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Toshihiko Saito, Ikutaro Shimizu, and Jiro Seki

National Salmon Resources Center,

2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan

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National Salmon Resources Center, Fisheries Research Agency

2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan

Abstract

An otolith microstructure analysis was applied for juvenile chum salmon collected from the Nemuro Strait, eastern Hokkaido, Japan, during late June 1999-2002.   Sea entry check on otoliths was used as a benchmark for counting otolith growth increments, and its radius (i.e., distance from the otolith core to sea entry check) was employed for estimating size at sea entry of individual fish.   The large part of fish migrated to the sea in late May, except for 2002.   The timing of seaward migration was coincident with temporal patterns of chum releases in the northern areas of the Nemuro Strait.   The annual fork length at sea entry ranged from 48.10 to 51.10 mm on the average, which was close to the average fork length at release.   Specific growth rates during coastal residency were weakly, but significantly correlated with fork lengths at sea entry, except for 2001.   The present study indicated that the otolith microstructure analysis is valuable for estimating early life history of juvenile chum salmon.

Introduction

The mortality during early ocean life is thought to be the most influential life stage for determining brood-year strengths in salmon (Parker 1968; Ricker 1976; Bax 1983).   Within a stock, mortality appears to be the size- and growth rate-dependent, i.e., smaller, slower-growing juveniles tend to have lower survival (e.g., Hearley 1982).   Thus, growth during early ocean life is an important component for understanding the process of mortality.

In general, growth during early ocean life has been estimated by tracking of marked fry such as fin-clipped, alizarin complexone (ALC) dyed, and otolith-thermal marked fish (e.g., reviewed by Mayama and Ishida 2003).   However, the estimation depends on the degree of recapture: duration and frequency of recapture of targeted fish.   Furthermore, since average size at release of marked fish is used as the initial point for growth estimation, if marked fish with

smaller than the average size at release are recaptured, these data lead to underestimate of the growth (at least it is impossible to estimate individual growth for the fish having smaller than the average size at release).   Such recapture of smaller fish than the average size at release is not rare case in the mark-recapture study.

Recently, a method for estimating individual growth history on the basis of otolith check has been proposed for juvenile chum salmon inhabiting coastal waters (Saito et al. 2007).   In the method, sea entry check and/or change in otolith increment appearance are used as a benchmark for daily increment count.   One of the advantages of the method is that one can estimate individually growth history in coastal waters, even if a mark-recapture study is not planned.   Moreover, timing and size at sea entry of individual fish are also estimated, thereby a study for examining the relationship between seaward migration history and coastal growth being possible.

Here, we used the otolith technique for juvenile chum salmon inhabiting coastal waters to examine whether the technique is applicable for field data.

Materials and Methods

Juvenile chum salmon were collected in the Nemuro Strait, eastern Hokkaido, Japan, during late June 1999-2002 (Fig. 1).   Six transects were set perpendicular to the shoreline and each transect had eight survey points at maximum.   Each survey point   was located at 0.05, 0.25, 0.5, 1, 2, 4, 6, and 8 km from the shore.   Two types of purse seine nets were used for juvenile collection; one was 150 m long and 10 m depth, and the other 40 m long and 4 m depth.   The smaller net was mainly used at the survey points located near shore areas (<0.5 km from shore).   Those areas were very shallow in depth (<10 m) and several fishing gears were frequently placed for coastal commercial fisheries.   Under such conditions of near shore areas, the operation with the larger net was impossible.   Collected juveniles were immediately stored in deep freeze (-35ºC) until laboratory analyses.

In the laboratory, thawed fish were measured for fork length (to the nearest 0.01mm) and body weight (to the nearest 0.01g), and then otoliths (Sagita) were removed under a compound binocular by using two fine forceps.   After removing adhering tissue, otoliths were rinsed in distilled water and then dried at room temperature.   Otoliths were mounted on glass slides with thermoplastic cement (Buehler Ltd., Illinois, USA).   The surface of otoliths was lapped with 3 or 1µm diamond paste until the primordia were clearly exposed.   After finishing the lapping of one side of the otolith, the thermoplastic cement was melted on a tiny flame of a gas burner and

the otolith was turned over with a fine forceps.   Another side of the otolith was also lapped with the same manner mentioned above.   Measurement of otolith radius and distance from the core to sea entry check (hereafter, otolith radius at sea entry), and daily growth increment counts were made with an otolith measurement system (ARP/W Version 4.18; Ratoc system engineering Co., Ltd., Tokyo, Japan).   The radius and distance were measured along the measurement axis, which was perpendicular to the axis running through the otolith rostrum and the otolith core. Ordinarily the measurement axis in mid-dorsal area of the otolith was used.   The measurements were carried out at a magnification of 400 or 1000×.   The characteristic of sea entry check was detailed in Saito et al. (2007).

Since the relationship between otolith radius and fork length of juvenile salmon seemed to be exponential (Fig. 2), we assumed the individual otolith-length growth trajectories are also described by exponential equations.   Furthermore, all individual otolith-length growth trajectories are assumed to start from a biological intercept (Campana 1990).   Under those assumptions, individual otolith-length growth trajectories passing through the biological intercept and the point at the capture (i.e., fork length and otolith radius at capture) were estimated.   In the present study, the average length and otolith radius at hatch (fish length 20.44 mm, otolith radius 111.11µm) was used as the biological intercept.   The size at sea entry was then back calculated by incorporating the otolith radius at sea entry into individual otolith-length growth trajectories.   Coastal residence period of juveniles was estimated by the number of growth increments that formed after sea entry check, because growth increments are thought to be daily formed during at least first two months of coastal residency (Saito et al. 2007).   Those otolith microstructure analyses could not be carried out for all juvenile salmon, because the processes of the analyses needed much hours of labor.   Alternatively, 20 specimens at the maximum were randomly selected at the interval of 5 mm in fork length for the analyses.   For each 5 mm interval fish group, the frequency of the estimated day at sea entry was calculated at the interval of 10 days, and the frequency was expanded to the whole group.   To conduct such sub sampling for all fish groups, we estimated timing of sea entry of all juvenile salmon.   This sub-sampling finally made 132-156 specimens every year.

To examine whether estimated timing and size at sea entry corresponded to the actual juvenile migration history, we compared those data with release information on timing and size at release.   During the study period, 1999-2002, chum fry were released from 10-11 river systems discharging to the study areas (from the Notsuke peninsula to the top of the Shiretoko peninsula).   Thus, information on timing of release, release numbers, and average fork length at release for those river systems was collected.   Those data were generally available from the

Salmon database (National salmon resources center 2000-2003).   In the Salmon database, the number of released fry from each river system was reported for each size (weight) category. The category was as follows; fry with less than 0.4 g in weight, fry with more than 0.5 g in weight, pre-fingerling with 50-80 mm in fork length, and post-fingerling with more than 80 mm in fork length.   During 1999 and 2002, all released chum fry were categorized to fry with more than 0.5 g or pre-fingerling in the study areas.   To estimate average fork length at release, we assumed that the fork length of the former category was 37.46 mm and that of the latter 50 mm. The former size was calculated by incorporating 0.5 g into the weight-fork length relationship obtained in this study.   The annual average fork length at release was then calculated by weighting those average lengths with the release numbers of each category.

To evaluate growth during coastal residency, specific growth rates (SGR) was calculated by using the following equation (LeBrasseur and Parker 1964); $SGR=(\ln FL_c - \ln FL_{se}) / t$, where FL_c and FL_{se} represent fork length at capture and that at sea entry, respectively, and t is days from sea entry to capture.   For FL_{se} and t, we used individually back-calculated fork length at sea entry, and the number of otolith growth increments after sea entry check, respectively.

Results

During the study period, late June 1999-2002, the number of survey points where purse seine operations were carried out ranged from 16 to 38 (Table 1).   The relatively low frequency of the purse seining was due to stormy weather, coastal fisheries, and net trouble.   Since total number of purse seining was limited, survey points where juvenile chum salmon were collected were also few.   Nevertheless, a substantial number of juvenile salmon was captured.   This may reflect the distribution pattern of juvenile salmon; fish tend to form patches rather than disperse in coastal waters.

Figure 3 shows size frequency distribution of juvenile salmon.   Average fork lengths (standard deviation) for 1999-2002 were 58.69 mm (5.95), 61.71 mm (8.02), 64.97 mm (8.18), and 63.06 mm (7.35), respectively.   The average fork length was significantly different among the years (one-way ANOVA; $F_{3,3815} = 137.88$, $p < 0.0001$: Scheffé's test; all multiple comparisons were significant. $p < 0.05$).

The estimated timings of sea entry appeared to be similar to the release timings of chum fry every year (Fig. 4).   The number of released chum fry increased gradually from early May (for 2002, from late April), reached its peak in late May, and then rapidly decreased in June. The annual number of released fry ranged from 105 millions in 2001 to 113 millions in 1999.

The peak of the timing of sea entry was also coincident with that of the release, except for 2002. In 2002, the proportion of chum fry released before middle May was relatively higher, as compared with that of the other three years. This tendency in released chum fry may be reflected to the timing of sea entry in 2002.

The estimated average fork length of released chum fry during 1999-2002 was 49.27 mm, 49.14 mm, 49.75 mm, and 49.36 mm, respectively. On the other hand, the average fork length at sea entry ranged from 48.10 to 51.10 mm (Fig. 5). The average fork length at sea entry for 2002 was significantly smaller than that for 1999 and 2000 (one-way ANOVA; $F_{3, 580} = 5.95$, $p < 0.001$: Scheffé's test; 1999 vs. 2002, and 2000 vs. 2002, $p < 0.05$, the other combinations, all $p > 0.05$). Since variations in the estimated fork length at release were unknown, statistical tests were inappropriate for comparing average fork lengths at release with those at sea entry. Furthermore, the average fork length at release was surely underestimate, because the minimum fork length in each size category was used for calculating the annual average fork length (see, above). Although the estimated average fork length at release contained some degrees of uncertainty, the average fork length at sea entry was apparently coincident with that at release.

Figure 6 represents frequency distributions of specific growth rates between the day of sea entry and that of capture. The annual average for 1999 and 2001 was significantly greater than that of 2000 and 2002 (one-way ANOVA; $F_{3, 580} = 30.12$, $p < 0.0001$: Scheffé's test; 1999 vs. 2000, 1999 vs. 2002, 2000 vs. 2001, and 2001 vs. 2002, $p < 0.0001$, the other combinations, all $p > 0.05$). Within each year, individual fork lengths at sea entry were weakly, but significantly correlated with their specific growth rates after sea entry, except for 2001 (Year 1999; $r = 0.30$, $n = 148$, $p < 0.001$, Year 2000; $r = 0.52$, $n = 156$, $p < 0.0001$, Year 2001; $r = 0.10$, $n = 132$, $p > 0.05$, and Year 2002; $r = 0.56$, $n = 148$, $p < 0.001$).

Discussion

The objective of the present study was to apply an otolith microstructure analysis proposed recently to the field data. The temporal patterns of estimated timing of sea entry showed similar tendencies in those of release numbers. Although the accurate values for annual average fork length at release were unknown, the annual average fork length at sea entry was also close to that at release. From those results, release operations (e.g., release timing and size at release) appear to influence individual sea entry events. Generally, released chum fry migrate seaward in a few days (Mayama and Ishida 2003). Thus, those coincidences observed in this study are thought to be quite reasonable.

In the study areas, about half of the number of fry released in late May every year. Taking the sampling period into account, we assessed mainly one month of coastal residency of released chum salmon. During this period, juvenile salmon attained about 59-65 mm in fork length on the average. Several authors reported that juvenile chum salmon with more than 70-80 mm in fork length migrate toward offshore (Mayama et al. 1982; Kaeriyama 1986; Irie 1990). According to the classification for early life history of chum salmon (Kaeriyama 1986), large part of juvenile salmon in the present study was considered as being categorized into inshore migration stage.

During about one month of coastal residency, specific growth rates of juvenile salmon after sea entry appeared to vary greatly among individual fish. The observed annual averages of specific growth rates ranged from 0.0065 to 0.0078. The average values were within the range of specific growth rates (0.005-0.020 for fork length) previously reported for Japanese juvenile chum salmon (Mayama and Ishida 2003). Although average specific growth rates more than 0.01 have been frequently observed in the previous studies, such high growth rates were not common in our estimation. Since those previous studies were mainly carried out in coastal waters of Honshu, more south than Hokkaido, this geographical difference might cause the difference in specific growth rates. Other explanation will be also possible. Seki (2005) reported that specific growth rates estimated in off the Pacific coast of Hokkaido ranged from -0.0025 to 0.0138. In his study, he pointed out a possibility that fish recaptures from limited study areas make estimation of specific growth rates small values because juveniles growing faster tend to migrate further distance (i.e., out of the study areas). Therefore, it is necessary to pay much attention for comparing specific growth rates obtained from different study programs.

Of four years' study, the result of three years demonstrated that specific growth rates were positively correlated with fork lengths at sea entry. This result suggested that juveniles migrating to the sea with larger body size tend to grow better after sea entry. In only 2001, however, there was no correlation between them. In salmonid species, conflicting evidence has been reported about the relationship between freshwater and marine growth performance (Snover et al. 2005). To understand the mechanisms of positive and negative relationships between pre- and post-smolt growth rates, Snover et al. (2005) constructed a model to evaluate growth rates under conditions of varying resource acquisition in response to the behavior-environmental interaction. According to their model, the distribution patterns of marine resources (clumped or dispersed) influenced the advantage (or disadvantage) of aggressive behavior (i.e., body size), resulting in positive (or negative) relationships between pre- and post-smolt growth. In the Nemuro Strait, zooplankton abundance in 2001 was five times higher than that in other three

years (Seki 2004). The high food availability for juveniles may offset size advantage at sea entry in 2001.

The present study indicated that the otolith microstructure analysis is valuable for estimating early life history of juvenile chum salmon. In particular, since this technique can examine relationships between sea entry behavior and growth performance after sea entry, the information obtained from this technique may be also useful for improving hatchery programs.

Acknowledgements

References

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

Campana, S. E. 1990. How reliable are growth back-calculations based on otoliths? Can.J. Fish. Aquat. Sci. 47: 2219-2227.

Healey, M. C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon 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 Natl. Fish. Res. Inst. 68: 1-142.

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.)

LeBrasseur, R. J., and R. R. Parker. 1964. Growth rate of central British Columbia pink salmon (*Oncorhynchus gorbuscha*). J. Fish. Res. Bd. Can. 21: 1101-1128.

Mayama, H., and Y. Ishida. 2003. Japanese studies on the early ocean life of juvenile salmon. N. Pac. Anadr. Fish Comm. Bull. 3: 41-67.

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 distribution of liberated fry in 1979. Sci. Rep. Hokkaido Salmon Hatchery, 36: 1-17. (In Japanese with English abstract.)

National Salmon Resources Center. 2000. Database on juvenile Pacific salmon released from Japan. 8(2), 108p.

National Salmon Resources Center. 2001. Database on juvenile Pacific salmon released from Japan. 9(2), 113p.

National Salmon Resources Center. 2002. Database on juvenile Pacific salmon released from Japan. 10(2), 122p.

National Salmon Resources Center. 2003. Database on juvenile Pacific salmon released from Japan. 11(2), 98p.

Parker, R.R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. J. Fish. Res. Bd. Can. 25: 757-794.

Ricker, W. E. 1976. Review of the growth rate of and mortality of Pacific salmon in salt water, and non-catch mortality caused by fishing. J. Fish. Res. Bd. Can. 33: 1483-1524.

Saito, T., T. Kaga, J. Seki, and T. Otake. 2007. Otolith microstructure of chum salmon *Oncorhynchus keta*: formation of sea entry check and daily deposition of otolith increments in seawater conditions. Fish. Sci. 73 (in press).

Seki, J. 2004. Fluctuation in zooplankton and distribution of juvenile chum salmon in the Nemuro Strait. National Salmon Resources Center Newsletter, 12: 1-6. (In Japanese.)

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. National Salmon Resources Center, 7: 1-104. (In Japanese with English abstract.)

Snover, M. L., G. M. Watters, and M. Mangel. 2005. Interacting effects of behavior and oceanography on growth in salmonids with examples for coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 62: 1219-1230.

Table 1. Summary of juvenile salmon survey conducted in the Nemuro Strait, eastern Hokkaido, Japan, in the late June 1999-2002.   The specimens for otolith microstructure analysis were selected from those fish to estimate growth history after sea entry.

Year	Date of survey	No. of survey points with purse seining	No. of survey points where juvenile chum salmon were collected	No. of captured juvenile chum salmon
1999	22-23 June	25	18	1901
2000	27-28 June	16	6	1222
2001	27-28 June	38	6	402
2002	26-27 June	31	16	752
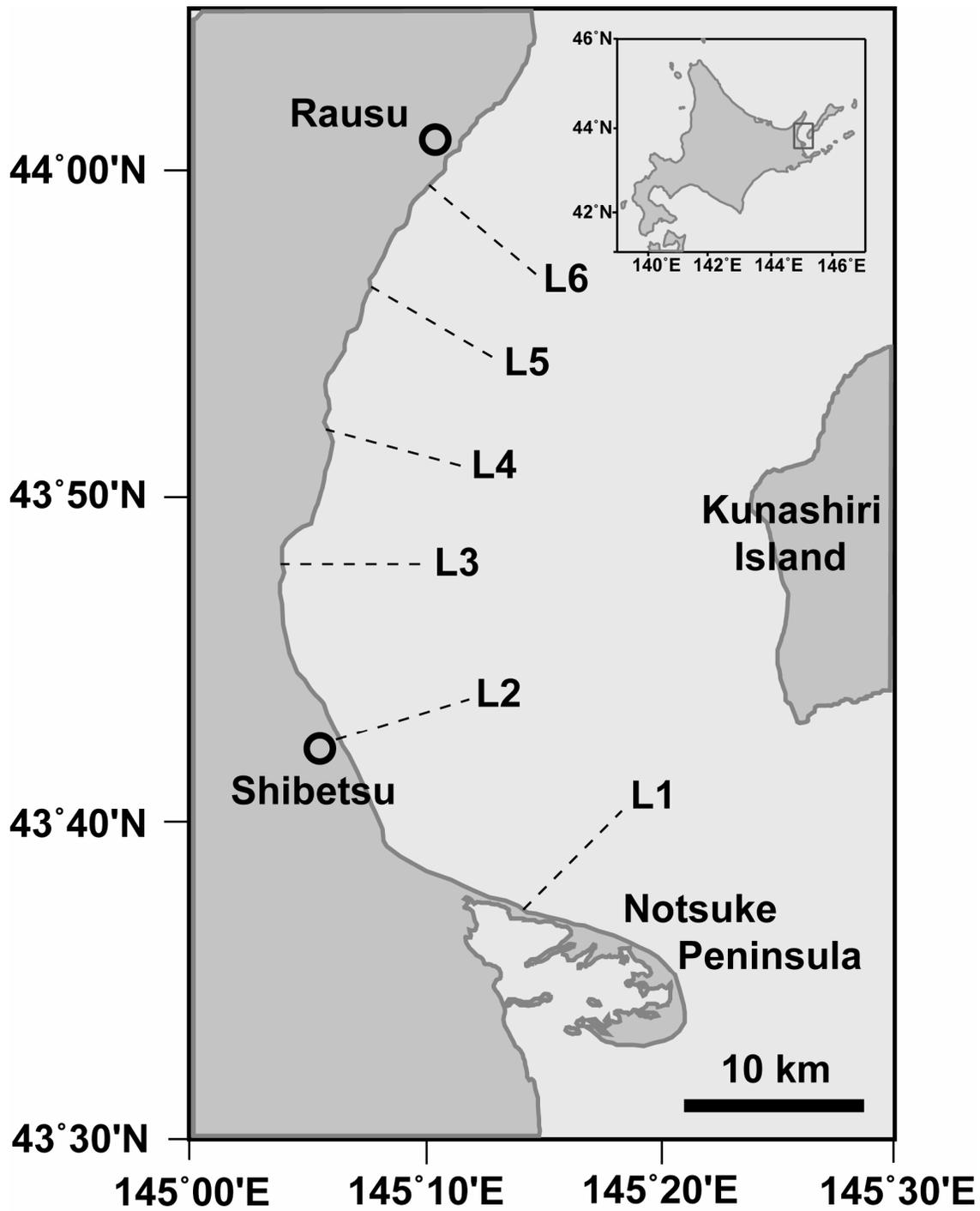
Fig. 1. Map of the study areas. L1-6 represent transect lines. Along each transect, eight survey points were set at the maximum. Each survey point was located at 0.05, 0.25, 0.5, 1, 2, 4, 6, and 8 km from the shore.
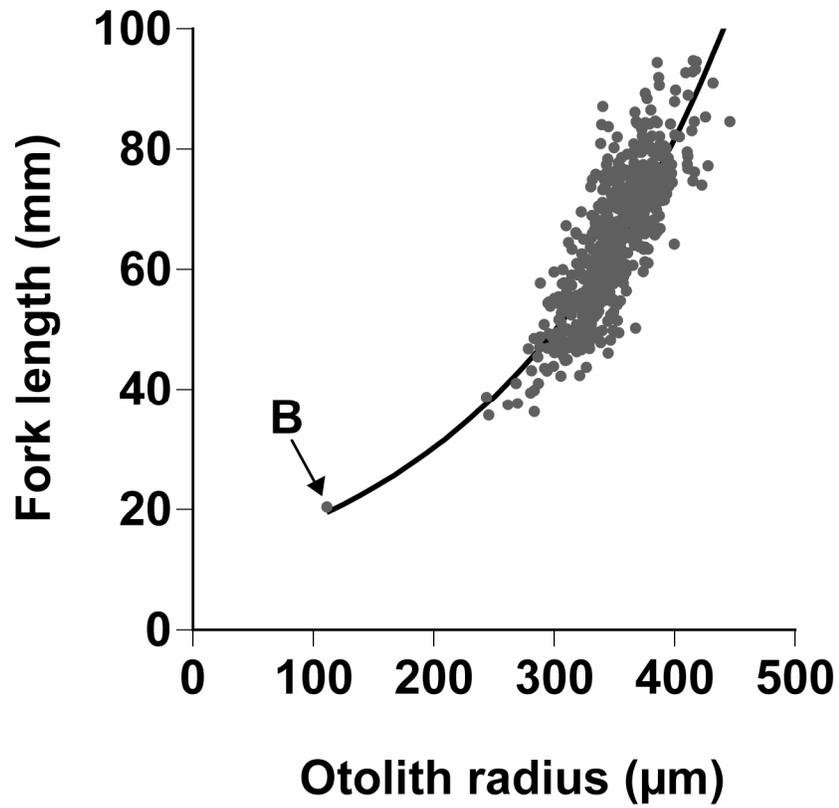
Fig. 2. Relationship between otolith radius and fork length for juvenile chum salmon collected from coastal waters (the Nemuro Strait), except for the data point "B". "B" represents the point at hatch (111.11 µm, 20.44 mm). The line shows a fitted exponential relationship.
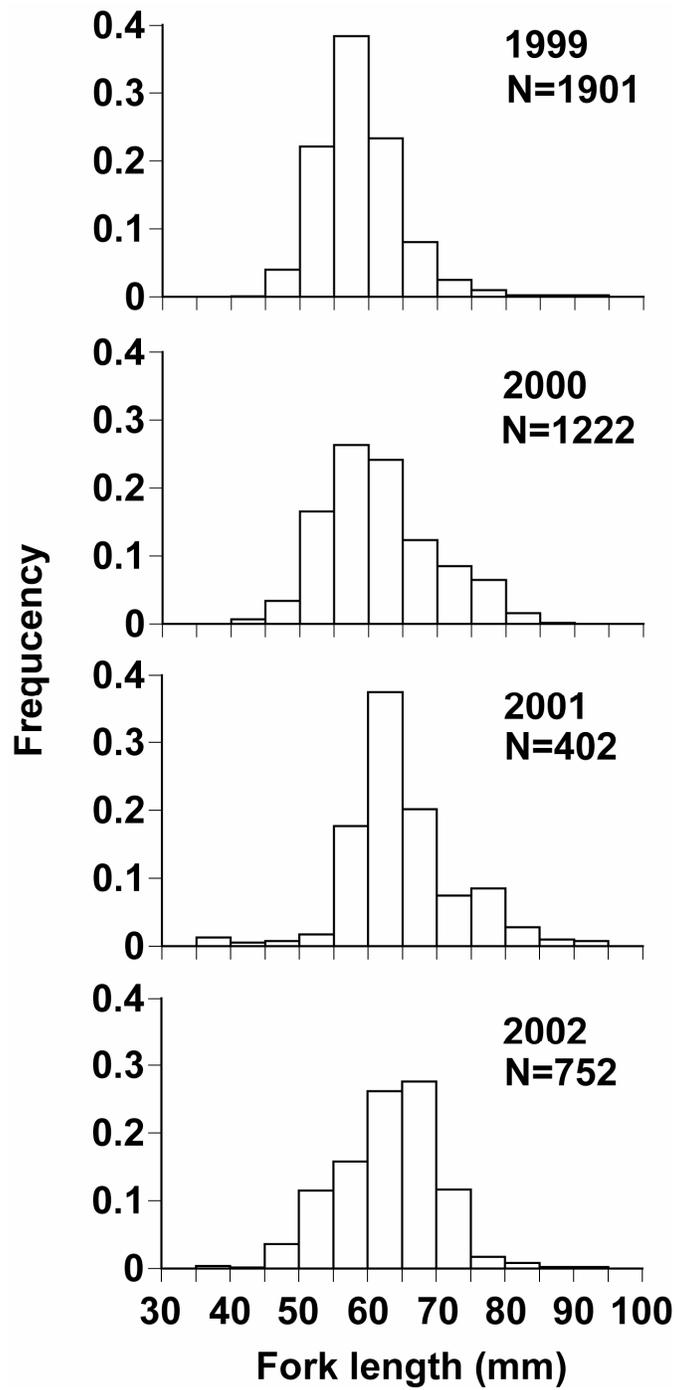
Fig. 3. Fork length distributions for juvenile chum salmon collected from the Nemuro Strait during late June 1999-2002. "N" indicates the number of collected fish.
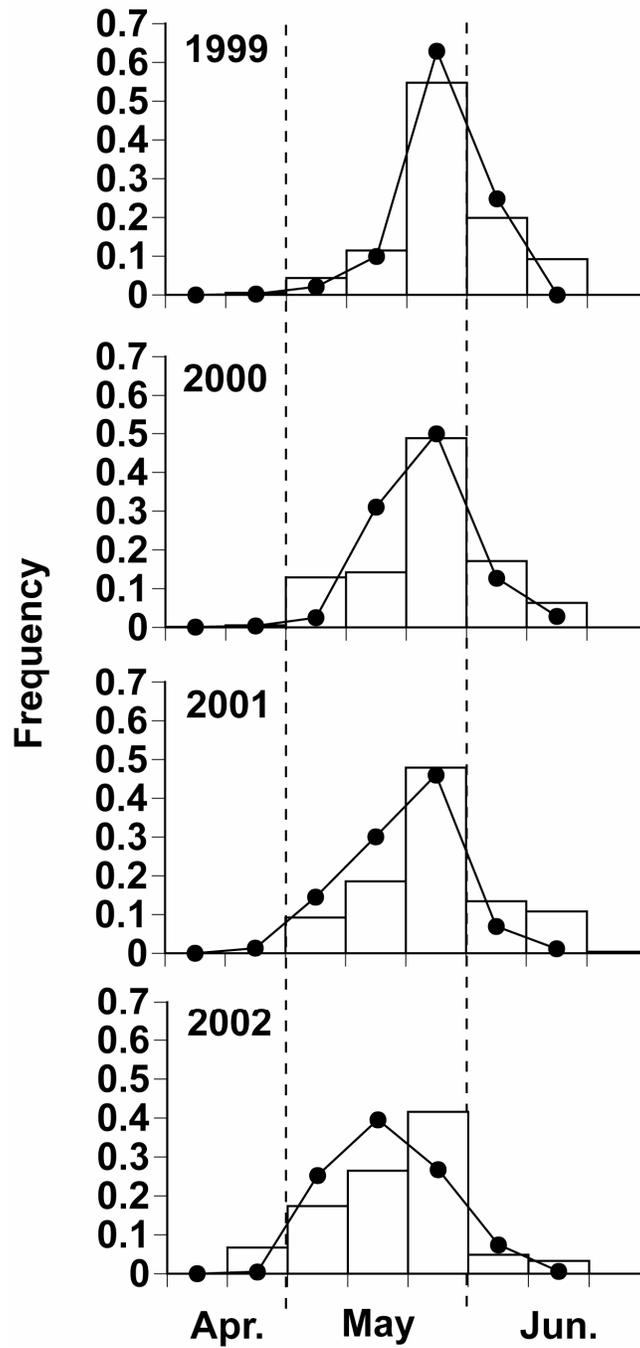
Fig. 4. Frequency distributions for the numbers of released chum fry (open bars) and of juveniles entering to the sea (lines) in the Nemuro Strait during 1999-2002. Timing of sea entry was estimated with an otolith microstructure analysis on the basis of juveniles collected in late June.
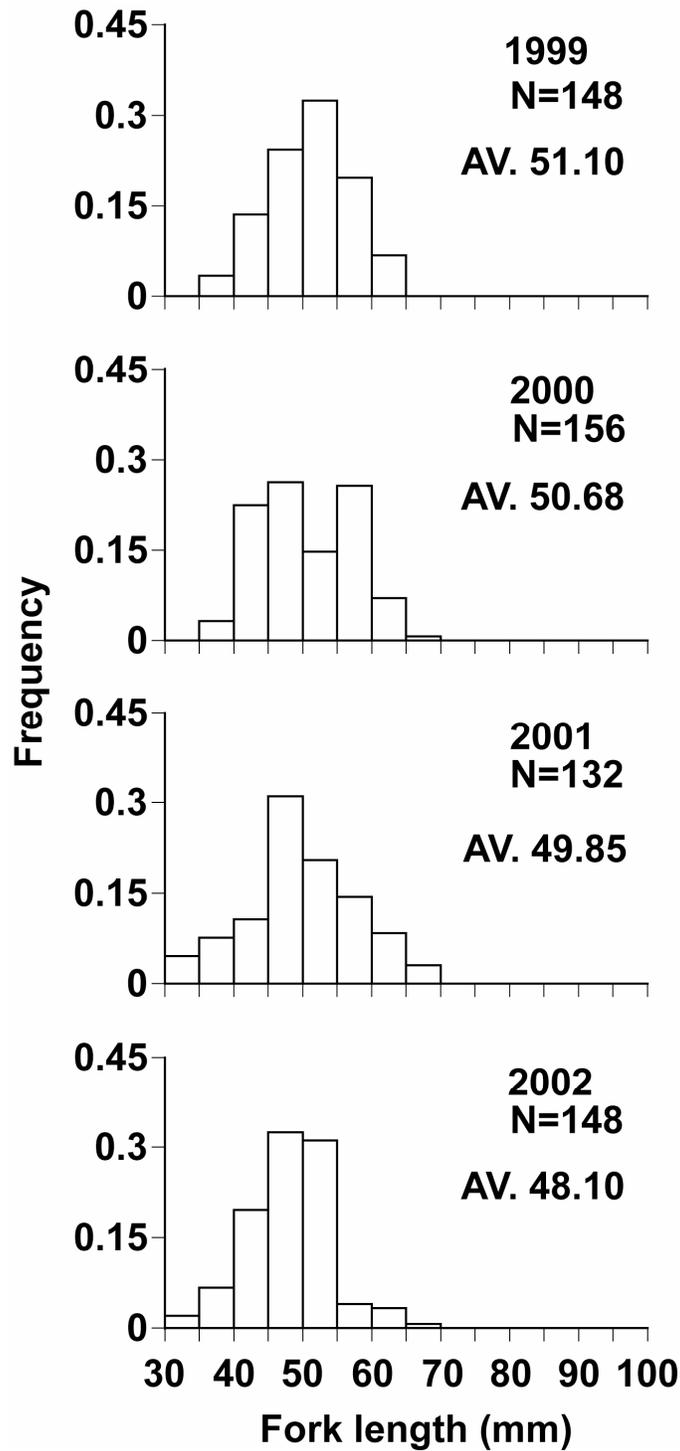
Fig. 5. Frequency distributions of fork length at sea entry for juvenile chum salmon collected from the Nemuro Strait. The fork length at sea entry was estimated with an otolith microstructure analysis on the basis of juveniles collected in late June. The abbreviation "AV." means average fork length.
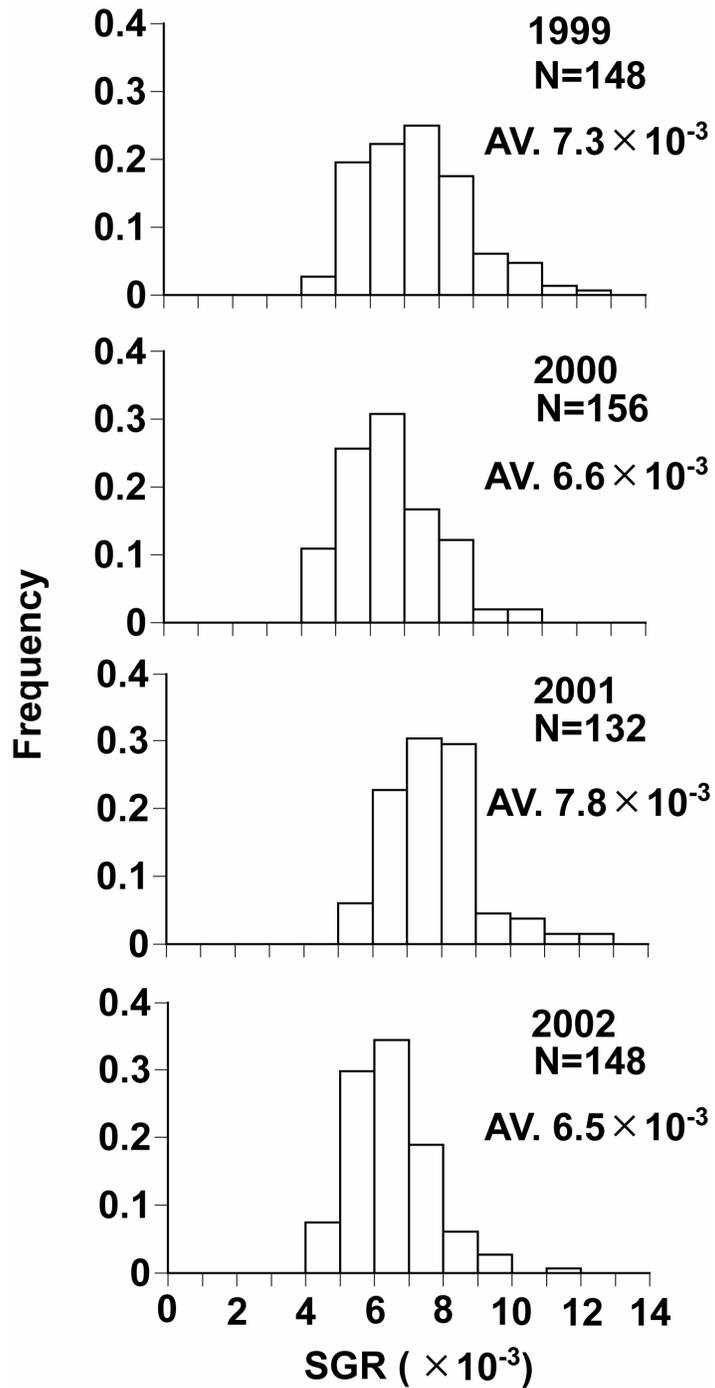
Fig. 6. Frequency distributions of specific growth rates (SGR) for juvenile chum salmon collected from the Nemuro Strait. The days after sea entry and fork length at sea entry were individually estimated with an otolith microstructure analysis on the basis of juveniles collected in late June. The abbreviation "AV." means average SGR.