Early Marine Migration of Juvenile Chum Salmon Along the Pacific Coast of Eastern Hokkaido

Kiyoshi Kasugai[1,3], Hayato Saneyoshi[1,3], Tomoya Aoyama[2,4], Yoshihito Shinriki[2,4], Anai Iijima[2], and Yasuyuki Miyakoshi[2]

[1]Doto Research Branch, Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-1-10 Maruyama, Nakashibetsu, Hokkaido 086-1643, Japan
[2]Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kitakashiwagi, Eniwa, Hokkaido 061-1433, Japan
Present addresses:
[3]Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kitakashiwagi, Eniwa, Hokkaido 061-1433, Japan
[4]Donan Research Branch, Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 189-43 Kumashi-Ayukawa, Yakumo, Hokkaido 043-0402, Japan

Kasugai, K., H. Saneyoshi, T. Aoyama, Y. Shinriki, A. Iijima, and Y. Miyakoshi. 2016. Early marine migration of juvenile chum salmon along the Pacific coast of eastern Hokkaido. N. Pac. Anadr. Fish Comm. Bull. 6: 61–72. doi:10.23849/npafcb6/61.72.

Abstract: The number of chum salmon returning to the eastern Pacific coast of Hokkaido has been rapidly decreasing over the last five years. The Kushiro River is the main production center for chum salmon enhancement in this area. In order to understand the recent decrease in the number of chum salmon returning to this area, we surveyed the distribution and migration of juvenile chum salmon in the coastal area of Kushiro from 2012 to 2014. Many juvenile chum salmon appeared in the nearshore area after late May–early June, corresponding to sea surface temperatures higher than 8°C. In the coastal area of Kushiro, a cold current with low salinity (called the Coastal Oyashio Current) flows westward near shore from spring to summer and may affect the distribution of juvenile chum salmon by altering the environmental conditions. We speculated that most juvenile chum salmon caught in the Kushiro nearshore area after late May might have grown outside this area because body lengths differed significantly between marked fish recaptured in ports and harbors and those in the nearshore area. In late June, the examination of the otolith marks applied to large juveniles that appeared in the Kushiro nearshore area suggests that most of the large juveniles were released in other regions of the Pacific coast, west of Kushiro. Most of the juvenile chum salmon were captured within 1 km of the Kushiro shoreline. Our results suggest that coastal environments in the nearshore area (< 1 km from shore) affect the distribution and survival of chum salmon. We further suggest that the Kushiro coastal area is an out-migration route for juvenile chum salmon from distant stocks along the Pacific coast of Japan.

Keywords: juvenile chum salmon, Hokkaido, Pacific coast, Kushiro, sea surface temperature, distribution, migration

INTRODUCTION

The returns of chum salmon (*Oncorhynchus keta*) to the Pacific coast of Hokkaido have decreased markedly in recent years (Miyakoshi et al. 2013). Because the mortality of Pacific salmon is reported to be high in their early ocean life (Parker 1962; Bax 1983; Pearcy 1992; Karpenko 1998; Wertheimer and Thrower 2007), declines in the number of chum salmon returning to the Pacific coast of Hokkaido might be caused by changing coastal ocean environments affecting their survival. The Kushiro River is the main production center for chum salmon enhancement on the eastern Pacific coast of Hokkaido (Fig. 1A). On the Pacific coast of Hokkaido, chum salmon returns have decreased remarkably, especially in the eastern area including the Kushiro River (Hokkaido National Fisheries Research Institute 2015). Two currents flow westward near the eastern Pacific coast: the Oyashio Current and the Coastal Oyashio Current (Isoda and Kishi 2003; Kono et al. 2004). The Oyashio Current, which becomes a major part of the Western Subarctic Gyre, is formed from the combination of Okhotsk Sea water and the East Kamchatka Current (Ohtani 1989; Talley and Nagata 1995; Yasuda 2003), and it is characterized by low temperatures (Talley and Nagata 1995). The Coastal Oyashio Current, which flows nearer the Hokkai-

All correspondence should be addressed to K. Kasugai.
e-mail: kasugai-kiyoshi@hro.or.jp

do coast than the Oyashio Current, originates in the Okhotsk Sea (Ohtani 1971; Isoda et al. 2003), and it is characterized by low temperatures and low salinity in winter and spring, and high temperatures and high salinity in summer and fall (Kono et al. 2004). Although the ocean environment in the nearshore areas of the eastern Pacific coast is poorly understood, it is known that the Kushiro area is one of the coolest areas in Hokkaido occupied by juvenile chum salmon (Ogasawara 1990).

Previous studies have shown that distribution and migration of juvenile chum salmon are affected largely by sea surface temperatures (SST) in Hokkaido (Irie 1990; Nagata et al. 2007; Kasugai et al. 2012). According to past research conducted in the Hiroo area (see Fig. 1A), located on the Pacific coast west of Kushiro, and adjacent to the Coastal Oyashio Current (Seki and Shimizu 1996), chum salmon fry released in a period with colder SST had lower survival than

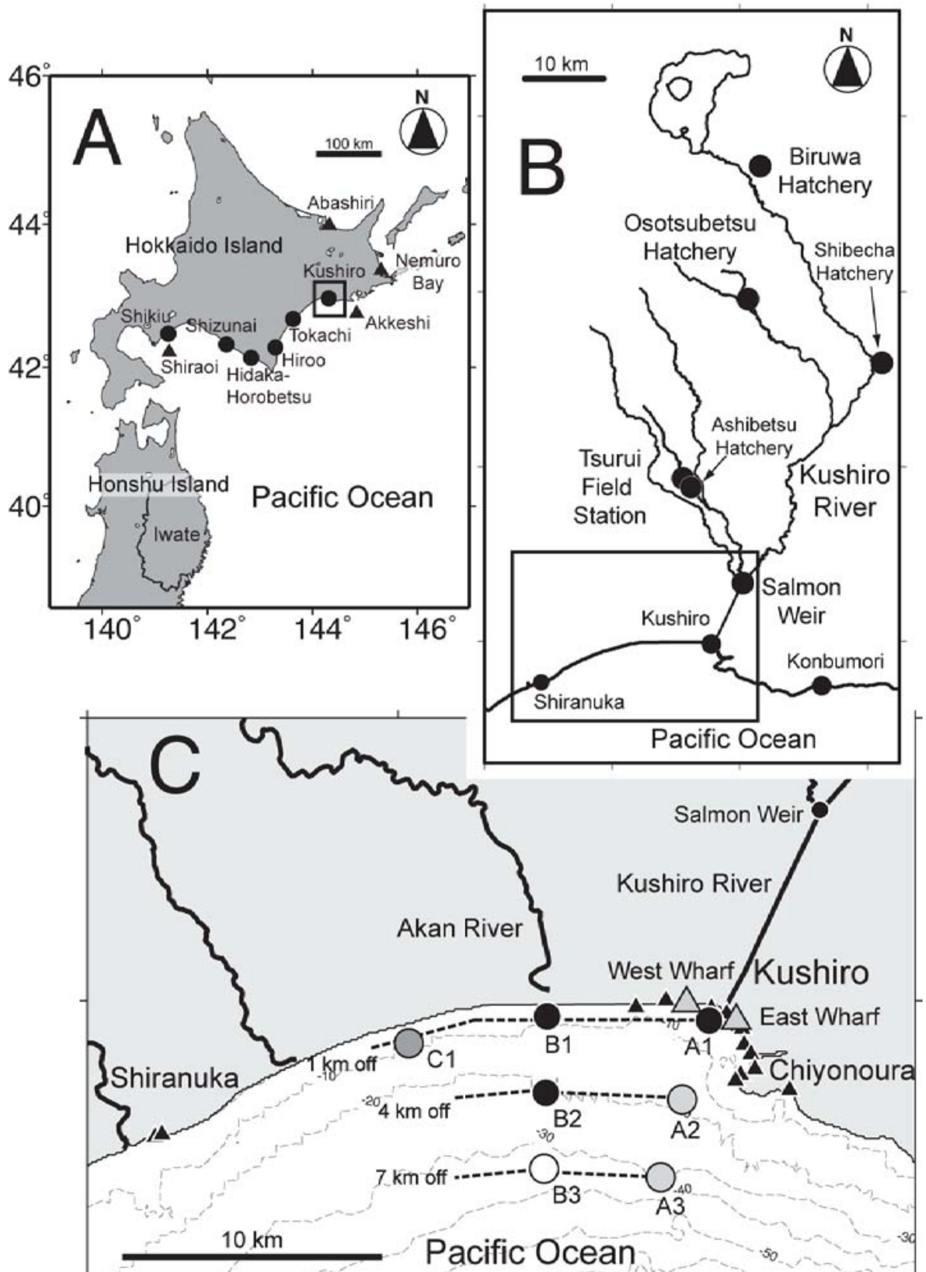

Fig. 1. Maps of the study area. A: release sites of otolith-marked fish (black circles) along the Pacific coast of Hokkaido; B: hatchery sites (black circles) in the Kushiro River; C: survey sites in the Kushiro area: black and gray circles indicate sites for fish collection with a surface trawl and environmental observations, white circle indicates site for environmental observation, gray triangles indicate sites for daytime fish observation and nighttime fish collection with scoop nets, and black triangles indicate sites for daytime fish observation.

Table 1. Fork length (mm), body weight (g), and number of otolith-marked chum salmon released into the Kushiro River in 2012–2014. Data on thermal otolith-marked fish are from Okamoto et al. (2012) and Tomida et al. (2013, 2014).

Year	Mark	Type/Hatch code	Release site	Release date	Mean fork length ± SD (range)	Mean body weight ± SD (range)	Number of fish released (thousands)
2012	ALC	Large ring	Osotsubetsu	17 April	43.75 ± 2.34	0.692 ± 0.140	900
	ALC	Double rings	Biruwa	2 May	54.73 ± 3.24	1.516 ± 0.323	780
	ALC	Small ring	Osotsubetsu	14 May	51.11 ± 3.53	1.252 ± 0.278	2,174
	Thermal	2-2-3-3H	Tsurui	16 April–30 May	57 (49–63)	1.60 (0.93–1.94)	8,905
	Unmarked		Ashibetsu	31 March–24 May	46 (42–51)	0.92 (0.60–1.25)	18,570
	Unmarked		Shibecha	10 April–18 May	52 (45–63)	1.33 (0.84–2.24)	7,630
	Unmarked		Osotsubetsu	2 May–17 May	51 (49–56)	1.26 (1.10–1.61)	12,117
	Unmarked		Biruwa	24 April–18 May	47 (45–49)	0.98 (0.82–1.12)	4,780
2013	ALC	Large ring	Osotsubetsu	19 April	48.94 ± 3.74	1.097 ± 0.294	966
	ALC	Double rings	Biruwa	19 April	45.82 ± 4.78	0.872 ± 0.327	1,000
	ALC	Small ring	Osotsubetsu	2 May	55.22 ± 4.35	1.634 ± 0.403	965
	Thermal	2-2-3-3H	Tsurui	15 April–29 May	57 (52–61)	1.59 (1.24–1.99)	8,742
	Unmarked		Ashibetsu	20 April–11 May	51 (44–57)	1.23 (0.76–1.69)	16,151
	Unmarked		Shibecha	2 May–10 May	46 (42–50)	0.97 (0.81–1.20)	3,930
	Unmarked		Osotsubetsu	23 April–10 May	53 (46–55)	1.42 (0.92–1.56)	7,721
	Unmarked		Biruwa	7 May–13 May	48 (47–50)	1.06 (1.00–1.21)	4,006
2014	ALC	Large ring	Osotsubetsu	4 April	41.30 ± 3.16	0.522 ± 0.172	986
	ALC	Double rings	Biruwa	5 April	39.61 ± 2.34	0.447 ± 0.121	960
	ALC	Small ring	Osotsubetsu	9 May	54.15 ± 3.93	1.560 ± 0.382	983
	Thermal	2-9H	Tsurui	11 April	57	1.53	1,229
	Thermal	2-2-3-3H	Tsurui	28 April–26 May	61 (56–63)	1.82 (1.37–2.01)	4,355
	Thermal	2-10H	Tsurui	29 May	54	1.33	3,020
	Thermal	2-6-2H	Ashibetsu	5 April–1 May	53 (49–55)	1.30 (1.09–1.50)	1,625
	Thermal	2-6-3H	Ashibetsu	26 April–9 May	51 (45–53)	1.17 (0.80–1.35)	2,138
	Unmarked		Ashibetsu	1 April–23 May	48 (45–52)	1.03 (0.78–1.30)	17,466
	Unmarked		Shibecha	14 March–21 April	44 (38–47)	0.85 (0.41–1.03)	2,970
	Unmarked		Osotsubetsu	27 March–14 May	48 (41–59)	1.08 (0.59–1.82)	13,983
	Unmarked		Biruwa	10 April–12 May	50 (48–52)	1.19 (1.04–1.33)	4,925

fry released in a period with warmer SST. This indicates that lower SST affects the survival in the early ocean life of chum salmon along the eastern Pacific coast. To elucidate the distribution and migration patterns of juvenile chum salmon around Hokkaido, it is important to understand the factors affecting their critical life period in this area.

Several studies have explored the relationship between juvenile chum salmon and coastal environments on the Pacific coast of eastern Hokkaido (Irie 1985a, b, 1987, 1990; Irie and Nakamura 1985; Seki and Shimizu 1996; Seki 2005). These studies revealed general distribution and migration patterns of juvenile chum salmon, but do not describe specific patterns for fish released in the Kushiro River. In the present study, we examined the distribution and migration patterns of juvenile chum salmon in relation to the coastal environments in the nearshore area of Kushiro.

MATERIALS AND METHODS

Stocking of Hatchery-reared Chum Salmon

In the Kushiro River, approximately 55 million hatchery-reared chum salmon are released annually in spring from four private hatcheries and one national hatchery (the Biruwa, Osotsubetsu, Shibecha, and Ashibetsu hatcheries of the Tokachi-Kushiro Salmon Enhancement Programs Association, and the Tsurui Field Station of the Hokkaido National Fisheries Research Institute; Fig. 1B). The actual numbers of stocked fish in the study period (2012–2014) were 55.9 million fry between late March and late May in 2012, 43.5 million fry between mid-April and late May in 2013, and 54.6 million fry between mid-March and late May in 2014 (Table 1).

Of the chum salmon stocked into Kushiro River, only fish reared at the national hatchery received otolith thermal marks (8.6–8.9 million fish). To distinguish the fish groups released from private hatcheries, we applied otolith marks by using fluorescent alizarin complexone (ALC). In 2011, 2012, and 2013, 3–4 million chum salmon eyed eggs were immersed in 200 ppm ALC solutions for 24 h. ALC-marked fry were released into the Kushiro River from two hatcheries (Osotsubetsu and Biruwa) on various dates in 2012–2014 (Table 1, Fig. 1B).

Field Sampling

To capture migrating fry, a rotary screw trap (cone diameter 1.5 m, EG Solutions, Inc., Corvallis, OR, USA) was installed near a salmon weir site in the Kushiro River, 8 km up from the river mouth (Fig. 1B, C). The rotary screw trap was operated from April to June. The livebox of the trap was emptied daily while the trap was operating. On Monday, Wednesday, and Friday, fish that were caught were fixed in a 5% neutral formalin solution to examine marked fish. In the coastal areas of Kushiro, the surveys were conducted in both ports and nearshore areas at 10-day intervals between late April and late July in 2012–2014. Surveys in the ports included daytime observations and nighttime collecting. During the day, we measured SST and visually counted the number of juvenile chum salmon at 24 sites: three sites in the Shiranuka Fishing Port, 14 sites in the Kushiro Port, one site in the Chiyonoura Fishing Port, and six sites in the Konbumori Fishing Port (Fig. 1B, C). Numbers of juvenile salmon in the ports were estimated visually. We first counted 50 fish directly. We then compared (by eye) the size of the (small) school to the size of a school along an approximately 100-m length of a quay at the port. During the night, juvenile chum salmon were collected with scoop nets (80-cm diameter, 2-m pole, 5-mm mesh) under a LED floodlight (3,000 lm) or headlamp for 30 min at two stations (East and West wharves) in the Kushiro Port and three other fishing ports (Shiranuka, Chiyonoura, and Konbumori; Table 2).

In the nearshore areas, trawl stations were set at 1, 4, and 7 km offshore at both the Kushiro (A1–A3) and Akan rivers (B1–B3), and 1 km offshore the Shiranuka coast (C1) (Table 2, Fig. 1C). A surface trawl net (mouth 8 m wide × 5 m deep, 18 m long, with wing nets 7 m long and a central bag with a 5-mm mesh) was towed by two fishing boats for 10–20 min at a speed of ca. 4 knots during the day. Catch per unit effort (CPUE) is the number of juvenile chum salmon caught per distance towed by the surface trawl net. Temperature and salinity were measured with a CTD (Compact-CTD, JFE Advantech, Nishinomiya, Japan) at each station. Inclement weather conditions precluded surveys from being conducted in late April, early May, early June, early July, and late July in 2012 and early July in 2013.

Fish captured in rivers, ports, and nearshore areas were fixed in a 5% neutral formalin solution for 4 hr, transferred to 70% ethanol, and then measured for body size. Fork length and body weight of each fish were measured to an accuracy of 0.01 mm and 0.001 g, respectively. Otoliths were extracted from all specimens. ALC markings were verified

Table 2. Spatial and temporal sampling of chum salmon and associated environmental observations off the Pacific coast of Japan, late April to late July 2012–2014. Sample collection included: a—fish collection with a surface trawl and environmental observations, b—environmental observations, c—daytime fish observations and nighttime fish collection with scoop nets, d—daytime fish observations.

Survey areas	Survey Line, harbor, or port	Distance from the shoreline/ port sites	Year		
			2012	2013	2014
Nearshore areas	Off the Kushiro River mouth	1 km	a	a	a
		4 km	a	-	-
		7 km	a	-	-
	Off the Akan River mouth	1 km	a	a	a
		4 km	a	a	a
		7 km	a	b	b
	Off the Shiranuka coast	1 km	-	-	a
Ports	Kushiro	West Wharf	c	c	c
		East Wharf	c	c	c
		12 other sites	d	d	d
	Shiranuka	1 site	d	d	c
		2 other sites	d	d	d
	Chiyonoura		-	c	c
	Konbumori	1 site	-	c	c
		5 other sites	d	d	d

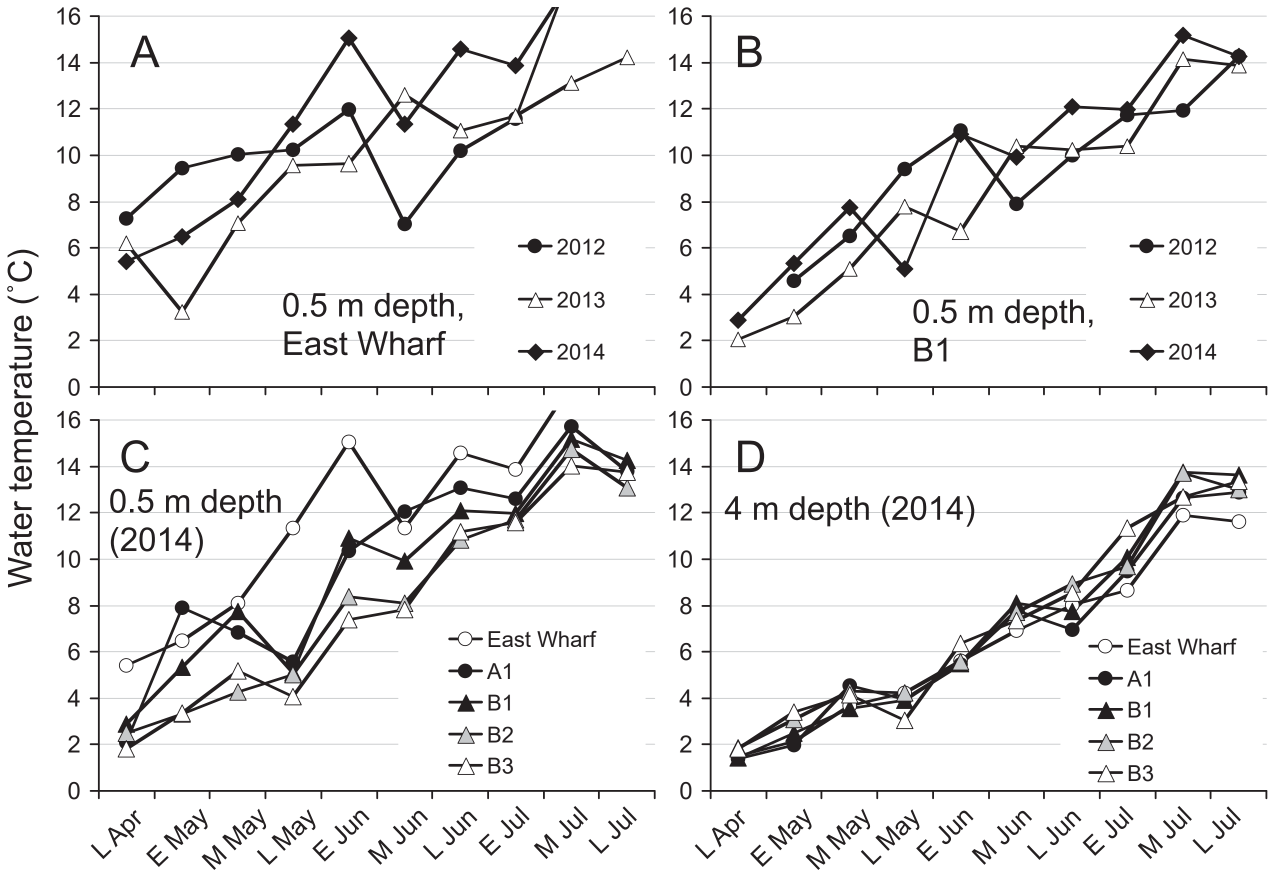

Fig. 2. Changes in water temperature A: at 0.5 m depth at the East Wharf of the Kushiro Port (EWKP) in 2012–2014; B: at 0.5 m depth at B1 (1 km off the Akan River mouth) in 2012–2014; C: at 0.5 m depth, and D: 4 m depth at EWKP, A1, B1, B2 and B3 in 2014. The stations are indicated in Fig. 1C.

under a fluorescent light with a microscope for all specimens in all three years. Thermal markings were verified by comparing with photographs (Okamoto et al. 2012) taken under a microscope after polishing otoliths from specimens caught in late June 2012.

RESULTS

Temperature and Salinity

Water temperatures generally increased seasonally at all localities and depths, with some degree of interannual variability (Fig. 2). The temperature at 4 m depth did not vary significantly among sites or years (Fig. 2D). Thermoclines and haloclines at 1–3 m depth were evident at East Wharf and at Station A1 (1 km off the Kushiro River mouth). In contrast, distinct thermoclines were not observed at Stations B1 and B2 during the survey period. The temperatures above the thermocline were lower with distance offshore, although the differences in temperature among the sites decreased with the progress of the season (Fig. 2C). When strong northerly winds were blowing a few days before survey days, temperatures and salinity at the ports were not stratified. For example, prior to our observations in early May (actually May 9th) 2013 (Fig. 2C, D) a north-northeasterly wind (maximum velocity: 11.0–15.3 m/sec) was blowing from May 6–8 (Japan Meteorological Agency 2015a).

Distribution of Juvenile Chum Salmon in Ports and Nearshore Areas

In the Kushiro Port, juvenile chum salmon were observed from late April to mid–late June. Periods of peak abundance varied by year: mid-May in 2012, early June in 2013, and late May in 2014. The number of fish observed in the Kushiro Port was highest in 2014, lowest in 2013, and intermediate in 2012, particularly in late May. Juvenile chum salmon numbers were highest when SST ranged from 8 to 13°C (Fig. 3). Late in the season, juvenile chum salmon were detected only in the eastern areas of the Kushiro Port, not in the western areas.

Juvenile chum salmon were caught with a surface trawl net in the nearshore areas generally from late May to late June during all three years. The value of the CPUE (fish/

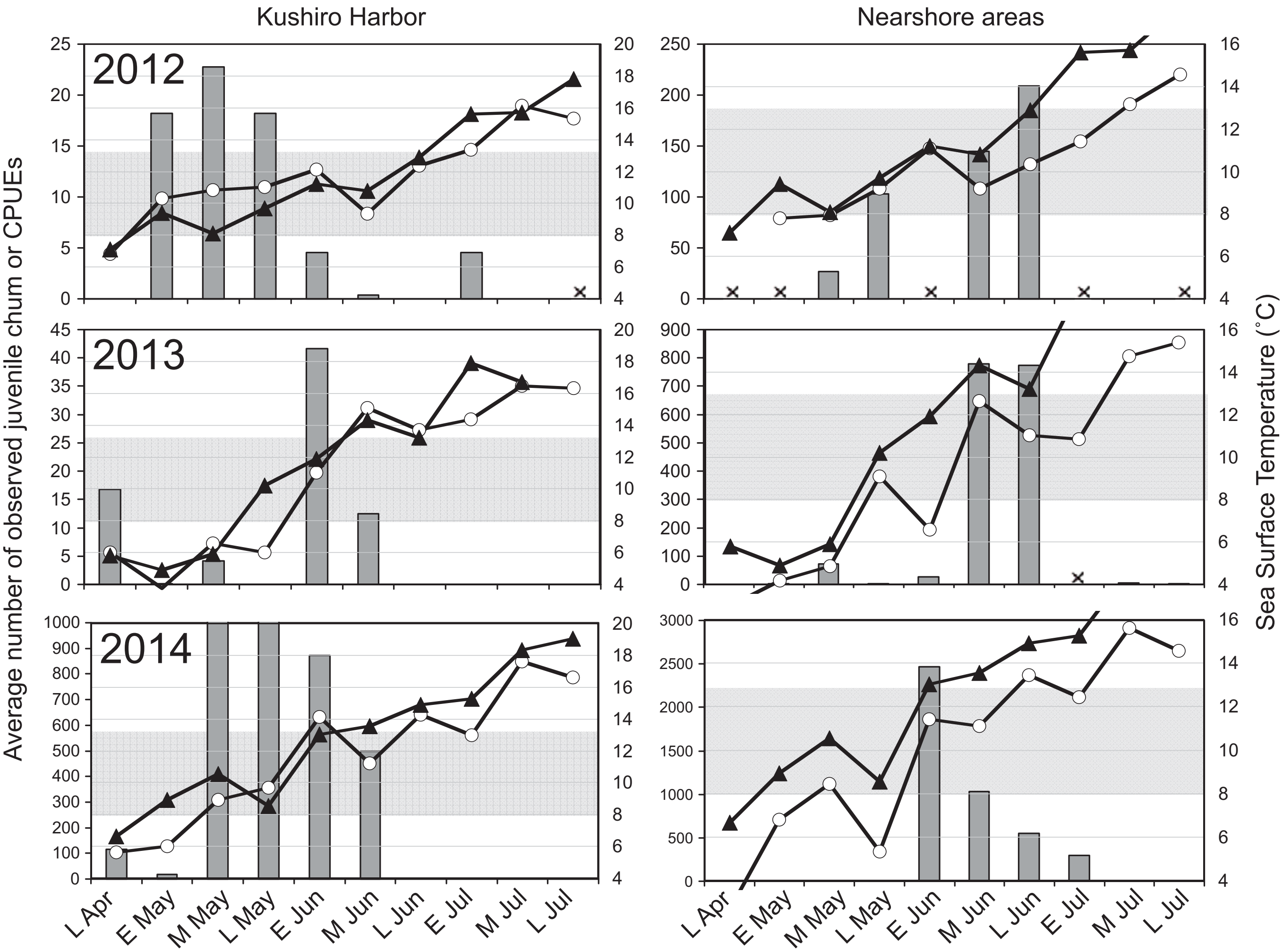

Fig. 3. Changes in average temperature and average number or average catch per unit effort (CPUE) of juvenile chum salmon in the Kushiro Port (left panels) and nearshore areas (right panels) in 2012–2014. Open circles are sea surface temperature, black triangles are air temperature at Kushiro, and bars are the average number of fish observed in the Kushiro Port (left panels) or the average catch per unit effort (CPUE: fish/km) in a zone 1 km off the coast (right panels).

km) peaked between early and late June in all three years. The CPUE in nearshore areas and in ports increased when SST exceeded 8°C (Fig. 3). The CPUE was higher at sites 1 km off the shore, although the CPUE was lower at sites > 4 km off the coast even when the SST at these sites was > 8°C.

The number of juvenile chum salmon in the ports exceeded 100 when the SST was between 5°C and 16°C, and similarly, the CPUE in nearshore areas was > 100 fish/km when the SST was between 4°C and 14°C (Fig. 4).

Body Size of Juvenile Chum Salmon

The most frequent size range of juvenile chum salmon generally did not change in the Kushiro Port, although it increased gradually in the nearshore area with the progress of the season (Fig. 5). In the nearshore areas, large fish (> 80 mm) appeared in late June in all three years. Examination of the otolith marks of juvenile chum salmon caught

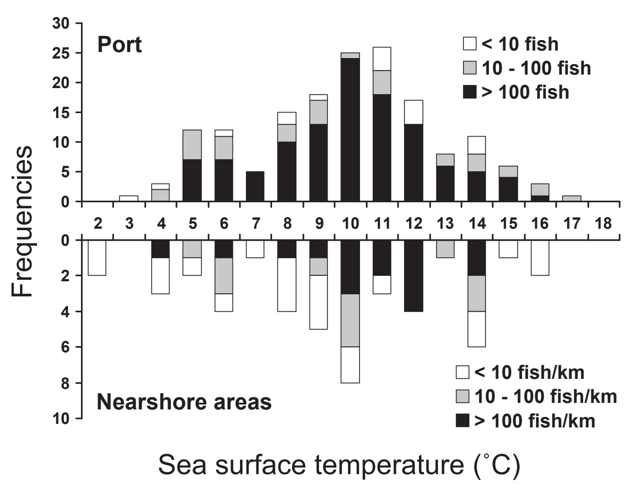

Fig. 4. Frequencies of each category of catch per unit effort (CPUE: fish/km) of juvenile chum salmon in relation to sea surface temperatures at each survey site in the ports (upper panels) and nearshore areas (lower panels) in the Kushiro area.

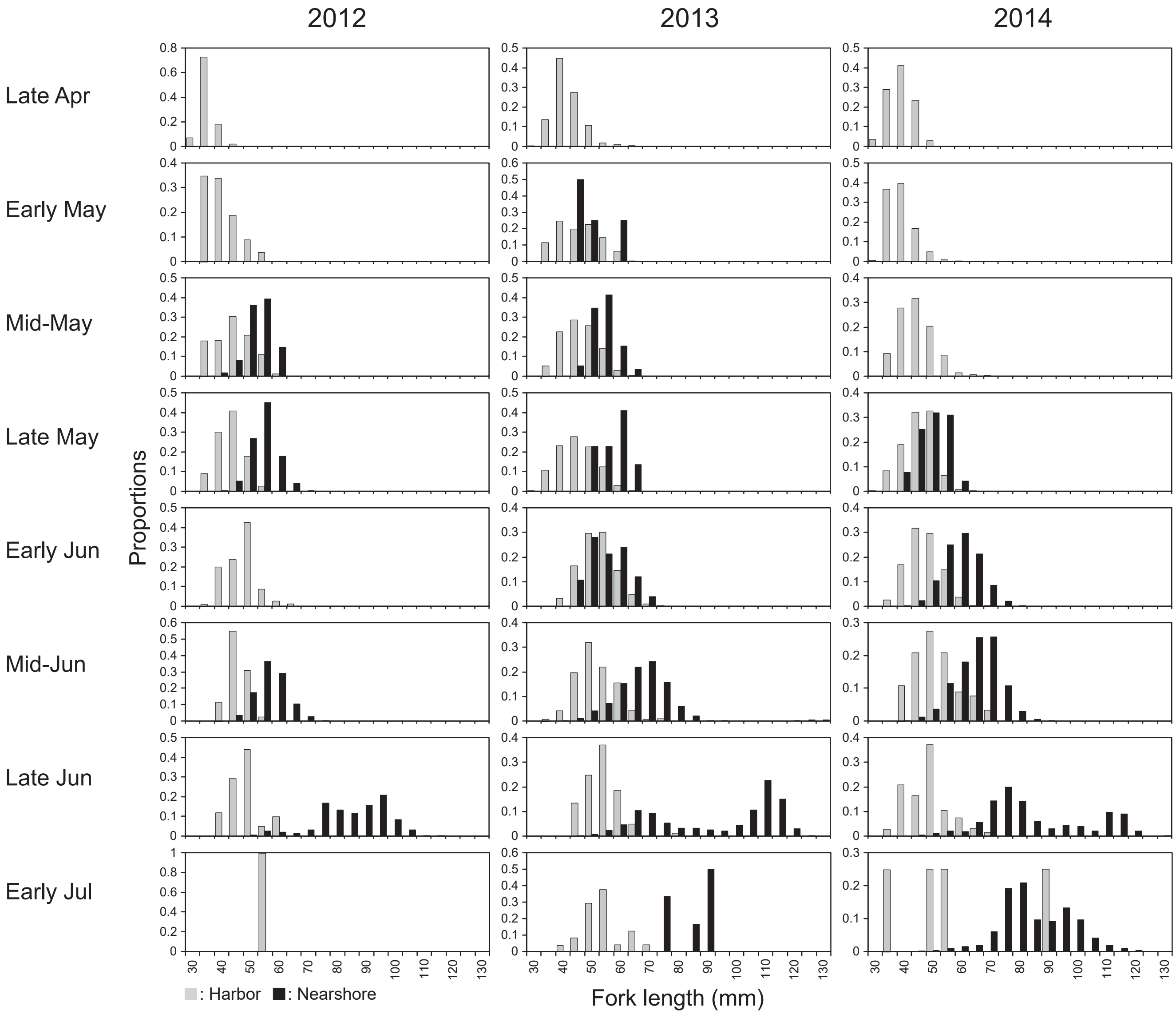

Fig. 5. Body length of juvenile chum salmon caught in the ports (gray bars) and nearshore areas (black bars) in 2012–2014.

in late June 2012 confirmed the presence of otolith-thermal-marked fish released from other rivers on the Pacific coast west of the Kushiro area (Table 3). The maximum size of the otolith-marked fish, excluding fish from the Hiroo area, did not differ, although the minimum size of the fish increased with distance from the release sites to Kushiro (Fig. 6). Fish released from sites farther west of Kushiro were significantly larger when caught in the Kushiro nearshore areas in late June 2012, compared to fish released at sites closer to Kushiro (Pearson's product-moment correlation, r = 0.733, P < 0.001).

Distribution and Body Size of Marked Chum Salmon Released in the Kushiro River

The ALC-marked fish released into the upper Kushiro River in 2014 were initially distributed on both sides of the river mouth in the Kushiro Port, and migrated to ports both west and east of the Kushiro Port and off the Shiranuka coast (C1, Fig. 1; Fig. 7). The ALC-marked fish released in early April in 2014 were recaptured in nearshore areas until early June, whereas those released in early May in 2014 were recaptured from late May to early July in nearshore areas. The fork lengths of fish released after mid-April were continuous among the lower Kushiro River, ports, and nearshore areas in 2013 and 2014 (Fig. 8). However, fork lengths of fish released in early April did not differ between fish captured in the river and in the ports, although the fish recaptured after late May were larger than the fish recaptured in the river, ports, and nearshore areas (Fig. 8).

Table 3. Number and percentage of otolith-marked fish caught in late June 2012 and number of otolith-marked fish released at each site in 2012. Data for the number of marked fish released, mean size at release, and date of last release are from Okamoto et al. (2012).

Release site	Distance from release site to Kushiro River mouth (km)	Number of fish	Percentage of total sample (%)	Number of marked fish released (thousands)	Mean size at release (mm)	Date of last release
Shikiu	353.5	3	0.69	6,368	60	26 May
Shizunai	251.2	16	3.68	6,592	65	18 May
Hidakahorobetsu	205.1	13	2.99	7,865	54	18 May
Hiroo	120.1	6	1.38	5,836	57	25 May
Tokachi	67.2	22	5.06	15,819	60	28 May
Tsurui	0	13	2.99	8,905	57	30 May
Kushiro (ALC)	0	3	0.69	3,854	44–55	14 May
Unmarked	-	359	82.53	-	-	-
Total	-	435	100.00	-	-	-

DISCUSSION

Distribution and migration of juvenile chum salmon in ports and nearshore areas might be influenced by SST. Large differences in the SST between a port and nearshore areas might have prevented juvenile salmon from leaving port waters in late May 2014. The range of SST that juvenile chum salmon experienced in ports and nearshore areas of the Kushiro region were similar to those reported previously (Irie 1990; Nagata et al. 2007; Kasugai et al. 2012). However, the maximum SST that many fish experienced in the ports was higher, and the minimum SST that many fish experienced in the nearshore areas was lower than those in other coastal areas of eastern Hokkaido (Abashiri: Nagata et al. 2007; Nemuro Bay: Kasugai et al. 2012). Higher maximum SST in ports and lower minimum SST in nearshore areas may be caused by the cold Coastal Oyashio Current that flows near the Kushiro coast.

Juvenile chum salmon that exited rivers were often observed in the ports, indicating that ports are important zones for early ocean life of chum salmon (Irie and Nakamura 1985; Irie 1990). Because the body length of the fish sampled in ports did not change during the study period, it is plausible that the population of juvenile chum salmon in ports was being replaced by the fish that moved from the river. Juvenile chum salmon with a body length > 45 mm may exit ports (Irie and Nakamura 1985) in search for food because of increasing food requirements and a shortage of large prey (Simenstad and Salo 1982; Irie 1990). The average body length of fish stocked into the Kushiro River in recent years is > 45 mm, indicating that juvenile chum salmon continuously exit ports.

Ports and harbors are usually enclosed by breakwaters that, combined with the decreased impact of waves, cause surface waters to warm up quickly creating a thermal stratification. Additionally, higher temperatures and lower salinity in ports indicate that fresh-water flow from the Kushiro River is retained within the port, thus enabling stratification to occur. Hence, SST usually increases faster in ports than in the nearshore areas, thus prolonging the juvenile chum salmon residence in ports until the SST in the nearshore areas is preferable. However, stratification in the water column at ports may easily be disturbed by winds causing a rapid drop in SST in the ports during the period when temperatures below the thermocline are low. A rapid decrease in temperature may also have a lethal effect on juvenile chum salmon (Brett 1952). Additionally, if the SST in the water outside of the ports remains < 8°C, juvenile salmon would likely not ‘decide’ to leave the ports. Consequently, fish may starve because of the shortage of large prey in ports (Irie 1987).

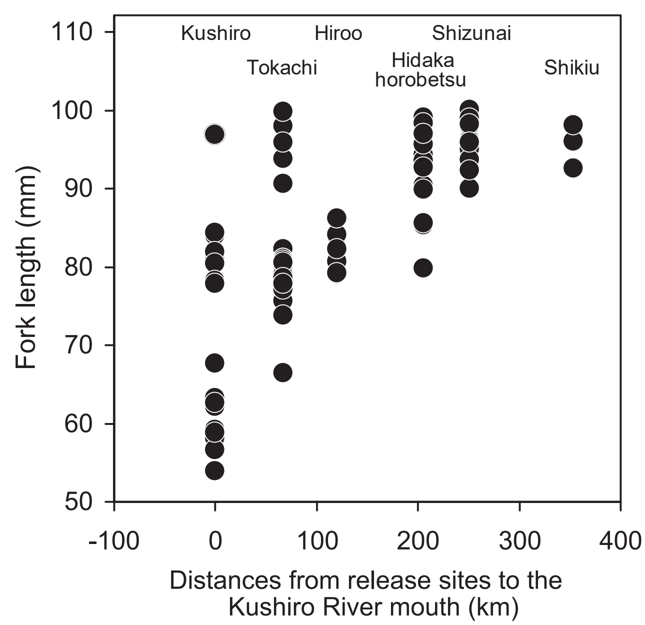

Fig. 6. Correlation between distances from the release sites to the Kushiro River mouth and the fork length of otolith-marked juvenile chum salmon recaptured in Kushiro nearshore areas in late June 2012.

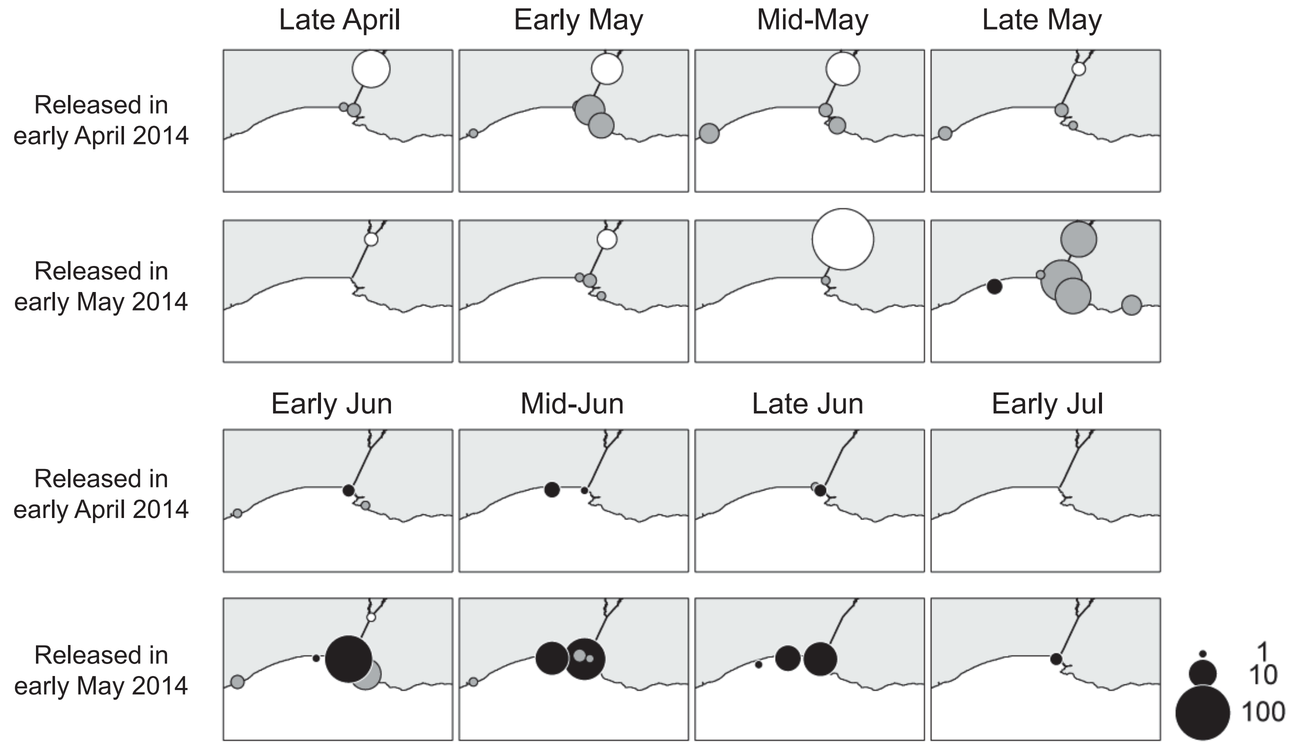

Fig. 7. Changes in distribution of alizarin complexone (ALC)-marked juvenile chum salmon released into the Kushiro River in 2014. White circles are fish caught in the lower reach of the river, gray circles are fish caught in the ports, and black circles are fish caught in nearshore areas. Size of circles indicates number of ALC-marked fish caught at each site.

In previous studies, juvenile chum salmon released into the Kushiro River were recaptured at Shiraoi, a location farther west from Kushiro (Nara 2006; Saito et al. 2013; Fig. 1A). Because chum salmon stocked in the rivers in Hokkaido are known to migrate to the Okhotsk Sea (Urawa et al. 1998, 2001), juvenile chum salmon that descended from the rivers on the Pacific coast of Hokkaido may migrate eastward (Irie 1985b, 1990). Therefore, westward migration of juvenile chum salmon may be passive and in the direction of the Coastal Oyashio Current. In contrast, ALC-marked fish were recaptured early in the season in ports both east and west of the Kushiro area, indicating that eastward migration along the shoreline is frequent (Irie 1990).

Differences in body size between the fish caught in the nearshore areas after late May suggested that juvenile chum salmon that exit the Kushiro River did not grow in the ports, but in other areas. Juvenile chum salmon stocked into the Kushiro River have been recaptured at locations far west of the Kushiro area (Nara 2006; Saito et al. 2013). Further, fish released into the Kushiro River have also been recaptured at Konbumori, east of Kushiro after early June (Sato et al. 2013; K. Kasugai, unpublished data). Fish released earlier into the Kushiro River are likely to have migrated westward (Saito et al. 2013). In the present study, body length of the ALC-marked fish released in April is significantly different from the length of fish in the nearshore areas after late May. These results suggest that fish released in the Kushiro River that are distributed in the Kushiro nearshore areas after late May might grow in locations west of Kushiro.

Juvenile chum salmon are reported to be distributed densely along the Pacific coast within 30 km off the coast of Hokkaido, with density increasing with proximity to the shore (Irie 1985a, 1990). On the Pacific coast of Hokkaido, juvenile chum salmon were observed within 5 km off Akkeshi Bay, 40 km east of Kushiro (Irie 1985b, 1990), and they were distributed densely within 2 km off Hiroo, west of Kushiro (Seki and Shimizu 1996; Seki 2005). In the present study, the highest density of juvenile chum salmon was at 1 km off the coast, whereas they were not detected at 7 km off the coast. Our results suggest that juvenile chum salmon are distributed within a narrower zone than previously reported. Juvenile chum salmon caught in the zone 1 km off the coast included fish released into the rivers west of Kushiro. Fish caught at Konbumori contained fish released in Iwate Prefecture of Honshu Island (Fig. 1A; Nara 2006; Hasegawa et al. 2013; Sato et al. 2013). Therefore, the coastal area of Kushiro is considered an important migration route for juvenile chum salmon released on the Pacific coast of Japan.

Larger juvenile chum salmon might begin to migrate offshore earlier than smaller fish (Mayama et al. 1982, 1983; Mayama 1985; Kaeriyama 1986; Irie 1990; Salo 1991); the threshold size for migration is between 70–80 mm in Hokkaido (Mayama et al. 1982, 1983; Mayama 1985; Irie 1990).

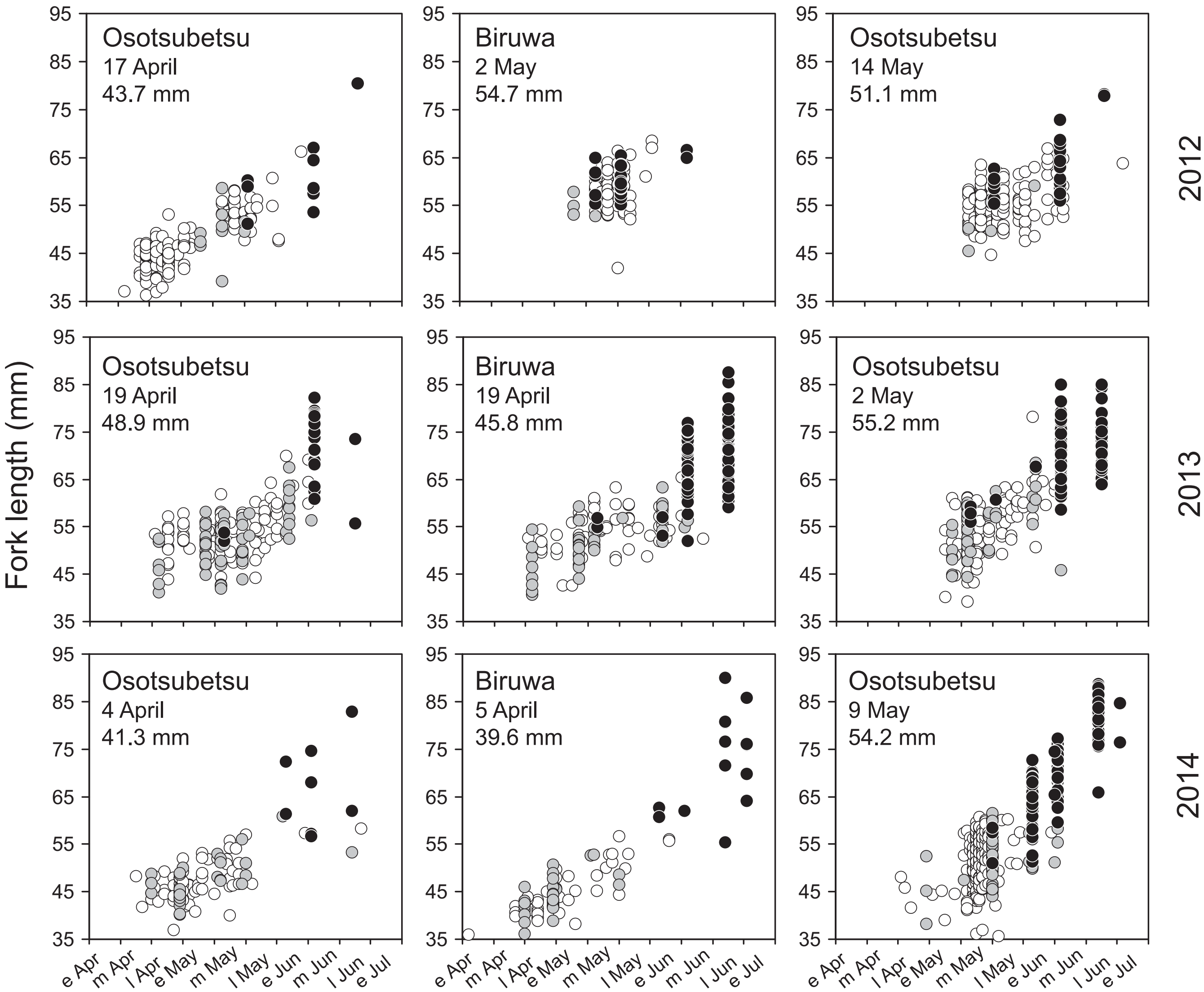

Fig. 8. Changes in fork length distribution of ALC-marked juvenile chum salmon in 2012 (upper), 2013 (middle) and 2014 (lower). White circles are juveniles caught in the river, gray circles are juveniles caught in the ports, and black circles are juveniles caught in nearshore areas. Captions in each panel indicate the name of hatchery, release date, and mean fork length at release, respectively (Table 1).

The minimum size of the otolith-marked fish increased with distance from the release sites to Kushiro, although their last release dates were similar among regions. The shorter the distance from the release sites to the Kushiro area, and the greater number of small-sized recaptured fish, suggests that survival after a long migration depends on body size.

In the early 1980s (1981–1985), many large juvenile chum salmon were distributed on the Pacific coast of eastern Hokkaido in early to mid-July (Irie 1985a, 1990), and the peak of distribution was later than that reported in the present study. The average SST anomaly in the area off Kushiro was -0.10°C in the spring (April–June) and -0.08°C in the summer (July–September) in the early 1980s, whereas the average SST anomaly varied from 0.07°C in the spring to 1.77°C in the summer in the early 2010s (Japan Meteorological Agency 2015b); therefore the SST in the early 1980s were lower than those in the early 2010s. The difference in SST might alter the migration periods of juvenile chum salmon along the Pacific coast of eastern Hokkaido.

Our study revealed distinct distribution and migration patterns of juvenile chum salmon in the Kushiro area, with juveniles migrating from the river mouth both eastward and westward of the coastal area. Future studies are needed to determine when and where early marine mortality events occur for the juvenile chum salmon of Kushiro.

ACKNOWLEDGMENTS

We express sincere thanks to the staff of the Tokachi-Kushiro Salmon Enhancement Program Association for rearing ALC-marked fish and helping with the surveys, the fishermen of Kushiro City, Eastern Kushiro City, and Shiranuka Fishery Cooperative Associations for operating fishing boats used for surveys, and Seiko Ito, Mikiko Minami, Chikako Shimokawara, Hiromi Nareyama, Atsuko Tokuie, Maki Yamase, and Sachiko Yoshikawa of the Salmon and Freshwater Fisheries Research Institute for measuring fish and extracting otoliths. We thank Joseph A. Orsi for providing valuable comments and revising the manuscript, and Nancy Davis and an anonymous reviewer for providing constructive comments and suggestions. A bathymetric dataset provided by the Japan Oceanographic Data Center was used to create Fig. 1C. This study was supported financially by the Tokachi-Kushiro Enhancement Programs Association, the Kushiro Set-net Fishery Association, and the Fisheries Agency of Japan.

REFERENCES

Bax, N. J. 1983. Early marine mortality of marked juvenile chum salmon (*Oncorhynchus keta*) released into Hood Canal, Puget Sound, Washington, in 1980. Can. J. Fish. Aquat. Sci. 40: 426–435.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon. J. Fish. Res. Board Can. 9: 265–323.

Hasegawa, K., T. Sato, and K. Sasaki. 2013. Distinguishing local growth from immigration-based size shifts for juvenile chum salmon communities in coastal Hokkaido, northern Japan. Fish. Sci. 79: 611–616.

Hokkaido National Fisheries Research Institute. 2015. Number of salmon caught by river, 1997–2014. (Available at http://salmon.fra.affrc.go.jp/zousyoku/river/river_cpt_sake_20150401_1997-2014.pdf accessed 19 June 2015).

Irie, T. 1985a. Occurrence and distribution of offshore migrating juvenile chum salmon along the Pacific coast of northern Japan. Soc. Sci. Fish. 51: 749–754. (In Japanese with English abstract).

Irie, T. 1985b. The origins and migration routes of offshore migrating juvenile chum salmon along the Pacific coast of northern Japan. Bull. Japan. Soc. Sci. Fish. 51: 1103–1107. (In Japanese with English abstract).

Irie, T. 1987. Ecological studies on juvenile chum and pink salmon in their early marine life – V. Feeding habits and prey size of juvenile chum salmon in small harbours in eastern Hokkaido. Bull. Hokkaido Reg. Fish. Res. Lab. 51: 1–10. (In Japanese with English abstract).

Irie, T. 1990. Ecological studies on the migration of juvenile chum salmon, *Oncorhynchus keta*, during early ocean life. Bull. Seikai Nat. Fish. Res. Inst. 68: 1–142. (In Japanese with English abstract).

Irie, T., and K. Nakamura. 1985. Ecological studies on juvenile chum and pink salmon in their early marine life – IV. The residence and growth of juvenile chum salmon in small harbour of eastern Hokkaido. Bull. Hokkaido Reg. Fish. Res. Lab. 50: 13–25. (In Japanese with English abstract).

Isoda, Y., and M.J. Kishi. 2003. A summary of "Coastal Oyashio" symposium. Bull. Coast. Oceanogr. 41: 1–3. (In Japanese with English abstract).

Isoda, Y., H. Kuroda, T. Myousyo, and S. Honda. 2003. Hydrographic feature of Coastal Oyashio and its seasonal variation. Bull. Coast. Oceanogr. 41: 5–12. (In Japanese with English abstract).

Japan Meteorological Agency. 2015a. (Available at www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php?prec_no=19&block_no=47418&year=2013&month=5&day=&view accessed 27 June 2015).

Japan Meteorological Agency. 2015b. (Available at www.data.jma.go.jp/gmd/kaiyou/data/shindan/a_1/japan_warm/cfig/warm_areaJ.html#title accessed 19 June 2015)

Kaeriyama, M. 1986. Ecological study on early life of the chum salmon, *Oncorhynchus keta* (Walbaum). Sci. Rep. Hokkaido Salmon Hatchery 40: 31–92. (In Japanese with English abstract).

Karpenko, V.I. 1998. Ocean mortality of northeast Kamchatka pink salmon and influencing factors. N. Pac. Anadr. Fish Comm. Bull. 1: 251–261. (Available at www.npafc.org).

Kasugai, K., M. Torao, H. Kakizaki, H. Adachi, H. Shinhama, Y. Ogasawara, S. Kawahara, T. Arauchi, and M. Nagata. 2012. Distribution and abundance of juvenile chum salmon (*Oncorhynchus keta*) in Nemuro Bay, eastern Hokkaido, Japan. N. Pac. Anadr. Fish Comm. Tech. Rep. 8: 58–61. (Available at www.npafc.org).

Kono, T., M. Foreman, P. Chandler, and M. Kashiwai. 2004. Coastal Oyashio south of Hokkaido, Japan. J. Phys. Oceanogr. 34: 1477–1494.

Mayama, H. 1985. Technical innovations in chum salmon enhancement with special reference to fry condition and timing of release. *In* Proceedings of the eleventh U.S.-Japan meeting on aquaculture, salmon enhancement. Tokyo, Japan, October 19–20, 1982. *Edited by* C.J. Sindermann. NOAA Tech. Rep. NMFS No. 27: 83–86.

Mayama, H., M. Kato, J. Seki, and I. Shimizu. 1982. Studies on the chum salmon released in the Ishikari River system – I. On the seaward migration and inshore distributions on liberated fry in 1979. Sci. Rep. Hokkaido Salmon Hatchery 36: 1–17. (In Japanese with English abstract).

Mayama, H., J. Seki, and I. Shimizu. 1983. Studies on the chum salmon released in the Ishikari River system–II. On the seaward migration and inshore distribution on liberated fry in 1980 and 1981. Sci. Rep. Hokkaido Salmon Hatchery: 37: 1–22. (In Japanese with English abstract).

Miyakoshi, Y., M. Nagata, S. Kitada, and M. Kaeriyama. 2013. Historical and current hatchery programs and management of chum salmon in Hokkaido, northern Japan. Rev. Fish. Sci. 21: 469–479.

Nagata, M., Y. Miyakoshi, D. Ando, M. Fujiwara, M. Sawada, H. Shimada, and H. Asami. 2007. Influence of coastal seawater temperature on the distribution and growth of juvenile chum salmon, with recommendations for altered release strategies. N. Pac. Anadr. Fish Comm. Bull. 4: 223–235. (Available at www.npafc.org).

Nara, K. 2006. Results of the first five-year program of NASREC. Nat. Salmon Resour. Ctr. Newslett. 16: 1–3. (In Japanese).

Ogasawara, J. 1990. Physics on the east and south coasts of Hokkaido. *In* Coastal oceanography of Japanese islands Suppl. Vol. *Edited by* Coastal Oceanography Research Committee, The Oceanographical Society of Japan. Tokai Univ. Press, Tokyo. pp. 473–483. (In Japanese).

Ohtani, K. 1971. Studies on the change of the hydrographic conditions in the Funka Bay II. Characteristics of the waters occupying the Funka Bay. Bull. Fac. Fish. Hokkaido Univ. 22: 58–66. (In Japanese with English abstract).

Ohtani, K. 1989. The role of the Sea of Okhotsk on the Oyashio Water. Umi to Sora 65: 63–83. (In Japanese).

Okamoto, Y., T. Ohnuki, S. Sato, N. Watanabe, Y. Miyauchi, T. Arauchi, M. Iida, and S. Urawa. 2012. Releases of otolith marked salmon from Japan in fall of 2011 and spring of 2012. N. Pac. Anadr. Fish Comm. Doc. 1418. 11 pp. (Available at www.npafc.org).

Parker, R.R. 1962. A concept of the dynamics of pink salmon populations. *In* Symposium on pink salmon. *Edited by* N. J. Wilmovsky. Univ. British Columbia, Vancouver. pp. 203–211.

Pearcy, W.G. 1992. Ocean ecology of north Pacific salmonids. Washington Sea Grant Program, Univ. Washington Press, Seattle. 179 pp.

Saito, T., K. Watanabe, K. Sasaki, and F. Takahashi. 2013. The dispersal pattern of juvenile chum salmon in the Pacific Ocean off the coast of Hokkaido, Japan. N. Pac. Anadr. Fish Comm. Tech. Rep. 9: 21–22. (Available at www.npafc.org).

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). *In* Pacific salmon life histories. *Edited by* C. Groot and L. Margolis. Univ. British Columbia Press, Vancouver. pp. 231–309.

Sato, S., K. Hirasawa, and S. Urawa. 2013. Stock origins of juvenile chum salmon migrating along the eastern Pacific coast of Hokkaido during early summer. N. Pac. Anadr. Fish Comm. Tech. Rep. 9: 23–24. (Available at www.npafc.org).

Seki, J. 2005. Study of characteristics of feeding habitat of juvenile chum salmon and their food environment in the Pacific coastal waters, central part of Hokkaido. Bull. Nat. Salmon Resour. Ctr. 7: 1–104. (In Japanese with English abstract).

Seki, J., and I. Shimizu. 1996. Effect time of larval release on return rate in chum salmon (*Oncorhynchus keta*) in the Hiroo River, Hokkaido, Japan. Bull. Japan. Soc. Fish. Oceanogr. 60: 339–347. (In Japanese with English abstract).

Simenstad, C.A., and E.O. Salo. 1982. Foraging success as a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon (*Oncorhynchus keta*) in Hood Canal, Washington. *In* Proceedings of the North Pacific aquaculture symposium. *Edited by* B.R. Melteff and R.A. Nevé. Alaska Sea Grant Rep. 82-2, Univ. Alaska, Anchorage. pp. 21–37.

Talley, L.D., and Y. Nagata (Editors). 1995. The Okhotsk Sea and the Oyashio Region. PICES Sci. Rep. 2. 227 pp.

Tomida, Y., T. Ohnuki, N. Watanabe, Y. Miyauchi, Y. Okada, M. Iida, and S. Urawa. 2013. Releases of otolith marked salmon from Japan between fall of 2012 and spring of 2013. N. Pac. Anadr. Fish Comm. Doc. 1484. 11 pp. (Available at www.npafc.org).

Tomida, Y., T. Ohnuki, S. Toda, Y. Goda, K. Ohmoto, M. Katou, and S. Urawa. 2014. Otolith marked salmon released from Japan between the fall of 2013 and spring of 2014. N. Pac. Anadr. Fish Comm. Doc. 1582. 13 pp. (Available at www.npafc.org).

Urawa, S., Y. Ueno, Y. Ishida, S. Takagi, G. Winans, and N. Davis. 1998. Genetic stock identification of young chum salmon in the North Pacific Ocean and adjacent seas. N. Pac. Anadr. Fish Comm. Doc. 336. 9 pp. (Available at www.npafc.org).

Urawa, S., Y. Ueno, Y. Ishida, L.W. Seeb, P.A. Crane, S. Abe, and N.D. Davis. 2001. A migration model of Japanese chum salmon during early ocean life. N. Pac. Anadr. Fish Comm. Tech. Rep. 2: 1–2. (Available at www.npafc.org).

Wertheimer, A.C. and F.P. Thrower. 2007. Mortality rates of chum salmon during their early marine residency. *In* The ecology of juvenile salmon in the northeast Pacific Ocean: Regional comparisons. *Edited by* C.B. Grimes, R.D. Brodeur, L.J. Haldorson, and S.M. McKinnell. Am. Fish. Soc. Symp. 57: 233–247.

Yasuda, I. 2003. Hydrographic structure and variability in the Kuroshio-Oyashio transition area. J. Oceanogr. 59: 389–402.