Recent Advances in Biotelemetory Technology on Salmon Homing Migration

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***Abstract*—One of the most interesting and challenging mysteries in biology is the homing mechanism of salmon to the natal river. Three biotelemetry instruments (ultrasonic transmitter, electromyographic radiotrasmitter, and micro-datalogger) have been applied to investigate homing migration of anadromous chum salmon (*Oncorhynchus keta*) from the Bering Sea to Japan as well as lacustrine sockeye salmon (*O. nerka*) and masu salmon (*O. masou*) in Lake Toya, Japan. Since each instruments has great advantages and/or minor disadvantages, we are developing an automatic salmon-tracking robot boat consisting of four interrelated equipment systems; a robot boat, an ultrasonic tracking system, a signal processing and control system, and a telecommunication system between a land base and the robot boat. These new biotelemetry technologies make it possible to clarify the amazing ability of salmon to their natal river.**

***Key words*—Biotelemetry, Homing Migration, Robot boat, Salmon**

I. Introduction

A number of studies have investigated the amazing abilities of salmon to migrate long distances from the ocean to their maternal river for spawning, but there are still many unknowns because of the lack of a suitable model system to follow the whole life cycle, especially during the oceanic migration (Ueda and Yamauchi, 1995). In addition to chum salmon (*Oncorhynchus keta*) migrating from the Bering Sea to Japan, we have used lacustrine sockeye salmon (*O. nerka*) and masu salmon (*O. masou*) in Lake Toya, Hokkaido, Japan, where the lake serves as a model "ocean", as good model fish for studying the physiological mechanisms of the homing migration in salmon (Fig. 1).

Fig. 1. Life history of two different types of Pacific salmonid species in Japan. Dotted line: chum and pink salmon; Solid line: sockeye and masu salmon.

Three biotelemetrical instruments (ultrasonic transmitter, electromyographic radiotransmitter, and micro-datalogger) have been applied to investigate the homing migration of lacustrine salmonid fishes. First, the homing migrations of mature sockeye and masu salmon, whose sensory cues were impaired, were tracked from the center of the lake to the natal area using ultrasonic transmitters. Second, physiological telemetry was used to estimate the energetics of adult masu salmon comparing fish in the lake with migrating fish in the stream using electromyographic (EMG) radiotransmitters. Third, swimming depth and ambient water temperature of mature male masu salmon during the spawning season were recorded using micro-dataloggers. Active transmitters can directly track and monitor fish movement, and do not be necessarily need to be recovered, but they are labor intensive since researchers must be constantly engaged in receiving the signals, although remort detection is possible in some cases. Micro-dataloggers can store data, including ambient temperature, swimming depth, swimming speed, heart rate, and light intensity, without constant monitoring, but they must be recovered before the data can be downloaded.

Since each technique has great advantages and/or minor disadvantages in clarifying physiological mechanisms of fish behavior, ten experts in the fields of ship engineering, signal processing, acoustic engineering, and computer science have carried out a collaborative research project to develop an automatic salmon-tracking robot boat in Lake Toya since 1999.

II. Ultrasonic tracking

Ultrasonic transmitters that emit pulsed signals have been used to investigate the migratory behavior of salmonids in the coastal sea (Quinn *et al*, 1989) and the central Bering Sea

(Ogura and Ishida, 1994). Moreover, ultrasonic tracking in combination with sensory ablation experiments, which blocked visual and olfactory cues or magnetic senses, have been performed several time with oceanic migratory salmonids (Døving *et al*., 1985; Yano and Nakamura, 1992; Yano *et al*., 1996). However, for sea-run anadromous populations, it is difficult to carry out physiologically controlled and manipulated experiments as fish move from the sea, in their pre-maturation phase, to their natal stream, where they become mature. On the other hand, lacustrine populations offer a good model system for studying the homing mechanisms of salmon from open water to their natal area for reproduction.

The homing migrations of mature sockeye and masu salmon, whose sensory cues were impaired, were tracked from the center of the lake to the natal area using the ultrasonic tracking system (Ueda *et al*., 1998). Both a mature male sockeye salmon with attached control brass ring and a mature male sockeye salmon whose magnetic cues was interfered with magnetic ring returned straight to the natal area after 1 h of random movement. A mature male sockeye salmon whose visual and magnetic cues were both blocked moved in a direction opposite to the natal area, and was rediscovered in the natal area on the following evening. A blinded male sockeye salmon was also moved to the shore of Naka-Toya far from the natal area in the evening. A mature control male masu salmon moved constantly along the coast, and stopped his movement at the mouth of river. A mature male masu salmon whose olfactory cue was blocked moved randomly along the coast, and then tended to move away from the coast. A blinded mature female masu salmon was released moved randomly away from the coast.

The ultrasonic location transmitters were combined with sensory ablation to evaluate homing capability, particularly orientation ability, of sockeye and masu salmon. Using this method, both visual and olfactory cues were necessary for successful homing in masu salmon. Similarly, visual cues were critical to the homing of sockeye salmon, while magnetic cues did not appear to be necessary for successful return to the natal area. However, the magnetoreceptor cells have been identified in the nose of rainbow trout (*O. mykiss*) (Walker *et al*., 1997), and futher study should be done to investigate magnetic cues in salmon. It is quite interesting to compare the straight movements of sockeye salmon with the coastal movement behaviors of masu salmon. These two species show large differences in ocean distribution with sockeye salmon distributed widely in the North Pacific Ocean, while masu salmonn are narrowly distributed in the west North Pacific Ocean (Kaeriyama and Ueda, 1998). The phylogenetic analysis among Pacific salmon and trout suggests that masu salmon are more primitive than sockeye salmon (Murata *et al*., 1993, 1996; McKay *et al*., 1995). These data suggest some evolutionary aspects of successful homing migration of salmonids where the narrowly distributed masu salmon only need coastal recognition ability, but widely distributed sockeye salmon must obtain open water cues for orientation.

III. EMG radiotransmitters and Micro-data loggers

Although ultrasonic tracking is particularly important to monitor the homing behavior of the ablated individual through constant tracking, both electromyographic (EMG) radiotransmitters that can estimate the energetics of migration and micro-dataloggers that can record swimming depth and ambient water temperature of migrating fish have also been used in Lake Toya (Ueda *et al*., 2000). In adult masu salmon, the preferred swimming speeds of individuals within the lake (during their pre-migratory searching phase) were compared with the same individuals in streams using EMG radiotransmitters (Leonard *et al*., in preparation). Masu salmon in the lake swam at a preferred speed of approximately 2 FL/s with remarkably little variation. In the stream, the variability in selected swimming speed was much larger, and often showed a bimodal pattern with one peak in the aerobic swimming speed range and the other in the anaerobic speed range. EMG telemetry had previously mainly been conducted on large river migrations and in the detection of species/stock differences (Hinch *et al*., 1996; Booth *et al*., 1997; Økland *et al*., 1997; Hinch and Rand, 1999). Micro-dataloggers (archival tags) assessed environmental preferences of mature masu salmon during spawning migration. The fish's behavior was characterized to in the searching period where it stayed in relatively shallow water and traveled around the periphery of the lake. During the period prior to upstream migration, the fish seemed to be selecting habitat by depth or lake area rather than by temperature. Between two upstream attempts, the fish was characterized as being in the recovery period where it stayed in deep, cool water (Naito *et al*., 2000). A number of interesting data have accumulating from micro-datalogger in salmonid fishes during the oceanic migration (Naito, 1997; Tanaka *et al*., 2000). Although each biotelemetry technology has great advantages as well as minor disadvantages, combination of different physiological biotelemetry techniques will allow us to understand the physiological mechanisms of salmon homing migration using our unique lacustrine model.

IV.Robot boat

Although our lake system has provided several interesting findings in salmon homing migration as a result of various types of tracking telemetry, these techniques have many disadvantages. In order to overcome these disadvantages, ten experts in the fields of ship engineering (Drs. K. Karasuno, K. Maekawa, Y. Toshimura, and H. Oda), signal processing (Drs. M. Suzuki and K. Matsuda), acoustic engineering (Mrs. K. Kamada , H. Murakami, and K. Minoshima), and computer science (Mr. M. Wada) have carried out a collaborative research project to develop an automatic salmon-tracking robot boat in Lake Toya since 1999.

We have developed four interrelated equipment systems of prot-type lacustrine salmon tacking robot boat (Fig. 2).

1) A robot boat is a swath type ship with styroform twin hull constructed by pipes, 2.5 m in length, 1.3 m in width, with a loading capacity of 120 kg, operating at 2 knots using two

electric thrusters. This boat is easy to disassemble, construct and carry to anywhere in the world.

2) An ultrasonic tracking system consists of a miniature ultrasonic transmitter and a position detecting unit. An ultrasonic transmitter is 50 mm in length, 11 mm in diameter, and 15 g weight in water, and 20 KHz in frequency. A position detecting unit is ALS-20DK (Kaiyo Denshi Co., Ltd) that can detect the distance, depth, and direction of a miniature pingers.

3) A signal processing and control system is operated by a personal computer on the boat that receives signals from DGPS (Differential Global Positioning System) that can detect boat position within 1 m difference, a gyroscope that can monitor boat tilting, and acoustic signals from ALS-20DK. Then, this computer processes these signals , and controls truster amplifyer for tracking an ultrasonic transmitter attached on the back of salmon.

4) A telecommunication system between a land base and the boat is operated by NTT-Docomo handy-phone circuit by a speed of 96000bps.

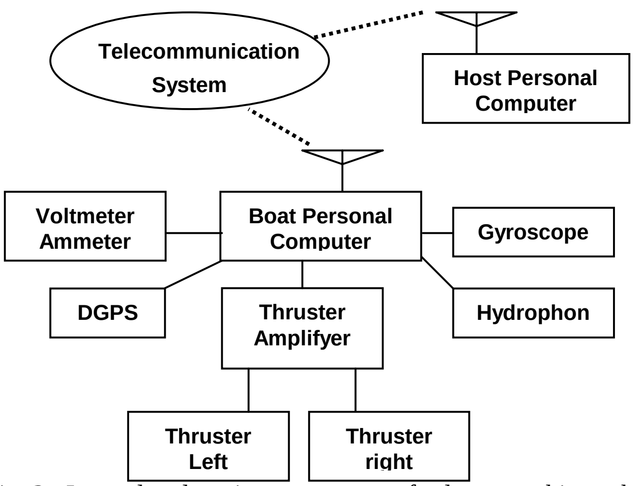

Fig. 2. Interrelated equipment system of salmon tracking robot boat.

On October 16, 2001, we attached a miniature pinger to a mature male lacustrine sockeye salmon of 1752 g in body weight, and on the following day, the first trial of automatic tracking of free-swimming fish was carried out. The robot boat tracked the sockeye salmon for 66 min for a distance of 800 m, but the trouble in the handy-phone circuit stopped the automatic tracking (Fig. 3). We are now improving the telecommunication system.

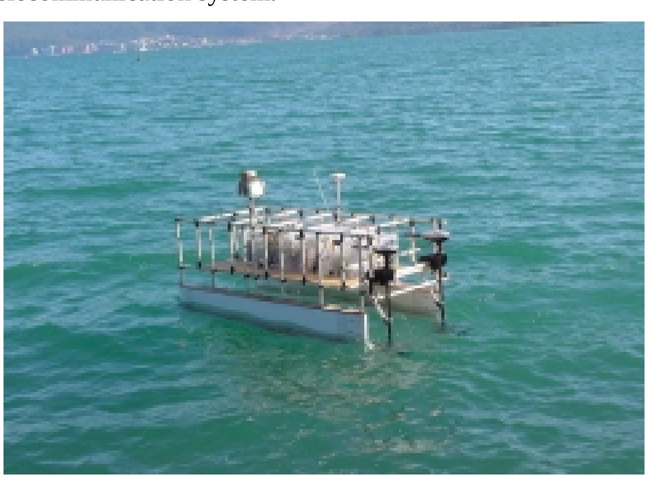

Fig. 3. The robot boat tracking lacustrine sockeye salmon in Lake Toya

The final goal of this project is to build the robot boat that can track salmon in the ocean. Moreover these newly developed biotelemetry technologies will be applicable in 3 dimensional analysis of fish swimming behavior in the fixed station as well as in self-navigation to monitor dangerous area, such as volcanic eruption.

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