Distribution and Abundance of Juvenile Chum Salmon (*Oncorhynchus keta*) in Nemuro Bay, Eastern Hokkaido, Japan

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Catches of chum salmon in Hokkaido increased after the 1970s and have remained over 30 million since the 1990s (Mayama and Ishida 2003). However, there are large differences in the amount of chum salmon catch among regions of Hokkaido (Saito and Nagasawa 2009; Nagata et al. 2012a, b). In the Nemuro region, catches of chum salmon constitute about 30% of the total catch in Hokkaido, however, the catches in the northern and southern areas differ (Fig. 1). Although the number of juvenile chum salmon released in both areas is almost the same, the catch in the southern area is about one-third the catch in the northern area.

Mortality of juvenile chum salmon in coastal waters just after entering the sea is thought to be higher than during other periods of their life history (Parker 1968; Healey 1982; Bax 1983; Fukuwaka and Suzuki 2002; Saito et al. 2011). Therefore, one of the ways to obtain higher survival would be to decrease mortality of juveniles in coastal waters. Coastal environments influencing mortality and distribution of juvenile chum salmon might differ and be specific to each region (Mueter et al. 2002). Juvenile chum salmon should be released from the hatchery at a time when coastal environments are suitable for their survival because release timing affects return of adult fish (Seki and Shimizu 1996).

We hypothesized that lower return of adult chum salmon to the southern Nemuro area may be caused by a mismatch between release timing and conditions suitable for survival in the coastal environment. For this investigation, we released juvenile chum salmon marked with alizarine-complexone at various times (late March–early May) and surveyed their distribution and abundance in coastal waters between late April and mid July 2007–2010. We investigated the suitability of coastal environments in the southern Nemuro area for survival of juvenile chum salmon. Furthermore, we proposed a release time for hatchery-reared fish to achieve better adult returns.

Table 1. Date and duration of time when specific sea surface temperature (SST) conditions existed at Betsukai Station (ST) in Nemuro Bay, Eastern Hokkaido, 2007-2010.

Year	SST > 6°C (date)	SST > 8°C (date)	SST > 13°C (date)	SST 8°–13°C (period)	SST 8°-13°C (number of days)
2007	6 May	29 May	16 June	late May to mid June	19
2008	7 May	5 June	12 July	early June to mid July	38
2009	4 May	13 May	26 June	mid May to late June	45
2010	6 May	10 June	21 June	early June to late June	12

At the Betsukai Station (ST), the dates when sea surface temperatures (SSTs) exceeded 8˚C varied from year to year; the earliest and latest dates were in 2009 and 2010, respectively (Table 1; Fig. 1). The earliest date when SSTs exceeded 13˚C was during 2007 and latest date was during 2008. The number of days when SSTs ranged between 8˚C and 13˚C was 12 to 45 days.

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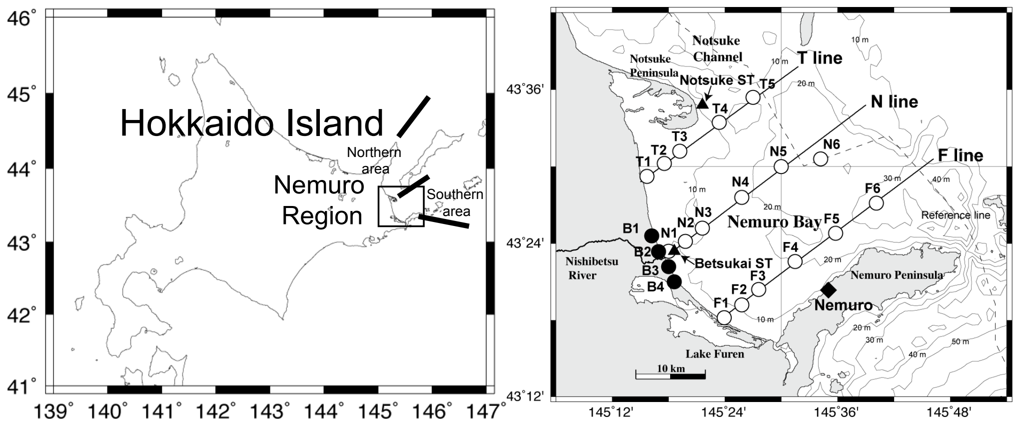

Fig. 1. Study area in the Nemuro region of eastern Hokkaido and positions of sampling stations in the littoral zone (B1-B4) and nearshore area (T1-T3, N1-N3, and F1-F3). Bathymetric data was provided by Japan Oceanographic Data Center.

In the littoral zone (B1-B4; Fig. 1), catch per unit effort (CPUE) exceeding 100 fish/net was observed at SSTs between 5˚-14˚C, and the frequency of high CPUEs was greater when SSTs were between 7˚-9˚C. In nearshore areas (T1-T3, N1-N3, F1-F3), CPUEs over 100 fish/km were observed at SSTs between 6˚-16˚C, and the frequency of high CPUEs was greater when SSTs were between 7˚-14˚C. The upper limit of SST experienced by juvenile salmon was lower in the littoral zone than in nearshore areas because fish migrated to the nearshore area as SSTs increased. The SSTs in nearshore areas where large numbers of juvenile chum salmon were caught was between 8˚-13˚C, which is consistent with previous reports (Pearcy et al. 1989; Kaeriyama 1986; Irie 1990; Seki 2005; Nagata et al. 2007).

Annual mean CPUE in the littoral zone was relatively low in 2007 and 2009 and relatively high in 2008 and 2010 (Fig. 2), however, no significant difference was observed. The number of days from 1 May until SSTs exceeded 8˚C at Betsukai ST was relatively high in 2008 and 2010 and relatively low in 2007 and 2009 (Fig. 2). The high annual mean CPUE in the

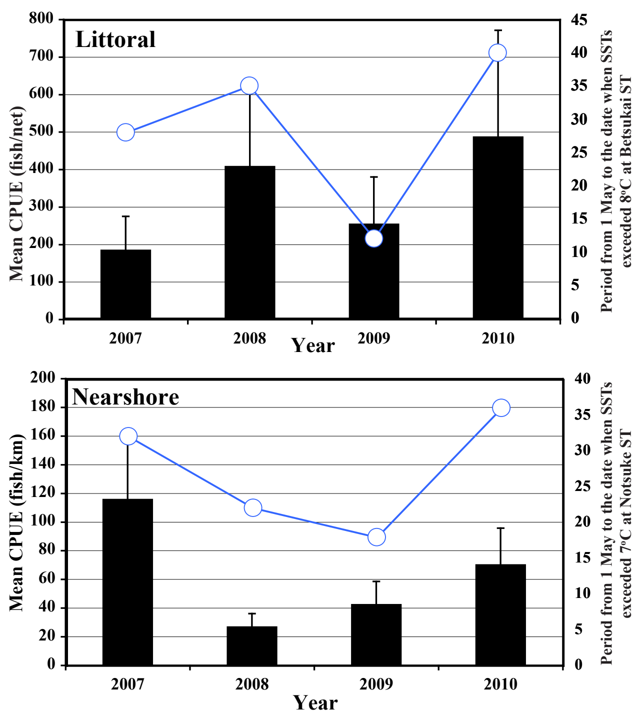

Fig. 2. Abundance of juvenile chum salmon and sea water temperature (SST) conditions in the littoral and nearshore areas in Nemuro Bay, eastern Hokkaido, 2007-2010. Upper panel: annual mean catch per unit effort (CPUE) of chum salmon in the littoral zone (black column and standard error) and number of days from 1 May to the date when SSTs exceeded 8˚C (line) at Betsukai Station. Lower panel: annual mean catch per unit effort (CPUE) of chum salmon in the nearshore area (black column and standard error) and number of days from 1 May to the date when SSTs exceeded 7˚C (line) at Notsuke Station.

littoral zone may be attributed to delayed SST increase at Betsukai ST because juvenile chum salmon cannot migrate to nearshore areas when SSTs are too low (Nagata et al. 2007).

Mean CPUE in nearshore areas when juvenile salmon were most abundant ranged from 681.75 fish/km in 2007 to 125.22 fish/km in 2008. The annual mean CPUE in nearshore areas was considerably higher in 2007 than in other years (Fig. 2). The amount of time that SSTs ranged between 8˚-13˚C at Betsukai ST was relatively short in 2007 and 2010. In contrast, the time period when SSTs exceeded 7°C at Notsuke ST, which is located outside Nemuro Bay, was longer in 2007 and 2010. The earlier timing for rising SSTs at Notsuke ST may spread the distribution of juvenile chum salmon out of Nemuro Bay, and thereby decrease the annual mean CPUEs in nearshore areas of the Nemuro region.

In the littoral zone and nearshore area, the date when the maximum number of marked chum salmon was recaptured varied from year to year. However, recapture of marked fish coincided with peaks in mean CPUE in the littoral zone and nearshore areas and did not coincide with release dates.

Stepwise multiple regression analyses were conducted to determine the relationships between number of recaptured marked fish and environmental variables. The number of days from 25 March to the release date (RELEASE), number of days from release date to the date when SSTs at Betsukai ST exceeded 8˚C (DAYS1), number of days when SSTs at Betsukai ST were 8˚-13˚C (DAYS2), and number of days from 1 May to the date when SSTs at Notsuke ST exceeded 7˚C (DAYS3) were used as predictors and the log-transformed number of marked fish recaptured in the littoral zone or nearshore areas was used as the dependent variable. Analysis of the littoral zone data showed RELEASE was significantly correlated with the quantity of recaptured marked fish ($p < 0.01$; Fig. 3). The later the release date the more recaptured marked fish were caught. In contrast, analysis of the nearshore samples showed RELEASE, DAYS1, and DAYS2 were significantly negatively correlated with the number of recaptured marked fish ($p < 0.05$). The absolute value of the adjusted regression coefficient was the highest for DAYS1, indicating that DAYS1 strongly influenced the number of marked fish recaptured in nearshore areas (Fig. 4). The number of marked fish recaptured in nearshore areas increased as time between the release date and the date when SSTs at Betsukai ST exceeded 8˚C decreased. These results suggest that high mortality may occur in the river and/or littoral zone before juvenile chum salmon migrate to nearshore areas.

Analysis of the nearshore data showed the intercepts of the growth curves were significantly different ($p < 0.01$; 2008 = 2009 > 2007 = 2010) among the groups released in mid April, although specific growth rates (SGRs; slopes) were not different. The SGRs and intercept of the growth curves were not significantly different among the groups released after mid April in 2007, 2008, and 2010. Environmental variability in coastal areas during spring may influence the growth of marked fish released in mid April more strongly than those released after mid April.

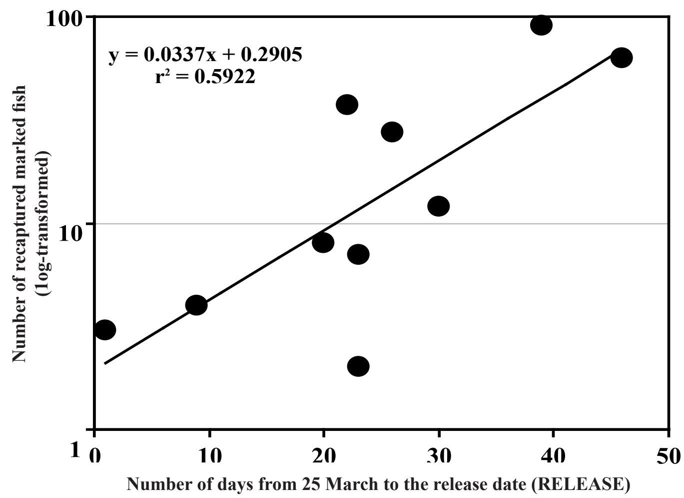

Fig. 3. Relationship between the number of days from 25 March to the juvenile chum salmon release date and the log-transformed number of marked fish recaptured in the littoral zone of Nemuro Bay, 2007-2010.

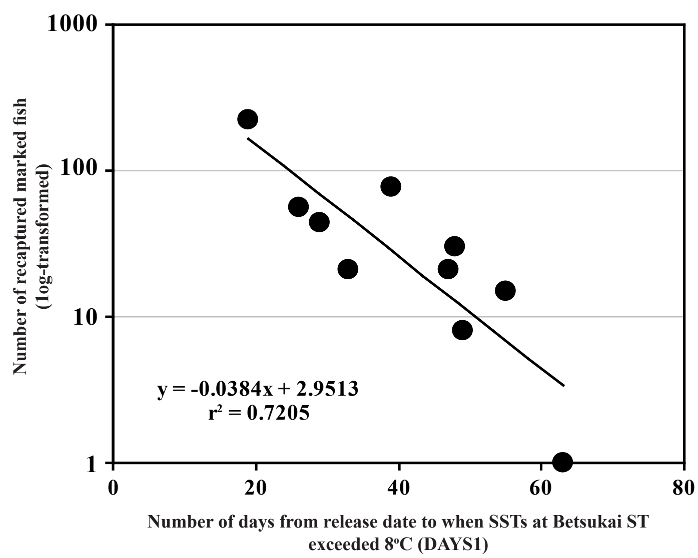

Fig. 4. Relationship between the number of days from the juvenile chum salmon release date to the date when sea surface temperatures exceeded 8˚C at Betsukai Station and the log-transformed number of marked fish recaptured in nearshore areas of Nemuro Bay, 2007-2010.

In conclusion, the SSTs in nearshore areas strongly influenced the distribution and abundance of juvenile chum salmon in Nemuro Bay. Delayed migration to nearshore areas from the river or littoral zone due to low SSTs may result in high mortality. Therefore, release timing of juvenile chum salmon in Nemuro Bay should be shifted from late March-late May to late April–mid May to increase juvenile chum salmon survival.

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