positioning information. Once animals go into water, almost nothing is given by the satellite systems. Even acoustic techniques are used; it is far beyond the spatial and temporal preciseness. To open the views to the deep and dark marine world, animal-mounting data logger system was developed since early 1980s. Applying the advanced techniques of microelectronics, miniaturization of data logger (micro-data logger) has been achieved and it gave us eyes to look the marine animals in the sea.

By using the techniques of the micro-data loggers we could measured the precise swimming behavior including even three-dimensional movements of the marine animals without linking the satellite service. We also could measure foraging behavior, when and how much animal took the prey in the water and also precise monitoring of the animal behavior, when and how they behaved during their foraging trip. Now we can measure either the interaction between individuals or their prey condition by micro-image data logger.

Future direction of this research is to develop the precise measuring techniques of the bio-chemical and bio-physiological condition in free ranging animals simultaneously with their behavior and environments. As well as above direction, we need to make effort to realize further miniaturization of the loggers and further large memory capacity.

How do we know salmon behavior ?
I. A microscale study: Behavior of individual salmon studied with data loggers

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Chum salmon *Oncorhynchus keta* is one of the seven species of Pacific salmon. Like other salmonid species, chum salmon exhibit a typical anadromous migration: they are born in the river, migrate to a feeding area in the Bering Sea and the northern North Pacific Ocean, and return to their natal river to spawn after four to six years. They are typical cold water fish; their upper lethal temperature does not extend beyond 24°C, and the critical temperature which defines the southern boundary of their feeding area is 10.2°C. Therefore, global warming due to the greenhouse effect of increasing CO_2 level in the atmosphere is a potential threat to the salmon life. It is important to clarify the physiological and ecological impacts of high water temperature on the salmon.

Coastal area of Iwate Prefecture, which is located at the central part of Sanriku Coast in northern Japan, is close to the southernmost natural spawning area of Pacific salmon. Returning season of chum salmon in this area is generally September to December. The surface sea water temperature is usually more than 18°C at the beginning of the season and decreases to about 12°C at the end, which appears to be unsuitably high for chum salmon. Moreover, in addition to the cold water mass of Oyashio, two other warm water masses of Tsugaru Warm Current and Kuroshio Current distribute off the Sanriku Coast complicatedly. How do chum salmon behave in such unsuitably warm water masses? Understanding of the homing behavior of chum salmon around the Sanriku Coast may provide an important insight to estimate the impacts of global warming on the salmon life.

To study salmon behavior in Sanriku Coast, we employed data logger tagging. The data logger tagging enables simultaneous recording of various data, such as depth, temperature and swimming speed of free ranging individual salmon, over a long time period in a broad area. Furthermore, the homing migration of salmon to their natal river promises high recovery of released loggers.

We found that the behavior of chum salmon drastically changed responding to the vertical thermal condition of sea water. In October, when the surface temperature was more than 18°C and sea water was thermally stratified, they preferred to stay deep water, making long dives to the bottom, but showed frequent ascents to the surface. In December, when the surface temperature was under 14°C and the thermally mixed layer was developed, they basically stayed less than 50 m deep, making restless descents and ascents. These data indicate that, in thermally stratified water with high surface temperature, chum salmon seek the coolest thermal refuge as they can exploit by their vertical movement. Since salmon are poikilothermic, the coolest thermal refuge leads salmon to minimize the metabolic energy cost. Thus the salmon regulate their body temperature, and hence the metabolic energy consumption rate, through seeking the coolest thermal refuge.

Then, why do salmon prefer shallow water in December? Why do they come back to shallow water even the temperature is unsuitably "hot" for them in October? It is generally accepted that salmon use olfactory cues to find their natal river. Since the river water is lighter than sea water, it distributes near the surface. Probably salmon are searching the odor of their natal river in the shallow water even if it is "hot". The minute to minute record by the logger allowed us to analyze the behavior of chum salmon in the surface water in detail, and we found the evidence which indicated that salmon were smelling the river water. In October, data loggers recorded the cool water masses that covered warmer sea surface in patches.

These cool water masses are the water draining from the river system, since river water at this season is cooler than sea water. Salmon stopped their vertical movement for minutes in such cool water masses.

As described above, chum salmon reduce their metabolic energy consumption by making deep dives in thermally stratified water. We closely analyzed the diving behavior of salmon with newly developed loggers which can record swimming speed, depth, temperature, and acceleration in two directions, parallel and perpendicular to the body axis. Acceleration parallel to the body axis is a good indicator of an angle of fish body and the other is that of swimming activity. Our study revealed that chum salmon swam much more actively when they were ascending than descending, whereas swimming speed was similar. The angle of fish body was more acute when they were descending. These data suggest that the density of the salmon is equivalent to that of sea water in the surface layer, but becomes larger in the deeper layer.

Application of data logger tagging to the salmon made us possible to know their minute to minute behavior. The detailed data on the response of homing chum salmon against the "hot" water masses are now accumulating. However, the study site is restricted to the coastal area and the study subject to homing adults at present. Further studies on the salmon at different life stages, at more broader area, and in the different sea water condition are indispensable.

How do we know salmon behavior? II. A mesoscale study: Behavior of salmon schools estimated from fish market statistics and routine marine meteorological data.

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Behavior of salmon *Oncorhynchus keta* schools estimated from fish market statistics and routine marine meteorological data will be introduced as an example for a mesoscale study of salmon behavior. Here, mesoscale means order of 10 km to 100 km in spatial scale and that of day to hour in temporal scale, such as the spatial and temporal scale in homing behavior of salmon from Sanriku Coast, the Pacific side in northern Japan, to rivers.

The fishermen's proverb in Sanriku Coast says, "the large salmon catch occurs just after dropping down of seawater temperature." It may be true since the salmon return from the northern sea where seawater temperature is lower than that of Sanriku Coast. They also say, "the large salmon catch occurs just after rainfall or blowing of westerly strong wind." Rainfall increases the amount of river water. The westerly wind is the monsoon in salmon fishery season. This strong wind carries the river water widely and rapidly off the bays of Sanriku Coast, because bay mouths are open to the east. These two phenomena, increase of the river water and the wider spread of river water to the open sea, may help salmon to identify their natal rivers by means of detecting the smell of the river water (Hasler and Wisby, 1950). Thus, it is possible that the fishermen's proverbs are scientifically true.

However, there are poor reports on the relationship between salmon catch and sea condition and/or weather condition. Then we tried to prove the fishermen's proverbs and to estimate the mesoscale behavior of salmon schools returning to Sanriku Coast by using fish market statistics and routine marine meteorological data.

We performed it in Otsuchi Bay as a model of Sanriku Coast because we have been obtaining the marine meteorological data by our system. The axis of the Otsuchi Bay leis in the direction of east and west, and the mouth is open to east, the North Pacific side. The length and width are about 7 km and 3 km, respectively. The depth at the bay mouth is about 80 m and becomes shallower toward the bay head linearly. Three natal rivers, Otsuchi River, Kozuchi River and Unosumai River, flow into the bay head.

Marine meteorological observation system has been operating since 1978 by OMRC of the University of Tokyo at the center and the north side in Otsuchi Bay. The parameters included seawater temperature in 5 layers of 1, 5, 10, and 15 m and meteorological components as wind velocity, precipitation, *etc* are monitored at 10 min interval on real time at the entrance hole of OMRC. Hourly mean or daily mean of 5 m-seawater temperature, wind speed and wind direction are used for analysis except daily-integrated precipitation.

Otsuchi Bay was divided into three areas; the bay mouth, the bay head and the river mouth. Then daily salmon catch of each area, which was calculated from the market statistics of stationary trap-nets, was discussed with marine meteorological conditions in 1996 and 1997.

The salmon catch in every area reached a peak of the fishing season when the seawater temperature became 13°C level in both years. The peak in the river delayed a few days compared with that in the bay moth in 1996 but it did not delayed in 1997. In 80% cases, the salmon catch at the day after the rainfall (>5 mm) or strong westerly wind (>10 m/s) became over 1.5 times larger than the previous day. The largest salmon catch in each year was observed at the day after the largest rainfall occurred, or the day after westerly wind (>10 m/s) blew for the longest period. These data suggest that the homing behavior of chum salmon was affected significantly by seawater temperature, rainfall, and westerly wind in Sanriku Coast.

Surprisingly, more than ten years before Hasler and Wisby (1950), Kubo (1938) has already reported the relationship between salmon catch and the weather condition in the Miomote