population) inhabit sandy beach surf zones mostly adjacent to estuary mouths (Healey, 1980; Allen and Pondella, 2006; Marin Jarrin, 2012). Along the west coast of North America, juveniles have been collected at beaches adjacent to estuary mouths during all stages of the tide and times of day in shallow and outermost parts of the surf in summer where they feed on a relatively high abundance and diversity of prey (Dawley et al., 1981; Marin Jarrin et al., 2009; Marin Jarrin, 2012). Reimers (1973) hypothesized that juveniles moved to surf zones due to increasing abundance of conspecifics and decreasing prey availability throughout the summer in a small Oregon estuary. Marin Jarrin (2012) found that juvenile Chinook salmon mostly used beaches that were immediately adjacent to their estuary of origin and hypothesized that juveniles were concurrently using estuarine and surf zone habitats. By using both habitats, Marin Jarrin (2012) suggested that Chinook salmon populations presented a spatially-split cohort, where the majority of juveniles reside in estuaries prior to moving offshore and a minority reside in surf zones for an unknown period of time before moving to deeper coastal waters.

Beck et al. (2001) refined the concept of nurseries and proposed a framework to characterize these important environments. Several subsequent studies also suggested that even though a species or population uses one main nursery where the majority of individuals reside, other habitats may serve as important alternatives to the main nursery (Secor, 2007; Fodrie et al., 2009; Vivier and Cyrus, 2009). We define alternative nursery habitats as environments where some individuals reside and encounter foraging and growth conditions similar to the main nursery. These alternative nurseries expand rearing habitat and therefore potentially increase the total number of individuals that survive to adulthood.

In the case of Chinook salmon, estuaries are considered the main nursery habitat during their first months of marine life (Reimers, 1973; Healey, 1980; Simenstad et al., 1982). However, surf zones could serve as an alternative nursery habitat because juveniles may experience high growth rates due to an abundance and high diversity of prey (Marin Jarrin et al., 2009) and low predation rates due to the turbid and high dynamic nature of surf zone waters (McLachlan and Brown, 2006). We tested the hypothesis that surf zones adjacent to estuary mouths provide an alternative nursery habitat for subyearling Chinook salmon. First, we determined that juveniles using surf zones and estuaries were part of the same cohort by comparing size at capture and size at and timing of marine entrance for juveniles collected in both habitats. We then compared catch, diet composition, stomach fullness and growth rates of juveniles collected simultaneously in two estuaries and two adjacent surf zones during three years. If surf zones provide alternative nursery habitats, we expected juvenile stomach fullness and growth rates to be similar between estuaries and surf zones. Based on previous studies, we expected catches to be higher in estuaries than in surf zones (Marin Jarrin, 2012). We hypothesized that even though diet composition would be different between habitats, prey diversity would be similarly high because of the diverse prey fields present in estuaries and surf zones and the opportunistic feeding nature of juvenile Chinook salmon (Gray et al., 2002; Schabetsberger et al., 2003; Marin Jarrin, 2007). Finally, we correlated catches between estuaries and surf zones to determine if surf zone use was related to juvenile densities in estuaries (Reimers, 1973).

2. Material and methods

2.1. Study region

This study was conducted in lower Coos and Alsea bays and their adjacent sandy beach surf zones (Coos and Alsea Surf) located in Oregon, USA during 2008–2010 (Fig. 1). Adjacent sandy beaches were located within 500 m of the estuary mouth. Coos and Alsea Surf are dissipative (shallower slope) sandy beaches (McLachlan, 1980; Short and Wright, 1983) experiencing moderate wave height in the summer (average wave height: 1–2 m) when sand accretion may transform them into intermediate beaches (Komar et al., 1976). Coos Surf is located immediately to the south of Coos Bay and is approximately 3 km long while Alsea Surf is located immediately to the south of Alsea Bay and is approximately 10 km long. Coos and Alsea Bay are drowned river mouth estuaries, influenced by high stream flows in fall and winter, and low to inexistent summer flows (Emmett et al., 2000). Coos and Alsea Bay are different in their sizes and classification based on human development (Table 1). Juvenile origin is also different between watersheds as juveniles at Coos Bay are of hatchery and natural origin while in Alsea Bay all juveniles are naturally-produced. Chinook salmon populations in both watersheds are currently considered stable (ODFW, 2005).

2.2. Fish collection

Prior research found that juvenile Chinook salmon were present in estuaries and adjacent surf zones during all stages of the tidal

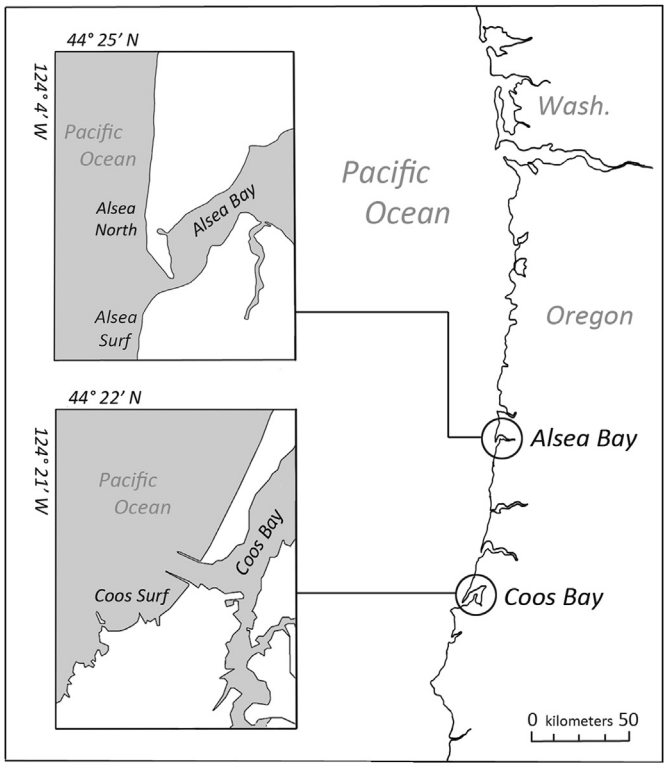

Fig. 1. Map with location of two estuaries (Coos Bay and Alsea Bay) and two surf zones (Coos and Alsea Surf) where juvenile Chinook salmon were collected during 2008–2010.