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THE BEHAVIOR AND AMBIENT TEMPERATURE OF HOMING CHUM SALMON MONITORED BY A DATA LOGGER

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Abstract: We studied the behavior of homing chum salmon in coastal waters using a data logger tagging method that will increase the duration of study and sample size without tracking effort We used data loggers, which can record the depth data and the temperature data simultaneously for 19.3 days at 5 and 10 s intervals, respectively. In late November 1994 off the coast of Sanriku, northern Honshu, we released eight homing adults with data loggers, three loggers were retrieved near the release site after 0.8–1 3 days. A possible reason for missing loggers is the accidental detachment of instruments General feature of vertical behavior of salmon was similar to previous results obtained by a transmitter-tracking system; salmon made a series of ascents and descents, whose vertical speed was about 0 1–0.3 m/s, and returned frequently to the surface water. As a result, salmon made large amplitude zigzag motions starting from the surface water The median thickness of the water column where salmon traveled through in two minutes was 3 2–6 5 m The vertical thermal structure was well mixed. There was no consistent tendency of behavior in relation to the ambient water temperature The observed large amplitude of vertical zigzag motion could be typical behavior of homing chum salmon in our study area in the isothermal water column. We conclude that use of a data logger holds promise for behavior studies of homing adult salmon, which facilitate recovery of the instruments by returning to natal rivers.

key words: chum salmon, homing migration, swimming behavior, data logger, coastal waters

Introduction

This paper describes an application of data loggers to study homing behavior and ambient water temperature of chum salmon in coastal waters. Pacific salmon migrate from the ocean to their natal river for spawning. The migration involves orientation in the open sea, coastal waters, and streams (DØVING *et al.*, 1985). It is well established that during their upstream migration adult salmon utilize olfactory cues to reach their spawning ground (HASLER *et al.*, 1978). In contrast, the navigation mechanism of salmon in the open ocean is still a matter of controversy (QUINN, 1991). To evaluate various hypotheses, behavior of salmon related to homing migration in a fjord system (DØVING *et al.*, 1985), channel (RUGGERONE *et al.*, 1990) and straits (QUINN, 1988; QUINN *et al.*, 1989) have been studied intensively. In the marine environment, the behavior of homing salmon has usually been studied using continuous monitoring by acoustic transmitter. In this method, a salmon attached with a transmitter must be tracked by a boat equipped with a directional hydrophone throughout the experiment. Thus difficulties in tracking limited the study site to coastal waters, the study duration to a few days or even less, and the number of observations to small size (BOEHLERT, 1997).

Newly developed data logger tagging can record various data, such as swimming depth, ambient temperature, internal temperature, and swimming speed, over a long term without need for continuous tracking. This work was pioneered with seals, and recent reduction in the size of data loggers has led to a proliferation of studies on smaller aquatic tetrapods and birds (KOOYMAN *et al.*, 1992). The success of the logger study depends greatly on recovery of the loggers. The salmon are suitable subjects for logger studies, since homing migration of the salmon to their natal river facilitates the logger recovery. The first application of data loggers to salmonids has already been conducted in Iceland and Japan in 1993 (BOEHLERT, 1997).

We developed a micro data logger that could record depth and temperature simultaneously. This logger is very small and can be applied to the studies on smaller pelagic fish like pacific salmon. Using this logger, we carried out a preliminary experiment to study the behavior of homing adult chum salmon (*Oncorhynchus keta*) in Otsuchi Bay, northern part of Honshu Island, Japan, in 1994. In the same area, there is a previous report on the homing behavior of chum salmon using tracking methods (ISHIDA *et al.*, 1988); thus it is possible to compare the data obtained by two different methods. The objective of this study was (1) to establish experimental procedures for applying loggers to study salmon behavior and (2) to describe general features of the data as compared with previous studies using acoustic tags.

Materials and Methods

Data loggers (Little Leonard Co. Ltd., Tokyo) used in the present study can record depth and temperature of seawater. The loggers were cylinder shape, 75 mm long, 19 mm in diameter, and weighed 35 g in air and 14 g in water, that is, equivalent to 1.2% of a 3 kg salmon. The logger can store 250000 data (8-bit) in 0.5 megabyte of Flush memory. We simultaneously recorded the depth and the temperature data at 5 and 10 s intervals, respectively. Theoretical maximum length of the data sampling is 19.3 days at these sampling rates. Resolution of the depth channel was 0.1 m and that of the temperature channel was 0.1°C within the ranges of measurement (0 to 200 m and −10 to 50°C, respectively).

The experiment was carried out in Otsuchi Bay, Iwate prefecture, northern part of Japan (Fig. 1), which has a width of 3.5 km at the bay mouth and a depth of less than 90 m. The Otsuchi, Kozuchi and Unosumai rivers, the natal rivers for the salmon

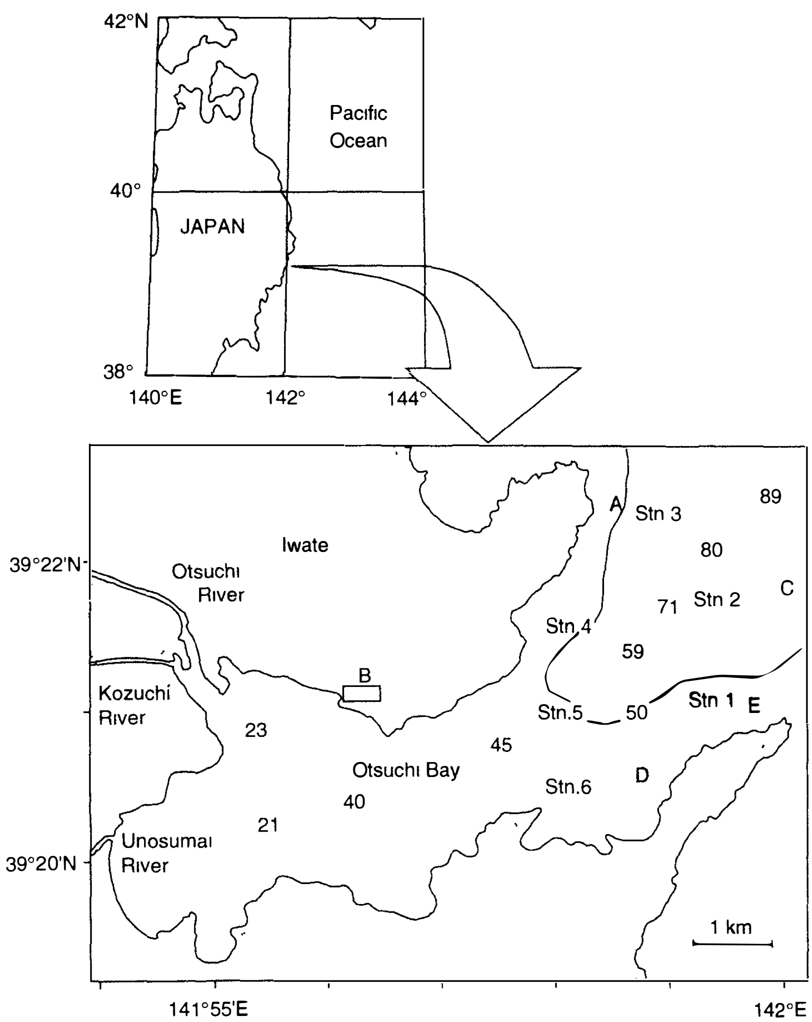

Fig. 1 The experiments were carried out in Otsuchi Bay, Iwate prefecture, northern Japan. Locations of salmon trap nets are indicated in the gray area. Salmon were captured in a trap net (A), transferred to laboratory (B), released from the bay mouth (C), then recaptured in nets at D (salmon 9401), A (9408), and E (9403) Vertical profiles of temperature and salinity were measured at Stations 1-6 Depths are in meters and the 50 m contour lines are indicated.

used in this study, flow into the bay. The distance from the river mouths to the bay mouth is about 6.5 km. The coast of Otsuchi Bay is covered with many salmon trap nets, giving the high possibility of recapturing tagged salmon. The chum salmon used in this study were homing mature adults. All fish were caught by a salmon trap net at the bay mouth (Fig. 1) around noon on November 22, 1994. In order to gain a high retrieval rate, we chose the fish at the final stage of sexual maturation, which are expected to ascend the one of the rivers flowing into the bay relatively soon. The fish were transferred into the outdoor tank of Otsuchi Marine Research Center, Ocean Research Institute, University of Tokyo located at the bay side. Fish were lightly anesthetized by 2-phenoxy ethanol, and total length and body weight were measured. All the fish were easily sexed because of the apparent secondary sexual characteristics. In a previous study (QUINN *et al.*, 1988), 2-phenoxy ethanol appeared to have no adverse effect on homing of pacific salmon. A data logger was sutured to the right side of the body, below the front edge of the dorsal fin, with nylon ties covered with a silicone tube. The laboratory address and request for fishermen to return any data loggers were printed on the sides of the loggers. After the attachment of loggers, the fish were transferred to a recovery tank and allowed *ca.* 40 hours to recover from anesthesia and surgery. On the morning of November 24, eight fish with loggers were released from the middle of the bay mouth (Fig. 1). The general features of salmon are summarized in Table 1. Immediately after the release, we took profiles of temperature and salinity from the surface to the bottom of the bay at Stations 1 to 6 using STD (Alec Electronics Co., Ltd.) (Fig. 1). The behavior of the salmon might be affected at the beginning of the release and in the trapnet due to tagging and handling stress. However, such a stress is difficult to assess. Therefore, we did not exclude any data from statistics.

Results

Logger recovery

Eight salmon were released and three loggers were returned by fishermen. Loggers alone were discovered detached from the salmon the day after the release. We obtained data from two loggers that had been attached to females (salmon 9401 and 9408), but another logger (salmon 9403) malfunctioned. The general features of salmon 9401 and 9408 are summarized in Table 1. The trapnets where salmon were recaptured were located inside the bay (salmon 9401) and at the bay mouth (salmon 9408 and 9403) (Fig. 1). The distances between release and recapture points were 2.8 and 2.0 km. We estimated the time of catch of the salmon from the depth data in loggers. Durations of data records were 19.7 and 29.9 hours for salmon 9401 and 9408, respectively.

Vertical movement

The records of behavior and ambient temperatures of salmon 9401 and 9408 are shown in Fig. 2a and 2b, respectively. Repeated descents and ascents formed a

Table 1. Body size, time and location of retrieval and data length for chum salmon which were released with data loggers on 24 November, 1994.

Salmon no.	Sex	Total length (cm)	Mass (kg)	Recapture		Data length (hour)
				Time	Location	
9401	F	56.5	2.4	dawn	D (midst of the bay)	19.7
9402	M	66.0	4.3	—	—	—
9403	M	65.7	4.3	dawn	E (mouth of the bay)	—
9404	M	69.0	4.6	—	—	—
9405	M	64.0	3.8	—	—	—
9406	F	62.0	3.9	—	—	—
9407	F	66.5	3.8	—	—	—
9408	F	65.5	3.8	noon	A (mouth of the bay)	29.9

Note: Data loggers attached to salmon no. 9401, 9403 and 9408 were retrieved the day after the release but the others were not. The logger of no. 9403 malfunctioned.

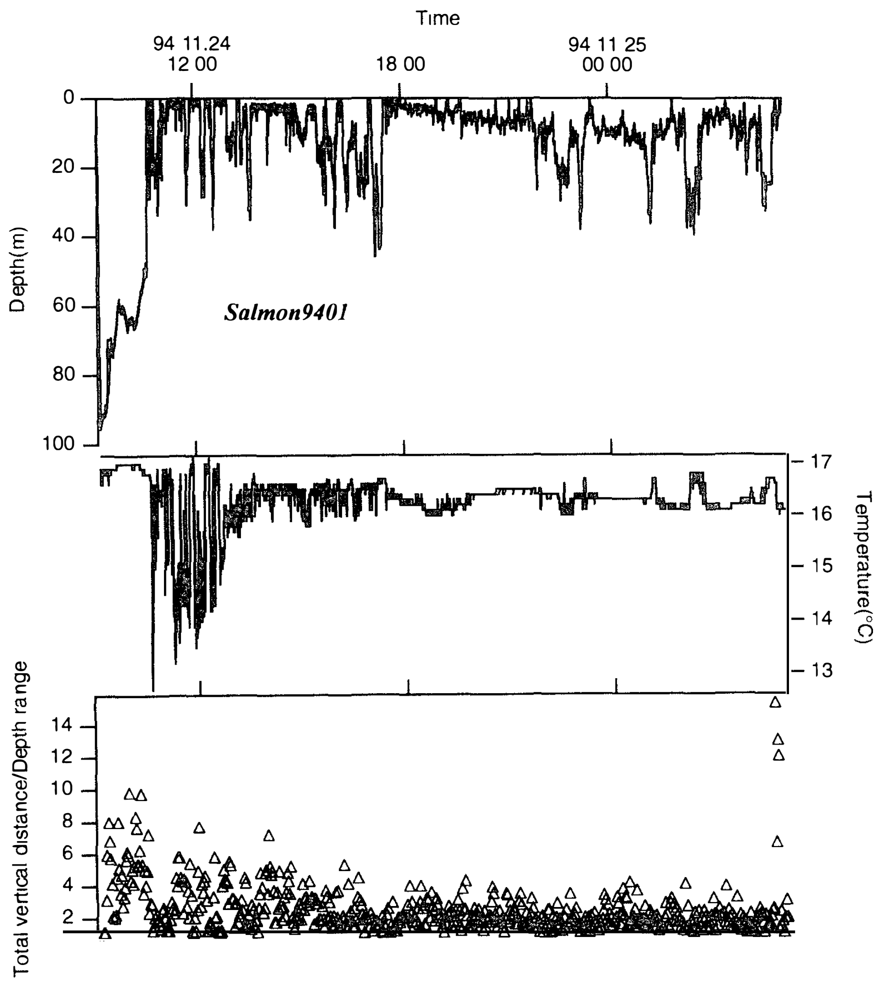

Fig. 2a Swimming depth (upper), ambient water temperature (middle), and the calculated ratio of total movement distance to depth range in which the salmon stayed for at least two minutes (lower) in salmon 9402 Sampling intervals of depth and temperature were 5 and 10 s, respectively

characteristic feature of the salmon behavior. With the result that ascent swimming followed the descent of salmon to the fish's former depth of travel, salmon spent a considerable time in the surface water. The median times between returns to the top 3 m of water were 80 (range: 15-8180, *n*: 117) and 105 (range: 15-5125, *n*: 239) s for salmon 9401 and 9408, respectively.

Immediately after the release, salmon 9408 made steep dives to approximately 100 m (Fig. 2b). These dives had jagged bottoms with frequent small changes in depth (Fig. 3). This type of dive with a relatively flat bottom occurred continuously up to 1400 LT (Fig. 2b). The bottom depth of these dives became gradually shallower with time. After the series of active vertical movements, salmon ceased the large zigzag movement almost completely and stayed in the water column between the depth of 1.0 and 1.4 m for one and a half hours (from 1505 to 1645). After dusk, the salmon restarted the active zigzag motion but remained shallower water than 20 m. A large amplitude vertical motion began again at around 0700 the following morning. With time elapsed,

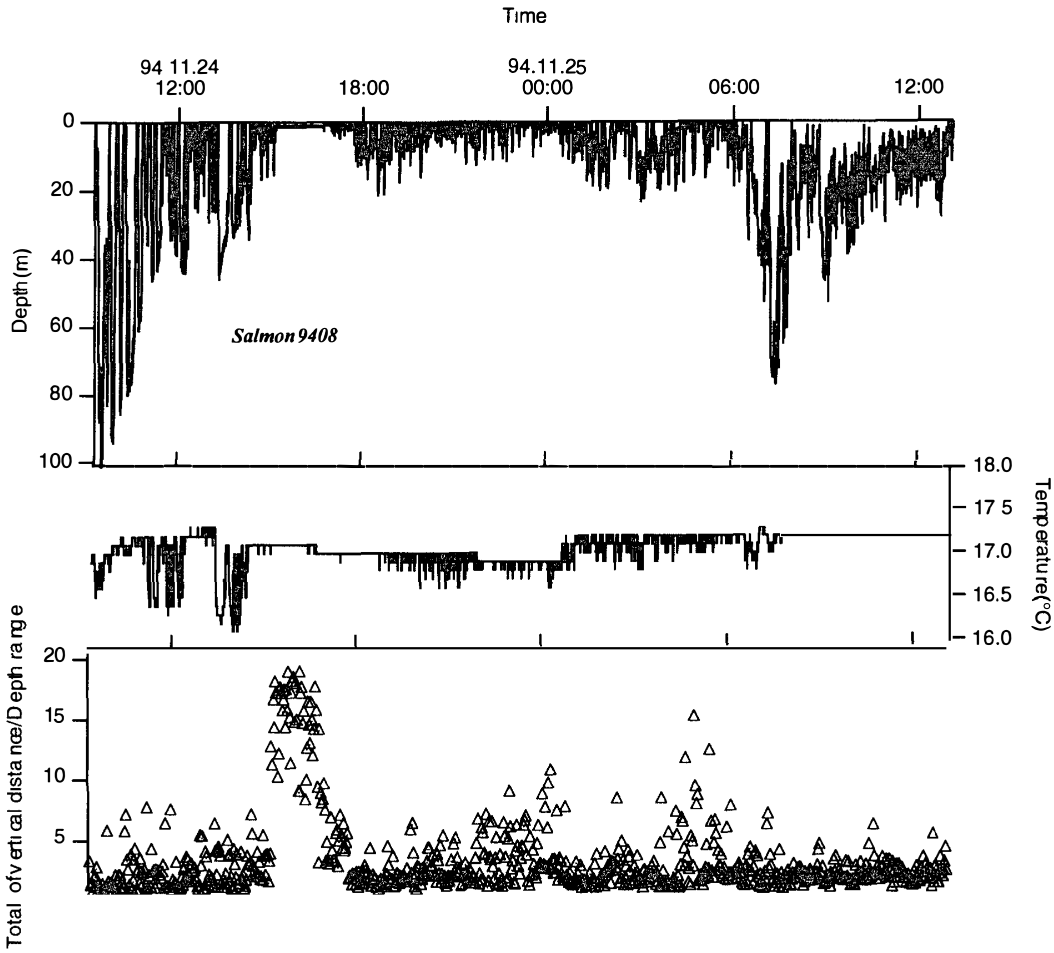

Fig. 2b. Same as Fig. 2a but for in salmon 9408.

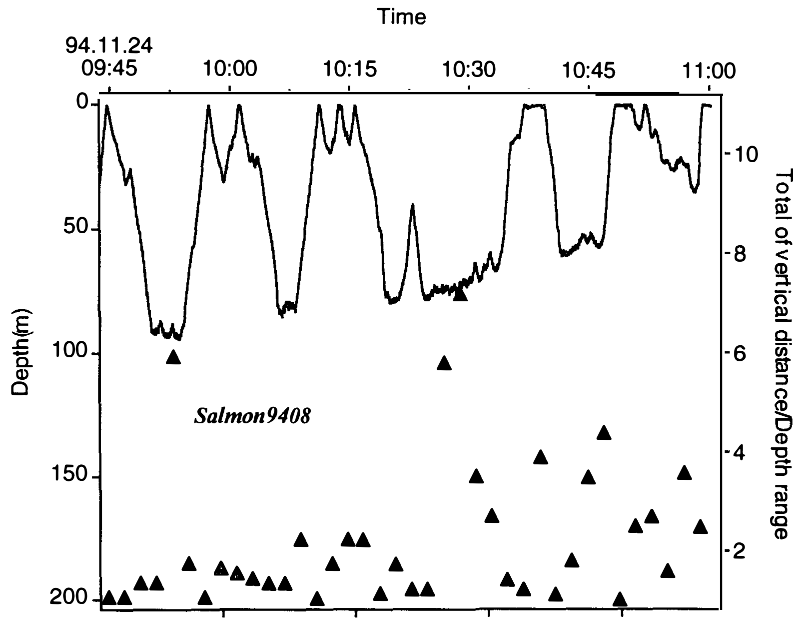

Fig. 3. Initial part of record selected to illustrate dives with jagged bottom by salmon 9408

the salmon tended to stay shallower again until the recapture around noon. The general feature of swimming depth of salmon 9401 was basically similar to that of salmon 9408 (Fig. 2a). Salmon 9401 also made an initial deep and long dive with a zigzag bottom. However, the movement pattern did not show a clear tendency in relation to the hour of day.

We calculated the moving speed, duration and distance of vertical movements of each salmon from the depth data. These values were calculated for each vertical movement, defined by the break points where the direction was reversed. To elucidate the nature of sustained vertical movements, slight movements of salmon, less than 1 m, have been excluded from the statistics. There were 1054 (salmon 9401) and 2727 (9408) vertical movements recorded. The relation of duration to vertical distance is plotted in Fig. 4. The correlation coefficients for the relationship of duration to vertical distance

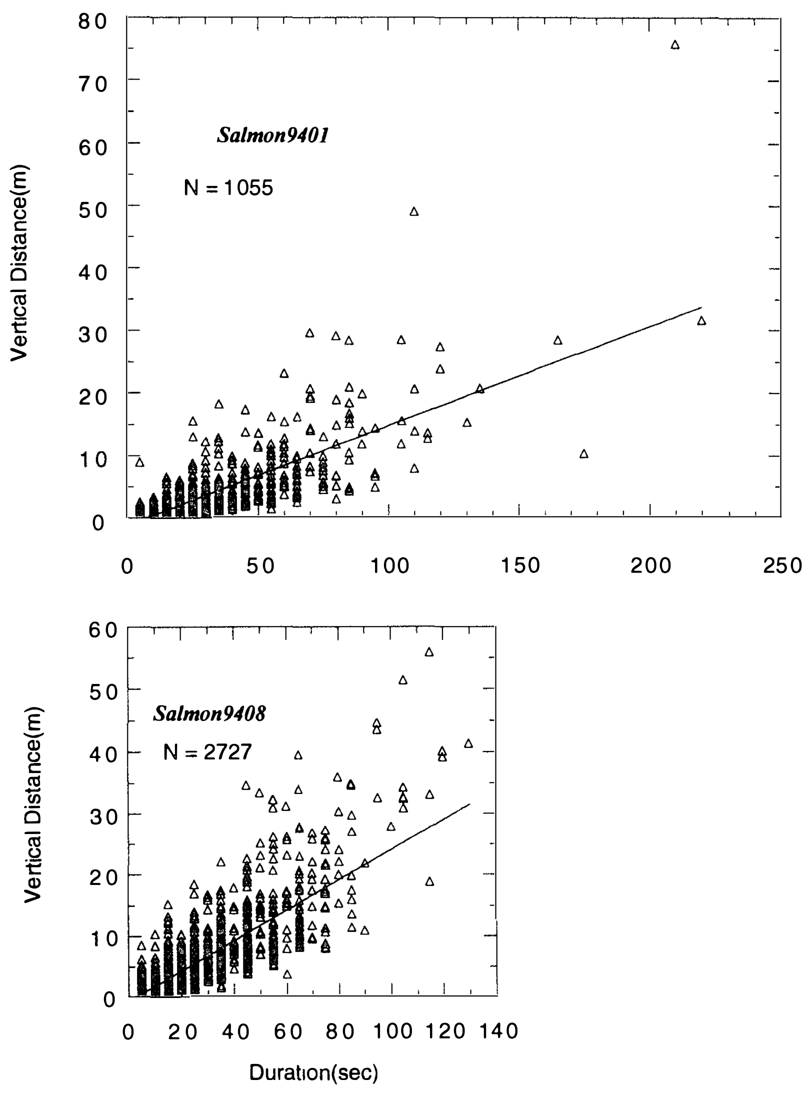

Fig 4 The relation of duration (D) and vertical distance (VD) of the movement of salmon 9401 (upper) and 9408 (lower). The regression equation for salmon 9401 is. $VD = -1.08 + 0.158D$, $R^2 = 0.56$, $N = 1055$, whereas that for salmon 9408 is. $VD = -0.697 + 0.248D$, $R^2 = 0.67$, $N = 2727$.

are 0.56 (salmon 9401) and 0.67 (9408). The maximum distances were descent of 75.8 m (no. 9401) and ascent of 56.0 m (9408), of speeds were 0.36 and 0.49 m/s, respectively. Large vertical motions, over 30 m, tended to be faster than shorter motions. Frequency analysis showed that movements of salmon 9401 were generally less steep and longer in duration than those of 9408; medians of vertical speed and duration of salmon 9401 were 0.1 m/s and 25 s, whereas those of 9408 were 0.2 m/s and 15 s, respectively. Salmon moved more quickly in the daytime (medians: 0.13 and 0.23 m/s for salmon 9401 and 9408, respectively) than nighttime (0.07 and 0.12 m/s). Over 90% of vertical movements of each salmon were shorter than 2 min. That is, salmon changed their direction in a few minutes and made a continuous zigzag motion in the specific water column.

To elucidate the water column where salmon stayed, depth data were re-analyzed per two minutes starting from the release time. Figure 5 illustrates the frequency analysis of upper and lower limits of the depth in the water column per two minutes. As salmon 9408 spent most of the time in dives returning frequently to the surface, 65% of the upper limits were in the top 5 m. In relation to submergence after dusk, the upper limit in salmon 9401 was the slightly deeper than that of salmon 9408. The slight bimodality in the distribution in salmon 9401 is due to the initial deep and long dives with jagged bottom. Figure 6 shows the frequency distribution of the thickness of water column where salmon stayed for at least two minutes. The medians for the water layer thickness

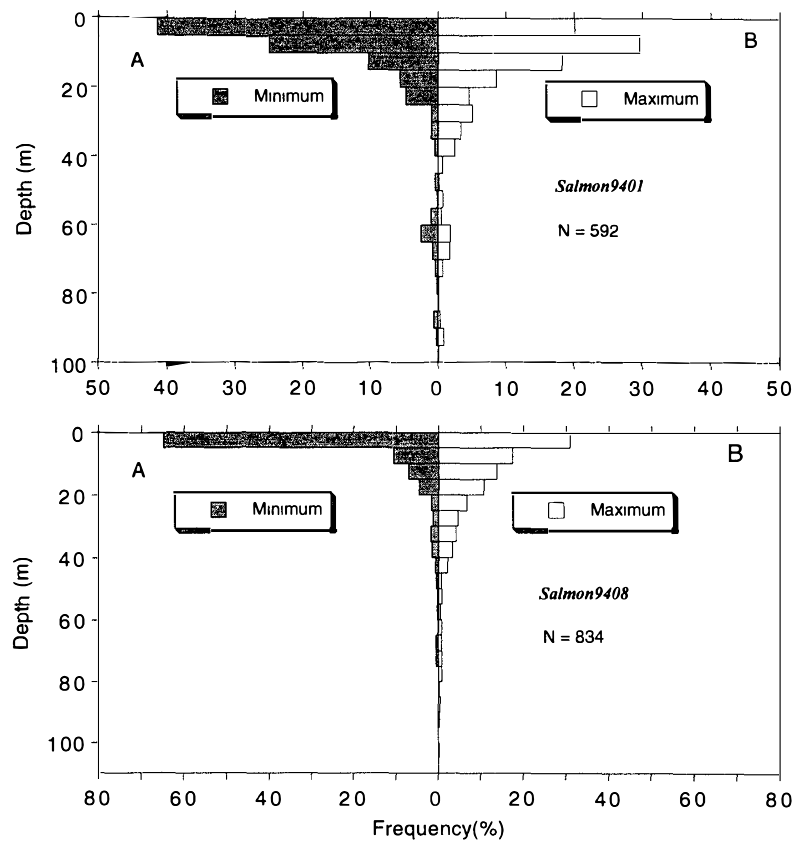

Fig. 5 Frequency of occurrence of minimum and maximum depths, which were analyzed in two minutes intervals, for salmon 9401 (A) and salmon 9408 (B), divided into 5 m intervals. The median values of maximum depths were 10.1 m (9401) and 10.5 m (9408), while those of minimum depths were 5.85 and 1.0 m, respectively.

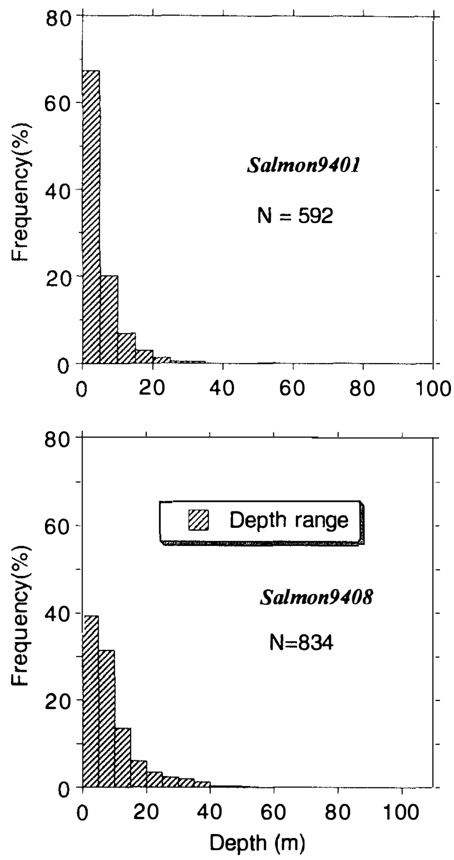

Fig. 6. Frequency of occurrence of depth range in which salmon stayed for at least two minutes, divided into 5 m intervals The medians are 3 2 m (no 9401) and 6.5 m (no 9408)

are 3.2 (salmon 9401) and 6.5 m (9408), respectively. This means that except for the initial dive, salmon 9401 moved within a narrow range, while salmon 9408 performed a continuous large-scale zigzag motion.

We also defined the ratio between the water layer thickness and total distance which salmon traveled in two minutes, as the degree of zigzag movement. The ratio of 1 indicates that salmon kept ascending or descending without change of direction for two minutes. A relatively higher ratio was calculated when the salmon stayed in the surface or at the bottom (Fig. 2a and 2b). This means that salmon frequently made small-scale zigzag movements near the surface or the jagged bottom alternatively. Although salmon 9408 did not show any large vertical motion from 1505 to 1645, the calculated ratio was more than 10, indicating that it was not a passive drift, but salmon kept actively moving in the surface water.

Temperature and salinity

At Stations 1-6, temperature was 16.0–17.0°C at the surface and 16.5–17.0°C at the bottom. Salinity was 33.9–34.0 psu at the surface and 34.1–34.2 psu at the bottom. In general, the water in the top 3 m was cooler and was almost isothermal beneath the surface layer (Fig. 7). Ambient water temperature sampled by salmon 9401 and 9408 was also 16–17°C (Fig. 1), except around 1.5 hours after the release of salmon 9401 when the fish was exposed to relatively low temperature (13–14°C) in the water column shallower than 1.0 m. However, vertical movement of salmon 9401 did not show a clear preference or avoidance for this low temperature.

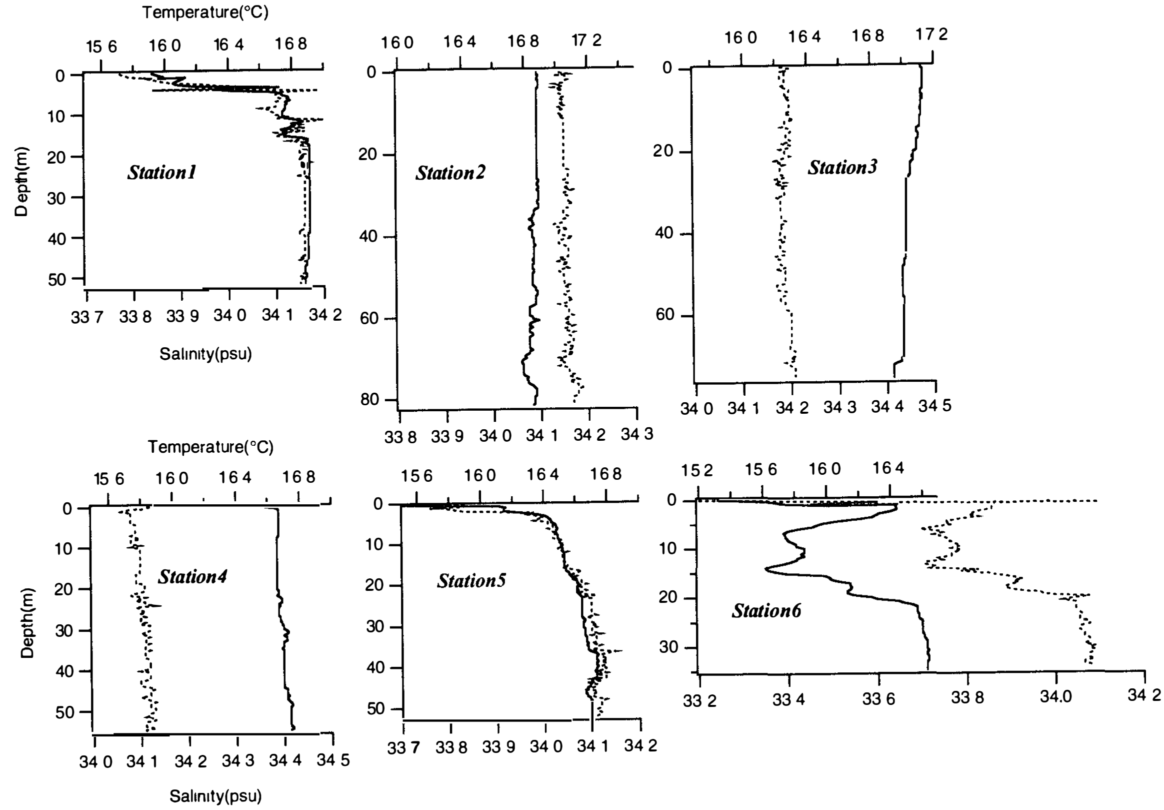

Fig. 7. Temperature and salinity profiles of station 1 to 6 (right) just after the release of salmon with data loggers attached. Solid line indicates temperature and dotted line illustrates salinity.

Discussion

General features of salmon behavior recorded in the present study did not differ from results obtained by ultrasonic telemetry tracking methods. In the previous studies using telemetry systems, speed of vertical movement of chum salmon generally ranged from 0.05 to 0.20 m/s (SOEDA *et al.*, 1987; YANO *et al.*, 1992). Salmon in coastal waters were less active and swam closer to the surface at night (SOEDA *et al.*, 1987; QUINN *et al.*, 1989). Large amplitude of vertical movement was observed on the chum salmon off the coast of Sanriku (ISHIDA *et al.*, 1988). In the present study, chum salmon moved vertically at about 0.1–0.2 m/s and showed a diurnal pattern of vertical movement that is active in day time. These quantitative similarities between our results and previous ones obtained by telemetry studies suggest that salmon bearing external data loggers behaved naturally.

We did not track salmon; therefore, horizontal movements and precise locations of the fish are unknown. However, it is possible to estimate them. A time depth diagram of initial dives indicated that salmon reached the bottom of the sea at that time, since the depths of jagged bottoms coincided with that of the bay mouth. Such initial diving behavior was observed immediately after the release in many tracking studies. A tendency of the jagged bottoms to become shallower suggests that salmon 9408 moved inward the bay after the release. Additionally, the locations where salmon 9402 were recaptured indicated horizontal movement towards the rivers.

Mellas *et al.* (1985) evaluated the effects of external attachment of transmitters (1.0 cm diameter, 2.9 cm and 3.0 g) on the swimming behavior of rainbow trout (range: 24.5–30.0 cm in folk length and 168–372 g in body weight) in laboratory experiments. External tags clearly reduced the swimming ability of the fish. They concluded that stomach tagging is the best method of transmitter attachment although a high regurgitation possibility was observed. To avoid the risk of losing the logger by regurgitation, we decided to attach the loggers externally. Moreover, because the present study depended on fishermen for logger recovery, it was crucial to make the loggers clearly noticeable to fishermen. Since adult chum salmon used in our study were approximately 10 times heavier than the fish used in the study of Mellas *et al.* (1985), they should be more tolerant to a stress from external tags. To reduce the effect of external attachment as much as possible, even smaller but still conspicuous loggers are needed. In the present study we could not retrieve salmon with data logger, but only loggers. A possible reason for the missing data logger was the accidental detachment.

It has been reported that the swimming depth of homing sockeye salmon seems to be controlled by orientation to the thermocline (Quinn *et al.*, 1989). The homing sockeye remained in a narrow depth range for a long period, interspersed with brief dives and descents. It is also reported that vertically stratified hydrographic features may be important for the orienting movements of the Atlantic salmon (Døving *et al.*, 1985). They reported that the fish made continuous small scale vertical movements in the fine-structure gradient thermal layer. At our study site in late November, clear stratification or steep gradient of the thermocline was not observed although the top 3 m of water tended to be cooler. This tendency of thermally mixed water is a typical feature off the Sanriku coast in winter (Ishida *et al.*, 1988). Salmon showed a preference for the surface water but they usually traveled through a wider range of depth than the top 3 m layer and did not show a clear preference for the cooler water at the surface. It is clear that chum salmon in the isothermal waters must use factors other than thermally stratified water. Ishida *et al.* (1988) reported the large amplitude of vertical movement of chum salmon, much the same as the behavior observed in the present study, in isothermal waters. They suggested that the function of large vertical movements was predator avoidance, although they did not observe any predators in their study. The consistent results between the report of Ishida *et al.* (1988) and the present study suggest that there could be another adaptive significance of vertical movement of homing chum salmon. One hypothesis is that chum salmon in isothermal waters exploit the guiding cue by large vertical movement. Further studies of homing chum salmon in the area and in thermally stratified waters are needed.

Although the present results do not provide sufficient statistical power, our conclusion is that the use of data loggers is a future possibility for studying the behavior of adult chum salmon in relation to environmental factors.

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