Micro Data Logger Analyses of Homing Behavior of Chum Salmon in Ishikari Bay

Authors: Kitahashi, Takashi, Ando, Hironori, Urano, Akihisa, Ban, Masatoshi, Saito, Seiichi, et al.

Source: Zoological Science, 17(9) : 1247-1253

Published By: Zoological Society of Japan

URL: https://doi.org/10.2108/zsj.17.1247

ZOOLOGICAL SCIENCE **17**: 1247–1253 (2000)

Micro Data Logger Analyses of Homing Behavior of Chum Salmon in Ishikari Bay

Takashi Kitahashi[1]*, Hironori Ando[1], Akihisa Urano[1], Masatoshi Ban[2], Seiichi Saito[3], Hideji Tanaka[4], Yasuhiko Naito[4] and Hiroshi Ueda[5]

[1]*Division of Biological Sciences, Graduate School of Science, Hokkaido University, Sapporo, Hokkaido 060-0810, Japan*
[2]*National Salmon Resources Center, Sapporo, Hokkaido 062-0922, Japan*
[3]*Faculty of Fisheries Sciences, Hokkaido University, Minato-cho, Hakodate 041-8611, Japan*
[4]*National Institute of Polar Research, Itabashi-ku, Tokyo 173-8515, Japan*
[5]*Toya Lake Station for Environmental Biology, Faculty of Fisheries, Hokkaido University, Abuta, Hokkaido 049-5723, Japan*

ABSTRACT—The profile of homing behavior in chum salmon (*Oncorhynchus keta*) that migrate from coastal sea to their natal river was not known well. We thus investigated temporal behavioral profiles of pre-spawning chum salmon in terms of water depth and temperature in Ishikari Bay using a micro data logger in 1997 and 1998. Fish were caught by a set net, tagged and attached with a data logger under MS222 anesthesia, and were released at the points 5 and 3 km off from the mouth of the Ishikari River in 1997 and 1998, respectively. A temporal profile of water depth and ambient temperature along the migratory pathway of recaptured salmon indicated that they usually stayed near the surface where water temperature was relatively low. Conductivity-temperature-depth recorder (CTD) data and the sea surface temperature estimated with National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) indicated that the influent of river water formed a low-temperature brackish subsurface layer near the mouth of the Ishikari River. These results indicate that chum salmon homing to the Ishikari River prefer low water temperature, and wander in the subsurface layer of nearshore area close to the mouth of the Ishikari River until they are motivated to migrate upstream. The main factor that regulates behavioral pattern of returned chum salmon in coastal sea should be distribution of water temperature.

INTRODUCTION

Salmon is an anadromous fish, born in the river, grow in the ocean and return to the natal river. They use odor memories learned as juveniles to guide their homing to the natal site as adults in the river (Hasler *et al*., 1978). The cues used to return to their natal site in the ocean may differ from those in the river, although the mechanisms of oceanic migration have not been determined. The mechanisms of migration in coastal water may involve elements of oceanic and riverine phases (Quinn *et al*., 1989).

Behavior of salmon at coast was studied mainly in atlantic and sockeye salmons (*Salmo salar* and *Oncorhynchus nerka*) (Stasko *et al*., 1976; Døving *et al*., 1985; Quinn, 1988; Quinn *et al*., 1989; Ruggerone *et al*., 1990). These reports indicated that homing salmon generally preferred shallow water. In these studies that applied an acoustic tracking technique, water temperature and salinity in the vicinity of the fish were measured occasionally. Such technique has difficulty to clarify exact ambient environment of their migratory pathway.

A use of a micro data logger has superior benefits in acquisition of information on parameters of ambient environment, since it can record various data, such as depth and temperature, simultaneously. The previous study using a data logger showed that chum salmon (*Oncorhynchus keta*) in the Sanriku population dived to the bottom where water temperature is relatively low, indicating that chum salmon prefer low water temperature (Tanaka *et al*., in press). The profile of homing behavior that migrate from coastal sea to their natal river was not known in the population of the Ishikari River, which pours itself into shallow Ishikari Bay.

The previous studies mentioned above raised a question, which is the main factor that determines behavioral pattern of chum salmon, water temperature or terrain. To clarify this question, it is important to analyze profiles of behavior using a data logger in shallow water. We therefore investi-

* Corresponding author: Tel. +81-11-706-3525;
FAX. +81-11-706-4448.
E-mail: taka@sci.hokudai.ac.jp

gated temporal behavioral profiles of pre-spawning chum salmon in terms of water depth and temperature in Ishikari Bay using a micro data logger in 1997 and 1998. Swimming area of salmon was inferred with the data of Conductivity-temperature-depth recorder (CTD) and sea surface temperature estimated with National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR).

MATERIALS AND METHODS

Study area

Behavior of homing chum salmon was studied in Ishikari Bay, Hokkaido, Japan (Fig. 1). As shown in Fig. 1, Ishikari Bay is shallow and wide: water depth of 2–5 km offshore area, 20 m; and that of 10 km offshore area, 30 m. A series of nets for salmon fishing were parallelly settled in nearshore area. Since the Ishikari River is a prominently big river, and a vast number (about 30 million) of juveniles are released only from the Chitose Salmon Hatchery (Point C, Fig.1) located 70 km upstream from the mouth of the Ishikari River, the salmon caught in Ishikari Bay are considered to belong to the Ishikari genetic stock.

Animals

Pre-spawning chum salmon migrating in Ishikari Bay were caught by a set net located at 2.2 km offshore (open bar in Fig. 1). They showed faint nuptial color. Gonadosomatic indices (gonad weight/body weight×100) of the fish that were simultaneously caught with them were 5.04±0.44 in males (n=29) and 15.94±0.44 in females (n=31). A total of 18 homing adults attached with a micro data logger were released on September 19, 1997 (5 males and 5 females), and on October 7, 1998 (4 males and 4 females). After anesthetization

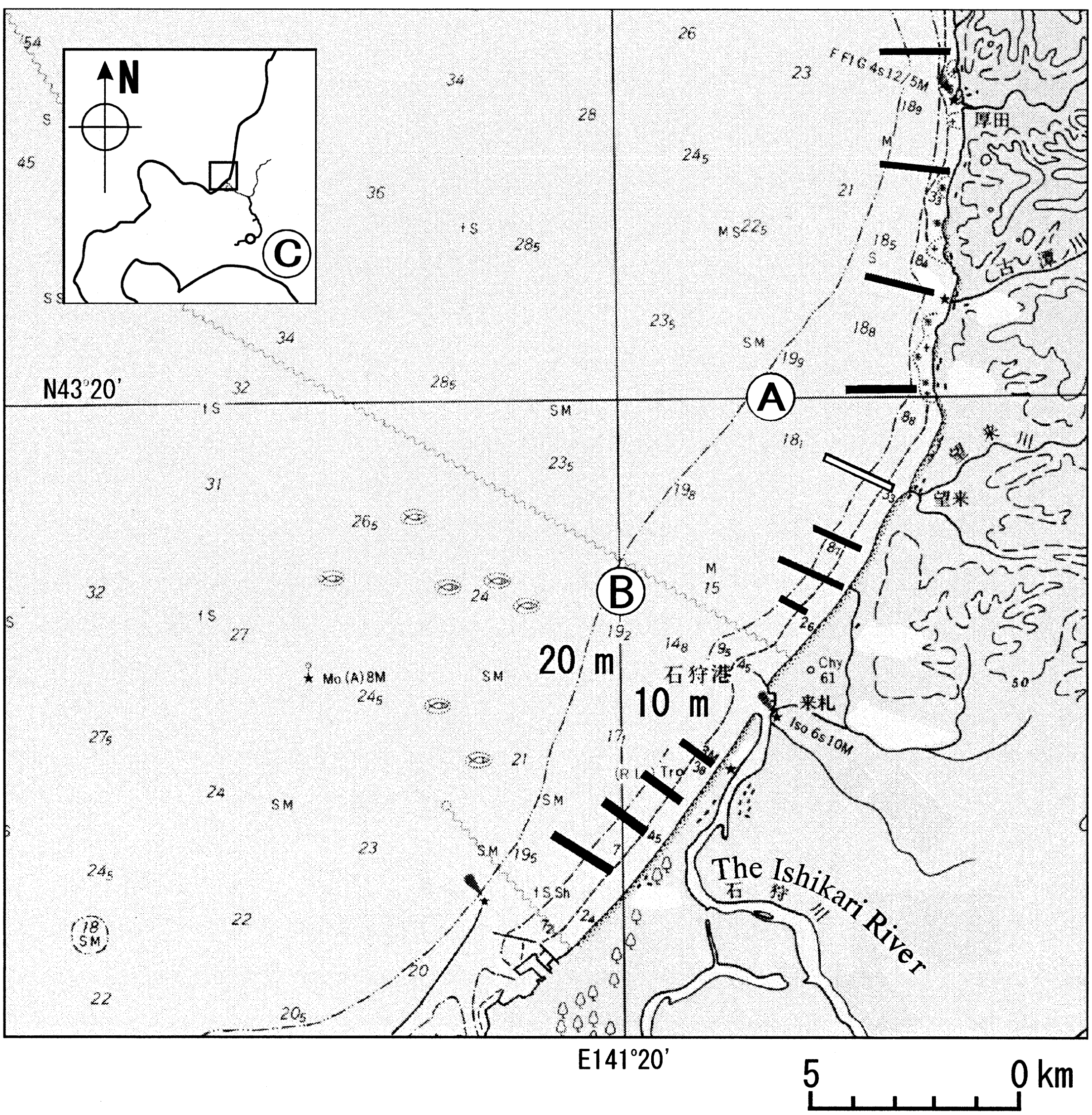

Fig. 1. Study region in Ishikari Bay, Hokkaido, Japan. Open and solid bars indicate the location of set nets. Homing adult chum salmon were captured by a set net shown by open bar, and released at point A (September 19, 1997) or at point B (October 7, 1998) after attachment of a micro data logger. The set nets that locate on north of the mouth of the Ishikari River are Atsuta set nets and those on south are Ishikari set nets. Point C represents location of the Chitose Salmon Hatchery. Numbers of small fonts in the sea area indicate water depth, and dash lines show 5, 10 and 20 m contours. (Modified from a chart of sea.)

with MS222, the fish were rapidly weighed and measured for fork length (mean fork length, 64.22±1.30 cm; and mean body weight, 3.24±0.19 kg). A data logger was dorsolaterally sutured with nylon ties to the body at the middle of trunk, below the front edge of the dorsal fin. Fish were released after recovery from the anesthetization. Soon after the releases, vertical profiles of water temperature and salinity were measured by a CTD (Alec Electronics Co., LTD. Model AST-1000) at the release points.

Release point

In 1997, fish were released at the point 2 km off from the set net by which the fish were caught (Point A, Fig. 1). All of these fish were recaptured by set nets within a few days in 1997, so that, in 1998, fish were released at the point 3 km off from the mouth of the Ishikari River (Point B, Fig. 1) in attempt to avoid recapture by set nets. Influence on vertical profiles of water temperature and salinity of river water of the Ishikari River at the Point B was stronger than that at the Point A (see Fig. 7B).

Data logger

We used a micro data logger which simultaneously records depth and temperature (Little Leonard Co. Ltd., Tokyo). The logger, which is cylindrical, is 90 mm long and 20 mm in diameter, and weighs 14 g in water, with 1 Mbytes of flush memory. Resolution of the depth channel was 0.05 m, and that of the temperature channel was 0.02°C. Accuracy was 0.5 m in the depth channel and 0.1°C in the temperature. Sampling rate was 5 sec in all channels.

Satellite observation and image analysis

Spatial distribution of sea surface temperature in the study area was analyzed using the NOAA AVHRR data (Saitoh, 1995). AVHRR data of the NOAA were received at the Faculty of Fisheries, Hokkaido University. Cloud-free images were selected from browse image data sets during the period around the day when the fish were released. For the AVHRR thermal infrared data, in-flight calibration was carried out first and then the calibrated data were processed to remove geometric distortions. A digitized coastline and geographical mark were superimposed on the geometrically corrected image. The collected satellite data on a fine day near the release day were then used to estimate sea surface temperature.

Data analysis

The records of water depth and ambient temperature on the micro data loggers were read by a computer, and the data that were collected after a set net arrest, which is apparently discriminable from freely-swimming stage, were eliminated for data analysis. The data from all individual fish in both 1997 and 1998 were first fractionized and ranked according to swimming depth, and then the durations spent at particular depth were accumulated altogether to see frequency distribution of swimming depth. Overall depth distribution and average depth were then calculated from the data. Records of ambient temperature from individual fish were similarly treated to see the most preferred temperature during free swimming. In addition, records of ambient temperature during the period when swimming depth was less than 0.3 m were similarly processed to estimate the preferred location of migration in Ishikari Bay in comparison with the satellite data. Since, immediately after release, almost all fish dove to the bottom (mean dive duration was 41 min), these initial dives were omitted from analysis.

RESULTS

Nine of ten fish (5 males, 4 females) were recaptured by some of the Atsuta set nets within two days in 1997. In 1998, two of eight fish (1 male, 1 female) were reached the Chitose Salmon Hatchery 14 and 18 days after the release, and three fish (1 male, 2 females) were caught by some of the Atsuta and Ishikari set nets by the next day. Because two loggers could not be retrieved, total of 12 loggers were retrieved after all. The records on micro data loggers could be read from nine individuals (six in 1997 and three in 1998), five males and four females, one of which reached the hatchery.

Fig. 2 shows a typical temporal profile of swimming depths and ambient temperature for salmon No. 114 in 1997. After the initial dive, salmon spent most of time just beneath the surface. Average migratory depth of salmon was 0.81 m in Ishikari Bay. The maximum depth recorded was 20.3 m, which was recorded 30 min after the release in the fish No. 114, in 1997 and 16.4 m, 1 hr after the release in the fish No. 113, in 1998. Occasionally they dived to the depth that seemed to be the bottom. The depth of the dives that fish reached tended to be decreased with time. They spent nearly 90% of time in the upper 1 m zone of the bay (Fig. 3). Fish No. 112, which was recaptured at the upstream of Ishikari River, also swam beneath the surface before entering the river (Fig. 4).

The temperature apparently increased when the fish dove from sea surface to the depth (Fig. 2). Ambient temperature ranged from 16.5 to 20.5°C in six salmon in 1997, and 13.5 to

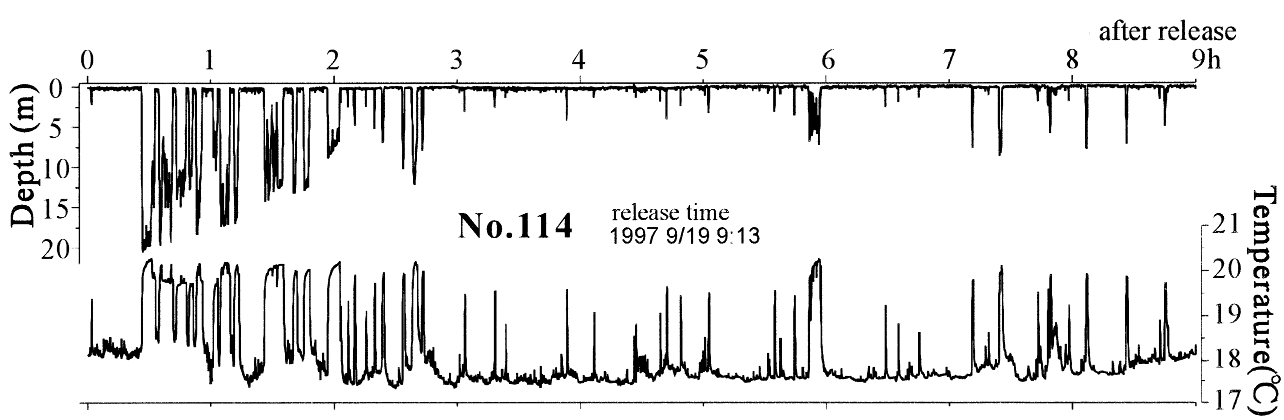

Fig. 2. Typical profiles of swimming depth and ambient temperature of homing chum salmon in Ishikari Bay in 1997. Note that the fish spent most of time at surface where the water temperature was relatively low.

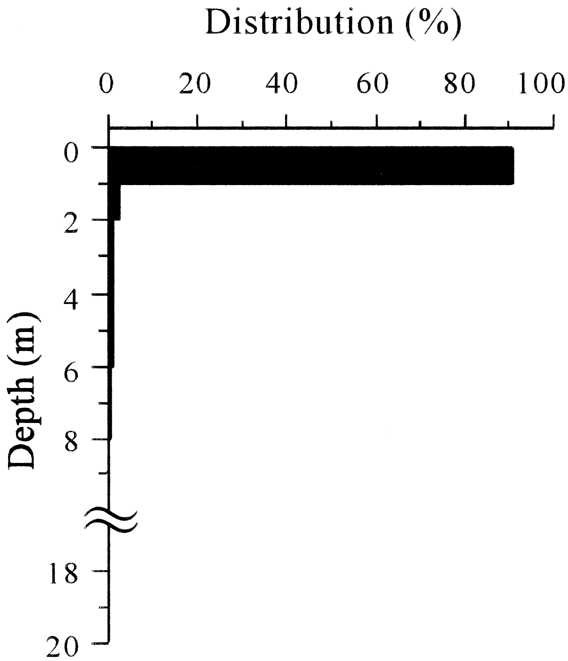

Fig. 3. Overall depth distribution expressed as a percentage of time spent at 1-m depth intervals. (1997: six fish, total 2569 minutes observation; 1998: three fish, total 739 minutes observation)

19°C in three salmon in 1998. In 1998, about 13.5°C of ambient water temperature, which seemed to be the temperature of river water, was recorded in the fish recaptured by a set net in Ishikari Bay (Fig. 5). Frequency distribution of ambient temperature that the fish preferred in the bay is shown in Fig. 6A and B, showing a peak at about 18°C in 1997 and at 16°C in 1998. Distributions of surface temperature recorded by the loggers shown in Fig. 6C and D indicate a peak at about 17.75°C in 1997 and at 15.5°C in 1998.

CTD data showed that water temperature and salinity of the surface of the sea were the lowest at the Point A when compared with deeper layers (Fig. 7A). A sharp thermocline and halocline occurred between 0–1 m. Water temperature and salinity of layers deeper than 1 m was steady (salinity, about 33.5; temperature, about 20°C) at the Point A. These data indicated that the influent of river water formed a low-temperature brackish subsurface layer. On October 7, 1998, water temperature was lower than that on September 27, 1997 in whole (Fig. 7B). The thermocline and halocline were not so sharp as compared with those seen at the Point A in 1997. At the Point B, salinity of 25.2 at the surface increased gradually to 33.8 at 6.5 m, and temperature increased from 16.1 to 18.9°C. These results indicated that river water spread vertically to deeper layer than 6 m at the Point B, probably because the point B was near the mouth of the Ishikari River.

Distribution of sea surface temperature in Ishikari Bay estimated from Satellites NOAA shown in Fig. 8 indicates that surface temperature was warmer in 1997 compared with that in 1998. The surface temperature of nearshore area was lower than that of off coast. In 1997, the area where the surface temperature was under 18°C was restricted within narrow nearshore portion. In 1998, the area where the surface temperature was under 16°C was also restricted within narrow nearshore area close to the river mouth. With CTD data, we considered that the influent of river water formed low-temperature brackish layer beneath the surface of nearshore region close to the mouth of the Ishikari River.

DISCUSSIONS

The present study showed that chum salmon homed to Ishikari Bay spent most of time in the relatively cool water. The fish spent nearly 90% of time in the upper 1 m surface layer in shallow Ishikari Bay. Similar behavioral pattern was observed in Ishikari Bay in both 1997 and 1998. Furthermore, the fish caught at the upstream region of the Ishikari River showed similar behavior during their stay in the sea. Chum salmon returned to Ishikari Bay thus showed strong preference to the relatively cool surface water.

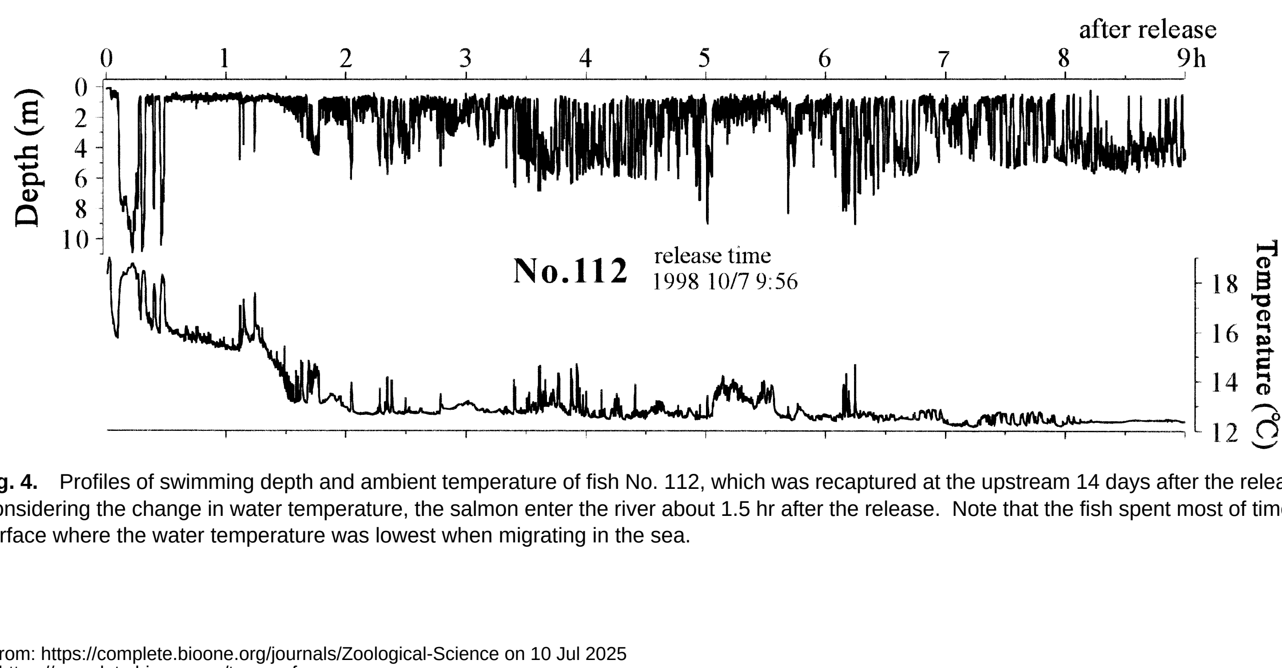

Fig. 4. Profiles of swimming depth and ambient temperature of fish No. 112, which was recaptured at the upstream 14 days after the release. Considering the change in water temperature, the salmon enter the river about 1.5 hr after the release. Note that the fish spent most of time at surface where the water temperature was lowest when migrating in the sea.

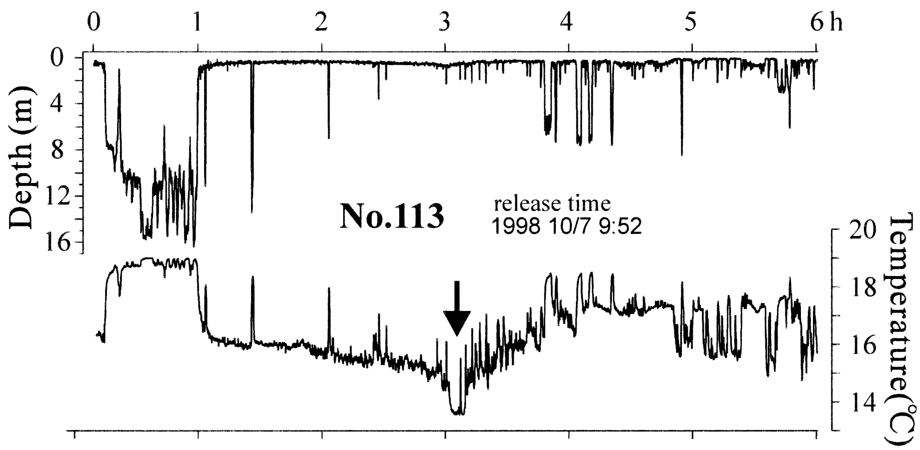

Fig. 5. Profiles of swimming depth and ambient temperature of fish No. 113, which was recaptured in the sea by a set net one day after the release. Considering the change in water temperature, the salmon reached the river mouth about 3 hr after the release (arrow).

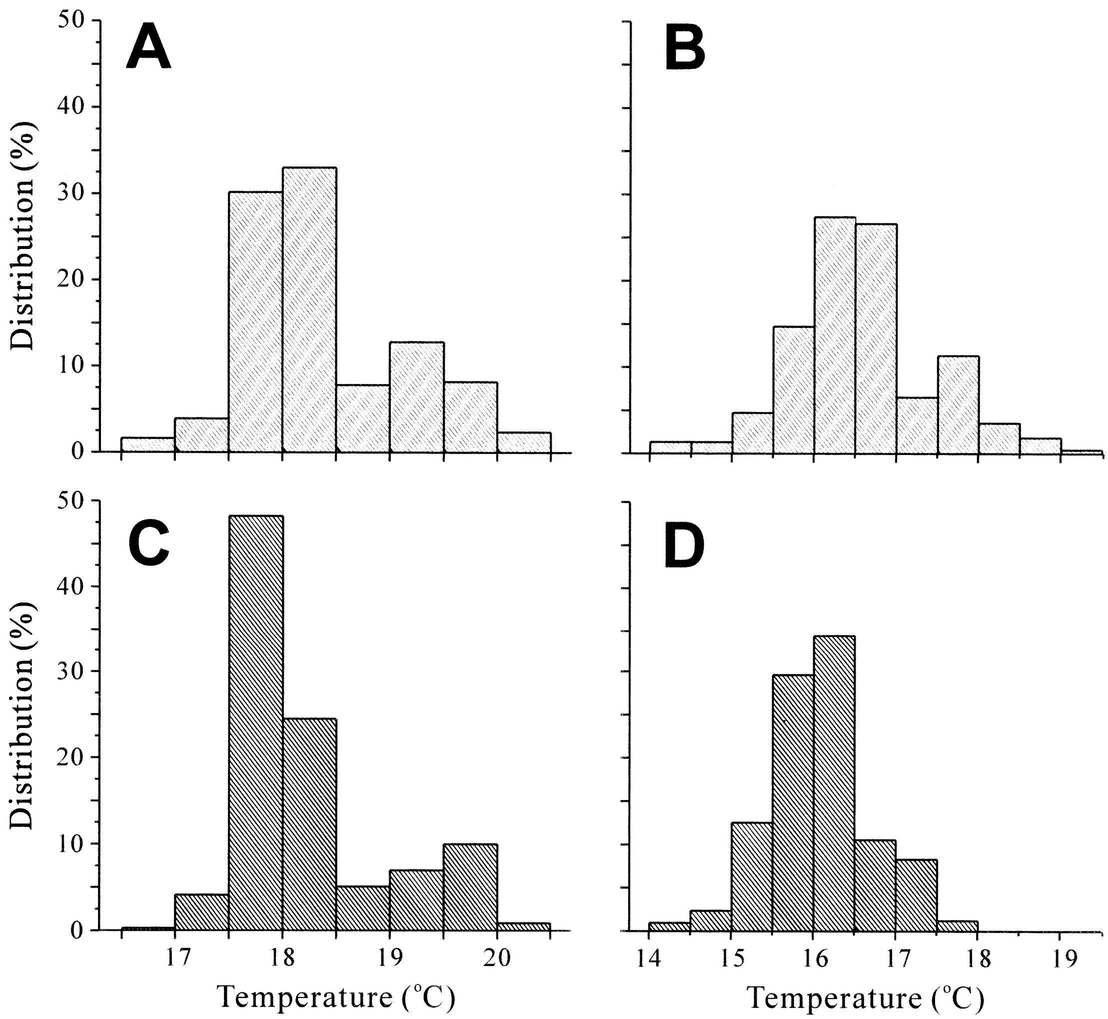

Fig. 6. Overall distribution of ambient temperature and those recorded at the surface layer (depth<0.3 m) expressed as a percentage of time spent at 0.5°C temperature intervals. (A) 1997: six fish, 2569 min observation. (B) 1998: three fish, 739 min observation. (C) records at surface layer in 1997 and (D) records also at surface layer in 1998.

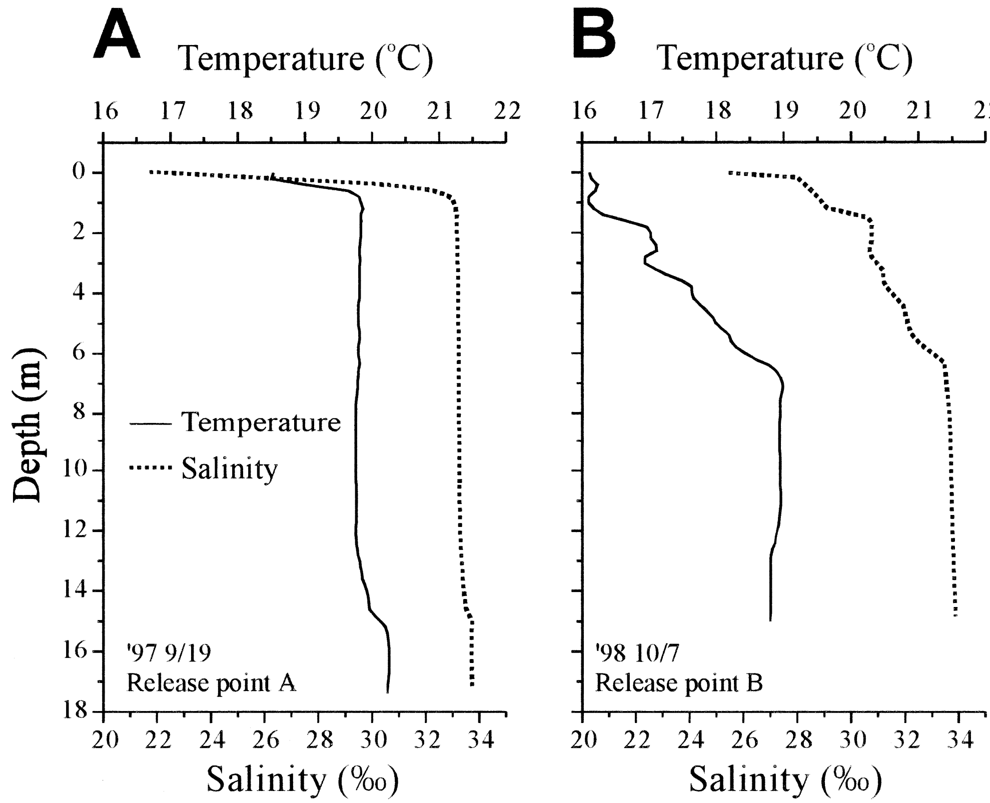

Fig. 7. Profiles of salinity and water temperature versus depths at the release points. (A) At the Point A on September 19, 1997. (B) At the Point B on October 7, 1998.

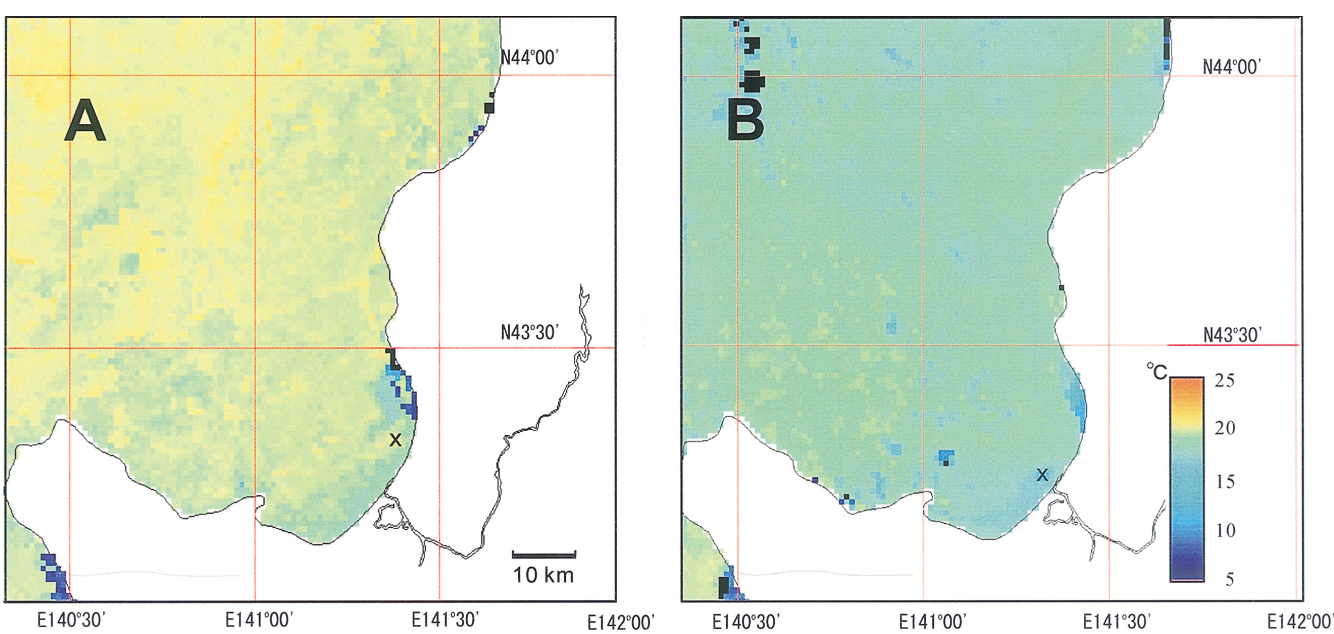

Fig. 8. AVHRR sea surface temperature images. Black color represents cloud. Release points are indicated as X in the figure. (A) September 24, 1997 (B) October 10, 1998

Chum salmon, particularly of early run, that returned to offshore Sanriku, Honshu Island, Japan, dived to over 100 m and stayed in the deep water for several hr (Tanaka *et al.*, in press). In autumn, temperature of the deep water was lower than that of surface water in offshore Sanriku (Sato and Maiwa, 1971; Tanaka *et al.*, in press), whereas Ishikari Bay was shallow and surface water of the nearshore region close to the mouth of the Ishikari River was relatively cool. Although the topography of temperature distribution is different between Sanriku and Ishikari, homing chum salmon coincidently preferred to stay in cool water in both areas.

Preferred ambient water temperature at the surface layer was relatively low (17.75 and 15.5°C in 1997 and 1998, respectively) in Ishikari Bay. When compared with distribution of sea surface water temperature, the preferred temperature corresponds to the surface temperature of the nearshore area close to the river mouth. In this area, the influent of river water formed low-temperature brackish layer beneath the surface. These data suggested that, prior to upstream migration, chum salmon homing to the Ishikari River selected the area where the water temperature was relatively low, and migrated around the nearshore area close to the mouth of the Ishikari River in Ishikari Bay.

Although all fish were released at the point close to the river mouth, only two fish were recaptured at the upstream hatchery in 1998. A fish once received river water was also re-captured in the sea (see Fig. 5). Thus, chum salmon caught in Ishikari Bay did not enter the river immediately after the release, even though they were released near the river mouth. It is probable that salmon require sufficiently motivated state to enter the river and to migrate upstream.

In conclusion, chum salmon homing to the Ishikari River prefer low water temperature like in Sanriku, and migrate in the subsurface layer, where they can trace the river water, in Ishikari Bay. The salmon thus wander in the subsurface layer of nearshore area close to the mouth of the Ishikari River until they are motivated to migrate upstream. The main factor regulating behavioral pattern of returned chum salmon should be the distributional pattern of water temperature.

ACKNOWLEDGMENTS

We thank colleagues in our laboratory and Mr. H Aihara (Atsuta Fishermen's Cooperative Association) for their help in sampling efforts. This study was supported in part by Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists to Takashi Kitahashi and Grants-in-Aid from the Ministry of Education, Science, Sports and Culture, Japan.

REFERENCES

Døving KB, Westerberg H, Johnsen PB (1985) Role of olfaction in the behavioral and neuronal responses of atlantic salmon, *Salmo salar*, to hydrographic stratification. Can J Fish Aquat Sci 42: 1658–1667

Hasler AD, Scholz AT, Ross MH (1978) Olfactory imprinting and homing in salmon. Am Sci 66: 347–355

Ruggerone GT, Quinn TP, McGregor IA, Wilkinson TD (1990) Horizontal and vertical movements of adult steelhead trout, *Oncorhynchus mykiss*, in the Dean and Fisher channels, British Colombia. Can J Fish Aquat Sci 47: 1963–1969

Saitoh S (1995) A VHRR on NOAA. In Oceanographic Application of Remote Sensing. Ed by Ikeda M, Dobson FW, CRC Press, Boca Raton, pp 407–417

Sato R, Maiwa T (1971) Studies on the chum salmon returning to Otsuchi River, Japan-II. Movement of mature fish to the river from coastal areas. Bull Jpn Soc Sci Fish. 37: 1037–1043

Stasko AB, Horrall RM, Hasler AD (1976) Coastal movements of adult Fraser River sockeye salmon (*Oncorhynchus nerka*) observed by ultrasonic tracking. Trans Am Fish Soc 1: 64–71

Tanaka H, Takagi Y, Naito Y (2000) Behavioural thermoregulation of chum salmon during homing migration in coastal waters. J Exp Biol 203: in press

Quinn TP (1988) Estimated swimming speeds of migrating adult sockeye salmon. Can J Zool 66: 2160–2163

Quinn TP, Terhart BA, Groot C (1989) Migratory orientation and vertical movements of homing adult sockeye salmon, *Oncorhynchus nerka*, in coastal waters. Anim Behav 37: 587–599

(Received May 22, 2000 / Accepted August 11, 2000)