North Pacific Anadromous Fish Commission
Bulletin No. 6: 87–95, 2016

Effects of Release Timing on the Recovery of Late-Run Chum Salmon in the Okhotsk Sea Coast of Hokkaido, Japan

Mitsuhiro Nagata, Daisei Ando, Makoto Fujiwara, and Yasuyuki Miyakoshi

Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kitakashiwagi, Eniwa, Hokkaido 061-1433, Japan

Nagata, M., D. Ando, M. Fujiwara, and Y. Miyakoshi. 2016. Effects of release timing on the recovery of late-run chum salmon in the Okhotsk Sea coast of Hokkaido, Japan. N. Pac. Anadr. Fish Comm. Bull. 6: 87–95. doi:10.23849/npafcb6/87.95.

Abstract: While early-run chum salmon *Oncorhynchus keta* in Hokkaido have increased in abundance since the 1980s, late-run chum salmon (those spawning after early November) have not. We surveyed along Hokkaido's Abashiri coast of the Okhotsk Sea to test the hypothesis that delayed releases of late-run chum salmon experienced high mortality due to mismatches with environmental conditions early in their marine life. ALC (alizarin complexone) -marked juveniles (0.7–0.9 million, ~5 cm mean fork length) were stocked in the Abashiri River in mid- and late May in 2004 and 2005 to investigate their subsequent marine distribution, and growth and recapture rates in relation to coastal conditions. Marked juvenile chum salmon that had been stocked in mid-May 2004 and 2005 were captured in late May–early June with a surface trawl more often 1 km from shore than farther away from the coast when SST exceeded 8°C. Juvenile chum salmon rapidly disappeared after late June– early July when SST exceeded 13°C, especially fish that had been stocked in late May 2004 that remained for only three weeks 1 km offshore, where their recapture rates were the lowest. Adults returning to the Abashiri River were collected at 10-day intervals from early October to early December in 2007 to 2009. The adult return rate for juveniles released in late May was the lowest of the four marked groups. Offshore movement of juvenile chum salmon was found to depend on SST. Temperatures exceeding 13°C resulted in accelerated offshore movement. To recover late-run chum salmon stocks, we recommend either the early release of juvenile chum salmon when sea temperatures are near 7°C, or the release of larger fish.

Keywords: chum salmon, ALC marking, SST, late run, delayed release, recapture rate, return rate, stocking strategy

INTRODUCTION

The abundance of early run chum salmon *Oncorhynchus keta* that return to rivers mainly in September and October increased in Hokkaido following the 1980s (Nagata and Kaeriyama 2004; Miyakoshi et al. 2013a) as a result of successful hatchery programs and favorable ocean conditions (Kaeriyama 1999). In contrast, later returning runs of chum salmon have not increased (Nagata and Kaeriyama 2004; Miyakoshi et al. 2013a). Most recently, warm September coastal water temperatures have been associated with low and variable returns of early-run chum salmon, especially in the Japan Sea that is affected by the Tsushima Warm Current (Kaeriyama et al. 2014). The Tsushima Warm Current enters the Okhotsk Sea as the Soya Warm Current, although the Soya Warm Current is driven by a difference in sea level between the Japan Sea and Okhotsk Sea (Aota 1984). If warm-water conditions persist, early-run chum salmon may decline in other areas of Hokkaido, including the Okhotsk Sea. A better understanding of factors controlling the survival of early- and late-run chum salmon is needed.

In order to evaluate stocking criteria, we previously investigated the spatial distribution, growth, and diet of juvenile chum salmon in relation to coastal water conditions in Abashiri Bay, eastern Okhotsk Sea coast of Hokkaido (Asami et al. 2007; Nagata et al. 2007). As most juvenile chum salmon were widely distributed when coastal seawater temperatures (SST) were between 8 and 13°C, we recommended avoiding stocking juvenile chum salmon when SSTs in coastal locations were either < 7°C or > 11°C (Nagata et al. 2007). In the current paper, we compared the spatial distribution, growth, and recapture rates of otolith-marked late-run chum salmon released on different dates in 2004 and 2005. When these marked chum salmon returned to the Abashiri River as 4- and 5-year olds from 2007 to 2009, we collected adults to estimate return rates, and also to verify earlier recommendations for release timing by Nagata et al. (2007).

All correspondence should be addressed to M. Nagata.
e-mail: nagata-mitsuhiro@hro.or.jp

Table 1. Release group (year-E: early-run; year-L: late-run), date of fertilization and stocking, number of marked-stocked fish recaptured in the coastal sea, number, and fish size of alizarine complexone (ALC)-marked juvenile chum salmon stocked in the Abashiri River in 2004 and 2005. Number of recaptured fish shows the total number captured 1–7 km off the coast. Recapture rate was computed as the ratio (%) of the number of recaptured juveniles to the number of marked-stocked juveniles. Sample sizes for fork length and body weight consisted of 100 fish from every group.

Release group	Date of fertilization	Date of release	ALC marks*[1]	Stocked number of marked fish	Mean fork length (mm)*[2]	Mean body weight (g)*[2]	Number of recaptured fish	Recapture rate (%)
2004-E	15 Nov. 2003	16 May 2004	L	886,000	46.79^{b}	0.90^{b}	379	0.043
2004-L	15 Nov. 2003	30 May 2004	D	671,000	47.90^{a}	0.97^{a}	88	0.013
2005-E	15 Nov. 2004	15 May 2005	L	810,000	47.27^{ab}	0.80^{c}	275	0.034
2005-L	15 Nov. 2004	31 May 2005	D	842,000	47.94^{a}	0.82^{c}	236	0.028

*[1] L and D represent single large ALC-banding and double ALC-banding marks, respectively.
*[2] The values not sharing a common small letter among different groups are significantly different in FL and BW ($p < 0.05$).

MATERIALS AND METHODS

Otolith Marking and Fish Stocking Procedures

For hatchery programs on Hokkaido, chum salmon are divided into three timing groups (early-, middle- and late-run) based on periods of commercial catch (September and earlier, October, and November and later), river catch by weir (pre-11 October, 11 October~5 November, and post-5 November), and spawning (pre-21 October, 21 October~10 November, and post-10 November). Accordingly, in this paper we defined late-run chum salmon as those that spawn after 10 November, and early-run chum as those that spawn before then.

In the Abashiri River, which runs into Abashiri Bay, 34 million hatchery chum salmon fry are released annually each May by two private hatcheries. Some of the eyed eggs fertilized on 15 November in 2004 and 2005 were immersed in 200 ppm alizarin complexone (ALC) solution for 24 h with different degree-days before hatching in the Aioi Private Salmon Hatchery (Nagata et al. 2007; Miyakoshi et al. 2007). Otoliths were marked with ALC bands and the fish were raised on artificial food in a raceway pond until release (Table 1). Differentially marked fry were released in mid- and late May in 2004 and 2005. To avoid potential size-selective mortality, eggs were incubated in low (6.9°C) and high (8.9°C) water temperatures to generate similar-sized individuals because embryo development depends on cumulative daily water temperatures (Kaeriyama 1989; Nagata et al. 2007). Although some significant differences in size were found among release groups, fish size ranges corresponded to the period when fry develop scales and transit as pre-fingerlings to coastal waters (Kaeriyama 1986).

Sampling Survey and Biological Analysis

Coastal Surveys in Early Life

Coastal surveys were as described by Nagata et al. (2007). Twelve study sites were established at 1 km, 4 km and 7 km offshore along the Abashiri coast (Fig. 1). Weather permitting, juvenile chum salmon were captured with a surface trawl (8-m-wide x 5-m-deep mouth, 18 m long, with wing nets 7-m long and a central bag with 5-mm mesh) towed along the 1–2 m surface layer for 1–2 km at 4–6 km/h during daytime (5:00–14:00) at 10-day intervals from late April to early July, 1–7 km off the coast. One additional site at the Abashiri fishing port was sampled with a trawl that was towed for 0.5 km. Use of the nearshore littoral zone

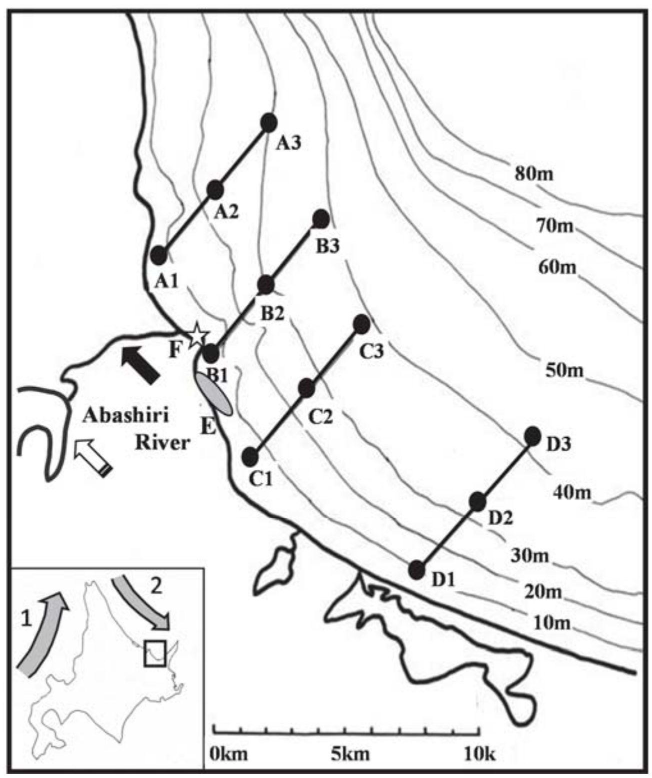

Fig. 1. Four transects (A–D, each with sampling sites at 1, 4, and 7 km from shore) off the Abashiri coast and study sites at the fishing port (E) and littoral zone (F) in the Okhotsk Sea. Arrows show stocking site (white arrow) for ALC-marked chum juveniles and the weir site (black arrow) to capture returned adults. Gray arrow shows the Tsushima Warm Current (1) and Soya Warm Current (2).

was evaluated using a beach seine (3.5-m-wide x 2-m-deep mouth, 10 m long, with wing nets 3 m long and a central bag with 3-mm mesh). Five seine sets were usually made, starting at 100 m offshore, at intervals of 50–100 m along the beach. Captured fish were preserved in 5% neutralized freshwater formalin and transferred to 70% ethanol after 12 to 24 h. Some fish were released soon after they were measured when large numbers of fish were caught. CPUE in the trawl was standardized as the number of chum salmon caught in a 2-km tow. Marked chum salmon were recaptured from early May to early July. Sea surface water temperature and salinity were measured at each study site with a CTD. Chum salmon were measured for fork length and wet body weight, to the nearest 1 mm and 0.01 g, respectively, and then their otoliths were taken to detect ALC marks. Recapture rates (*R*) of marked chum salmon juveniles, in four groups were calculated using data on marked juveniles, which were widely and quantitatively recaptured at 1–7 km offshore after dispersal from near shore, as

$$R = \Sigma_i m_{i,} / M,$$

where m_i is total number of marked fish (CPUE) caught in a 2-km trawl at 1 km, 4 km, and 7 km offshore at sampling *i*. *M* is total number of stocked-marked juvenile chum salmon.

Collection of Returning Adults

A weir was operated near the mouth of the Abashiri River from early September to early December each year (Fig. 1). Collected adults were transported to raceway ponds near the weir or the Aioi Private Salmon Hatchery for temporary holding. About 500 adults (male to female ratio 1:1) were sampled randomly after fertilization at 10-day intervals from early October to early December. Fish were measured for fork length to the nearest 1 mm, and scales (collected from above the lateral line, posterior to the dorsal fin, and anterior to the anal fin) and otoliths were taken to determine age and to detect ALC marks, respectively. Total numbers of marked fish (*M*) were calculated for 4- and 5- year-olds in each group as

$$M = \Sigma_i \Sigma_j N_{i,j,t} \bullet m_{i,j,t} / n_{i,j,t},$$

where $N_{i,j,t}$ is the total number of adults caught in the weir for 10 days corresponding to sampling *i* for *j*-year-old in year *t*, $m_{i,j,t}$ is the number of marked fish out of the adults collected at sampling *i* for *j*-year-old in year *t*, and $n_{i,j,t}$ is the number of adults collected at *i* sampling for *j*-year-olds in year *t*.

Detection of Otolith Marks and Ageing

Otoliths from juvenile chum salmon were examined for ALC marks using ultraviolet light microscopy without polishing the otolith surface except when it was difficult to

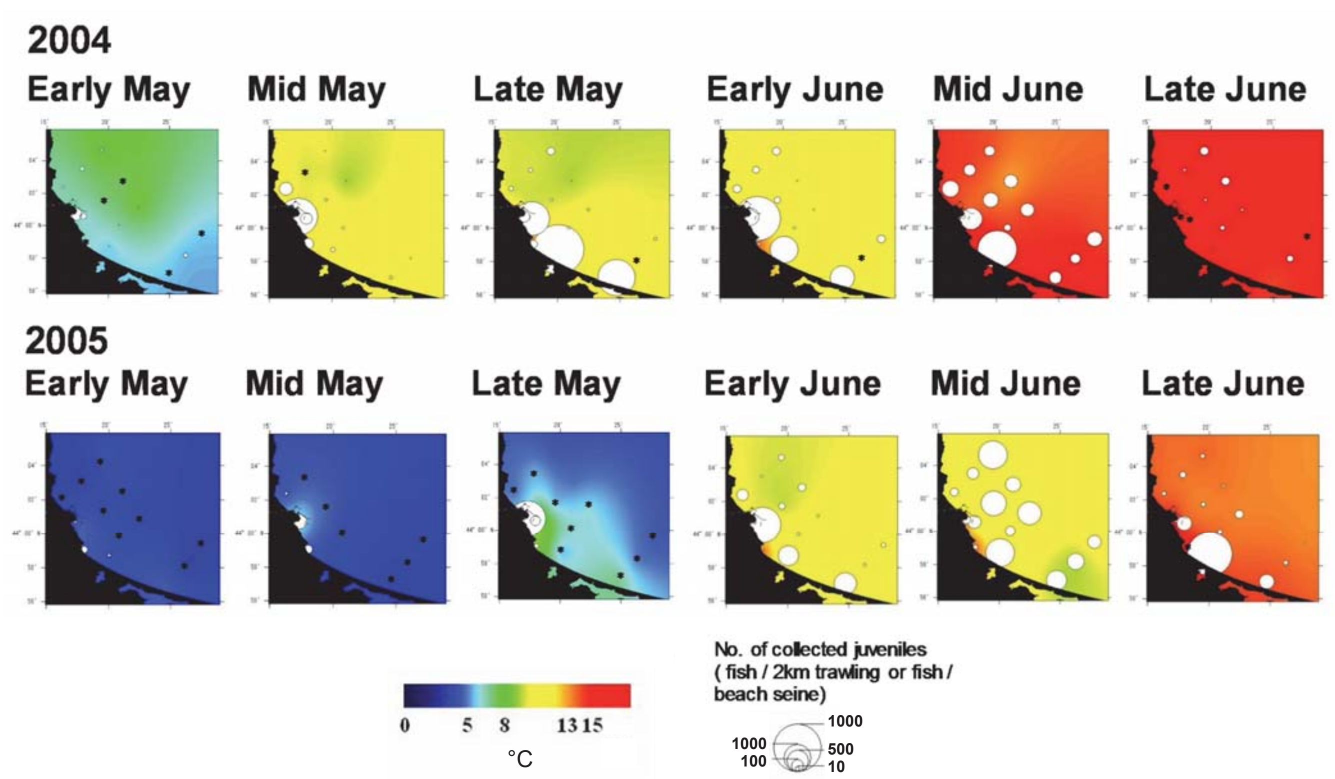

Fig. 2. Schematic diagrams showing sea surface temperatures (SST) and catch per unit effort (CPUE) of juvenile chum salmon by time period. CPUE is the number of juveniles caught per 2-km tow by trawl at the fishing port, 1 km, 4 km, or 7 km off the Abashiri coast, or by beach seine at littoral sites on the Okhotsk Sea coast in 2004 and 2005. * indicates a site was sampled but no fish were caught.

identify marks because the surface of an otolith was unclear. All adult chum salmon otoliths were polished and examined for ALC marks using this approach.

Scales were pressed on acetate slides. Adult ages were determined by scale reading according to Kobayashi (1961). In the Abashiri River, Miyakoshi et al. (2013c) found age composition varied from 3- to 7-year-olds; most of the adults caught in this study were 4 and 5 years old. Therefore, only 4- and 5-year-old fish were used to estimate the adult return rate.

Statistical Analysis

Differences among marked groups in fork length and body weight were compared with a one-way analysis of variance (ANOVA). Specific growth rates (slope (b) of the growth curve ($L_t = a \bullet e^{bt}$ where L_t is the fork length at time t) were computed using fork lengths of marked juveniles at release and recapture at 1 km offshore and compared among the different groups and years using analysis of covariance (ANCOVA). If a significant difference occurred, multiple comparisons were evaluated using Scheffe's test (Zar 1984). The differences in the proportion of 4- and 5-year-olds and in the frequency pattern of each 10-day number of marked fish were compared among groups using a G-test (Sokal and Rohlf 1981).

RESULTS

Sea Surface Temperature

Surface seawater temperatures (SST) of coastal waters differed between 2004 and 2005. Sea surface temperatures in 2004 reached 5°C in early May and 8°C in mid-May, and then increased rapidly, eventually exceeding 13°C in mid-June (Fig. 2). In contrast, SST in 2005 were cooler. In 2005, although SST reached 5°C in late May within 4 km offshore, it did not exceed 8°C until early June, eventually reaching 13°C in late June.

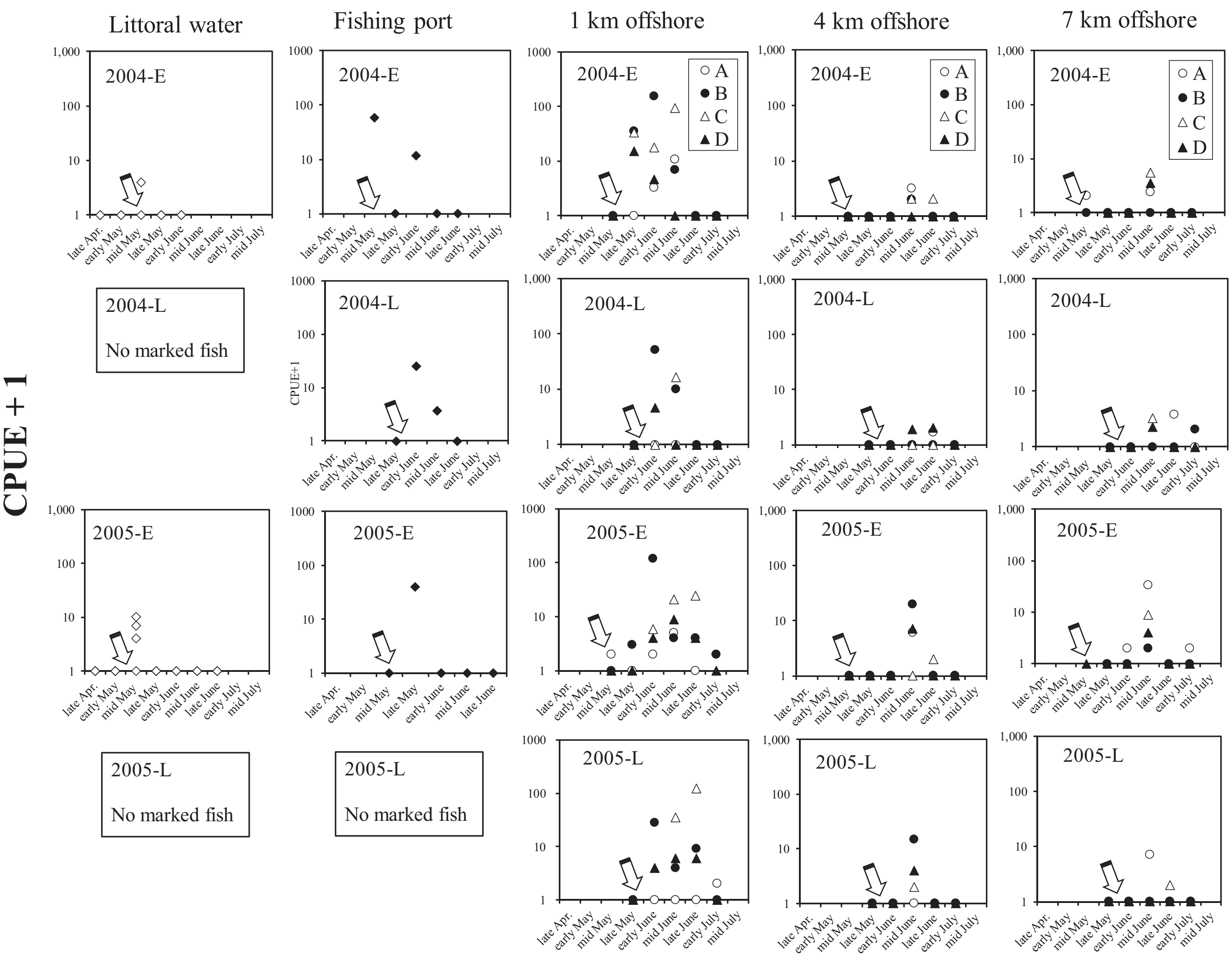

Fig. 3. CPUE (catch per unit effort, the number of juveniles per beach seine or per 2-km tow) of marked juvenile chum salmon recaptured in the littoral zone, the fishing port, and 1 km, 4 km, and 7 km off the Abashiri coast in the Okhotsk Sea in 2004 and 2005. A–D corresponds to each transect shown in Fig. 1. Arrows indicate time of release.

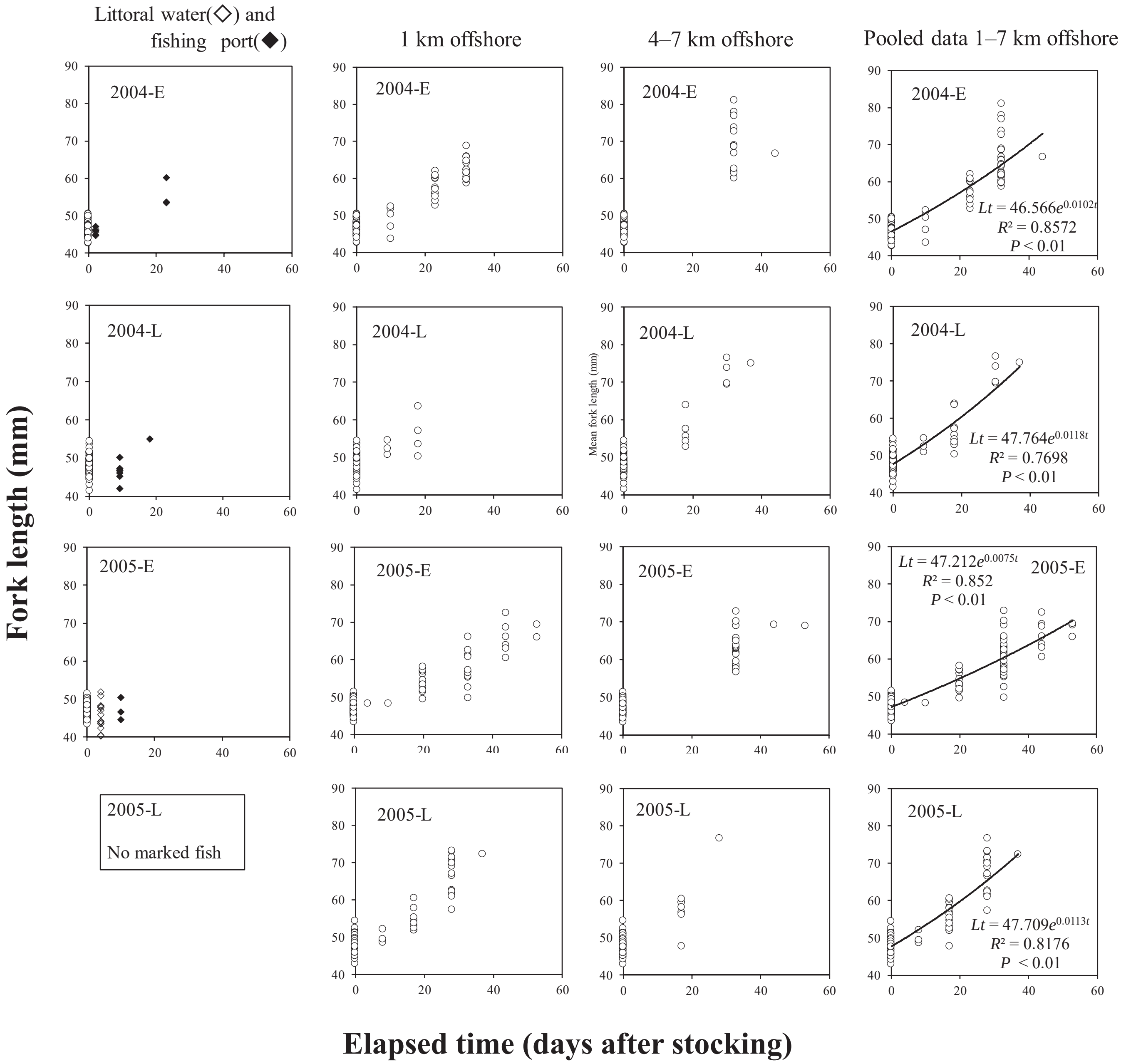

Fig. 4. Individual fork length of ALC-marked juvenile chum salmon stocked in the river and recaptured in the littoral zone and the fishing port, 1 km, and 4–7 km off the Abashiri coast in the Okhotsk Sea in 2004 and 2005. Exponential equations between fork length (L_t: mm) and elapsed time (t: days) are provided using stocked juveniles (t = 0) and the pooled data of fish caught 1 km, 4 km, and 7 km offshore.

Spatial Distribution of Juveniles

More juvenile chum salmon were caught along the coast from May to July in 2004 (61,585) than in 2005 (38,511). High CPUEs exceeding 1,000 juvenile salmon/2-km tow at 1 km offshore occurred earlier in 2004 (late May to mid-June) than in 2005 (early to late June; Fig. 2). Although CPUEs in the 4- and 7-km offshore transects were very low in both years, their peak CPUEs were 10–20 days later than those 1 km offshore. Peaks in each year were similar in mid-June. While many juvenile salmon were captured in May 2004, almost none were captured in May 2005, except 1 km offshore in May when SSTs were below 8°C. In early June 2005, high abundances were found not only 1 km offshore but also at 4 and 7 km offshore. Juvenile chum salmon remained near the 1-km site later in 2005 than in 2004, the warmer year. However, most fish that were caught were unmarked fish whose origin could not be identified. Marked juvenile chum salmon were recaptured in either the littoral zone and/or the fishing port, except for 2005-L (Fig. 3). After their short nearshore residence, marked juveniles were recaptured 1–7 km offshore for (generally) longer periods than closer

Table 2. Intercept and slope (specific growth rate: SGR) of the exponential equation computed using individual FLs in each group that was stocked in the river and then recaptured 1–7 km offshore. Plots of data are shown in Fig. 4.

Release group	L_t*2 = $a \cdot e^{bt}$	
	Intercept (a)	SGR (b)
2004-E	46.566 D*1	0.0102 B
2004-L	47.764 A	0.0118 A
2005-E	47.212 C	0.0075 C
2005-L	47.709 B	0.0113 AB

*1 The values not sharing a common letter among different groups are significantly different from each other (p < 0.05).
*2 L_t is the fork length at time t.

to shore. The vast majority of marked juveniles were recaptured 1 km offshore (release group 2004-E: 96% of total marked juveniles captured 1–7 km offshore, 89% of group 2004-L, 72% of group 2005-E, and 89% of group 2005-L). Marked juveniles of group 2004-E were recaptured 1 km offshore from late May to mid-June, and marked juveniles of group 2005-E were recaptured mainly from early to late June (Fig. 3). Marked juveniles released in groups 2004-L and 2005-L were recaptured 1 km offshore beginning in early June, but the last recapture of fish in group 2004-L was in mid-June, earlier than for group 2005-L (late June). High abundances of juvenile marked chum salmon occurred each year when SSTs ranged from 8 to 13°C. While fish from groups 2004-E, 2005-E, and 2005-L were recaptured over at least a one-month period 1 km offshore, fish from group 2004-L were captured at this location for only 20 days. Although marked juveniles at 4 km and 7 km showed no clear pattern in either year, perhaps because of low sample sizes, marked juveniles in group 2004-L that rapidly disappeared 1 km offshore were recaptured 4–7 km offshore in late June and early July.

Recapture rates of ALC-marked juveniles were estimated by the total number of marked fish recaptured in coastal waters (1–7 km offshore) divided by the number of marked chum released. Recapture rates (%, the number of captured fish per the number of released fish) varied between 0.13 and 0.43% (Table 1). The highest recapture rate, 0.43%, was recorded for group 2004-E, followed by group 2005-E (0.34%), and group 2005-L (0.28%). The lowest (0.13%) was recorded for group 2004-L.

Growth of Marked Juveniles

Individual fork lengths of recaptured ALC-marked juvenile salmon were plotted against the time since stocking (Fig. 4). Fork lengths of marked juveniles in the littoral zone and the fishing port did not appear to increase compared to fork lengths of fish caught 1–7 km offshore. While most marked juveniles in release groups 2004-E, 2005-E, and 2005-L, 1 km offshore, exceeded 60 mm fork length at final catch, marked juveniles in group 2004-L (small sample sizes) were almost all < 60 mm, but at 4–7 km offshore they attained fork lengths of 60 mm as well as the other groups. Because relationships between FL and elapsed time appeared to be exponential in the marked juvenile chum salmon stocked in the river and recaptured 1–7 km offshore (Fig. 4), equations ($L_t = a \bullet e^{bt}$) were computed to estimate specific growth rate (SGR; slope of the line). Equations for the four groups were statistically significant (p < 0.01). There were significant differences in slopes (ANCOVA, $F_0 = 29.96 > F_{0.001, 3, 548} = 5.51$) and intercepts ($F_0 = 16.46 > F_{0.001, 3, 551} = 5.51$) among the release groups. While multiple comparisons showed SGR for group 2005-E was significantly lower than those for the other three groups (p < 0.05), there were no significant differences between groups 2004-E and 2005-L and between groups 2004-L and 2005-L (Table 2).

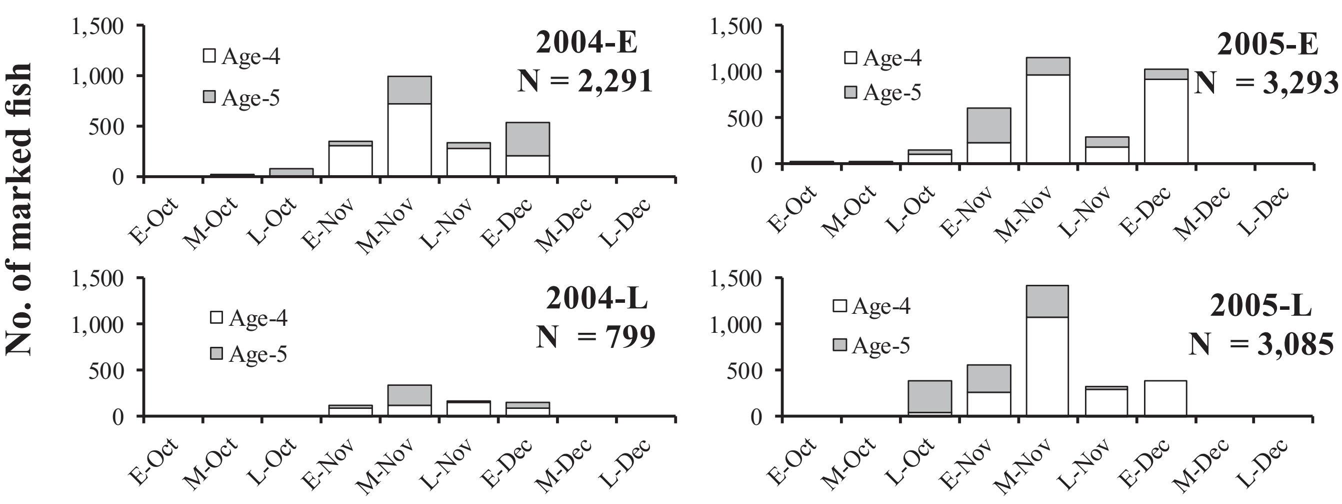

Fig. 5. Estimated number of marked adults that returned to the Abashiri River from early October to early December by release group.

Timing and Rate of Adult Returns

Marked adults from each release group were recaptured mainly from late October to early December, although there were no significant differences in frequency among the four groups ($p > 0.05$, G-test). Peak returns were in mid-November, consistent with the fertilization date (15 November) of their parents (Fig. 5). The proportion returning at four and five years did not vary between early and late release groups ($p > 0.05$, G-test). Early release groups had higher return rates (survivals) than late groups and fish released in 2005 survived better than those released in 2004 (Table 3).

DISCUSSION

The duration of early marine coastal residence varied among groups of juvenile chum salmon depending on release timing and coastal seawater temperatures. Researchers in previous studies have caught juvenile chum salmon when coastal waters were ~5°C around Hokkaido (Irie 1990; Seki 2005), but catches were far higher when coastal waters were between 8 and 13°C (Kaeriyama 1986; Irie 1990; Seki 2005; Nagata et al. 2007). In this study, unmarked and marked juveniles were captured primarily in 8–13°C sea water, so it seems reasonable to conclude that this temperature range is favored by young chum salmon around Hokkaido. Juvenile chum salmon released into the Abashiri River from mid- to late June first moved near shore (the littoral zone and the fishing port), afterward dispersing widely 1–7 km offshore of Abashiri Bay. In particular, over the long term they were more abundant 1 km offshore, suggesting that this area plays an important role as nursery area. In 2004, fish released early (mid-May) appeared to move quickly offshore, presumably when SST had reached ~8°C. In contrast, in 2005 it was not until late May or early June that SST reached 8°C. Most of the early release group in 2005 moved offshore 10 days later than those in 2004. However, this delayed offshore movement for the early release group in 2005 did not appear to affect their growth. The late (May) release group moved offshore more quickly in 2004, the warmer year, than it did in 2005. The rapid dispersal of the late group in 2004 was probably responsible for the lower recapture rate and small size of the fish caught 1 km offshore.

Miyakoshi et al. (2012) examined the spatial distribution and growth in the Abashiri River of these release groups before seaward migration. Few fish from the late group in 2004 were recaptured in mid-June when the river water temperature exceeded 20°C, indicating their survival was probably low unless they migrated to sea immediately after release (Miyakoshi et al. 2012). In addition, according to Nagata et al. (2007), some juvenile chum salmon were caught near shore in the littoral zone when SST was below 8°C. None was recaptured in the littoral zone when SST exceeded 13°C. Kaeriyama (1986) identified two causes for offshore movement: searching for prey, and avoiding unsatisfactory environmental conditions such as high water temperature. The release group in 2004 probably moved offshore because the water was too warm.

High mortality of salmon during their early life may be caused by size-selective predation (Parker 1971; Healey 1982; Willette et al. 2001; Malick et al. 2011). Mortality in chum salmon juveniles was strongly size-selective over the size range from 44 to 55 mm FL (Healey 1982). The brief coastal residence 1 km offshore resulting from the delayed release and the quick elevation of temperatures to 13°C may have given juvenile salmon a survival disadvantage by maximizing the intensity of predation. Species recognized as predators of juvenile chum in the coastal waters of Abashiri Bay include masu salmon *O. masou*, pointhead flounder *Hippoglossoides pinetorum*, kurosoi rockfish *Sebastes schlegelii*, and saffron cod *Eleginus gracilis,* although the intensity of predation was not examined (Miyakoshi et al. 2013b). If mortality during early marine life strongly affected overall survival, the 2004-L group with the lowest recapture rate should have had the lowest survival—and it did.

The timing of spawning in salmonids is genetically determined (Bye 1984). In this research, all marked juvenile chum salmon were produced from eggs fertilized on the same date (15 November) to avoid any temporal biases that may have been caused by run timing and differential fishing pressures. While most fish from the four groups returned in late October to early December, their peak was in mid-November, consistent with the date of fertilization in both years. Average elapsed time from river capture to egg fertilization ranged from three to seven days when fish were captured and reared for maturation in November in the Abashiri River

Table 3. Return rates (survival indices) for each group released in 2004 and 2005. The number of 4- and 5-year-old marked adults was estimated using the equation described in the methods. The return rate was calculated as the ratio (%) of the total number of adults to the number of marked juveniles.

Release group	2004-E	2004-L	2005-E	2005-L
(a) No. of released juveniles	886000	671000	810000	842000
(b) No. of returned adults	2291	799	3293	3085
No. of age-4 adults	1496	461	2409	2074
No. of age-5 adults	795	338	884	1011
Return rate to river (b x 100 / a)	0.259	0.119	0.407	0.366

(Nara 1997). Therefore, marked adults from the same brood year were thought to return to the river with almost the same process of migration and maturation in coastal waters.

While there was almost no difference in return rate between the early (0.407) and late (0.366) groups in the 2005 brood year, the return rate of the late 2004 group (0.119) the previous year was lower than the early group (0.259), which was consistent with the low recapture rates of the late group in coastal waters. Therefore, these results support our speculation based on observations during early life. In the eastern Okhotsk Sea, including the Abashiri area, there is a significant relationship between the commercial catch (Y) along the coast and the catch in the river (X) for brood stock ($Y = 1962\ X^{0.6186}$, $r = 0.897$, $p < 0.001$) for 1987–2012 return years (M. Nagata unpublished data). The commercial catch was about 10 times the river catch. Therefore, potential economical losses caused by delayed releases can be significant.

Nagata et al. (2007) recommended that juvenile chum salmon be released when SSTs were between 7 and 11°C to utilize desirable seawater conditions along the Abashiri coast as defined by relationships between spatial distribution, growth of juveniles, and coastal environmental parameters, such as SST and prey abundance (Asami et al. 2007). As SST had already reached 7–8°C in early May 2004 (Fig. 2), early to mid-May releases would be expected to survive better than later releases. Asami et al. (2007) and Sawada et al. (2007) suggested that when the Soya Warm Current became predominant in the Abashiri Bay from May to June, a "low temperature and low salinity" condition shifted to a "high temperature and high salinity" condition. The Soya Warm Current is driven by a difference in sea level between the Japan Sea and Okhotsk Sea (Aota 1984). According to Sawada et al. (2007), the sea level difference between Wakkanai in western Okhotsk Sea and Abashiri was earlier and greater in 2004 than in 2005, and as a result salinity and SST in 2004 increased early. Therefore, sea level differences among these sites is used as an index of the strength of the Soya Warm Current and the timing of SST increases in Abashiri Bay. When juvenile chum salmon from the late run are released late because of cold water temperatures in incubating and rearing water and/or low hatchery capacity, the resulting small juveniles would be expected to show reduced offshore movement as shown in the present study, likely due to size-selective mortality (Parker 1971; Healey 1982; Willette et al. 2001; Malick et al. 2011). Pearcy et al. (1989) suggest that rearing chum salmon fry to a larger size may be a useful method to enhance hatchery runs into estuaries, especially if size-selective predation is intensified by retarded growth resulting from high temperatures or lack of prey. Therefore, if water temperatures in a hatchery are too cold, acceleration of egg development by raising the water temperature may help to produce larger fish with improved survival. If hatchery capacity is limited, the number of salmon produced may need to be reduced to avoid producing salmon that will need to be released late.

ACKNOWLEDGMENTS

We deeply appreciate Y. Yoshida and staff of the Abashiri Fisheries Cooperative Association, K. Chida and staff of the Abashiri City Science Center, and staff of the East Branch of the Fisheries Technical Guidance Office for supporting the coastal and beach fishing surveys. Also M. Nagase of the Aioi Hatchery and staff of the Kitami Salmon Enhancement Programs Association for ALC mass marking, fish production and collection of adult data. J.R. Irvine of the Pacific Biological Station in Canada made helpful comments on drafts of this manuscript.

REFERENCES

Aota, M. 1984. Oceanographic structure of the Soya Warm Current. Bull. Coast. Oceanogr. 22: 30–39. (In Japanese).

Asami, H., H. Shimada, M. Sawada, H. Sato, Y. Miyakoshi, D. Ando, M. Fujiwara, and M. Nagata. 2007. Influence of physical parameters on zooplankton variability during early ocean life of juvenile chum salmon in the coastal waters of eastern Hokkaido, Okhotsk Sea. N. Pac. Anadr. Fish Comm. Bull. 4: 211–221. (Available at www.npafc.org).

Bye, V.J. 1984. The role of environmental factors in timing of reproductive cycles. *In* Fish reproduction: strategies and tactics. *Edited by* G.W. Potts and R.J. Wootton. Academic Press, London. pp. 187–205.

Healey, M.C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 39: 952–957.

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 summary).

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).

Kaeriyama, M. 1989. Development and growth of the genus *Oncorhynchus* 1. Concepts and effective accumulative temperature on development and growth. Tech. Rep. Hokkaido Salmon Hatchery 158: 22–28. (In Japanese with English abstract).

Kaeriyama, M. 1999. Hatchery programmes and stock management of salmonid populations in Japan. *In* Stock enhancement and sea ranching. *Edited by* B.R. Howell, E. Moksness, and T. Svåsand. Fishing News Books. London. pp. 153–167.

Kaeriyama, M., H. Seo, and Y. Qin. 2014. Effect of global warming on the life history and population dynamics of Japanese chum salmon. Fish. Sci. 80: 251–260. doi:10.1007/s12562-013-0693-7.

Kobayashi, T. 1961. Biology of chum salmon, *Oncorhynchus keta* (Walbaum), by the growth formula of scale. Sci. Rep. Hokkaido Salmon Hatchery 16: 1–102.

Malick, M.J., L.J. Haldorson, J.J. Piccolo, and J.L. Boldt. 2011. Growth and survival in relation to body size of juvenile pink salmon in the northern Gulf of Alaska. Mar. Coast. Fish. 3: 261–270. doi:10.1080/19425120.2011.593467.

Miyakoshi, Y., M. Fujiwara, D. Ando, H. Shimada, M. Sawada, H. Asami, and M. Nagata. 2007. Distribution and growth of juvenile chum salmon in the Abashiri Bay, eastern Hokkaido, in relation to sea surface temperature. N. Pac. Anadr. Fish Comm. Tech. Rep. 7: 21–22. (Available at www.npafc.org).

Miyakoshi, M., D. Ando, M. Fujiwara, H. Hayano, and M. Nagata. 2012. Downstream migration of chum salmon released in the Abashiri River. Sci. Rep. Hokkaido Fish. Res. Inst. 82: 19–26. (In Japanese with English abstract).

Miyakoshi, M., M. Nagata, S. Kitada, and M. Kaeriyama. 2013a. Historical and current hatchery programs and management of chum salmon in Hokkaido, Northern Japan. Rev. Fish. Sci. 21: 469–479. doi:10.1080/10641262.2013.836446.

Miyakoshi, M., M. Nagata, D. Ando, M. Fujiwara, and T. Aoyama. 2013b. Fish predators of juvenile chum and pink salmon in coastal waters of Abashiri region, eastern Hokkaido. Sci. Rep. Hokkaido Fish. Res. Inst. 83: 41–44. (In Japanese with English abstract).

Miyakoshi, M., D. Ando, M. Fujiwara, M. Torao, H. Hayano, and H. Urabe. 2013c. Characteristics of body size of chum salmon returning to Okhotsk rivers in Hokkaido. Sci. Rep. Hokkaido Fish. Res. Inst. 84: 21–29. (In Japanese with English abstract).

Nagata, M., and M. Kaeriyama. 2004. Salmonid status and conservation in Japan. *In* The proceedings of world summit on salmon. *Edited by* P. Gallaugher and L. Wood. Simon Fraser University, Burnaby. pp. 89–97.

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. 1997. The number of days from capture to an egg-taken procedure in the adult chum salmon and pink salmon rearing for maturity. Tech. Rep. Hokkaido Salmon Hatchery 166: 13–27. (In Japanese).

Parker, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28: 1503–1510.

Pearcy, W.G., C.D. Wilson, A.W. Chung, and J.W. Chapman. 1989. Resident times, distribution, and production of juvenile chum salmon, *Oncorhynchus keta*, in Netarts Bay, Oregon. Fish. Bull. NOAA 87: 553–568.

Sawada, M., H. Shimada, H. Asami, H. Sato, Y. Miyakoshi, D. Ando, M. Fujiwara, and M. Nagata. 2007. Seasonal and annual changes of oceanographic condition during early ocean life of chum salmon in the coastal waters of Okhotsk Sea, eastern Hokkaido. N. Pac. Anadr. Fish Comm. Tech. Rep. 7: 75–77. (Available at npafc.org).

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

Sokal, R.R., and F.J. Rohlf. 1981. Biometry, Second Edition. W.H. Freeman, New York. 859 pp.

Willette, T.M., R.T. Cooney, V. Patrick, D.M. Marson, G.L. Thomas, and D. Scheel. 2001. Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. Fish. Oceanogr. 10 (Suppl. 1): 14–41.

Zar, J. H. 1984. Biostatistical analysis, Second Edition. Prentice-Hall, New Jersey. 718 pp.