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when fish entered water shallower than 10 m. In deeper water the wave is smoothed and no noise was observed. The tide will affect data as well. However, the effect of relative change of depth on animal behavior, depth change occurs in time scale shorter than the tidal scale (0.0093 cm/sec for a 2 m tide). Thus, it seemed to be negligible in measuring such relative change of depth. For temperature, the sensor we used has $\pm 0.1^\circ\text{C}$ accuracy. To ensure $\pm 0.1^\circ\text{C}$ of actual accuracy, the minimum required resolution is 10 bits against 720 span for -22°C - 50°C range. Thus, so far as temperature $\pm 0.1^\circ\text{C}$ accuracy was assured.

We developed the microdata logger to use as an archiving data tag and tested it in a variety of target animals from marine mammals to fish. The experiments were successfully conducted except for initial unexpected errors of both hardware and software. However, once these problems were solved, the tags showed high reliability as instruments for research.

IX. FISHWAYS FOR UPSTREAM DIADROMOUS MIGRANTS

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Abstract

This paper presents a short review of some recent advances in fishway technology such as new types of fishways and new data on velocities in fishways and on fish swimming ability. It also includes new concepts such as maintaining a fishway's effectiveness in high water stages and the need to offer equal opportunity for successful migration to all diadromous migrants.

1. Evolution of streaming-type fishways

Types of fishways

Fishways can be broadly classified into three types: pool-type, streaming-type and operation-type. Pool-type fishways consist of a series of pools separated by baffles, such as pool-weir fishway and vertical-slot fishway. Streaming-type fishways do not have baffles and pools, even though some have vanes such as Denil fishway, and have continuous flow from top to bottom in the unit channel. The operation-type fishway, such as fish locks and lifts, cannot fulfill its function without some operation.

Smooth-bed channels

According to Tannatt (1938), Clay (1961) and Katopodis (1982), the earliest recorded fishways appeared in the 17th century in Europe, and the type was probably streaming-type featuring diagonal baulk and gently-sloping, open channel. The diagonals and the gently-sloping, open channels collect and concentrate a flow of water sufficiently deep and wide for fish to use when swimming over an obstruction, where there would otherwise be neither adequate depth nor guiding lead (Tannatt, 1938).

Such smooth-bed channels are suitable only for gently-sloping, low weirs/dams. If the slope is too steep, the pass would provide an excessive flow velocity to the fish, and if the slope is too slight the length would be too long for fish to ascend without resting.

Installation of boulders

In order to decrease flow velocity, installation of boulders has been done since early times. An example still existing can be seen in a Scottish uniform-gradient fish pass with rows of upright boulders/blocks at regular intervals to break up the water flow (Scottish Office, 1995). Also in Japan, boulder-installed channels have been a traditional fishway style for a long time, and recently because of the "more-naturalized stream-repair works" initiated by the Ministry of Construction, the construction of rapids-like fishways has been increasing (Nakamura, 1995).

In this case, however, it should be noticed that fish cannot sufficiently utilize their swimming ability in highly disturbed flow; their propulsive energy often only produces higher frequency turbulence, not higher velocity. This is similar to the case of fish swimming near the water surface where they sometimes lose 80% of their swimming energy by generating waves (Videler, 1993). Similar case can be seen in an experiment on motor-boat movement in a Denil-like fishway (Pohjamo, 1995). In this experiment, a wide channel roughened by vanes similar to the bottom part of Denil fishway and a small motor-boat model were employed. According to the author, the first test showed that the boat could not completely ascend the relatively slow but highly disturbed flow. In the second test, a narrow flat plate was set on the vanes at the center of the channel bottom. In spite of the increase in flow velocity, a successful ascent was achieved.

Boulder-installed curved slope

These experiences seem to teach us that we should return to the initial concept of streaming-type fishway mentioned above in relation to the diagonals, etc. That is, boulders should be installed to provide a straight, sufficiently deep and undisturbed passing route as much as possible, by collection and concentration of water flow in between the streamline rows of laid boulders. The concept was employed in a boulder-installed fishway along with the idea of a curved slope by Nakamura (1994).

Roughened surface for eel/lamprey and crustaceans

At the present time, the world's highest dam incorporating a fishway is probably the Petea Dam (73 m in height) in New Zealand. This fishway uses stone chips glued inside inclined PVC pipe and was installed for climbing fish such as eels (Mitchell, 1995). Also in a fishway in Finland, brushes are installed on the bottom of vertical-slot for lampreys (Pohjamo, 1995).

In order to give an effective climbing pass for crustaceans such as crabs and freshwater shrimps, roughened channels, using in some cases cellular concrete, seem to be effective (Hamano et al., 1995). At a dam of 35 m-height in Okinawa, Japan, a steep concrete ditch in which the bottom is covered by cobbles is effective as a crustacean fishway (Nakamura, 1995).

Velocity vector in standard Denil fishways

As is well known, Denil fishways are the product of scientific investigation into roughened channels. Standard (or plain) Denil fishways show a characteristic velocity profile in which the velocity decreases from the water surface towards the bottom. According to a computer calculation, the magnitude of the velocity vector, however, does not decrease so much as mentioned above; the direction of the vector however drastically changes from horizontal in the water surface to vertical in the bottom. This has also been observed in an other experimental study (Katopodis, 1995).

Passing route of relatively small fish in steep-pass fishways

In contrast, velocities in steep-pass fishways decrease from the channel bottom towards the surface. The water surface with low velocities is, however, too disturbed for smaller fishes to employ their swimming ability sufficiently as mentioned above, so that they seem to choose the lower layer with higher velocities to achieve a successful ascent (Wada et al., 1996)

Resting pools in a long denil fishway

A field experiment on a narrow, but long and steep, Denil fishway (70 m-length, 1/3-slope) was carried out at a Japanese sabo-dam in 1993 (Nakamura *et al.*, 1995). Even after the improvement of resting pools, a fish release test showed that the number of fish passing through each pool decreases exponentially. This fact seems to suggest that having resting pools does not guarantee complete rests with the result that some fish tire and are washed downstream. To avoid such a risk, more resting pools should be installed at short intervals; we might say that streaming-type fishway thus actually becomes a pool-type at extreme lengths in the total system, to ensure safety of the fish during their ascent.

Boat-pass Denil (the larinier pass)

This type, known as “the Larinier Pass” in Scotland (Scottish Office, 1995), has no side vanes, but is fitted instead with chevron-shaped vanes along the bottom of the channel. The inventor, M. Larinier, mentions in his book (Larinier et al., 1994) that this type is suitable only for large fish such as salmon and trout. However in an identical fishway of 45 m-length and 1/14-slope at a diversion weir on the Toyo river, in Japan, juvenile Japanese sculpin *Cottus hilgendorfi* and floating goby *Chaenogobius annularis* (several centimeters in body length) successfully used the fishway (FISCO, 1994). This fact suggests that these fish use the small but calm spots behind the vanes as their rest area; thus the boat-pass Denil is a kind of pool-type for them.

2. Appearance of hybrid fishway**Discharge-fluctuations as a trigger to accelerate fish-ascent**

For many upstream migrants, fluctuations of stream conditions such as flow discharge, water temperature and turbidity seem to be a kind of trigger to initiate upstream migration movements. For example, remarkable increases of ascending fish at low obstacles are sometimes observed during the period of stormflow (Mayama and Takahashi, 1977). If stormflows result in an acceleration in upstream migration for some fishes, fishways effective in high water stages would be recommended for such fishes.

In the previously mentioned boulder-installed curved slope, the idea of the curved slope was introduced based on its effectiveness under high flow conditions.

Pool and chute fishways

The pool and chute fishway has been developed as the result of a similar consideration by Bates (Bates, 1990). This fishway is a cross between a pool & a vee-shaped weir fishway at low flow and a roughened chute having vee-shaped vanes at high flow. At low flow, the fishway performs as a pool-type fishway with plunging flow, whereas at high flow, a high rate of streaming flow passes down the center of the vee-shaped baffles which work as vanes (Bates, 1992).

Steepest pool-type fishways

In order to satisfy the potential need for steeper pool-type fishways, an experimental study has been carried out in our laboratory using an “endless” fishway model. After some trials and errors in baffle design, an allowable flow through notches was obtained with a reasonably calm space in pools, with a baffle design where two slightly different baffles work in pairs. The flow on the baffles is, interestingly, somewhat similar to the flow in the boat-pass Denil; we might say that pool-type fishways possibly become streaming-type at extreme slopes, but still meet the condition of providing fish resting spaces.

3. Other advances

New operation-type fishways

One of the troublesome things in fish locks including the Borland fishway is the difficulty in forcing fish to exit upstream. One of the recent attempts to overcome this weak point is to employ a vertical slot at the fishway exit (Kamula, 1995). Another example is to introduce a pressure chamber. The pressure chamber has a duct opening to allow fish to pass through and a diffuser to reduce the pressure at either end of the chamber. Only one passageway and one diffuser is opened at a time (Grande, 1995). The key point of these ideas is to provide continuous guidance flow at all times.

New information from fishes

Data for lake sturgeon have been recently presented in Katopodis' swimming ability diagram (Katopodis, 1995). From the data, we can see that sturgeon have lower swimming performance than salmon in the dimensionless representation, i.e., for the same body length, lake sturgeon performance is lower than that of subcarangiform fish throughout the burst and prolonged ranges. Sturgeon, however, grow to much larger lengths than subcarangiform fish, so that the absolute swimming speed of a large sturgeon may be similar to the absolute swimming speed of a much smaller salmon; thus velocity criteria for fishway design may be similar (Katopodis, 1995).

A new type of radio tag (electromyographic or EMG tag) that gives both fish position and an indication of muscle activity was tested in the Fraser Canyon, Canada, in the summer of 1993. The purpose of the tagging program utilizing this new tag was to gain deeper insight into the effect of water velocity and temperature on salmon migration and determine the energy cost to the fish at difficult passage points in the river (McGechaen, 1994). Similar biotelemetry technology has been applied at some other fishways (Katopodis, 1995).

One of the interesting preliminary findings in such field research is that areas downstream from some sand bars, normally considered zones of rest prior to continuing upstream migration, seemed to be areas of high energy use (McGechaen, 1994), or to be areas where salmon experience higher stress. We may expect the day when we understand how the target fish feel in our designed fishways. The day when similar benefits will be given to smaller and economically-lower valued fish, but having equal rights in our sustainable eco-system, might be in the 21st century.

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