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Field Experiment on the Migration of Fishes to a Paddy Field with a Small Fishway

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Abstract

Medaka (*Oryzias latipes*) populations have recently declined to such a level that they are listed as a species in danger of extinction in the Red Data Book. And a decline in the numbers of catfish and loach has been reported in various parts of Japan. One cause of their decline is the increase in the drop height between paddy fields and water channels, particularly drainage channels. For catfish, loach, and medaka, paddy fields are important spawning grounds or habitats. This report describes the results of a study conducted by the construction of an experimental fishway that fish can use to migrate into an idle paddy field beside Lake Kasumigaura and for the observation and determination of the actual migration of fish swimming through the fishway during a 2-year period from 1997 to 1998. It was observed that immediately after the opening of the sluice gate between Lake Kasumigaura and the channel, the number of fishes migrating to the experimental site, which were assumed to have been carried by water flowing from the Lake, reached a peak.

Discipline: Irrigation, drainage and reclamation
Additional key words: biological diversity, paddy irrigation systems, fish protection

Introduction

Paddy field areas in the lower watersheds of rivers are the habitat of carp (*Cyprinus carpio*), Prussian carp *(Carassius carassius* subsp.), catfish (*Silurus asotus*), loach (*Misgurnus anguillicaudatus*) and medaka (*Oryzias latipes*) that are very familiar to the people of Japan. The "schools of medaka" mentioned in the children's song were a common sight in small channels beside paddy fields until the period of high speed economic growth that began in the cities in the late 1950s and early 1960s. But medaka populations have recently declined to such a level that they are listed as a species in danger of extinction in the Red Data Book. And a decline in the numbers of catfish and loach has been reported in various parts of Japan. One cause of their decline is the increase in the drop height between paddy fields and water channels, particularly drainage channels. When the height of a drop between paddy fields and a drainage channel is increased to prevent heavy rains from causing flood damage or to dry the fields in order to improve the operating conditions of agricultural machinery or to increase rice yields, obviously, fish can no longer migrate to the paddy fields. For catfish, loach and medaka, paddy fields are important spawning grounds or habitats. The existence of a drop between the paddy field and drainage channel is a question of survival for these fish species.

But needless to say, to prevent flood damage, it would be very difficult presently to eliminate these drops. A method of allowing these fish species to migrate into the paddy fields while retaining the present drops must be studied, and one approach under consideration is to install fishways appropriate to these species.

This report describes the results of a study conducted by the construction of an experimental fishway that fish can use to migrate into an idle paddy field on the shoreline of Lake Kasumigaura and for observing and determining the actual migration of fish swimming through the fishway during a two-year period from 1997 to 1998.

Outline of the experimental site and experimental method

1. Outline of the experimental site

As shown in Fig. 1, the experimental site was an idle paddy field with a surface area of 1,100 m^2 beside a water

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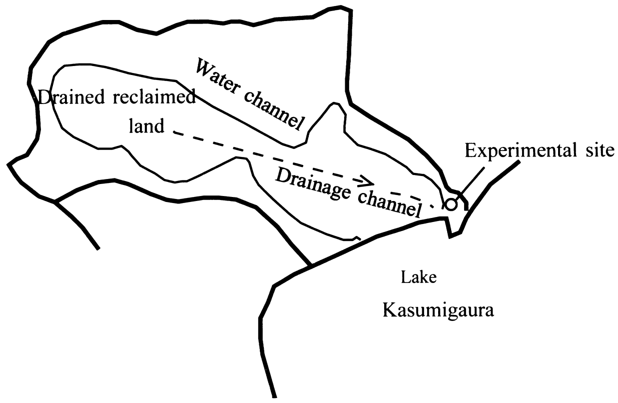

Fig. 1. Location of the experimental site

channel on Kasumigaura Reclaimed Land Yogoiri. During the irrigation season, a sluice gate on the reclaimed land irrigation channel that flows beside the idle paddy field is opened and the level of the water in the channel is almost identical with that of Lake Kasumigaura. The paddy fields including the experimental site located around the reclaimed land are supplied with water through a pipeline from a pump house on the lakeshore and the channel receives water drained from the paddy fields outside the reclaimed land. The difference between the paddy field surface at the experimental site and the water level in the channel during the irrigation period fluctuates between approximately 0.3 and 0.5 m.

2. Experimental method

(1) Configuration of the experimental site

Fig. 2 shows the flow of the water and the location of the fishway, etc. at the experimental site. Of the 3 submerged pumps installed inside the water channel, 1 pump supplies water to the experimental site from the part closest to the channel (Zone B: approx. 150 m^2) while the other 2 pumps are used to supply water to the part farthest from the channel (Zone A: approx. 900 m^2). A total of between 200 and 600 L/min of water can be supplied by operating these separately. A quantity of water ranging from 300 to 350 L/min was continuously supplied from Zone A during both 1997 and 1998. The retention time when 350 L/min was supplied was about 5 h. In 1998, from mid-April when the water supply started until June, water was supplied only from Zone B without being retained in Zone A, to allow millet and similar plants grown from seed in Zone A to become firmly established after germination.

The fishway was installed at a location of the experimental site closest to Lake Kasumigaura and an observation hut was constructed beside the fishway to monitor the migration of fishes up the fishway, the water temperature, etc. A spawning ground (Zone C: approx. 60 m^2) was constructed at the upstream end of the fishway. In the spawning ground, the ground elevation was adjusted so that the water would be between 0.3 and 0.05 m in depth, and to observe plant selection properties as a spawning ground, plants such as reed canarygrass (*Phalaris arundinacea* L.) , creeping bentgrass (*Agrostis stolonifera* L.) and Japanese parsley were planted. These plants grow naturally at the experimental site.

(2) Fishway construction

Fig. 3 shows an aerial view of the fishway that was constructed as a trial. As the Figure reveals, it was made by reducing the size of a stepped-type fishway for paddy field use. The fishway was designed so that both relatively large fish such as carp and Prussian carp and smaller fish such as medaka could migrate through it, and considering the fact that although under certain conditions it would be necessary to supply water by pump, the

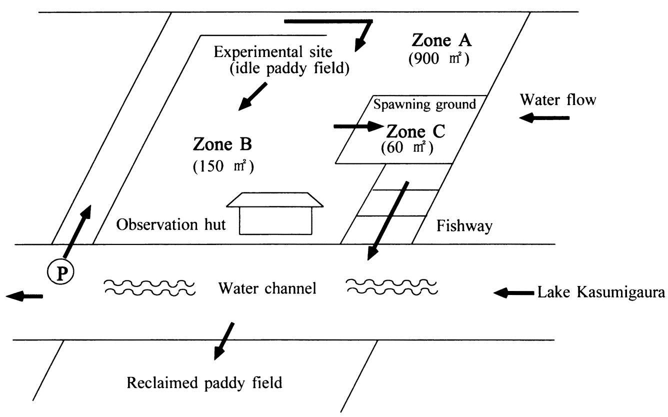

Fig. 2. Schematic diagram of the experimental site

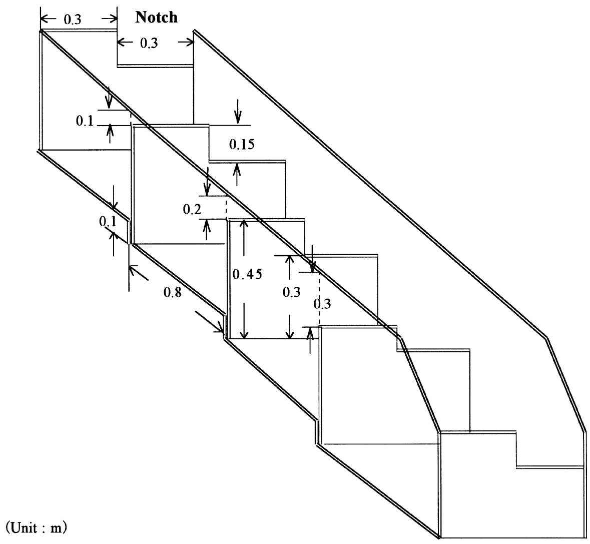

Fig. 3. Configuration of fishway and dimensions of all the parts

fish should migrate through the smallest possible quantity of water. The difference in the level of each step was 1.0 m, the full width was 0.6 m including an overflow section width of 0.3 m, the pool length was 0.8 m, and the pool depth was 0.3 m. A total of 5 steps were provided in the fishway because the difference between the paddy field surface and normal water level of the channel was estimated to be 0.4 m.

(3) System for counting migrating fish and method for species confirmation

The number of fishes migrating through the fishway was measured by sensing the fish with optical sensors and confirming the results with a video monitor (continuous monitor). As shown in Fig. 4, the optical sensors were installed at 3 locations arranged vertically upward from just above the water on both sides of the highest separation barrier in the fishway. This arrangement was planned to enable the system to distinguish fish migrating upstream from those migrating downstream in the fishway so that when heavy rainfall, etc. raised the water level at the experimental site, thereby preventing the lower sensors from functioning, the upper sensors would still operate.

But because the reliability of the optical sensors is low, leading to many sensing errors, a video camera installed at the observation hut continuously monitored the overflow part of the highest step in the fishway. In summary, the migration of the fish in the fishway was confirmed by checking the video monitor whenever the optical sensor detected fish moving upstream to visually determine whether or not fish actually migrated at that time. The range that could be observed by this continuous monitoring system was almost identical with that shown in Fig. 4.

The fish species were confirmed by passing the fish through a transparent acrylic channel with a width of 0.2 m immediately after they migrated to the experimental site to observe the fish with a submerged camera installed beside the acrylic channel (submerged monitor). But this monitoring was only attempted during the 1998 survey period and it could not be performed continuously.

During both years, a video camera was set up, when convenient, to conduct more detailed studies on the way that fish migrated through the fishway.

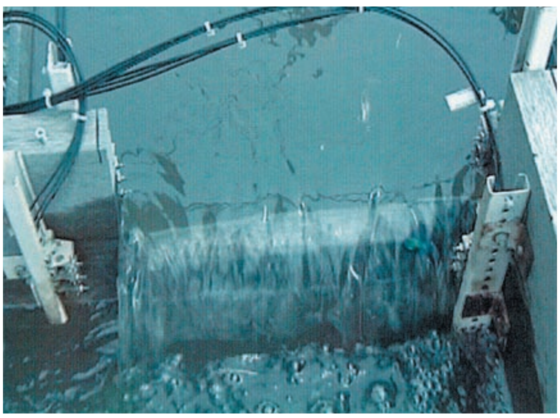

Fig. 4. Location of optical sensor installation (Hata, May 1998)

(4) Water temperature observations

Assuming that the water temperature could be a factor that may induce fish to migrate to the fishway, water temperature sensors installed in the channel at a point 3 m upstream from the fishway and at 2 locations inside the pool at the highest step of the fishway continuously recorded the water temperature during the experimental period.

Results and conclusions

1. Fish species migrating to the fishway

The survey conducted in 1997 and in 1998 involved continuous monitoring of the highest overflow part in the fishway from the observation hut constructed beside the fishway. Because this permitted only the confirmation for relatively large fish, a transparent acrylic channel was installed at the top of the fishway in 1998 so that fish that migrated up the fishway had to pass through it in order to enter the spawning ground and the inside of the transparent tube was monitored by a submerged camera. But these observations were not conducted throughout the experimental period.

Table 1 shows the fish species that were confirmed by this submerged monitoring system during a total of 45 h from April 29 to May 6.

In addition, continuous monitoring confirmed that the fish migrating through the fishway included carp, while the collection and observation of fish in the spawning ground verified that yoshinobori (*Rhinogobius* sp.), catfish (*Silurus asotus*) and sweetfish (*Plecoglossus*

Table 1. No. of fishes observed by the submerged camera

Species	No. of passages*	Percentage (%)
Carassius sp.	164	84
Oryzias latipes	19	10
Misgurnus anguillicaudatus	12	6
Total	195	100

*Results of monitoring during 45 hours in total from April 29 to May 6,1998.

altivelis altivelis) migrated through the fishway. Close range video recording confirmed that medaka and loach migrated upward by jumping over the fishway.

2. Relationship of water temperature to measurement results of the number of migrating fishes

Fig. 5 shows the results of migration measurements for 1997 and 1998. In 1997, the sluice gate between Lake Kasumigaura and the channel was fully opened on the evening of April 27. The same figure shows that the number of fishes migrating to the experimental site that were assumed to have probably been carried in immediately afterwards by water flowing from Kasumigaura increased and reached a peak 3 days later on April 30. As shown in Fig. 6, the maximum daily water temperature in the channel at this time exceeded 20°C. Later, the number of migrating fishes gradually declined. It was confirmed that almost 1,000 fishes had migrated during the two-week experimental period. In 1998, the sluice gate was fully opened on the morning of April 29. Incidentally, in that year, good weather that had prevailed continuously since mid-April changed to continuous rain late in the month. As Fig. 5 shows, in 1998 the peak of migration occurred on April 21. The maximum daily water temperature in the channel at that time was, as before, more than 20°C. Since the temperature of the water in the channel corresponds to the temperature of water immediately after it enters from Lake Kasumigaura, it can be concluded that the temperature was almost identical with that of the water along the shore of Lake Kasumigaura.

It is assumed that the difference in the water temperature is, as a factor that induces fish migration, one of the most important indices[3]. Briefly, theoretically, as fish progress up a stream, they change their course to the course of a stream of warmer water entering the original stream. If this is so, it can also be assumed that the fish will not change their course to a flow of cooler water. Fig. 7 shows a comparison of the number of migrations per hour with the difference between the temperature of the water discharged from the experimental site and the water in the channel during the two-day peak of migration in 1997. It reveals that large numbers of fishes migrated up the fishway during times when the water temperature difference was negative, suggesting that the water temperature difference is not necessarily the decisive factor.

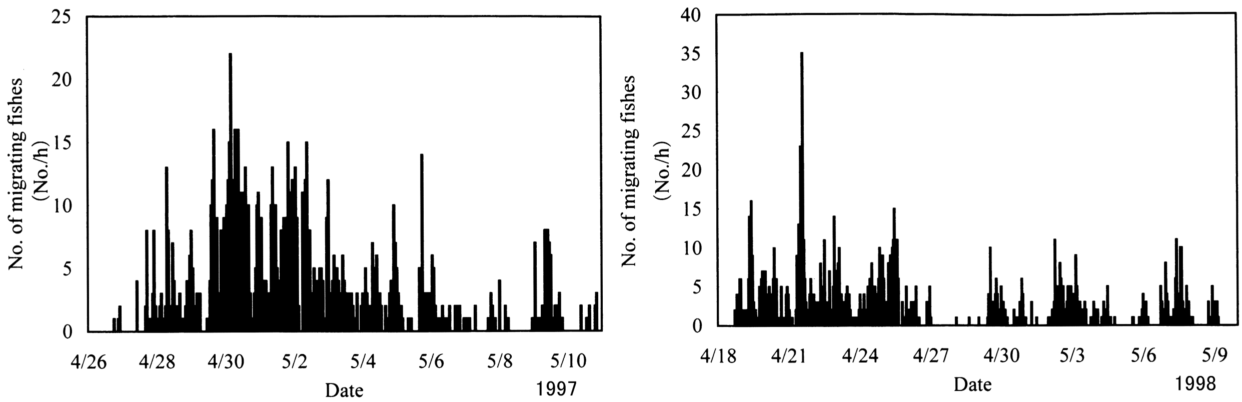

Fig. 5. Results of measurements of numbers of migrating fishes

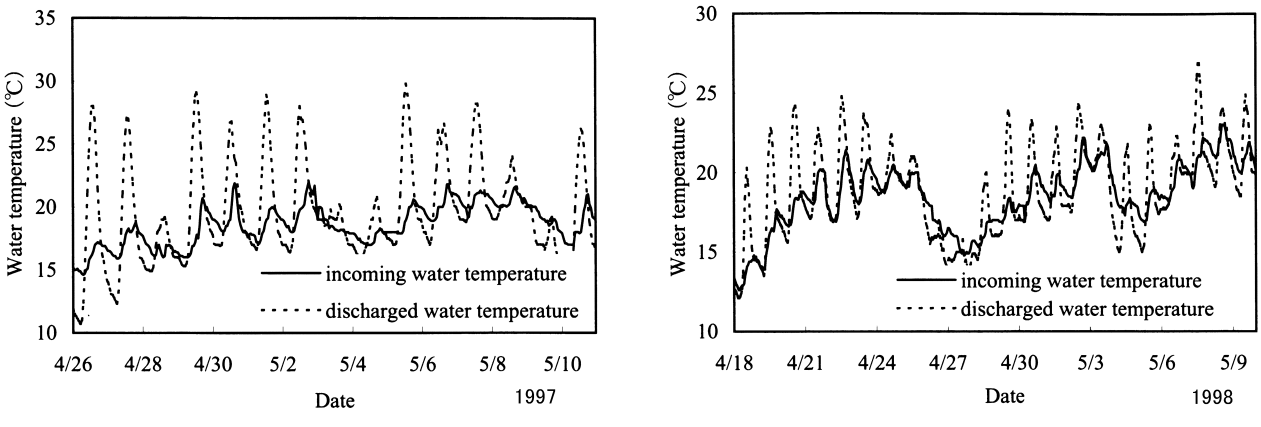

Fig. 6. Water temperature fluctuations during the experimental period

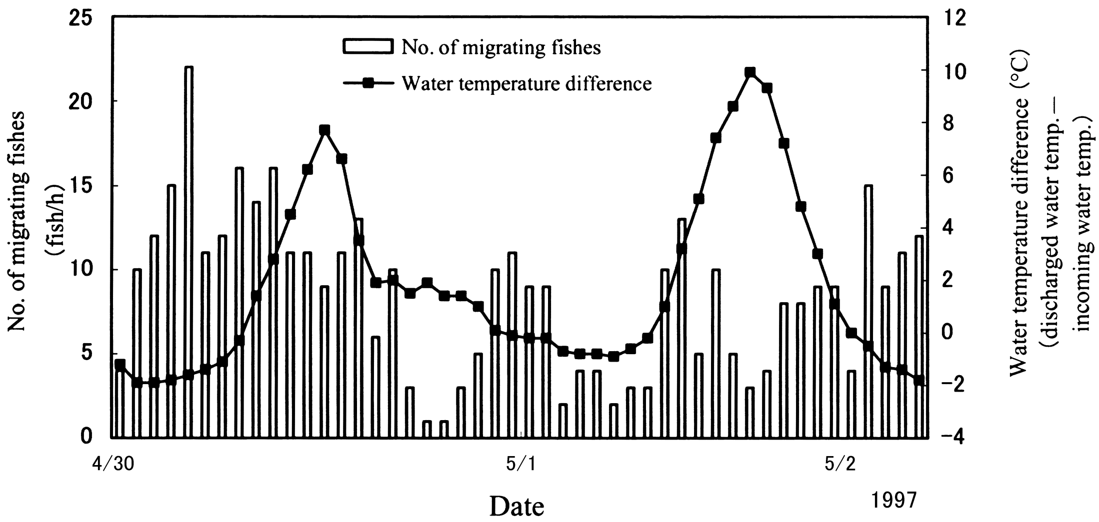

Fig. 7. Difference in temperature of water discharged from the experimental site and water in channel (12:00 a.m. April 30 to 12:00 a.m. May 2, 1997)

It would be premature to reach conclusions based on the above results, but it could be assumed that the impulse to spawn of both species of fishes that inhabit the channel and species of fishes that enter the channel from Lake Kasumigaura is at its peak when the water temperature begins to increase in April and initially reaches 20°C (daily average of 18°C or more).

But what is the factor that induces the fish to finally jump from the channel into the experimental site? Once a fish species that is stimulated by heated water has been stimulated in this way, it may boldly jump into an incoming channel without concern for slight temperature differences. It has been reported that fish that migrated one year to a certain location migrated to the same location in the following year[2]. But because all of the fishes that migrated to the experimental site were doing so for the first time, it is assumed that this behavior is an inherited character. It is possible to consider that turbidity and odor are among the properties of water other than temperature, but this has not been confirmed.

At any rate, fish easily notice the existence of an incoming stream of water because of the foam, changes in water currents, sound, etc. At this time, therefore, it can be stated that once fish are stimulated to spawn by a rise in the water temperature, they will boldly jump up into an incoming stream of water in anticipation of finding spawning grounds beyond it even if the temperature of this incoming stream of water is slightly low. However, further studies should be carried out to clarify this aspect.

3. Function of the fishway

The fishway used for this study was constructed on the assumption that the longest fish using it would be 40 cm. Fig. 8 shows the fishway viewed from its upstream side. In the study section, since carp are uniformly long, with few exceeding 60 cm in length, this fishway seems to be too small for carp. However, based on the author's own experience with past field observations, it would be suitable for catfish and carp that are smaller than 40 cm.

But because it has been confirmed that medaka that are only 3 cm in length can migrate up the fishway and that loach have also succeeded, a drop of 10 cm in height would not be a problem for these small fish.

Precautions to be taken in designing a fishway have already been described[1]. A study of the results of continuous monitoring has confirmed that in many cases, fish jump over the overflow part from the quiet water close to

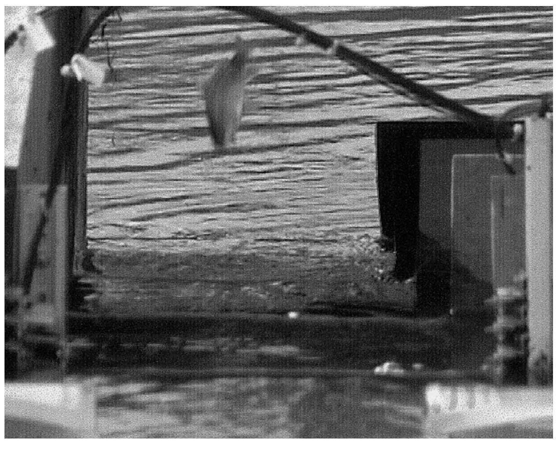

Fig. 8. View of the channel from the top of the fishway (Hata, May 1998)
Jumping Prussian carp.

the overflow part and directly under the separation wall without overflow (hereafter referred to as "non-overflow separation wall"). For small fish such as medaka in particular, this quiet part is important.

Fig. 9, which shows a diagram depicting an example of the results of measurements of the flow rate distribution in the highest pool, indicates the transversal distribution of the flow rate of the top layer (3 cm below the surface). This figure reveals that near the non-overflow separation wall, there are gentle currents moving at a flow rate of 5 cm/s.

But will fish be able to migrate easily if the above hydraulic conditions are satisfied? An analysis of the continuous monitoring results revealed that an unexpectedly large number of the fishes that jumped were unable to complete the migration. Fig. 10 shows the results of calculations of the percentage of all the fishes which jumped that ultimately successfully migrated up the fishway set up for a 12-hour period during the day and a 12-hour period at night during a four-day period from 6:00 p.m. on April 18 to 6:00 p.m. April 22, 1998. The same figure indicates a clear difference between migration success rates during the daytime and during the nighttime. During the daytime, many fishes successfully jumped from the quiet water in the non-overflow part, but at night, almost all attempted to jump almost vertically from directly below the overflow part and many of them failed to migrate. For this reason, it is assumed that since the eyesight of Prussian carp declines at night, they misjudge their jumping direction. And because of the need for continuous monitoring at the experimental site, lighting was installed during the night.

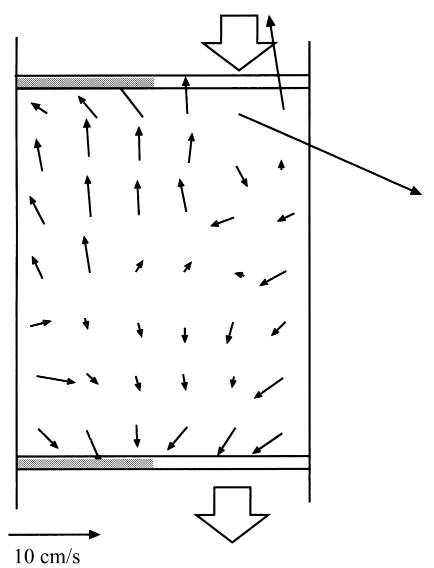

Fig. 9. Transversal view of the distribution of the flow speed on the surface of the highest pool of the fishway

4. Spawning and hatching of Prussian carp

Among the fish that migrated to the experimental site, it was only possible to confirm that Prussian carp spawned inside the spawning ground. But because young medaka and loach were later observed, it is assumed that these species spawned in the spawning ground even though eggs were not observed.

Observations made after April 29, 1998 confirmed that Prussian carp had spawned at 23 locations by May 9. Fig. 11 shows the spawning grounds marked by colored flags. The areas where eggs were deposited were concentrated near roots where soil formed mounds rather than on submerged stems and leaves. Many eggs were deposited on reed canarygrass (*Phalaris arundinacea* L.) and on plants such as creeping bentgrass (*Agrostis stolonifera* L.), and others that spread horizontally rather than on Japanese parsley and sweet rushes.

Fifty Prussian carp eggs were collected 3 times and placed in 2 L polyethylene bottles. After 10 days, an average of 12 fry were produced, indicating a hatching rate of 24%. Considering the water quality conditions such as DO (dissolved oxygen) concentration, this hatching rate was probably higher than that possible under natural conditions.

5. Medaka and loach remaining at the experimental site

Medaka and loach remained at the experimental site even when the site was drained in the last 10 days of August in both 1997 and 1998. Fig. 12 shows medaka photographed immediately before drainage in the last 10 days of August 1998. For these fishes, paddy fields are not only spawning grounds and habitats for immature fish but also lifelong habitats where one generation replaces

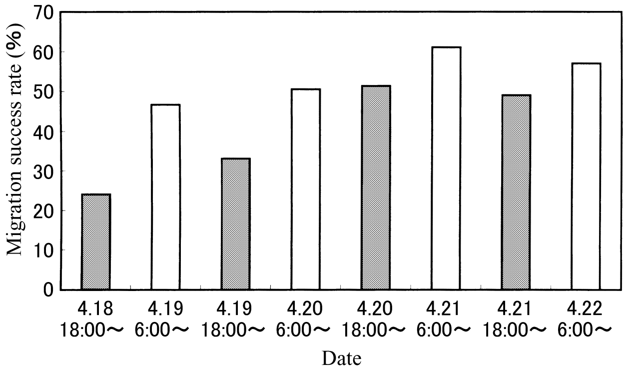

Fig. 10. Difference between the success rates of fish migration in the daytime and nighttime (6:00 p.m. April 18 to 6:00 p.m. April 22, 1998)

Fig. 11. Flags marking spawning grounds (Hata, May 1998)
Center, creeping bentgrass;
other plant, reed canarygrass.

Fig. 12. School of medaka (*Oryzias latipes*) swimming in the spawning ground immediately before drainage (Hata, August 1998)

another. It is, therefore, essential to supply water to such paddy fields throughout the year in order to preserve these fish species.

Future challenges

This report described the results of an experiment conducted in 1997 and 1998 to study the migration of fish to an idle paddy field through a small fishway.

For convenience, the experiment was conducted in a channel that, during the irrigation season, was fully linked to Lake Kasumigaura and where the height of the drop between the channel and the paddy field was relatively small, approximately 40 cm. Compared with the conditions throughout Japan, this experimental site enjoyed good conditions. Future studies must be carried out at locations with higher drops.

And to simplify the observation task, the surface area of the spawning ground was small, only 60 m^2, but in fact it should be wider and its depth more varied. To meet the needs of medaka and loach in particular, part of it should be a pond that is submerged throughout the year. Future studies on the appropriate arrangement and density of biotopes for fish must be undertaken.

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