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Preliminary report of swimming behavior and the response to temperature of lacustrine masu salmon, *Oncorhynchus masou* Brevoort, monitered by data logger during the spawning migration in Lake Toya

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Abstract: Swimming depth and ambient water temperature of male masu salmon (*Oncorhynchus masou* Brevoort) during the spawning migration in Lake Toya was examined using a micro data logger. Soon after release, the fish swam along the coast and mean swimming depth and water temperature were 14.2±7.96 m and 13.8±3.80℃. Then, the fish swam into a stream where mean swimming depth and water temperature were 1.6±3.28 m and 18.3±1.58°C. The fish returned to the lake again where mean swimming depth and water temperature were 33.4±14.1 m and 5.5±1.45℃. Finally, the fish swam into a stream again and stopped any vertical movements. The results show that the fish swam in coastal waters at a higher water temperature despite the likely higher energy expenditure and swam in deep, cooler water to recover between two upstream migration attempts. We hypothesize that temperature is not an important parameter for upstream migration and probably navigational mechanisms and hormonal motivation for spawning have affeted ambient temperature selection in lacustrine masu salmon during the spawning migration.

key words: masu salmon, data logger, swimming depth, temperature selection, spawning migration

Introduction

Salmonids are typical anadromous fish, which migrate to the ocean and subsequently return to their natal river for spawning. During this migration, they cross the coastal and estuarine zones where hydrographic conditions vary widely, potentially forming a strong hydrographic barrier for the fish. How salmon select their environment during migration in the coastal area to achieve successful spawning is one of the key questions in understanding migration and homing behavior. Mechanisms of homing behavior have been examined by many biologists (Hasler and Wisby, 1951; Hara *et al.*, 1965; Ueda *et al.*, 1998). Despite the critical importance of homing behavior (Fry, 1971; Gihousen, 1980; Berman and Quinn, 1991), there has been little concerted effort to understand how temperature affects the choice of migratory path, particularly with respect to fine scale temporal and spatial movements (Døving *et al.*, 1985).

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Recent studies revealed that migratory chum salmon in the coastal area repeatedly swim to a depth exceeding 100 m and then ascend to the surface, and swimming depth varies with season (Tanaka *et al.*, 1998). This may indicate behavioral temperature selection in the natural environment by selection of swimming depth. Tanaka *et al.* (1998) suggest that homing chum salmon (Sanriku coast of Iwate Prefecture, Northern Honshu, Japan) spent most of their time in the lower temperature layer (8–16°C) or bottom layer (deeper than 100 m) thus avoiding warm surface temperatures of 16–20°C in October. In December, they swam in the surface waters, which were less than 14°C.

Salomonids migrating to their natal river encounter a variety of natural environmental barriers, such as islands and inlets, rivers, tidal and none-tidal currents, and vertical gradients of water temperature and salinity that can affect their path selection (Gregory and Quinn, 1990). Fish in fresh water lakes, particularly small lakes, may have fewer environmental determinants because there are no currents or salinity changes and less geographical variation. The most prominent and typical behavioral modifier may be water temperature due to the thermal stratification of surface water. Therefore, lakes are an effective place to examine how such thermal differences affect fish behavior in relation to their swimming depth preferences during the spawning migration.

To study this question, we conducted experiments with masu salmon, *Oncorhynchus masou*, at Lake Toya in Hokkaido in 1996. Masu salmon smolts in Lake Toya do not migrate to the ocean, but rather grow and mature in the lake. Adult fish migrate within the lake and finally swim upstream in streams in September when a strong thermal stratification has developed. It is unclear, however, whether lacustrine masu salmon possess an accurate homing ability since juvenile fish or smolts could migrate between the streams and lake at any time. It seems possible that there is no critical imprinting period in these fish to memorize their natal stream.

Although techniques, such as VHF or ultrasonic, acoustic transmitters, have been used for measuring fish behavior and ambient temperature, we have applied the technology of miniaturized dataloggers which have been newly developed for the behavioral study of fishes and small marine birds (Naito *et al.*, 1997). These data loggers allow us to obtain data on a finer scale (both depth and temperature) over a longer duration experiment.

Materials and methods

Lake Toya is a round formed, volcanic lake with an average and maximum depth 116 m and 179 m, and is 70 km^2 area. Several small streams flow into the lake.

We conducted the experiment in late September 1996 during the migration and spawning season. Fish were caught by gill net and taken to the Toya Lake Station for Environmental Biology, Faculty of Fisheries, Hokkaido University. Body size was measured and fish were externally examined for gonad condition. Fish were then anaesthetized by 2-phenoxy ethanol and data loggers attached. Body length of fish used for this experiment were ranged 41.5–50.0 cm and 781.4–1487.5 g. Fish condition was examined and one female and two males were selected since they were apparently in the final stages of reproductive maturation. The data logger was sutured using nylon string to the anterior part of the dorsal fin following the technique developed in chum

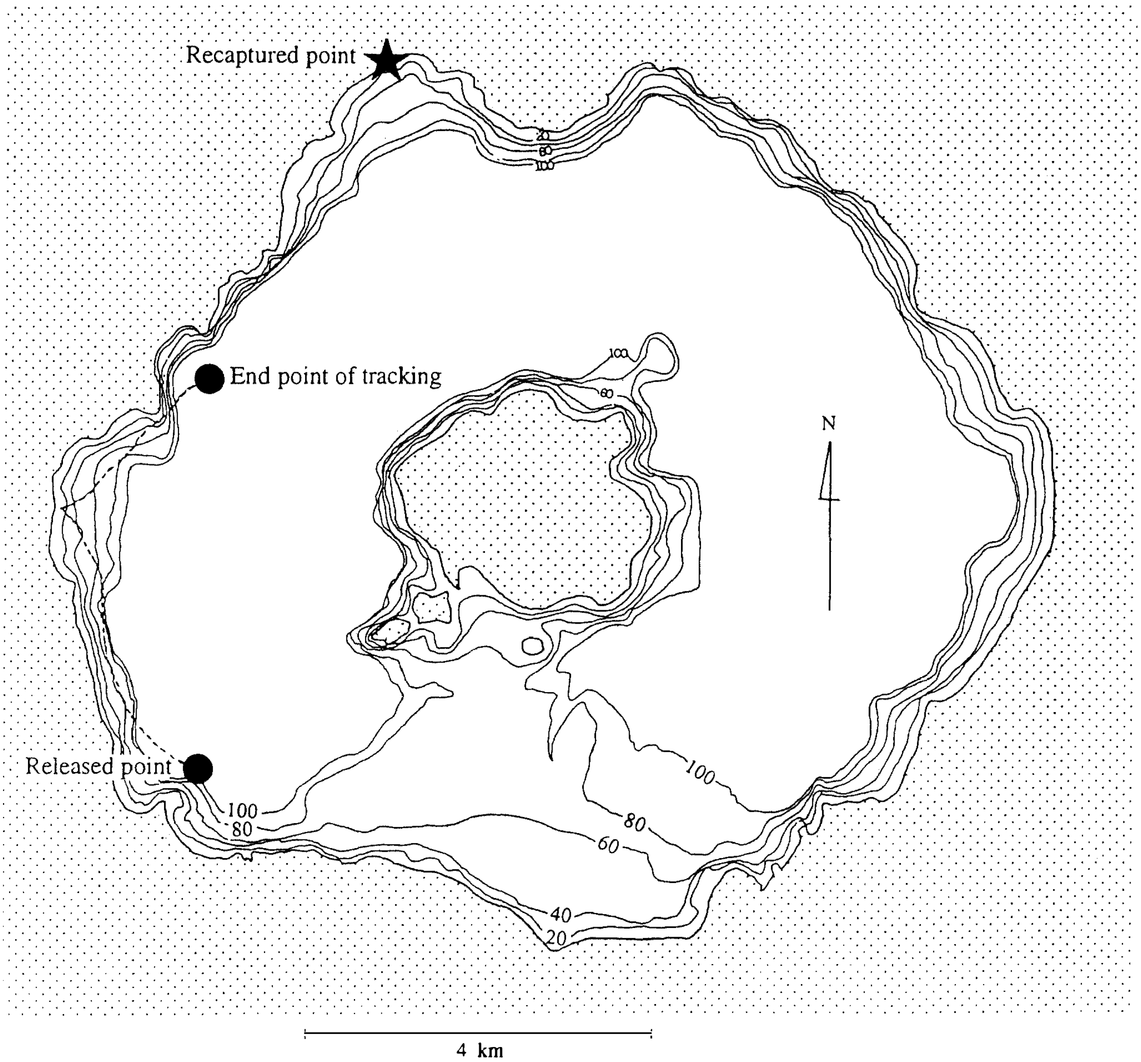

Fig. 1. The topography of Lake Toya showing the points of fish release and recapture as well as migratory path as tracked using a ultrasonic location tag.

salmon (Tanaka *et al.*, 1998). Fish were released near the southeast coast of the lake (Fig. 1) on 22 September, 1996. We also conducted fish tracking using ultrasonic locational pinger tags (V8-2L, Vemco, Halifax, Canada) which were inserted into the stomach of the same fish.

The data loggers used for measuring depth and ambient temperature were torpedo shaped, 13 mm in diameter and 75 mm in length, and weighed 15 g (in air) and 7 g (in water) equivalent for 1.91 to 1.00% of fish body weight. The logger can store data up to 250000 bits with 8 bit resolution to at least 1 m and 0.2°C accuracy in depth and temperature respectively. We sampled both temperature and depth simultaneously at 5 second intervals, which enabled us to gather data for up to 7.2 days.

Results

Among three fish released, one male (BL: 46.8 cm, BW: 1154.6 g) was recaptured and returned by fisherman from the northern coast of the lake (Fig. 1). Approximately three days of data were recorded on the logger. A boat equipped with a Global Positioning System for determining location initially tracked the fish. The fish was tracked soon after release for a total of eight hours beginning at 0955, 22 September. Tracking ceased when the signal was lost. During eight hours of tracking, the fish moved several hundred meters toward offshore area (deeper water) for a few hours, and subsequently returned to the shallow coast, and finally moved to the north along the coast (except for several minutes around 1500).

The data from the logger show that the fish escaped towards deep water just after release for a few hours. After recovery from the escape movement, time serial data on swimming depth and ambient temperature were separated into four different phases (Fig. 2). During the 1st phase, the fish traveled close to the coastline and maintained a shallow swimming depth. This depth pattern was maintained after failure of tracking by a pinger tag and it is suggested that the fish continued to move along the coastline. Mean depth and temperature were 14.2 ± 7.96 m and 13.8 ± 3.80°C respectively and the fish stayed in the layer shallower than 20 m of water depth more than 90% of the time

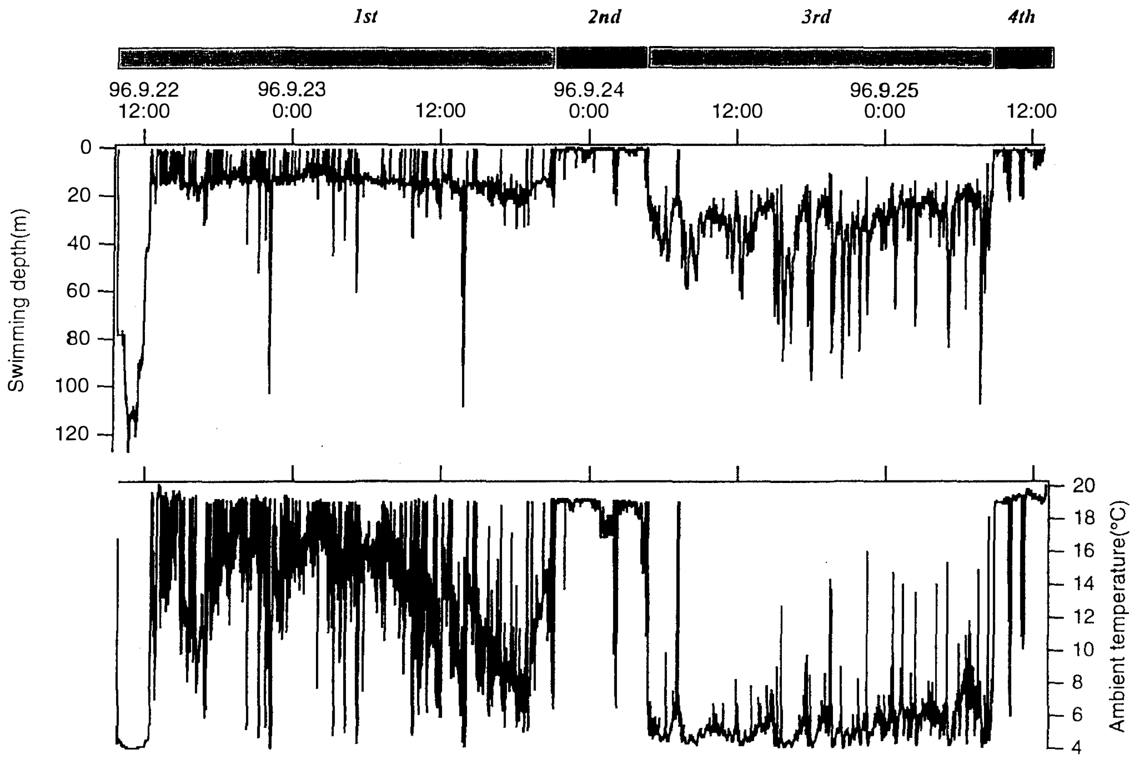

Fig. 2. Time serial records of swimming depth (upper) and ambient water temperature (lower). Four different phases in depth and temperature are identified from data on swim depth and temperature as 1st, 2nd, 3rd, and 4th. Fish moved in shallow water along the coastline (1st phase) and entered in the very shallow and warm temperature area, provably river area (2nd phase). Then fish moved offshore deeper area (3rd phase) and again returned to very shallow area (4th phase).

during this phase, although it did make several descents to as deep as 110 m. Despite the shallow depth, the fish experienced large temperature variability with temperature ranging 4–20°C, indicating that fish did not preferentially select a temperature, but rather selected a preferable depth or area (coastline).

At approximately 2113, 23 September the fish came into extremely shallow water (less than 5 m) and remained there until around 0444, 24 September. During the 2nd phase, the data logger recorded mean depth of 1.6 ± 3.28 m and mean temperature of 18.3 ± 1.58°C. For more than 90% of the time during this phase, the fish stayed in water less than 5 m in depth where the water temperature was between 14 and 19°C. The occurrence of the fish swimming extremely close to the surface in warm water was observed suggesting that the fish was in stream water. However, the fish moved several times towards deeper water (up to 25 m depth) where temperature decreased to 6–7°C.

Thereafter, the fish moved towards much deeper water until around 0851, 25 September. During the 3rd phase, mean swim depth and temperature were 33.4 ± 14.1 m and 5.5 ± 1.45°C respectively. More than 90% of time during this phase, the fish stayed at a depth of deeper than 20 m and more than 95% of time in water colder than 8°C. In this period, the fish swam deeper and in colder water than the other phases indicating that the fish moved toward deeper water offshore. The steep slope of the bottom topography of the lake suggests that the fish moved quickly from the coast to the offshore area (Fig. 1).

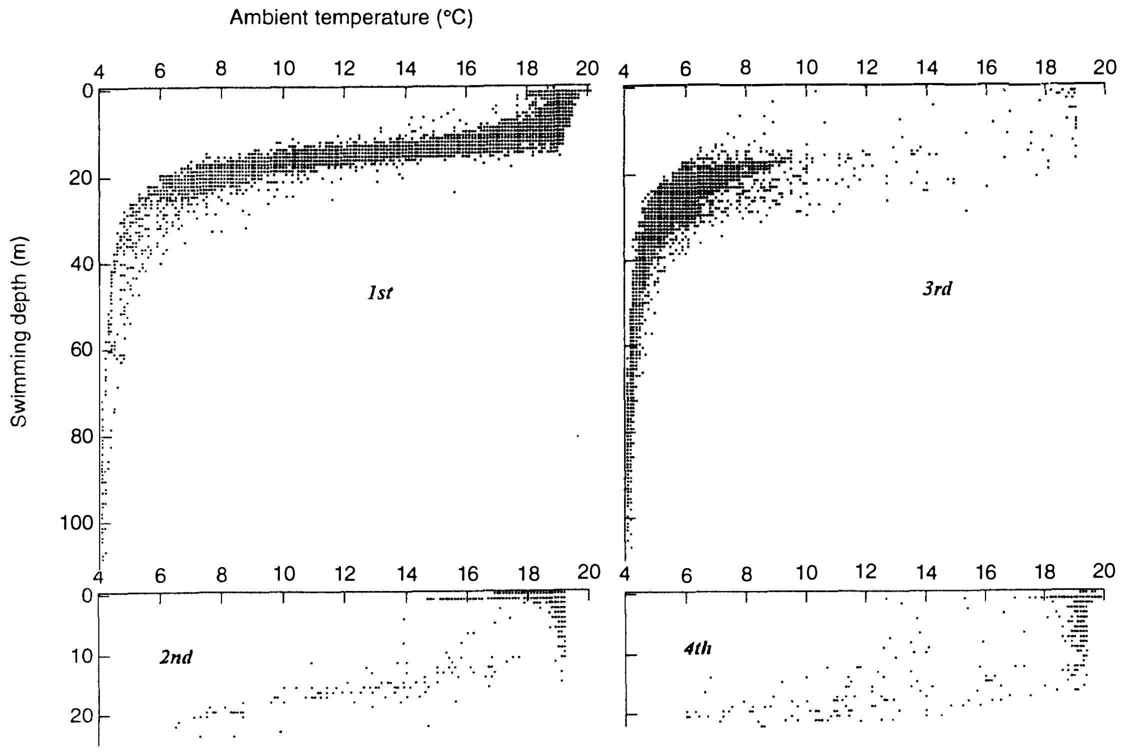

Fig. 3. Depth and temperature profiles in 1st, 2nd, 3rd, and 4th. Very clear spring layer in the shallow water was observed. In 1st phase fish stayed shallow and warmer water and in 3rd phase fish reversed area to deep and colder water. Fish experienced very warm temperature in the very surface in 2nd and 4th phases, particularly in 2nd phase suggesting that fish appeared in river area where warm water run off.

In the final phase, the fish ascended up to the 20 m depth, returning to the shallow layer at about 1300, 25 September and then the fish stopped any vertical movements which indicated that the fish died in a stream where it was captured a few days later.

To examine vertical water temperature distribution, depth-temperature profiles were taken in each phase using data obtained during descents and ascents (Fig. 3). In the coastal phase, the fish moved in both the surface and deeper waters and a full profile was obtained. From the profile, we suggest that the fish stayed in the shallow layer above the thermocline (15–30 m) during the first and second phases. In the offshore phase, surface temperature data was not obtained due to deep swim depth of the fish. However, it is intuitive that the fish stayed below the thermocline considering the likely occurrence of the themocline at the same depth as seen in the coastal phase.

Discussion

Despite having retrieved only one data logger with information for the movements of one fish, it is possible to suggest some movement patterns based on this data for the spawning migration of masu salmon in Lake Toya. The fish selected a shallow, warm layer during the 1st phase while the fish selected a deep, cool layer during the 3rd phase. Although we were not able to demonstrate that the fish actually participated in reproductive behavior during the second phase, it is apparent that the fish entered a stream area and stayed for some time. Therefore, we propose that the swimming behavior during the 1st phase is indicative of the period prior to the upstream migration while the 3rd phase occurs between two attempts to migrate upstream. Before the first attempt, the fish selected a shallow coastal area despite the warm temperature which would cause a higher metabolic rate and energy expenditure (Brett and Glass, 1973). During the spawning migration, fish may select from two environmental choices: shallow, warm water or deep, cool water. Normally, salmonids prefer the cooler temperatures that are found in the shallow areas (Brett, 1995). This suggests that this individual sacrificed energy for some behavioral advantages.

The mechanism of homing is still not known for this species. However, assuming that fish use olfactory stimulation to detect their natal river (Hasler and Scholz, 1978; Stabell, 1992; Ueda and Yamauchi, 1995), it is logical that the fish selected the shallow water along the coast despite the high water temperatures. According to our unpublished data, released mature chum salmon (*Oncorhynchus keta* Walbaum) caught in the mouth of Otsuchi River (Sanriku, Japan) in early October returned to the river in a short time when surface water temperature was as high as 18–20°C. Both experiments show that mature fish select shallow water regardless of temperature indicating the strong motivation for homing and reproduction. On the other hand, it is still unclear why fish migrate along the coast. The coastal area may provide navigational aids including the detection of depth and bottom topography and these cues may act in conjunction with olfactory signals.

During the 3rd phase, the fish selected a stable temperature condition rather than selecting a constant swimming depth. Berman and Quinn (1991) reported that spring chinook salmon (*Oncorhynchus tshawytscha* Walbaum) had a refuge and maintained their body temperature 2–5°C below the ambient temperature before leaving for their spawning ground in the Yakima river, resulting in a 12–20% decrease in basal metabolic demand. Also according to our research on chum salmon, it has been suggested that immature chum salmon stayed in cooler water of 100–200 m in depth in Otsuchi Bay area in early October when surface water was 18–20°C while fish come to the surface waters in November and December when temperature decreased to 8–12°C. This suggests that deep water swimming behavior in the early migratory season is a result of warm water avoidance, likely in order to save energy. Our data suggest that this could also be occurring during the 3rd phase.

The fish selected a shallow depth during spawning migration, likely for navigation reasons, and the fish neglected the temperature environment whereas the fish selected a preferred temperature during the period between two attempts to migrates upstream, perhaps for metabolic reasons. It is impossible to make strong conclusions from this study due to the small amount of data and information regarding lacustrine masu salmon reproductive behavior and spawning migration, however, we suggest that fish respond to temperature conditions in relation to their reproductive condition by evaluating fine scale swimming depth and ambient temperature.

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