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# Stock-Specific Movement and Distribution of Juvenile Chinook Salmon, *Oncorhynchus tshawytscha*, in Sandy Beach Surf Zones of Oregon and Washington, USA

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**Abstract** Sandy beach surf zones serve as alternative nursery habitats for juvenile Chinook salmon (0 age) during their early marine residency, a period considered critical due to high and variable mortality rates. Despite the importance of early marine residence, the extent of juvenile salmon surf zone use and movement along sandy beaches is not well understood. Juvenile Chinook salmon distribution and movement were studied in shallow surf zone habitats by sampling from 2006 to 2010 with a beach seine 11 beaches adjacent and distant to four estuary mouths in Oregon and Washington, USA. The estuary of origin of each juvenile was determined using genetic stock identification methods and coded wire tags. Surf zones sampled were within littoral cells, which are stretches of the coastline bordered by rocky headlands, and included estuaries with and without Chinook salmon populations. Juvenile salmonids were only collected at littoral cells with Chinook-inhabited watersheds. Most juveniles (95 %) were present at sandy beaches adjacent (<500 m from estuary mouth) to their estuary of origin. Few Chinook salmon (5 %) were collected at littoral cells that contained non-natal estuaries. These results indicate that juvenile Chinook salmon inhabiting surf zones mostly use beaches adjacent to their estuaries of origin, but some juveniles may reside in beaches distant from their point of ocean entry.

**Keywords** Sandy beach surf zones · Juvenile Chinook salmon · Genetic stock · Movement · Habitat use

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## Introduction

Sandy beaches and their surf zones account for most of the open shoreline of the world (Defeo et al. 2009). In Oregon and Washington, USA, 60 % of the oceanic coastline consists of sandy beaches, which are part of littoral cells (Komar 1997; Don et al. 2006). Littoral cells are bordered by rocky headlands that act as boundaries between water circulation cells that form in the littoral cells and restrict transfer of sediment to offshore regions or to other cells (Komar 1997).

The surf zones of sandy beaches are semi-enclosed environments, which may be influenced by adjacent habitats such as coastal ocean, beach and dune systems, rocky substrates, estuaries, and river mouths. Surf zones are well studied around the world, e.g., Belgium, Brazil, The Netherlands, and South Africa (McLachlan 1980; McLachlan and Brown 2006). The surf zone fish community is mostly composed of larvae and juveniles that may use the area for rearing or migration. The surf zone, with its shallow turbid waters, may provide early life stages of fishes with an abundant supply of potential prey and refuge from predators (Barreiros et al. 2004; Sato et al.

2008; Marin Jarrin and Miller 2013). Other factors found to positively influence fish abundance and species richness on sandy beach surf zones include habitat structure, the abundance of detached macrophytes, and water temperature appropriate for relatively high growth rates (Allen and Pondella 2006; McLachlan and Brown 2006; Marin Jarrin and Miller 2015).

Chinook salmon (*Oncorhynchus tshawytscha*) is an economically, ecologically, and culturally important anadromous semelparous species that spawns in most rivers of western North America discharging into the Pacific Ocean from San Francisco, California to Alaska (Quinn 2005). Chinook salmon populations are often referred to by the season when adults return to their natal rivers for spawning. Most fall Chinook salmon juveniles initiate their migration to the ocean during their first or second year of life and are therefore referred to as "subyearlings" or "yearlings" (Healey 1983). In Oregon and Washington, most fall Chinook salmon migrate to the ocean as subyearlings (Rich 1920; Reimers 1973; Nicholas and Hankin 1988). Therefore, subyearling fall Chinook salmon reside in streams, rivers, and estuaries for several months during their first year of life before moving to the coastal ocean (Rich 1920; Reimers 1973; Healey 1991).

Juvenile Chinook salmon use of streams, estuaries, and the coastal ocean, and the relationship between habitat use and habitat structure, current speed and water depth, has been thoroughly studied (reviewed in Healey 1991; Bottom et al. 2005; Quinn 2005). Estuaries have received particular attention because juveniles are nurtured here during their ocean migration due to the high foraging potential, refuge from predation, and physiological transition to marine waters (Reimers 1973; Healey 1980; Simenstad et al. 1982). In streams, estuaries, and the coastal ocean, small juveniles are usually present in shallow habitats and close to shore potentially because water temperatures, high prey populations, and few predators there favor high growth and survival (Simenstad et al. 1982; Duffy and Beauchamp 2011).

Recently, Marin Jarrin et al. (2009) confirmed that subyearling Chinook salmon also inhabit sandy beach surf zones adjacent to estuary mouths before moving to the coastal ocean. Juvenile salmon were present in the surf zone during all tidal stages throughout the day during the summer. Continuing with this line of research, Marin Jarrin and Miller (2013) determined that shallow surf zones adjacent to estuary mouths can serve as alternative nursery habitat for some juveniles (<10 % of population) because surf zones support salmon foraging and growth at rates similar to estuaries. In the present study, we identified sandy beaches used by juvenile Chinook salmon and examined salmon movement alongshore and away from their estuary of origin. We also determined whether juveniles move to deeper offshore waters as they move away from natal systems, potentially re-entering surf zones distal to their natal system, or follow the coastline, and remain in shallow nearshore waters. We expected that because of their small size and the deep waters surrounding rocky headlands, juvenile salmon within a surf zone would remain in shallow waters and follow the coastline, thus limiting their movement to within a littoral cell until they migrate to deeper waters. We sampled juveniles at 11 beaches over 5 years to determine whether these salmon limited their movement to within their littoral cell of origin. Estuary of origin was determined using standard genetic stock identification methods and coded wire tags (CWTs), and the findings were compared with locations of capture.

## Methods

### Study Region

The 11 beaches sampled during the summers of 2006–2010 were dissipative (shallow slope) sandy beaches (McLachlan 1980; Short and Wright 1983) located in six Oregon and Washington littoral cells (Fig. 1). Oregon and Washington sandy beaches experience mixed semidiurnal tides, with a 2 m mean and 3.6 m maximum daily amplitude. Wave action is extreme (average wave height >3 m) during winter and moderate (average 1–2 m) in summer (Komar et al. 1976). Eight beaches were adjacent to estuary mouths (referred to as adjacent beaches, <500 m from an estuary mouth), and three were distant beaches (>15 km from an estuary mouth). Adjacent beaches were pairs of sites located immediately to the north and south of the estuary mouths of the Columbia River, Tillamook Bay, Alsea Bay, and Coos Bay. The distant beaches were located between these four estuaries and were randomly selected. Nine beaches (eight adjacent and one distant) were located in littoral cells with watersheds that produce Chinook salmon, whereas two other distant beaches were within littoral cells without Chinook-inhabited watersheds. The sizes of the four estuaries varied considerably: Columbia River (327 km$^2$), Tillamook Bay (37 km$^2$), Alsea Bay (10 km$^2$), and Coos Bay (54 km$^2$) (Oregon Coastal Atlas: http://www.coastalatlas.net/, Accessed 14 July 2015). The Columbia River is a river-dominated estuary, which, due to snowmelt during spring and summer, produces a large low-salinity (<28) plume that varies in its geographical position with wind direction (Burla et al. 2010). Tillamook, Alsea, and Coos bays are drowned river mouth estuaries with little to no stream flows during summer and small plumes (Cortright et al. 1987). Chinook salmon populations in the Columbia, Tillamook, and Coos basins include fish of both hatchery and natural origin, while the population in Alsea Bay is exclusively naturally produced. Approximately 100,000,000, 500,000, and 2,000,000 subyearling

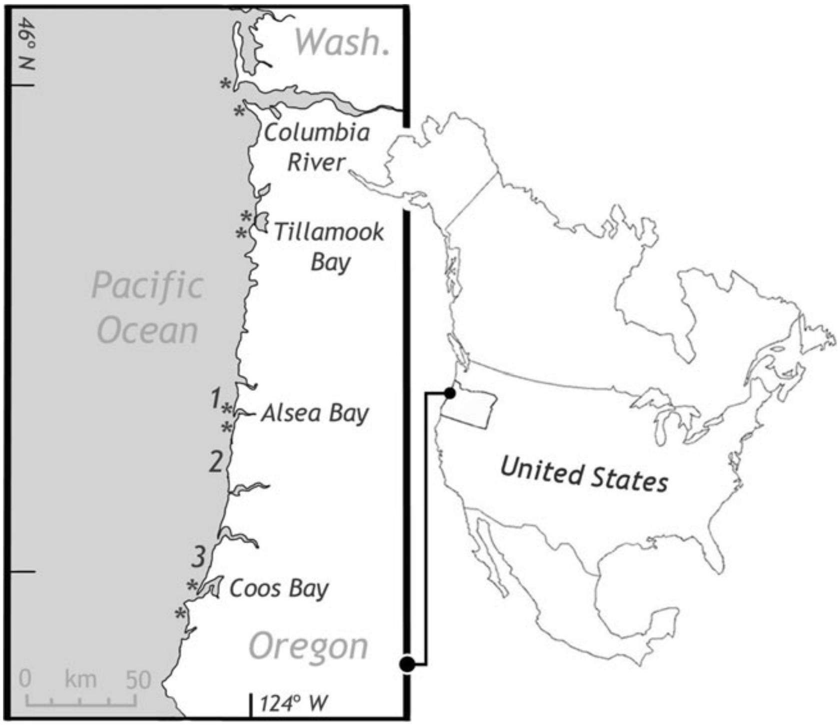


**Fig. 1** Map with location of collection sites. Eight beaches (*asterisks*) were located immediately north or south of four estuaries shown: Columbia River, Tillamook Bay, Alsea Bay, and Coos Bay. Three distant beaches are located at least 15 km from an estuary mouth and indicated as *numbers*. Beaches adjacent to the four estuaries shown are part of the Clatsop Sandy Shore, Rockaway Sandy Shore, Newport and Coos Sandy Shore littoral cells, respectively. The three distant beaches are part of the Beverly, Heceta, and Coos Sandy Shore littoral cells, respectively. Chinook salmon that exit the Columbia River can be part of multiple genetic stocks, including Upper Columbia Summer and Fall and Spring Creek Group Fall; fish that exit Tillamook and Alsea bays are part of the Northern Oregon Coast stock, and those that exit Coos Bay are from the Mid-Oregon Coast stock

Chinook salmon smolts are released annually from hatcheries in the Columbia River, Tillamook Bay, and Coos Bay watersheds, respectively (Regional Mark Processing Center web-page: http://www.rmpc.org, Accessed 14 July 2015).

## Surf Zone Collection

To determine the distribution of juvenile Chinook salmon along the Oregon coast, we sampled in the surf zone from June to September 2006–2010 using a beach seine (1.5 m high and 15 m wide with a 1.0-cm mesh) as detailed in Marin Jarrin et al. (2009). Sampling occurred during lower low spring tides in the morning for consistency. Juvenile Chinook salmon have been collected in surf zones during the whole tidal cycle at different depths and throughout the day during the summer (Dawley et al. 1981; Marin Jarrin et al. 2009). Initially, we sampled the beach south of Coos Bay (hereafter referred to as Coos South) in 2006 and 2007 (Table 1). On each sampling day in 2006 and 2007, we completed one to two tows. We completed four to six tows each day from 2008 to 2010. In 2008, we expanded our sampling to nine beaches (Table 1). This expansion of our collection efforts allowed us to determine whether juveniles were present both north and south of estuaries and only on beaches adjacent to estuary mouths. In 2009, we sampled at five adjacent beaches (Table 1), including two new beaches, to expand our collection sites around the Columbia River. In 2010, we sampled at two beaches (Table 1).

Juvenile Chinook salmon were collected, euthanized with MS-222 (tricaine methanesulfonate, Argent Chemical Laboratories, 150 mg $l^{-1}$) buffered with baking soda (sodium bicarbonate, 300 mg $l^{-1}$), and transported to the laboratory on ice. In the lab, we measured the fork length (FL, cm) of all juveniles, collected and stored tissue samples in ethanol (90 %) for genetic analysis, and checked each fish for fin clips and CWTs. During 2006–2007, we haphazardly took tissue samples from 36 % of juvenile salmon for genetic analysis. From 2008 to 2010, tissue samples were taken from all juvenile Chinook salmon we collected.

We determined river or estuary of origin for juvenile Chinook salmon using genetic stock identification methods and CWTs (Jefferts et al. 1963; Manel et al. 2005). Size and date at tagging also were determined using CWT data (Regional Mark Processing Center web page).

In Oregon and Washington, CWTs are mostly implanted in juvenile salmon of hatchery origin (Regional Mark Processing

**Table 1** Description of sampling years, number of days beaches were sampled, number of days juvenile Chinook salmon were collected, and number of fish collected (sampling days, days with collection, number of fish)

| | Columbia River | | Tillamook Bay | | Alsea Bay | | Coos Bay | | Distant beaches[a] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | North | South | North | South | North | South | North | South | 1 | 2 | 3 |
| 2006 | – | – | – | – | – | – | – | 7, 3, 48 | – | – | – |
| 2007 | – | – | – | – | – | – | – | 6, 4, 214 | – | – | – |
| 2008 | – | – | 6, 3, 16 | 6, 2, 6 | 6, 3, 32 | 6, 4, 6 | 6, 2, 12 | 6, 2, 50 | 3, 0, 0 | 3, 0, 0 | 4, 1, 8 |
| 2009 | 6, 3, 10 | 6, 0, 0 | 6, 3, 12 | – | – | 6, 2, 5 | – | 6, 3, 10 | – | – | – |
| 2010 | – | – | – | – | – | 10, 2, 2 | – | 10, 9, 160 | – | – | – |

Beaches sampled are located immediately adjacent to the north or south of each estuary listed. Distant beaches were at least 15 km from an estuary mouth (Fig. 1). Samples were taken around the morning lower low spring tides

"–"indicates no sampling occurred

[a] Location of distant beaches can be found in Fig. 1

Center web page), and in our study, all juveniles that had CWTs were of hatchery origin. We assumed that CWT data would reflect habitat use and movement of fish of hatchery and natural origin.

We used tissue samples collected from juvenile Chinook salmon (2006–2010) to estimate stock origins. Samples were digested to extract DNA employing silica membrane-based kits (e.g., © Promega Corporation wizard kits) following protocols provided by the manufacturer. The isolated DNA was used in PCR amplifications of the 13 Chinook salmon microsatellite DNA loci that have been standardized by the Genetic Analysis of Pacific Salmonids (GAPS) consortium (Seeb et al. 2007). Stock of origin (or genetic stock group) was estimated using a baseline of population data compiled from the GAPS database (Seeb et al. 2007; Teel et al. 2015). The baseline included data for Chinook salmon populations ranging from northern California to southern British Columbia, which allowed us to differentiate among the major genetic stocks of Chinook salmon that would potentially contribute to our samples of juveniles. We used the genetic stock identification computer program ONCOR (Kalinowski et al. 2007), which uses the likelihood model of Rannala and Mountain (1997), to assign each fish to its most likely stock of origin. For our region of origin analysis, we only included individuals that could be assigned to a stock with a probability >0.90.

We compared the geographical region of the stock to the littoral cell in which the fish was collected. When the stock of origin was within the littoral cell in which a juvenile was collected, we concluded that the fish had remained within its littoral cell. The stocks in our analysis that originated within the study area were from four regions: Mid-Oregon Coast, Northern Oregon Coast, Columbia River, and Southwest Washington (Fig. 1). Both of the Oregon coastal regions include multiple estuaries. Therefore, when juvenile salmon were found to be from the Oregon regions, we used CWTs, when available, to determine the river of origin of the fish or hence estuary of origin.

## Results

Over 5 years, we collected 591 juvenile Chinook salmon at eight different sandy beaches. Only one other salmon, a juvenile coho salmon (*Oncorhynchus kisutch*, 10.7 cm fork length or FL) from Alsea South was collected in our study. No juvenile Chinook salmon was collected at Distant Beach 1 and 2 and Columbia South. The majority of juvenile salmon were captured at Coos South (82 %, Table 1) and between July 1 and September 1 (99 %). Size of the Chinook salmon in the surf zone varied from 5.9 to 14.4 cm FL, with the majority (63 %) between 9 and 11 cm FL. Based on their size, data from CWTs, and genetic analysis, all juveniles were categorized as subyearlings (Fisher et al. 2007). The largest juvenile salmon (12.5 ± 1.9 SD cm FL) were collected during 2008 at Distant Beach 3, which was located 15 km north of Coos Bay.

We collected juveniles more often at beaches adjacent to estuary mouths (16 days or 53 % of days sampled, 31 tows) than at beaches distant from estuary mouths (1 day or 10 % of days sampled, 2 tows). Juvenile salmon were collected at beaches both north and south of estuaries except at Columbia South during 2009. We collected juveniles at only one distant beach, Distant Beach 3, which is located 15 km north of Coos Bay. This was the only distant beach located in a littoral cell with Chinook-inhabited estuaries.

Most (81 %) juvenile Chinook salmon analyzed for their genetic stock of origin had probability assignments >0.90 and, therefore, were used for further region of origin analysis. The majority of these juveniles (95 %) were collected in the littoral cell associated with their region of origin, although this varied by littoral cell (Fig. 2). For juvenile salmon collected around Coos Bay (i.e., Coos South, Coos North, and Distant Beach 3), the majority originated in that littoral cell (range 96 % in 2006 to 100 % during 2009). The majority of the juveniles collected in a littoral cell that did not encompass their region of origin came from an adjacent region (69 %, $n$ = 16). Individuals from one stock group (Upper Columbia summer/

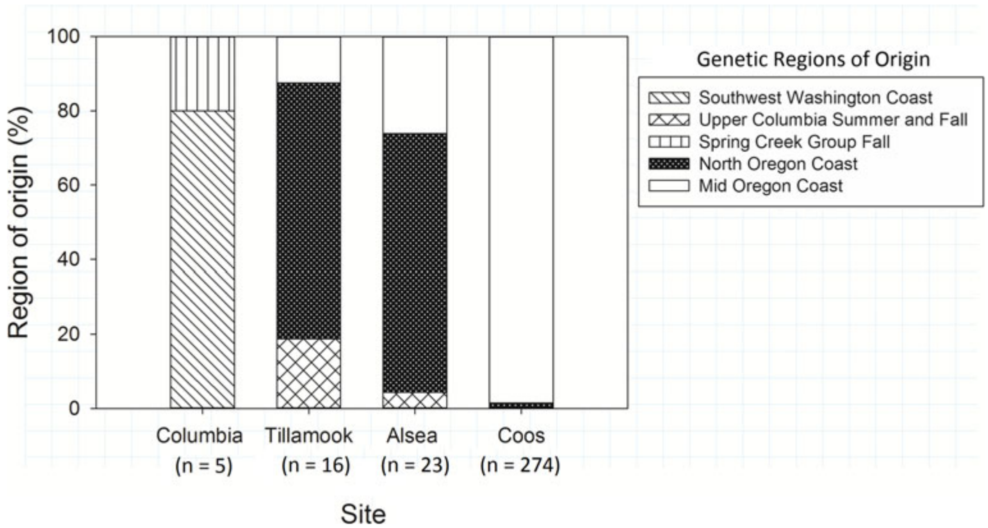


**Fig. 2** Bar graphs showing genetic region of origin of juvenile Chinook salmon collected at eight beaches during the summers of 2006–2010. Juveniles were collected at beaches located immediately to the north of Columbia River (Columbia), north and south of Tillamook Bay (Tillamook), north and south of Alsea Bay (Alsea) and north and south of Coos Bay (Coos), and Distant Beach 3 located 15 km north of Coos Bay *Upper Columbia Summer and Fall and Spring Creek Group Fall are Columbia River genetic stock groups

fall Chinook salmon), however, were identified in samples from three littoral cells including the Tillamook North ($n = 3$), Alsea North ($n = 1$), and Coos South ($n = 1$) sites.

During 2008–2010, 38 juveniles with adipose fin clips and 15 with CWTs were considered of hatchery origin. Most (13) of the juvenile Chinook salmon with CWTs had exited from the nearest estuary (Coos Bay) and were collected at Coos South. The two other fish were a late fall run from Forks Creek Hatchery in South West Washington and a fall run from Little White Salmon National Fish Hatchery in Central Columbia River. The Forks Creek Hatchery fish was released in the Willapa Bay watershed, Washington, as a subyearling and collected at Columbia North, which is within the same littoral cell, while the Little White Salmon National Fish Hatchery fish was released in the Columbia River as a subyearling and collected at Tillamook North, which is in a different littoral cell (Fig. 1).

## Discussion

Our study is the first to evaluate the use and movement of juvenile Chinook salmon in sandy beach surf zones, an alternative nursery habitat, during their first summer of life by comparing their region of origin with the location of capture (Marin Jarrin and Miller 2013). Juvenile Chinook salmon were primarily distributed in the littoral cell surrounding their natal estuary, and within a littoral cell, they were present mostly in surf zones adjacent to the mouth of their estuary of origin. However, we also collected several individuals in our samples (5 %) at locations distant from their estuary of origin.

Subyearling Chinook salmon have been known to remain near their estuary of origin when they first enter the ocean (Healey 1983; Trudel et al. 2009; Tucker et al. 2011), and small juveniles in estuaries and the coastal ocean reside in shallow waters (Bottom et al. 2005; Peterson et al. 2010; Bi et al. 2011). Subyearlings originating from Oregon rivers are particularly known to follow this pattern; they are primarily distributed along the Oregon coast at the end of their first summer of life and stay closer to shore than other stocks in the region (Teel et al. 2015). Similarly, our data indicate that juvenile salmon within sandy beach surf zones mostly remain close to their estuary of origin and do not use beaches outside their littoral cells. Juveniles may not migrate to other littoral cells because rocky headlands extend into deep waters and impede their movement. These findings are further supported by the fact that fish collected in the present study were smaller than subyearlings collected offshore (59–144 mm FL, present study; 90–140 mm FL, Schabetsberger et al. 2003; 87–198 mm FL, MacFarlane 2010; 95.1–153.7 mm FL, Duffy and Beauchamp 2011).

Columbia South was the only beach adjacent to an estuary at which we did not collect juveniles and the only beach that lacked “trough” areas. Troughs are depressions on the beach topography created by sand bars that form offshore and propagate shoreward during summer. As the sand bars move shoreward, they develop finger-like structures that weld to the shoreline producing sheltered trough areas and adjacent exposed surf areas (Short and Wright 1983; Ruggiero et al. 2005). Due to differences in depth and beach slope, trough and flat areas present different wave conditions and circulation that may influence faunal assemblages (Harvey 1998; Watt-Pringle and Strydom 2003; Marin Jarrin and Miller 2015). Perhaps juvenile salmon were absent at Columbia South because this beach lacked troughs. The absence of troughs at Columbia South appears to be a persistent pattern since they were absent in 2007 and 2008 (Ainsworth J. Oregon Department of Fish and Wildlife, personal communication).

Other factors that could explain the lack of juvenile Chinook salmon catches at Columbia South are the relatively long jetty (~10.4 km) on the south side of the Columbia River and the relatively deep waters (>10 m) at the end of this jetty, which may provide habitat for large piscivorous fish that could deter juveniles from accessing surf zones. The absence of juvenile Chinook salmon could also be due to the large amount of rearing habitat available within the Columbia River estuary or to physical transport processes, because unlike the other three estuaries adjacent to our sampling sites, the Columbia River estuary has significant river flow and a large coastal plume during the summer (Burla et al. 2010). This plume can extend south and away from the coast or north along the coast depending on river flow and coastal winds (Burla et al. 2010). The river flow and plume may therefore have quickly directed juvenile salmon away from the estuary mouth keeping them from using Columbia South. The lack of juvenile salmon at Columbia South, however, was not likely due to the presence of jetties, habitat availability within the estuary, or physical transport because we collected juvenile Chinook salmon at beaches adjacent to other estuaries and jetties (i.e., Coos Bay and Tillamook Bay) and from the Columbia River at Columbia North.

Juvenile salmon seldom used distant beaches within their littoral cells of origin despite the presence of trough areas at these beaches. Our results are similar to another study that examined juvenile fish movement within surf zones, which found that on average juvenile Florida pompano (*Trachinotus carolinus*) and gulf kingfish (*Menticirrhus littoralis*) remained within a 100-m stretch of beach for up to 30 days despite a high potential for dispersal (Ross and Lancaster 2002). Potential reasons for this lack of movement from adjacent to distant beaches are that adjacent surf zones are (1) more physically similar to estuarine habitats than distant beaches (i.e., finer sediments and lower salinities, Dahlberg 1972), (2) offer habitat that supports similar foraging and growth rates as estuaries (Marin Jarrin and Miller 2013), and (3) contain higher abundances of potential prey than distant beaches (Munilla et al. 1998; Marin Jarrin 2007). For example, water temperature and salinity in 2008 among Coos South, Coos North (adjacent beaches), and Horsfall (distant beach) were not significantly different (ANOVA, $F_{2,13} < 1.6$, $p > 0.2$). Therefore, juvenile Chinook salmon may have remained in adjacent beaches because of the biological similarities with the estuarine habitat they had recently exited.

The greatest daily catches of subyearling Chinook salmon occurred at Coos South. Although we cannot explain the consistently high abundance of juveniles there, certain physical characteristics of this beach could have contributed to our result. Coos South is short in length (~3 km long) with a rocky headland and a jetty south and north of the beach, respectively. These characteristics may concentrate juveniles between the headland and jetty as well as constrain circulation cells that trap prey in the surf zone (Marin Jarrin 2007). Alternatively, juvenile Chinook salmon may be attracted to Coos South due to low interspecific competition for prey (i.e., underused resources, Skúlason and Smith 1995). For example, silver surfperch, *Hyperprosopon ellipticum*, whose diet is similar to Chinook salmon in surf zones (Marin Jarrin 2007), was often collected at all beaches except Coos South (Marin Jarrin and Miller 2015).

At present, it is unclear how far into the surf zone juvenile Chinook salmon reside. Our study examined juveniles in shallow (<1.5 m depth) portions of the surf zone. Based on variation in sediment size and mysid shrimp species, Llewellyn (1982) suggested that in Oregon, surf zones extend up to 15 m in depth. However, Dawley et al. (1981) sampled the outermost surf zone in northern Oregon and southern Washington and collected many juvenile Chinook salmon <12 cm FL; their results suggest the entire surf zone is a habitat for Chinook salmon that have recently entered the ocean.

The sample size in our study of surf zone habitats was lower than recent stock-specific studies of juvenile salmonid movement in Oregon and Washington estuarine and marine habitats (591 vs. >1000 individuals, Trudel et al. 2009; Roegner and Teel 2014; Teel et al. 2015). Sample sizes in our study were smallest at the beaches surrounding the Columbia River, Tillamook Bay, and Alsea Bay. Despite the small number of juveniles at the beaches surrounding these three estuaries, the pattern was similar to that observed at beaches surrounding Coos Bay where juveniles from mostly local stocks were present. The relatively small sample size in our study was partly due to the small percentage (<10 %) of Chinook salmon populations that may use sandy beach surf zones (Marin Jarrin 2012) and the small areas we sampled when compared to studies of the open ocean and estuaries (Fisher and Pearcy 1995; Roegner and Teel 2014; Teel et al. 2015). Our study is strengthened by the fact that we only used high probability genetic assignments and complemented the genetic information with CWTs to determine the origins of juvenile salmonids. Therefore, despite our small sample sizes, we consider our results accurately depict Chinook salmon surf zone use.

Sandy beaches and adjacent surf zones are the most common habitat types of open shorelines (Defeo et al. 2009), particularly around estuary mouths. This megahabitat is constantly being impacted, and potentially modified, by human-caused stresses (Defeo et al. 2009). In the near future, climate change is predicted to impact sandy beaches and surf zones through changes in water temperature and increases in sea surface and wave height (IPCC 2013). Juvenile Chinook salmon that used surf zones in our study mostly inhabited beaches adjacent to the mouth of their estuary of origin. Previous research suggested that when large numbers of subyearling Chinook salmon inhabit estuaries, some juveniles concurrently use surf zones (Marin Jarrin and Miller 2013). Using multiple habitat types can confer resilience to anadromous fish populations by increasing their access to resources and reducing the possibility that a catastrophic event (e.g., floods, droughts, predation pulse) eliminates a cohort (Hilborn et al. 2003; Secor 2007; Schindler et al. 2010). Considering the potential impacts of climate change on coastal environments and the importance of surf zones for juvenile Chinook salmon, and in particular beaches adjacent to estuary mouths, management actions directed at reducing the impacts of human activities and climate variability should be encouraged.

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