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Migration rates of hatchery Chum Salmon (*Oncorhynchus keta*) fry in the Columbia River estuary

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Abstract

Tidal freshwater and estuarine habitats are critical environments where wild juvenile Chum Salmon (*Oncorhynchus keta)* feed and grow prior to entering the ocean. However, the importance of these systems for rearing of hatchery-raised Chum Salmon fry is less clear. Hatchery fry are typically larger than wild fry and evidence suggests that very large fry (> 6.5 g) may be ready to enter the ocean at the time of release. For smaller hatchery fry (1-3 g), reported migration rates are variable, and little is known about migration rates through a large estuary. To better understand whether estuary rearing along the riverine-estuarine gradient contributes to increased growth of hatchery Chum Salmon fry, we examined migration rates and spatial variation in length in the lower Columbia River and estuary (LCRE). We released hatchery fry marked with coded-wire tags in April 2013 and subsequently beach seined at 9 sites throughout the tidal freshwater zone as well as an estuarine site near the river mouth. This was the first use of coded-wire tags to track Chum Salmon fry in the Columbia River system. We captured the first hatchery fry at the mouth of the Columbia River 40 hours after release (migration rate ≥ 20 kilometers/ day). Hatchery fry at downstream sites were significantly larger than those near the release location. Results suggest larger hatchery fry may have limited reliance on the estuary, but additional research is required to determine whether these faster migrating individuals contribute disproportionately to adult returns.

Introduction

Tidal freshwater and estuarine habitats are critical environments for juvenile Chum Salmon (*Oncorhynchus keta)* to feed and grow rapidly (Simenstad and Salo 1980; Bax and Whitmus 1981; Simenstad et al. 1982), and physiologically transition to salt water prior to migrating to the ocean (Simenstad et al. 1982; Iwata and Komatsu 1984; Quinn 2005). Chum Salmon fry and fingerlings (defined as ≤ 60 and > 60 millimeters (mm) fork length (FL), respectively; Roegner et al. 2012;) are often found in shallow-water habitats, including tidal flats, emergent wetlands, and slough habitats (Healey 1982a; Pearcy et al. 1989; Roegner et al. 2008). The period of residency for these fry migrants varies among estuarine systems, ranging from days (Congleton et al. 1981; Hillgruber and Zimmerman 2009) to weeks (Mason 1974; Beacham and Starr 1982; Hale et al. 1985) to months (Hermann 1971; Dorcey et al. 1978; Pearcy et al. 1989); smaller fry appear to reside in estuaries longer than larger fry (Healey 1979; Pearcy et al. 1989). However, there are trade-offs between delaying migration to achieve the larger body size associated with increased survival in the ocean (Healey 1982a), and prolonging exposure to estuarine predators (Hunter 1959; Hargreaves and LeBrasseur 1986; Fresh and Schroder 1987; Magnhagen 1988), or missing the optimal window for smolting (Iwata et al. 1982).

Although the importance of estuary habitat for rapid growth of wild Chum Salmon fry is well established (2–8.6% of body weight per day; Healey 1982a; Simenstad et al. 1982; Pearcy et al. 1989), less is known about the importance of estuary rearing to hatchery fry, particularly in larger estuaries. Hatchery Chum Salmon fry are typically released at the fed-fry stage (Mahnken et al. 1998) and may be substantially larger than wild fry at the time they enter estuaries. Although sizes vary by location, wild fry may range from 30–40 mm (Healey et al. 1982a), with reported average fork lengths of 36–38 mm (Burril et al. 2009) or 40–41 mm (Pearcy et al. 1989). In contrast, hatchery fry may exceed the length of co-occurring wild fry by > 15 mm or quadruple the body weight (Reese et al. 2009), with reported average lengths of 44–53.7 mm (Shreffler et al. 1990) or 46–92 mm (Pearcy et al. 1989). At restoration sites in the Grays River, WA, most wild Chum Salmon fry were < 45 mm compared to hatchery releases that ranged between 53 and 58 mm (Roegner et al. 2010). At these larger sizes, hatchery fry may be ready to acclimate to salt water (Iwata and Komatsu 1984; Quinn 2005) and migrate seaward. Limited estuarine growth was observed for hatchery fry in Hokkaido, Japan; average fork length measured 49.1–49.7 mm when Chum Salmon were released from the hatchery, whereas those entering the sea measured 48.1–51.1 mm FL (Saito et al. 2006). However, there can be substantial variation in the size of individuals within and among release groups (1.5–4.0 g/fish, Northern Southeastern Regional Aquaculture Association unpublished data, 1977–2012; 0.75–6.5 g/fish, Pearcy et al. 1989), which may affect individual migration rates through the estuary (Pearcy et al. 1989).

The speed at which fry migrate away from the release site may affect survival rates in estuarine systems (Pearcy et al. 1989). For example, studies have shown that survival is higher for hatchery Chum Salmon fry that immediately emigrate from the release site relative to those that remain at the release site (Fukuwaka and Suzuki 2002; Wertheimer and Thrower 2007). Although possible mechanisms have not been resolved for this common observation, it does appear that the days to weeks after release is a critical time period for survival. Considering that overall fry mortality rates from direct-ocean and small-estuary releases may be in excess of 31% during the 2–4 days following release (Bax 1983), decreased mortality of rapidly migrating fry may result in a disproportionate contribution of these individuals to the adult return. However, it is not clear whether rapid migration would occur in larger estuaries where increased habitat opportunity or increased prey abundance could support extended rearing by larger hatchery fry (Sibert 1979; Quinn 2005).

The lower Columbia River and estuary (LCRE) provided an ideal location to evaluate variation in size and migration rates of hatchery Chum Salmon fry in a large estuary because of the existence of a hatchery program with freshwater release sites and suitable habitat both upstream and downstream of the release site (Roegner et al. 2012). Unlike the majority of Chum Salmon hatchery programs that support commercial harvest, Columbia River programs support conservation efforts to recover wild populations. Historically, an estimated 1 million Chum Salmon adults returned to the Columbia River (NPPC 1986). Beginning in the 1940s, populations declined precipitously to < 2,000 adults (Howell et al. 1985; Johnson et al. 1997) as a result of decades of over-harvest (Smith 1979; Howell et al. 1985; Nehlsen et al. 1991), altered hydrology and reduced ecosystem function (Bottom et al. 2005), and the loss and degradation of freshwater and estuarine habitats (Nehlsen et al. 1991; Bottom et al. 2005). As a consequence, Columbia River Chum Salmon were listed as “threatened” under the Endangered Species Act in 1999 (ESA 1973; NMFS 1999) as a single Evolutionarily Significant Unit (ESU). At the time of listing 15 of 17 populations in this ESU (Myers et al. 2003) were considered extirpated (Kostow 1995). As part of recovery efforts, Washington and Oregon developed conservation broodstocks to buffer against further population declines and as a source for reintroduction into extirpated populations (WDFW 2014; ODFW 2010).

In this paper, we identified migration patterns of hatchery Chum Salmon fry during the post-release time period when they inhabited the LCRE. To do so, we released hatchery fry marked with coded-wire tags (CWT) in a freshwater tributary near the estuary, and conducted beach seining to recapture individuals as they migrated seaward. Specific objectives were (1) to identify when the first fry from our release arrived at ocean entrance, and (2) to determine whether fish that migrated immediately were significantly larger than those that remained near the release site. Results from this study provide insight into migration patterns in a large estuarine system. Future research will be required to determine whether larger, faster-migrating fry disproportionately contribute to broodstock returns, and whether there are specific hatchery rearing and release strategies that can maximize survival through the tidal freshwater pathway to the estuary.

Methods

The LCRE is a large, river-dominated estuary at the border of Oregon and Washington. Habitat composition in the LCRE has changed over time due to wide spread dredging, diking, and filling, and this has affected the estuarine habitat types occupied by Chum Salmon juveniles (Roegner et al. 2012). Historically, vegetated tidal wetlands (herbaceous and scrub-shrub) comprised 179.4 km^2, of which only 65.4 km^2 remain (Marcoe and Pilson 2017), representing a loss of 63.6% of vegetated tidal habitat. Concomitantly, there has been an increase in tidal flat habitat (from 50.4 to 61.5 km^2; Marcoe and Pilson 2017). Tidal influence extends to Bonneville Dam (235 river kilometers; rkm), but salinity intrusion in the estuary varies in response to river discharge and tidal cycles but is usually restricted to the lower 25 km (Kärnä et al. 2015). Cathlamet Bay is generally a tidal freshwater environment during the juvenile chum migration, while brackish conditions predominate below rkm 15 (Figure 1). During the spring, when Chum Salmon fry are migrating through the system, discharge may exceed 10,000 m^3/s; Chawla et al. 2008) and the tidal range may be up to 3.6 meters (m; Kärnä et al. 2015). At the time of this study, river discharge ranged from 9,852 to 10,590 m^3/s, as recorded at the USGS Beaver Army Terminal gauge station, near Quincy, OR (Station ID = 14246900, rkm 87). This study occurred in the lower portion of the LCRE within rkm 0–41 on the Oregon side of the river.

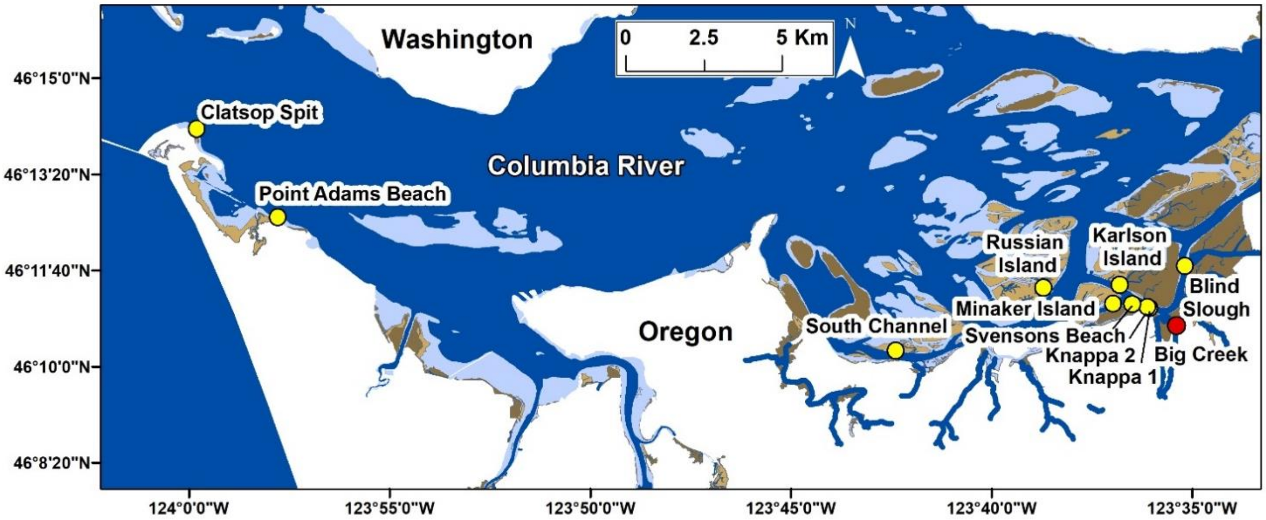

Figure 1. Seine locations (yellow dots) and hatchery release location in Big Creek (red dot) for Chum Salmon (*Oncorhynchus keta*) in the Columbia River estuary, 2013. Cathlamet Bay (not labeled) encompasses the area around the South Channel Sample Site. Estuary habitat categorized as: permanently inundated (dark blue), intermittently exposed (light blue), lower flooded (surge plain feature dominated by herbaceous vegetation; light brown), dredge spoils/ upper flooded (surge plain feature dominated by forest or scrub/shrub vegetation; dark brown), and non-tidal (white) by O'Connor et al. *in press*.

The Big Creek Hatchery Chum Salmon broodstock is derived from predominantly wild Chum Salmon adults collected in the Grays River, WA. Fish are spawned at Grays River Hatchery in November and eyed eggs are transferred to Big Creek Hatchery in January, where they are reared to the fed-fry stage in April. All fry are implanted (hereafter, marked) with a standard-length coded-wire tag (CWT) following the manufacturer's protocol (Solomon and Vander Haegen 2017). During and after marking, fish are checked for CWT loss. These are the only Chum Salmon fry marked with a CWT in the Columbia River basin, and as such, presence of a CWT indicates the fish originated in the Big Creek Hatchery broodstock. Three to five days after marking, fry are released; release dates correspond to when wild Chum Salmon fry are migrating to the estuary. During marking, fork length (FL) was measured on Chum Salmon fry (n = 120) at the beginning of each day. Chum Salmon fry were released on 15 and 17 April 2013 from two locations each day. For the first release location, fry were flushed directly from the hatchery raceway into Big Creek (rkm 5.3). For the second location, fry were released into Big Creek in tidewater (rkm 1.7).

Following the first fry release, beach seining occurred for three days throughout the Oregon side of the LCRE (Figure 1; Table1). A total of ten seine sites were selected *a priori* based on previous observations of juvenile Chum Salmon (Roegner et al. 2008), distance to Big Creek Hatchery, location along potential migration routes, or suitability of the substrate for seining (Figure 1; Table 1). Three sites (Karlson Island, Minaker Island, and Point Adams Beach) were designated as standard sites and were seined daily. Depending on the number of crews that were seining (three the first day, two each subsequent day) and the time it took to process fish at these sites, additional upriver, downriver, and intermediate sites were also seined (Table 1). Upriver sites were located within 2 km of the hatchery release site. These sites were tidally influenced but were located in the freshwater portion of the estuary, while the downriver seine site at Point Adams Beach was tidally-influenced and located in saltwater, 6 km from the end of the Columbia River spit. This site contained limited rearing habitat, and it was assumed that any Chum Salmon fry captured here were likely either finishing their physiological transition to saltwater or *en route* to the ocean. Seine sites were shallow (< 4 m) with sand, silt, or gravel substrate.

Table 1. Sample sites, location within Columbia River, distance from Big Creek, and number of beach-seine sets made April 16–18, 2013. Upriver sites are located near Big Creek Hatchery (primarily downstream of the hatchery), and downriver sites are located near the mouth of the Columbia River.

Sample site	Site description	Location in Columbia River (rkm)	Distance from Big Creek (km)	Number of sets		
				16 April	17 April	18 April
Blind slough	Upriver	41	1.0	2	0	0
Knappa Beach 1	Upriver	39.25	0.8	2	0	0
Knappa Beach 2	Upriver	38.75	1.3	2	0	0
Svensons Beach	Upriver	38.25	1.8	1	0	0
Karlson Island	Upriver	38.1	1.9	1	3	2
Minaker Island	Upriver	38.1	1.9	3	2	2
Russian Island	Upriver	35.6	4.4	0	0	2
South Channel	Intermediate	30.7	9.3	0	1	3
Point Adams Beach	Downriver	5.4	34.6	3	5	4
Clatsop Spit	Downriver	0	40.0	2	0	0

Fish were captured using two beach seines. The first measured 50 m x 3 m with variable mesh size (outer panels = 1.9 cm, inner panels = 1.27 cm, and mesh in the bag = 0.95 cm; details in Roegner et al. 2012); the second measured 38.1 m x 3 m with variable mesh size (outer panels = 1.9 cm, inner panels = 1.27 cm, and mesh in the bag = 0.63 cm; Sims and Johnsen 1974). To fish the seine, one end was anchored on the beach, and the other was towed in a semicircle by a skiff. Crews retrieved the second end of the net from the skiff and pulled both ends of the seine toward the beach simultaneously so that all fish crowded into the bag. When the seine was drawn into a semicircle, the sampled area was approximately 400 m^2 for the first seine and 231 m^2 for the second. Fish were removed to a flow-through bucket that was secured in the river and a second seine set was done immediately in the same location. If less than 30 total salmonids were captured in the first two seine sets, a third set was completed. All seining occurred during full daylight and within three hours of low tide to minimize the total habitat available to fish and, by extension, increase the density of fish in remaining wetted areas (Sims and Johnsen 1974). Moreover, because seining only occurred during low tide, changes in distribution of hatchery fry were not confounded by tidal migrations.

Fish from consecutive sets were processed together. To do so, fish were separated into buckets according to species. Non-salmonids were tallied and released. Salmonids (except Chum Salmon) were tallied according to life stage and presence of a mark (e.g., fin clip or CWT) and then released. All Chum Salmon were anesthetized with tricaine methanesulfonate (MS-222; concentration = 90 mg/L) buffered with sodium bicarbonate (concentration = 180 mg/L) until a loss of equilibrium was observed. Fork length was measured to the nearest mm and the fish was scanned for a CWT using a T-wand manufactured by Northwest Marine Technology[1]. Chum Salmon were then transferred to a flow through tank, held until they recovered from anesthesia, and released in shallow water at the capture site.

Analysis

Migration distances and rates were calculated for Chum Salmon fry captured 16–17 April because these fish were all released on 15 April. Migration distance was calculated as the total distance (km) a fry could travel from the hatchery release point to each seining location, following the most direct path. From these migration distances, migration rates (km/ hour) were calculated for each individual using the hour of release as the start time for the calculation. This represented a minimum migration rate because fry could have taken a more circuitous route that was not detected in our beach seining or could have made small-scale upstream and downstream migrations with the tide (e.g., 500 m; Pearcy et al. 1989).

Length frequency distributions for Chum Salmon captured at upriver (Karlson, Minaker, and Russian Islands) and downriver (Point Adams Beach) seine sites, 16–18 April, were compared using a Kruskal Wallis test using R (Version 3.2.1, R Core Team 2015) package PMCMR (Pohlert 2016). This nonparametric test was selected because the length frequency distribution of marked fish was skewed. A one-tail test was used to determine if marked Chum Salmon fry at downriver sites were larger than marked Chum Salmon fry at upriver sites.

Results

A total of 108,506 Chum Salmon fry were marked 7 – 11 April. By two weeks after marking, 100% of fry still retained the CWT. Length variation was observed during marking (mean = 67 mm FL, range = 58 – 73 mm FL). However, it was subsequently determined that larger fish were marked at the beginning of each day when these length measurements were recorded and that resulting length-frequency data overly represented larger fish. Because of this bias, comparisons of the lengths of fry captured during seining could not be compared to length at release. Fry were released from Big Creek Hatchery on 15 April (n = 58,131) and 17 April (n = 50,375). In the first release group, average fry weight =2.7 grams/ fish and in the second, average weight = 2.5 grams/

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[1] Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA or the Oregon Department of Fish and Wildlife, ODFW.

fish. Fry were released at 1700 h at high tide. Mean daily water temperatures increased slightly from 15 April (mean = 11.36 ◦C) to 18 April (mean = 12.11 ◦C), measured at NOAA station 9439040 near Astoria, OR.

From 16 to 18 April, a total of 617 Chum Salmon fry were captured in the estuary; approximately 15% had a CWT (n = 92), indicating origin from Big Creek Hatchery. Seining was conducted at 10 sites throughout the Oregon side of the estuary, but four sites (Knappa Beach 1 and 2, mouth of Blind Slough, and Svensons Beach) were difficult to effectively seine and were dropped after the first day. A total of 40 sets were made at sample sites and CWT Chum Salmon were captured in 20 of these sets. Unmarked Chum Salmon fry were captured at seven sites and marked Chum Salmon at five sites (Table 2). At both upriver and downriver sites, catch of marked fry decreased from 17 to 18 April, despite a second hatchery release on the evening of 17 April; catch of unmarked fry increased over the same period (Table 2). At the Point Adams Beach site (downriver) sites, catch-per-unit effort (CPUE) decreased over the study (Figure 2); this site was part of a long-term monitoring study on juvenile abundance in the estuary, and beach seining in this current study occurred on the declining limb of peak abundance in the estuary (Figure 2), as observed during that long-term monitoring study.

Table 2. Sample dates, sites, and the total number of marked (with a coded-wire tag) and unmarked Chum Salmon (*Oncorhynchus keta*) fry captured during seining in the lower Columbia River Estuary, April 16–18, 2013.

Date	Site	Marked chum	Unmarked chum	Total chum
16-Apr	Blind Slough	0	3	3
	Knappa Beach 1	0	0	0
	Knappa Beach 2	0	0	0
	Svensons Beach	0	0	0
	Karlson Island	16	63	79
	Minaker Island	10	2	12
	Point Adams Beach	0	79	79
	Clatsop Spit	0	9	9
17-Apr	Karlson Island	20	82	102
	Minaker Island	0	2	2
	South Channel	5	25	30
	Point Adams Beach	16	76	92
18-Apr	Karlson Island	4	20	24
	Minaker Island	1	1	2
	Russian Island	7	50	57
	South Channel	4	70	74
	Point Adams Beach	9	43	52

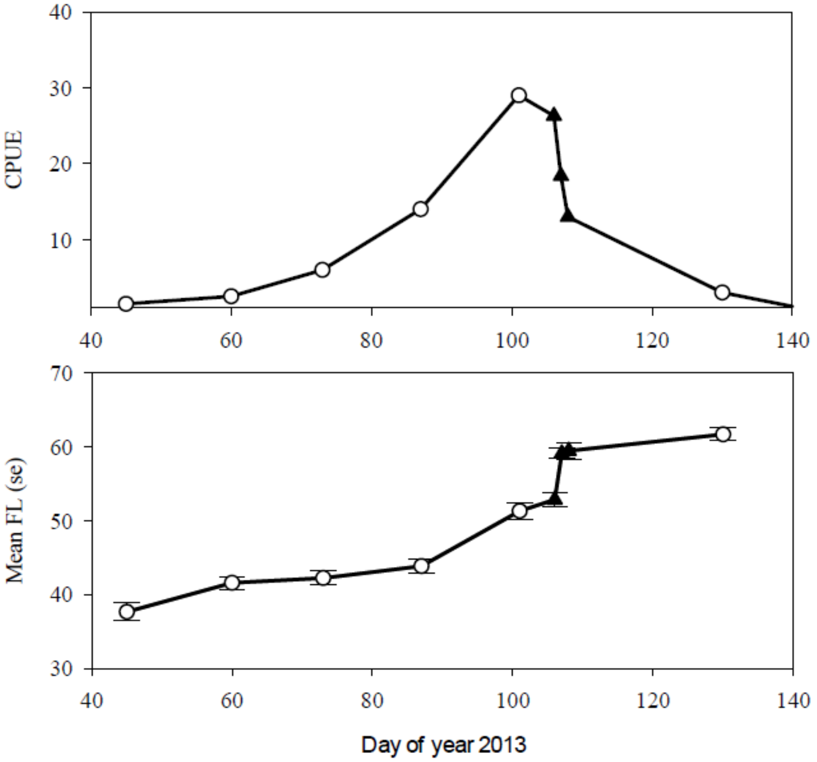

Figure 2. Time series of Chum Salmon (*Oncorhynchus keta*) abundance (catch per unit effort; CPUE) and mean fork length (mm) of marked and unmarked fry captured during the 2013 outmigration period from a separate, concurrent study. These CPUE data were collected as part of a long-term monitoring project at Point Adams Beach, Oregon. Triangle symbols indicate time of the hatchery release experiment from the present study.

In addition to Chum Salmon, other marked and unmarked salmonids were captured (Table 3), along with an abundance of non-salmonids. A total of 409 marked (fin-clipped) and 384 unmarked Chinook Salmon (*Oncorhynchus tshawytscha)* were captured (Table 3). Although they occurred at all seine sites, they were most common at Point Adams Beach. Marked Coho Salmon (*O. kisutch)* yearlings (n = 20), marked Steelhead (*O. mykiss;* fork length range = 177 – 212 mm; n = 6), and unmarked Cutthroat Trout (*O. clarkii*; fork length range = 196 – 300 mm; n = 2) were also captured; they occurred at upstream and downstream sites, but were primarily caught on day three of seining. For non-salmonids, Threespine Stickleback (*Gasterosteus aculeatus)* were hyper-abundant (n = 38,255), primarily around Karlson Island. Starry Flounder (*Platichthys stellatus;* n = 56), Peamouth Chub (*Mylocheilus caurinus;* n = 48), Killifish *(Fundulus diaphanus;* n = 5), Sculpin (*Cottus* spp; n = 2), and Lamprey (*Entosphenus tridentatus;* n = 1) were also captured.

Table 3. Sample sites and the total number of each subyearling (Sub), yearling (Yearling), marked (Mark) and unmarked (Un) salmonid species (excluding Chum Salmon; *Oncorhynchus keta*) captured during beach seining in the Columbia River Estuary, April 16–18, 2013.

	Coho			Chinook	_	Steelhead	Cutthroat
Sample site	Mark/ Yearling	Un/ Sub	Mark/ Sub	Un/ Yearling	Mark/ Yearling	Mark/ Smolt	Un/ Smolt
Blind Slough	0	4	8	0	0	0	0
Knappa Beach 1	0	15	0	0	0	0	0
Knappa Beach 2	0	4	0	0	0	0	0
Svensons Beach	0	5	14	0	0	0	0
Karlson Island	10	83	69	1	5	0	1
Minaker Island	1	22	8	2	17	4	0
Russian Island	0	13	37	2	2	1	0
South Channel	0	4	3	0	0	1	1
Point Adams Beach	9	185	49	45	197	0	0

Migration rates varied among hatchery fry each day (Table 4). On the first day of seining, CWT fry were captured at Karlson Island (Big Creek Slough) and Minaker Island (Calendar Slough) in Cathlamet Bay. Both sites were 1.9 km from the hatchery release site at the mouth of Big Creek. Seining occurred between 1200 and 1410 h and migration rates were 0.088–0.098 km/hr (2.1 – 2.4 km/ day). On the second day of seining, individuals were detected again at Karlson and Minaker Islands, and also at Russian Island (Prairie Channel; 4.4 km from Big Creek), near Lois Island (South Channel; 9.3 km from Big Creek), and at Point Adams Beach (34.6 km from Big Creek; Tables 1 and 4). Detections at Point Adams Beach corresponded with a minimum migration rate of 0.85 km/ h (20.4 km/ day), assuming Chum Salmon fry migrated along a direct route between Big Creek and Point Adams Beach.

Table 4. Minimum migration rates (kilometers/hour) of hatchery Chum Salmon (Oncorhynchus keta) fry in the lower Columbia River Estuary, April 16–17, 2013. Migration rates for fish captured on April 18th were not calculated because captured fish could have been released on either April 15th or 17th.

Date	Location	Captured Chum fry	Seine time	Hours since release	Minimum migration rate (km/ h)
16-Apr-13	Minaker Island	8	1200	19.00	0.098
16-Apr-13	Karlson Island	16	1336	20.60	0.091
16-Apr-13	Minaker Island	2	1410	21.17	0.088
17-Apr-13	South Channel	5	0950	40.83	0.228
17-Apr-13	Karlson Island	9	1106	42.10	0.044
17-Apr-13	Karlson Island	9	1339	44.65	0.042
17-Apr-13	Karlson Island	2	1400	45.00	0.042
17-Apr-13	Point Adams Beach	1	925	40.42	0.855
17-Apr-13	Point Adams Beach	15	1135	42.58	0.811

Hatchery Chum Salmon captured at downriver sites were significantly larger than those captured at upriver sites (upriver mean fork length = 60.7 mm, range = 43 – 71 mm; downriver mean fork length = 67.5 mm, range = 63–72 mm; *P* < 0.017; Figure 3). In addition, hatchery Chum Salmon contributed to an increase in mean size of Chum Salmon fry captured at Point Adams Beach (Figure 2).

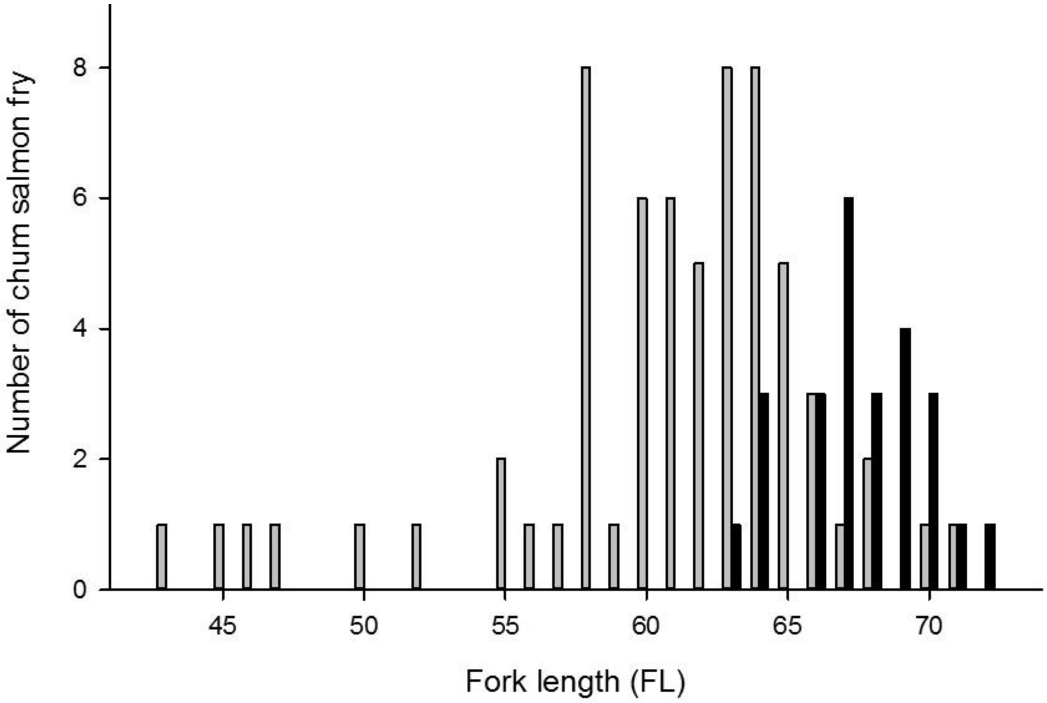

Figure 3. Length frequency of marked Chum Salmon (*Oncorhynchus keta)* fry at upriver (Karlson, Minaker, and Russian Islands; gray bars) and downriver (Point Adams Beach; black bars) seine sites in the Columbia River estuary, 16–18 April, 2013.

Discussion

Migration rates and spatial variation in the length of Big Creek Hatchery Chum Salmon fry were examined as a first step in understanding whether estuary rearing contributes to increased growth or survival of hatchery Chum Salmon fry, in general. This was the first use of CWT to track migration patterns of Chum Salmon fry in the LCRE. Hatchery fry were captured at the mouth of the Columbia River 40 hours after release, resulting in a migration rate of at least 20 km/ day. Variation was observed in the length frequency of Chum Salmon fry captured at upstream and downstream sample sites; fry at downstream sites were significantly larger than those upstream. The range in migration rates and spatial variation in body size has several possible explanations, including hydrological variation, size-selective migration rates, growth during migration, or size-selective predation.

Chum Salmon migration rates vary seasonally (Simenstad and Salo 1980; Bax and Whitmus 1981), but the rates observed in this study (> 20 km/ day) exceeded those reported for hatchery fry in other estuaries and near shore environments, regardless of season. In the only other Chum Salmon fry mark-recapture study performed in the LCRE, Bottom et al. (2008) conducted a habitat use investigation in the Grays River system using fluorescent paint to mark batches of hatchery-reared Chum Salmon fry. However, the authors failed to detect any marked fish in the days following release, although numerous smaller, naturally produced fry were captured. Bottom et al. (2008) concluded the larger, hatchery-reared fry migrated rapidly from the system (>9 km) within a tidal period. In contrast, in Hood Canal, a large fjord in Washington, Chum Salmon fry migrated 8–14 km/ day in February and March and slowed to 3–7 km/ day from April through June (Simenstad et al. 1982). Similarly, Morita et al. (2015) observed migration rates of 2.6–8 km/day from the hatchery release site in the Chitose River, Japan, to the ocean (a distance of 80 km). Observed migration rates also exceeded those reported for tidal migrations (passive upstream and downstream feeding migrations associated with tides; < 0.5 km/day; Pearcy et al. 1989). Relative to those shorter tidal migrations, the longer migration distances observed in this study suggest that individuals captured at Point Adams Beach were migrating seaward and not exhibiting a tidal migration. Hydrological conditions differed among the studies referenced here and could account for variation in migration rate. In the Columbia River, it takes 30-50 hours for water to turn over in April (Kärnä and Baptista 2016). The 40 hour migration time to Point Adams Beach observed in this study falls within that range, but further research is needed on hourly migration rates (particularly in relation to river discharge and tides) to determine the role of hydrology on migration rates.

Spatial variation in size structure could be produced if larger fry in the release group migrated faster or earlier than smaller fry. In Netarts Bay, a small estuary on the Oregon coast, Pearcy et al. (1989) observed that large hatchery Chum Salmon fingerlings (> 6.5 g) migrated to the ocean immediately following release, and that the half-life of estuary residence time for smaller hatchery fry (~ 2.2 g) was 4.9 days. Ioka (reported in Pearcy et al. 1989), large hatchery fingerlings (8 g) migrated immediately after release. In comparing sizes of Chum Salmon fry in the mainstem channel to those in shallow water, Roegner et al. (2016) found larger fry in the faster moving channel environment. Similar to these studies, larger individuals were detected at Point Adams Beach within two days of release. However, unlike these studies, mean length of faster-migrating fry and fingerlings in our study only measured 67.5 mm, corresponding to ~ 2.7–3 g. A second explanation is that larger fry could be physiologically ready to migrate at release time and passively migrate downstream on an outgoing tide. In this case, smaller fry would actively maintain their position farther upstream in the tidal freshwater regions or near shore and larger fry could be actively or passively migrating downstream on an outgoing tide, perhaps utilizing the main river channel (Roegner et al. 2016). Regardless of which migration strategy occurred, it does appear that the size of downstream migrants was smaller than what has been reported for immediate migration following other hatchery releases.

Spatial variation in length frequency distributions could also result from growth during migration if habitat along the migration corridor or towards the outer estuary were more productive than habitat near the release site. In the Nanaimo Estuary in British Columbia, growth rates of 1 mm/day were observed (Healey 1979). Even higher growth rates were observed in inshore habitats in Southeast Alaska (1–1.6 mm/day; Orsi et al. 2000). In Netarts Bay, growth rates of hatchery fry ranged from 0.33–0.55 mm/day, although smaller fish grew more rapidly than larger fish (Pearcy et al. 1989). Likewise, in Taku Inlet, Southeast Alaska, mean length of smaller hatchery fry (1.9 g at release) increased significantly as they transitioned from inner to outer inlet habitat in the littoral zone (Reese et al. 2009), whereas mean length of large fingerlings (3.9 g at release) did not increase during this habitat transition (Reese et al. 2009). Bottom et al (2011) documented the mean size of Chum Salmon fry was consistently larger at estuarine stations than in the tidal freshwater habitat in the LCRE. In our study, mean length of hatchery Chum Salmon at the downstream site exceeded that of the upriver site by 6.8 mm (Figure 3). Although spatial variation in growth rates could have affected the size distribution of upriver and downriver fry, it would be unlikely to explain this big a difference in mean length over such a short period of time.

Finally, body size might have been similar between individuals that migrated rapidly and those that remained near the release site, but size-selective predation could have resulted in removal of smaller individuals during migration. Hatchery releases are known to attract predators to the release site (Collis et al. 1995; Kawamura et al. 2000; Kawamura and Kudo 2001). In this study, smolts (hatchery Coho Salmon and Steelhead, and unmarked Coastal Cutthroat Trout) co-occurred with Chum Salmon fry in all seine sets, but more smolts were captured near the release site than the downstream site. Coho Salmon smolts are a major predator of Chum Salmon fry in the estuary and near shore environments (Hunter 1959; Parker 1971; Hargreaves and LeBrasseur 1986; Fresh and Schroder 1987; Magnhagen 1988; Roegner et al. 2010), and evidence suggests that predation may be size-selective (Parker 1971; Good 1983; Hargreaves and LeBrasseur 1986); Coho Salmon smolts may consume prey ranging from 42% to 50% of their body length (Sibert and Parker 1972; and Semko 1954, described in Hargreaves and LeBrasseur 1985; respectively). In this study, Coho Salmon smolts ranged from 130–155 mm FL; smolts at 130 mm could potentially consume prey up to 54.6–65 mm FL and would have exhibited size-selective predation, whereas larger smolts (155 mm FL) could have consumed prey up to 65.1–77.5 mm FL, encompassing most of the size range observed in the hatchery release. Coastal Cutthroat Trout are also a major predator of Chum Salmon fry, preferentially consuming the smallest fry available (Duffy and Beauchamp 2008). Bird predation may also be an important mortality source, although common bird predators (Caspian Terns *Sterna caspia*, and Double-Crested Cormorants *Phalacrocorax auritus*) appear to prefer larger, yearling sized Chinook and Coho Salmon and Steelhead (Collis et al. 2002). Currently, there is limited evidence documenting predation by Coho Salmon on Chum Salmon fry in the LCRE (Roegner et al. 2010), but only anecdotal accounts of predation by Steelhead smolts on Chum Salmon fry (R. Dietrichs, personal communication). Further research is needed to investigate the degree to which predation on Chum Salmon fry occurs and whether it affects length variation or migratory behavior in the LCRE.

Although both minimum migration rates through a large, complicated estuarine system and spatial variation in length frequency distributions of Big Creek Hatchery Chum Salmon fry were estimated, there was one potential limitation to this study. Seining was conducted over a three day period and it is possible that different migration rates would have been observed over a longer time frame or at a different time of year. In particular, the study did not address the residence time of hatchery fry in upriver sample sites. However, the objectives of the study were to identify how quickly hatchery fry could migrate to ocean entrance and whether there was any variation in size associated with those fry that rapidly migrated and those that remained upstream. These questions were addressed by the study design.

Migration rates observed in this study suggest larger hatchery fish may have less reliance on rearing habitat in the LCRE than naturally produced fry; the importance of estuarine rearing to smaller fry is unresolved because many still remained near the release site when the study ended. In other estuaries, hatchery Chum Salmon fry of a similar size range to those in this study remained in the estuary environment for a longer time frame (Pearcy et al. 1989); however, Chum Salmon exhibit a fry-migration life history trait in the LCRE (Bottom et al. 2011). Limited rearing habitat in tidal freshwater environments of the LCRE may result in more rapid migration rates than have been observed in other estuaries. Of concern are the large changes that have occurred in the estuarine food web (Bottom et al. 2005), including a substantial loss or degradation of wetland-based Chum Salmon rearing habitat (Marcoe and Pilson 2017). Degradation of estuary habitat has been shown to decrease fry survival (Chinook Salmon fry; Magnusson and Hilborn 2003), and that may be true in the Columbia River estuary as well. Efforts to improve the marine survival of both hatchery and wild Chum Salmon fry may benefit from targeted restoration of historical tidal freshwater and estuarine rearing habitats.

In the Columbia basin, hatchery production of Chum Salmon fry supports recovery of listed wild populations. As such, the survival of fry through the estuary and nearshore environments has a direct effect on adult returns to the hatchery (Bax 1983; Fukuwaka and Suzuki 2002) and the ability to meet reintroduction goals in support of recovery plans. Improved survival of hatchery fish has been linked to releasing fed fry instead of unfed fry (Mayama 1985; Isaksson 1988; Mahnken et al. 1998; Wertheimer and Thrower 2007) and evidence suggests that mortality rates are lower for juvenile Chum Salmon > 55 mm FL (British Columbia; Healey 1982b). Results from this study suggest length variation in the release group correlates with migration rates through the estuary. If these larger, faster migrating individuals contribute disproportionately to adult returns, as they have been shown to do elsewhere (Pearcy et al. 1989), it may be useful to develop size-at-release goals for hatchery fry tied to maximizing survival through the estuary and near shore environments.

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