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Perspectives for Fish Protection in Japanese Paddy Field Irrigation Systems

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Abstract

In recent years there has been an increasing activity related to the preservation of living organisms (biological diversity) worldwide. It is obvious that the long-term trends contributing to this movement include the deterioration of the natural environment in rural villages associated with the introduction of technology solely intended to boost yields along with the urbanization of daily life as a consequence of the remarkable progress in agricultural production technology achieved since World War II. This report describes, firstly the role of paddy field areas as fish habitats compared with natural rivers, secondly the classification of fishes into several groups from the viewpoint of migration. And also it describes the influences of the present paddy field irrigation systems on fish habitat and forecasts future trends in this area.

Discipline: Irrigation, drainage and reclamation
Additional key words: biological diversity, aqua-ecosystem, agricultural water channel

Introduction

In recent years there has been an increasing activity related to the preservation of living organisms both within and outside of Japan, including the signature of the Convention on Biological Diversity (Biodiversity Treaty, 1992), the enactment of the Law on the Preservation of Species of Wild Plants and Animals in Danger of Extinction (1992) and the enactment of the National Biodiversity Strategy (1995). And with the implementation of the Farm Village Natural Environment Improvement Project as a new Agriculture and Farm Village Improvement Project (1994), it is now possible to preserve and create habitats for living organisms. It is obvious that the long-term trends contributing to this movement include the deterioration of the natural environment in rural villages associated with the introduction of technology solely intended to boost yields along with the urbanization of daily life as a consequence of the remarkable progress in agricultural production technology achieved since World War II.

This report describes the effects of present paddy field irrigation systems on fish and forecasts future trends in this area.

Roles of agricultural water channels and paddy fields in the life of fish

1. Evaluation of the roles of agricultural water channels and paddy fields in the migration of fish

Although many inland bodies of water are linked to the sea, environmental conditions vary widely between the seacoast and the source of a watershed. As a consequence, the evolution of fishes has been a process of adaptation to various environments, as each species acquired and expanded its habitat. The habitats of freshwater fishes can be broadly categorized into upper reaches, middle reaches, and lower reaches of rivers. As illustrated by the fact that agricultural water channels, those relatively large water channels that draw water from the middle reaches of rivers for example, are the habitats of middle reach fishes, species choose their habitats according to this river categorization. There are also species that inhabit only small streams (small agricultural water channels). The habitat categorization — char (*Salvelinus pluvius*) – trout (*Oncorhynchus masou*), – dace (*Tribolodon hakonensis*) – carp (*Cyprinus carpio*) from upstream to downstream in a natural river — is primarily based on differences in their adaptation to the water temperature and DO (dissolved oxygen) concentra-

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tion.

In the lower reaches, species such as carp, Prussian carp (*Carassius carassius* subsp.) or catfish (*Silurus asotus*) migrate from rivers to paddy fields through agricultural water channels (generally drainage channels) during the spawning season. In this case, both the rivers and the agricultural water channels play specific roles so that it is possible to consider that they exist in a complementary relationship.

Fig. 1[3] depicts the location of agricultural water channels and paddy fields from the perspective of fish migration. A brief explanation of this figure follows.

(1) Three-spined stickleback (*Gasterosteus aculeatus aculeatus*) — ocean-migrating type and land-locked type

The fish called three-spined stickleback, one of a group of small fishes called sticklebacks whose dorsal fins, etc. are shaped like spines, is widely distributed in the northern hemisphere from the sub-arctic zone to the temperate zone. During the spawning period, stickleback males construct nests made of water plants, lure females to these nests to lay their eggs, then the males fertilize the eggs. For this reason, aquatic plants (submerged water plants whose leaves are under the surface of the water) must be present for sticklebacks to spawn.

As shown in Fig. 1, there are ocean-migrating and land-locked three-spined sticklebacks. In the spring, ocean-migrating three-spined sticklebacks begin to migrate up rivers to agricultural water channels near the river mouth. In the Hokuriku region, they spawn in April and May and the newborn fish return to the ocean at the end of June.

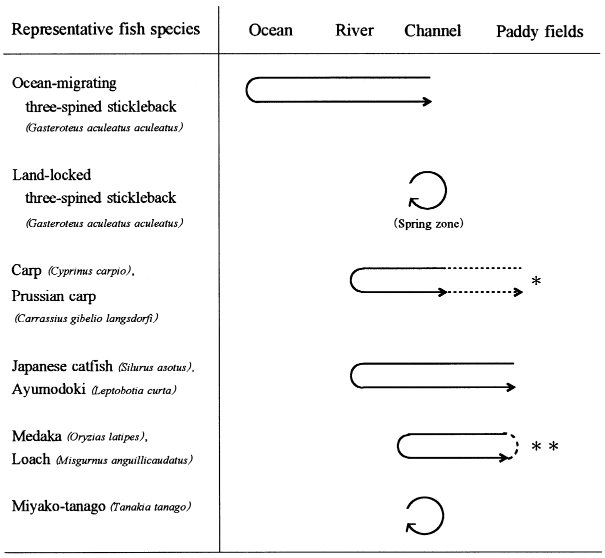


Fig. 1. Location of channels and paddy fields for the migration of fish

*If they can migrate to a paddy field, they spawn there. **Live permanently in paddy fields.
Arrowheads indicate the spawning location.

Recently, measures such as construction of spawning grounds for ocean-migrating three-spined stickleback in parts of rivers farthest from the ocean have been implemented[5]. Because it is assumed that essentially, agricultural water channels are more appropriate habitats for ocean-migrating three-spined sticklebacks, it is probably necessary to introduce these systems into agricultural water channels.

Land-locked three-spined sticklebacks never migrate to the ocean. In Honshu, land-locked three-spined sticklebacks can only live in low temperature parts (not warmer than 20°C) of springs throughout the year. This implies that their preservation in the real sense is impossible without preserving these springs.

(2) Carp, Prussian carp and catfish

Carp, Prussian carp and catfish are familiar fish in the lower reaches of watersheds. In the Kanto region, carp and Prussian carp migrate up rivers in April and May to enter agricultural water channels where they spawn on the stalks of ditch reeds. If they can migrate to paddy fields, they spawn in these paddy fields.

Catfish are also extremely fond of paddy fields. It may be appropriate to state that catfish need paddy fields even more than carp and Prussian carp. This is because their eggs are not nearly as adhesive as those laid by carp and Prussian carp. Once the eggs of carp and Prussian carp have adhered to the stalk of a reed, there is no danger that they are carried away by the force of flowing water. But because catfish eggs are scattered about without any apparent particular objective, they could be washed away by a slightly fast current of water.

As Fig. 2 indicates, catfish males induce the females to lay eggs by wrapping themselves around the female neck muscles like a collar. Unlike carp and Prussian carp that attempt to lay their eggs on the stalks or leaves of reeds (author's personal view), catfish drop them at scattered locations after tightly embracing for a little while (several seconds). For this reason, catfish probably more strongly require wetlands such as paddy fields where the water is almost motionless than carp or Prussian carp. Another species, ayumodoki (*Leptobotia curta*) that has been designated as a precious natural resource, also requires paddy fields to spawn.

Other benefits of paddy fields for all the fishes that spawn in them are that they provide both safe environments for the young fish and plenty of water fleas (*Daphnia pulex*) and other feed. Fig. 3 shows eggs laid on the wall of a fishway by Prussian carp during an experiment on fish migration to paddy fields conducted by the author starting near Lake Kasumigaura.

(3) Medaka (*Oryzias latipes*) and loach (*Misgurnus anguillicaudatus*)

Medaka and loach are fishes that can be called the champions of paddy field zones. Both medaka and loach want to migrate to paddy fields.

Loach must migrate because they copulate in much the same way as catfish and their eggs display little adhesiveness. Medaka migrate to paddy fields in large numbers. Or else they remain in paddy fields with little desire to leave them. In this way, they are clearly different from carp, Prussian carp and catfish described previously. Once carp, Prussian carp and catfish have spawned, they migrate back to the water channels comparatively quickly, showing little interest in the amenities of the paddy fields. If the water remained in paddy fields all year round, medaka and loach might stay there.

(4) Miyako-tanago (*Tanakia tanago*)

Many Japanese bitterlings spend their entire lives in agricultural water channels, etc. A typical example is miyako-tanago that has been designated as a precious natural resource. Japanese bitterlings are unusual in that they lay their eggs inside the gills of bivalves. This occurs because their eggs are not adhesive, which implies that Japanese bitterlings cannot thrive where bivalves cannot live. Unfortunately little information is currently available about the ecology and habitat environment of bivalves.

2. Typology of paddy fields and of the roles of agricultural water channels compared with rivers

The following is a typology of the roles of agricultural water channels from the migration perspective.

(1) Type I Paddy field & water channel system as spawning grounds and young fish habitats: cradle

Normally fish live in rivers and lakes, migrate to channels and paddy fields to lay their eggs during the spawning season, and although the young fish remain there for a certain period of time, they eventually migrate back to the rivers or lakes. The paddy fields and channels play the role of a cradle for these fish.

These fish can be further categorized as ocean-migrating sticklebacks that migrate from the ocean and as carp, Prussian carp, catfish and ayumodoki that migrate from rivers.

Type I-1 Cradle for fish from the ocean

Type I-2 Cradle for fish from rivers and lakes

(2) Type II Paddy field & water channel system as a lifelong habitat: residence

Fishes in Type II are distinguished from those which live in rivers, in a sense that they do not migrate from paddy fields or agricultural water channels. Fish species belonging to this type are classified into 3 groups: medaka, loach, etc. that either migrate to paddy fields to spawn or can remain permanently in paddy fields; Japanese bitterlings that do not necessarily migrate to paddy fields; and sticklebacks that cannot survive where there are no springs.

Type II-1 Water channel & paddy field system

Type II-2 Water channel

Type II-3 Springs

(3) Type III Paddy field & water channel system as a pseudo-river : “play ground”

Agricultural water channels and paddy fields usually play a role in the lives of fish species other than those

Fig. 2. Catfish spawning in a paddy field (Hata, June 1996)
The male wraps its body around the female for several seconds.

Fig. 3. Prussian carp eggs laid on the wall of the fishway at the migration experimental site (Hata, April 1997)
The eggs adhere near the center of the Figure.

described above. Various species temporarily enter water channels that are connected to a river, and paddy fields to look for feed, but do not intend to make these waters their permanent habitat or to spawn. It is natural for oikawa (*Zacco platypus*) to swim far up into paddy field drainage ditches and for dace (*Tribolodon hakonensis*) to swim in water supply channels. This activity is referred to as “wandering in”, but it can also be described as the use of the channels by these fish species as “play grounds” formed by removing barriers in the channel systems to link them to the rivers.

(4) Type IV Water channel as part of a natural river

In some cases, a mountain stream, etc. that is formed as a part of a natural river under the effects of topographical factors has been used as a paddy field drainage channel without any modification. In such cases, it is easier to analyze its properties by considering that it is part of the river instead of being a separate channel. Because such water channels are used as spawning grounds, their improvement must be performed carefully. Fig. 4 shows a case where the improvement of an agricultural drainage channel in the upper reaches of a river destroyed an amago (*Salmo masou macrostomus*) spawning ground[1].

The above was an attempt at a typology of the roles of agricultural channels by comparing them with rivers, but it is not always possible to clearly demarcate these roles spatially and a single water channel or paddy field may simultaneously play 2 roles.

Technological problems created by paddy field irrigation systems

1. Blocking of migration

A paddy field irrigation system draws water from a river, transports this water to paddy fields through channels, then returns the water to the river through drainage channels. There are many barriers preventing the migration of fish in these systems. It is appropriate to indicate that if the fish species (and other living organisms) described above are to be conserved in their natural state, which involves the development of new generations of fish, it is essential to guarantee their ability to migrate.
Under the present circumstances, their migration is obstructed at every point as described below.

- Water intake weir
- Drop works and weirs inside water supply and drainage channels
- Links between water supply channels and paddy fields
- Drops between paddy fields and drainage channels
- Channels that are dry when the irrigation season is discontinued
- Drops between channel spillways and drainage channels
- Drops between main drainage channel outlets and rivers

Fig. 4. Improved water channel in an upper watershed (Hata, July 1986)[1]
It destroyed an amago (*Salmo masou macrostomus*) spawning ground.

Fig. 5a. Discharge sluice gate on the Hyakken river (Hata, June 1997)

Fig. 5b. Drop directly below a sluice gate (Hata, June 1997)

In fact, it is impossible for species such as ocean-migrating sticklebacks, carp, Prussian carp and catfish to enter channels from rivers. In regions where field improvements have been completed, a high drop has been constructed above the natural water level of the river. Fig. 5 shows the trunk drainage channel outlet where water flows into the Hyakkengawa River in Okayama City. The drop here was only about 30 cm high at that time, and many carp were observed jumping over the barrier, with many successfully reaching the channel.

Cases beneficial for fish are extremely rare. It is possible to understand the need to construct a sluice gate at an outlet to prevent water from flowing back up a channel when the river rises under the effects of heavy rainfall, but it is possible to prevent such a back flow from occurring at a discharge point without constructing a large drop. Many of the barriers described above could at least, be removed by the use of technology.

2. Cross-sections of channels

Presently, not only water supply channels, but most of the drainage channels are made of concrete, a practice that has been criticized for various reasons. However, I believe that it would be too hasty to conclude that concrete is not beneficial. It may not be attractive, but if the bottom of the channel consists of natural soil, even a wall-type channel made of concrete slabs is, while not ideal, somewhat better than a channel with its 3 surfaces made of concrete. A channel with a natural soil bottom can create diverse habitat environments as plants grow forming uneven surfaces without any artificial intervention. Fig. 6 shows an example of a natural habitat for miyako-tanago in the Kanto Region. It was formed inside a wall-type channel made of concrete slabs.

Fig. 7 shows examples of cross-sections ranked according to their suitability as fish environments. Fish can only pass through those at Level 0, but where natural soil has accumulated at the bottom, the channel provides a good habitat environment.

Fig. 6. Channel that is the natural habitat of miyako-tanago (Hata, June 1993)
We discovered a trap someone had set, and immediately after, a poacher appeared.

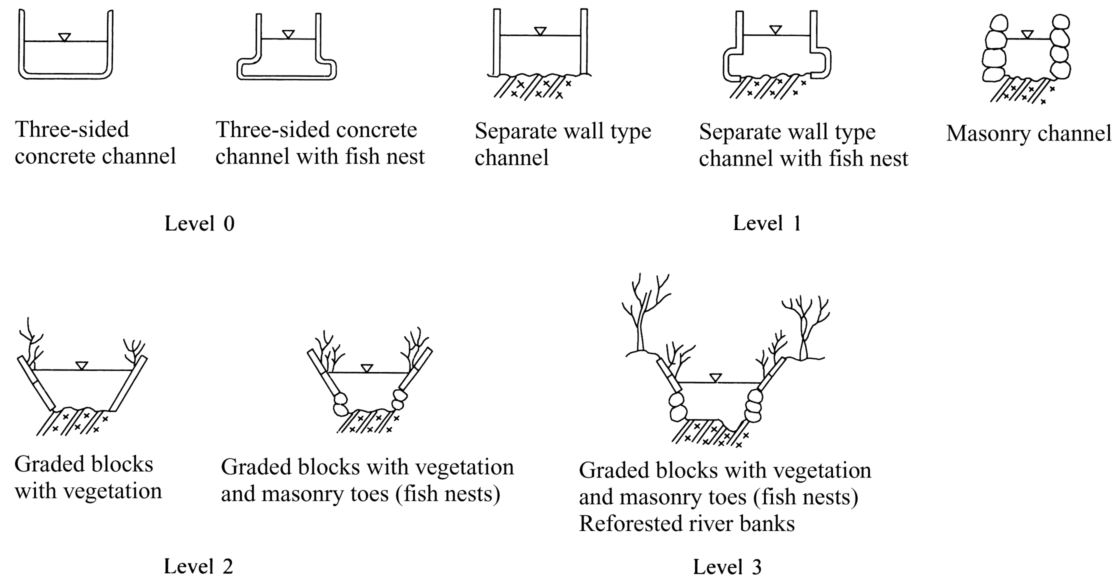
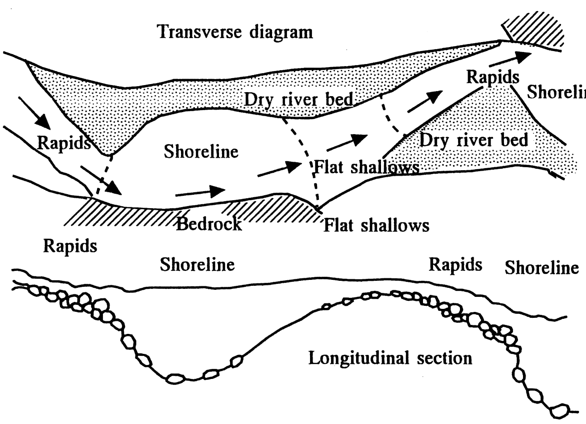


Fig. 7. Ranking of channel cross-sections[3]

3. Effects of channel alignment

In its natural state, a river meanders as it flows according to the topography. Where it meanders in its middle reaches, it inevitably forms shallows and deep pools. Fig. 8[4] is likely to appear in any textbook on river ecology, but the deep pools formed here are M-type deep pools, one of the types shown in Fig. 9.

In shallows, adhesive algae grow on the surface of rocks and many aquatic insects can be seen behind the rocks, making shallows a rich source of feed for fish. They also act as spawning grounds for many fish species. The quantity of feed found in deep pools, on the other hand, amounts to only a fraction of that available in shallows. Mizuno pointed out that the importance of deep pools had been under-estimated because of the tendency for research to give high priority to productivity and quantification[4]. Fish too do not feed all day. They need deep pools as places to rest or sleep and shallows on the bank opposite to a deep pool are places of refuge during flooding.



Water depth	Deep	Shallow	Shallow
Water surface	Smooth	Ripples	White waves
Flow rate	Slow	Fast	Fastest
Bottom material	Sand	Submerged stones	Pumice stone
River bed shape	Pool	Flat shallows	Rapids
		Shallows	

Fig. 8. Schematic diagram of the configuration of a natural river in the middle reaches

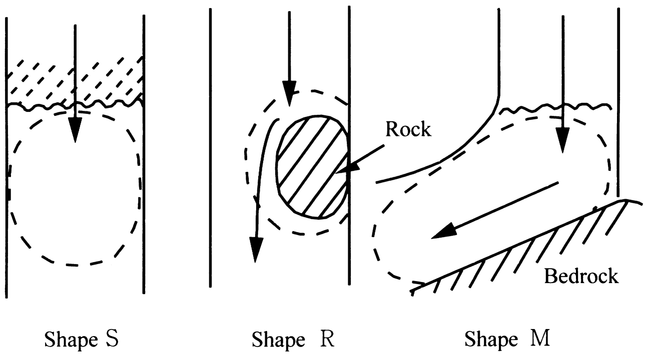


Fig. 9. Three basic deep pools[4]

Agricultural water channels are straight to meet the needs of artificial land consolidation and their cross-sections are almost always rectangular or trapezoidal. It is preferable to have a channel meander to form shallows and deep pools wherever possible, but it is not absolutely necessary to provide a water channel with a meandering alignment. Deep pools are not formed only by meanders; they can also be created by constructing low drops, placing large stones, or by excavating part of the channel. In summary, a channel could be formed by diversifying the way its water flows, or considering the fish species that will inhabit it, in remaining aware of the need for feeding space, rest space, habitats and places of refuge for young fish.

Fig. 10 shows Prussian carp in a drainage channel; they gather here under bridges and at bends in the channel. Where it is impossible to provide natural covering such as vegetation, it is necessary at least to cover the channel at scattered locations.

Future perspectives

1. Paddy field management and conservation of fishes

It is safe to state that for the most part, in Japan, field improvement of paddy fields has been completed, water

Fig. 10. School of Prussian carp under a small bridge in a water channel (Hata, June 1995)

supply channels and drainage channels have been separated, many water supply channels have been replaced by pipelines, and drainage systems have been improved, and these have contributed to more convenient cultivation work and markedly reduced the danger of flood damage. But on the other hand, along with the application of agricultural chemicals, these advances have damaged the rich natural spaces that once nurtured living organisms.

It should be possible to restore the former abundance without removing convenience or safety. I would like to point out a few facts related to the migration of fish to paddy fields.

Firstly, it is technologically relatively easy to secure the migration of fish. Fish can migrate upstream if each drop is limited to a height of 10 cm and separated by a distance of about 1 m, or in other words by reducing the gradient to 1/10.

Secondly, even if upstream migration is possible, depending on the type of cultivation practiced and its timing, fish are inevitably exposed to danger. With the rice seedling transplanting method currently used, water is supplied and puddling is performed in a field before transplanting of rice is conducted, but then the water is usually drained before transplanting. It is, therefore, necessary to modify the process from puddling to transplanting. In the case of paddy fields in Okayama City that the author has observed for several years, the direct sowing method of rice in well-drained paddy fields has been applied with water supplied after the plants had become about 20 cm tall. Because fish immediately begin migrating to the fields after water is supplied, the danger inherent to the transplanting method can be eliminated.

Thirdly, a certain quantity of water is required to motivate fish to migrate. Based on past observations by the author, the overflow part of drop works must be at least 30 cm wide and have a capacity of about 100 L/min.

The fourth point is the application of agricultural chemicals. In the case of Okayama City, immediately after water is supplied to the fields, insecticides and herbicides are applied, but observations carried out about 1 month after spawning confirmed that the young Prussian carp and carp were healthy. It is probably impossible not to use any chemicals at all, but at any rate, they should be applied judiciously.

The fifth point is that water is removed from paddy fields by midsummer drainage or intermittent irrigation, by draining water when the irrigation season is discontinued and so on. This is disastrous for medaka and other species that remain in paddy fields.

For the above reasons, the author now realizes that it would be difficult to tell farmers that they may cultivate their rice paddies anyway they wish.

2. Effects of the formation of a wetland

Considering the above circumstances, I would like to suggest that part of a paddy field in the downstream area of a trunk drainage channel be purchased to form a wetland, as shown in Fig. 11 This could be achieved by lowering the elevation of the ground of the purchased paddy field to the normal water level of the drainage channel to form an extremely shallow wetland (similar to a paddy field). Part of it could be further lowered to form a pond. In such a case, it would provide an outstanding habitat for fish and other living organisms.

It would also be possible to obtain another benefit: purification of water. A paddy field or similar shallow wetland is likely to exert a considerable water purification effect[2]. At an experimental site for fish migration, the degree of purification effect provided by such a wetland has been studied, indicating that when water remained at the experimental site for 3 h, the nitrogen content of incoming water that was 1 mg/L (water from Lake Kasumigaura) was reduced to 0.5 mg/L and water clarity was markedly enhanced. This year, the dominant species of vegetation is Japanese parsley (as of June) and I enjoyed eating boiled greens with dressing. It is safe to state that along with the preservation of living organisms and the purification of water, another invaluable effect of wetlands is the delicious food products they offer. With about 30% of paddy fields now idle, it should be possible to create wetlands in part of these idle fields in order to

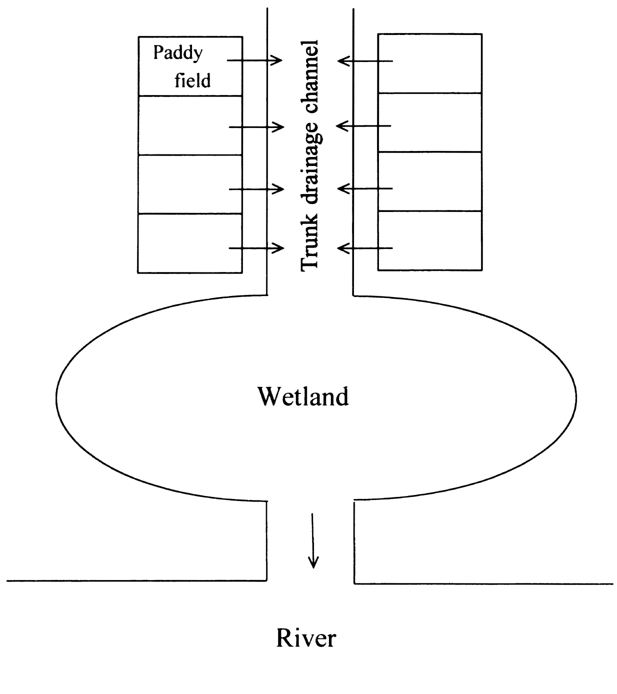


Fig. 11. Location of constructed wetland

take advantage of their diverse beneficial effects .

3. Need for support for maintenance

The construction of water channels with bottoms and sides made of concrete has reduced the collapse of channel banks, but another major reason for their introduction has been the farmers' desire to minimize weeding and other maintenance activities. The result is the appearance of contradictory objectives such as a desire to preserve fireflies associated with a wish to minimize the growth of vegetation.

Particularly serious problems occur in relation to the conservation of rare species such as those designated as precious natural resources, as the farmers are being asked to become involved in the management of conservation. Weeding and cleaning channels are definitely not pleasant tasks for anyone. In natural habitats of miyako-tanago located in the Kanto Region, the farmers must report poachers to the police.

Because the conservation of fish and other living organisms are activities with a strong public character but unrelated to agricultural productivity, it is clearly an error to force farmers to practice the management required for conservation.

In this regard, in addition to autonomous unpaid activities by local people, some kinds of measures should be introduced to enable local governments to assist people who actually carry out such management activities.

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