Research article

Habitat Evaluation of Agricultural Waterways where Environmental Improvement Was Practiced for Recreation

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Abstract In rural areas, agricultural irrigation and drainage systems developed for paddy fields have a high potential to become components of green infrastructure by providing ecosystem services. In order to manage and operate agricultural waterways as green infrastructure, the habitat evaluation of aquatic organisms is important. In this context, we conducted a habitat evaluation of aquatic organisms in the waterway network where environmental improvement was practiced to promote recreational use by residents. Based on evaluation results, the physical characteristics of canals with high biodiversity were investigated. The Evaluation Program for Fish Habitats in Agricultural Canals, which was developed for non-professional users such as residents, was applied to biological (fishes and crustaceans) and physical data collected in the waterway network in the town of Koura, Shiga Prefecture, Japan. The model generated by the program showed high fitness (0.80 for fishes, 0.76 for crustaceans), which suggests the program applies to waterway networks including various types of watercourses. The characteristics of the canals which were assigned a high habitat score by the program included 1) deeper water depth, 2) higher velocity for fish, 3) lower velocity, 4) higher vegetation coverage, and 5) gravel canal bed for crustaceans, relative to the low-scoring canals. The canals in diversion parks developed as part of environmental improvement efforts tended to have these characteristics and higher scores. Therefore, our findings suggest that conserving irrigation canals and developing diversion parks in waterway networks, which were conducted as part of environmental improvement efforts in the target area, contributes not only to promoting recreational use by residents but also to habitat conservation.

Keywords habitat evaluation, agricultural waterways, environmental improvement, green infrastructure

INTRODUCTION

Green infrastructure is defined as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services in both rural and urban settings (European Commission, 2013). Agricultural waterways for irrigation and drainage have been historically developed in rice-farming regions. Such waterways were traditionally used not only for irrigation but also for fisheries, recreation, and domestic use. Therefore, agricultural waterways have a high potential to become components of green infrastructure by providing ecosystem services.

However, recent modernization of agricultural landscapes and infrastructures modified only for efficient agricultural production and accelerated to use as grey infrastructure (Lee et al., 2015). Thus, improving irrigation infrastructures as green infrastructure based on sustainable ecosystem service use, such as recreational use, is a recent fundamental challenge (Matsuno et al., 2006; Katayama et al., 2015; Nishida, 2018). In this context, the habitat evaluation of aquatic organisms is important to manage and operate agricultural waterways as the green infrastructure.

Currently, agricultural waterways in rice-farming landscapes have been modified for the modernization of irrigation systems. Particularly, irrigation canals have been converted into pipelines to distribute water efficiently. Further, even in open canals, concrete lying degrades habitat conditions. Such negative impacts of modification for aquatic organisms have been reported (e.g., Nishida et al. 2018) and could be a significant concern for the availability of ecosystem services. However, consideration of the availability of such waterways for people is limited in planning and managing agricultural landscapes as green infrastructure in addition to habitat conservation and restoration.

In a waterway network in Koura town, Shiga Prefecture, Japan, environmental improvement was practiced promoting the recreational use of residents. Recreation constitutes cultural ecosystem services of agricultural waterways and is important from a well-being perspective for the formation of rural living environments. However, it is not known that such modification for recreational use benefits to restoration of ecosystem services (Lin et al., 2020). In restoration practice, considering the habitability of aquatic organisms with such environmental improvement is key for the availability of wider ecosystem services (Matsuno et al., 2006).

OBJECTIVE

The study aims to assess the habitability of aquatic species in agricultural waterways adapted for recreational purposes.

METHODOLOGY

Study Area

The study was conducted in a waterway network in the town of Koura (35.2°N, 136.26°E), Shiga Prefecture, Japan. Koura town is a rural area located on the alluvial fan formed by the Inukami River (Fig. 1). In this area, it was planned to convert all irrigation systems to pipelines for water shortage in 1981.

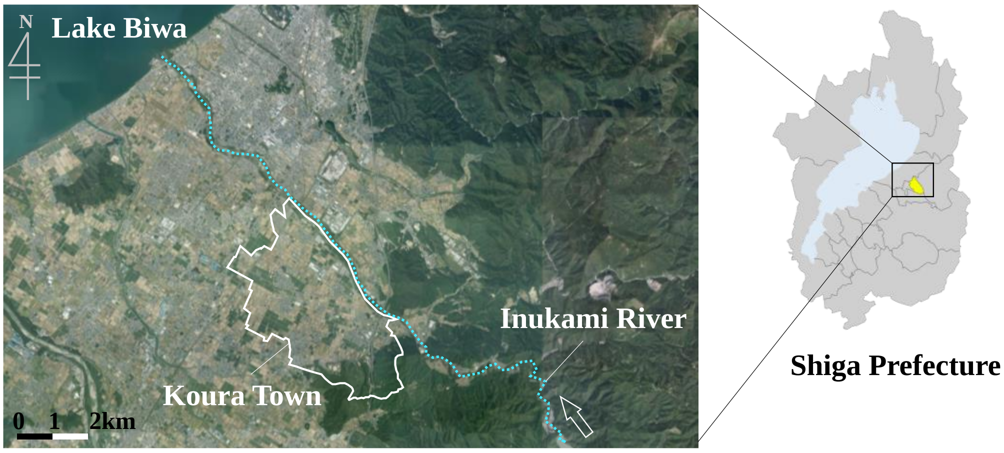

Fig. 1 Location of the study area, Koura Town, Japan
An aerial photograph is quoted by the Geospatial Information Authority of Japan and modified partially.

However, implemented the water environment improvement project in 1989, the irrigation and drainage canals were drastically altered to improve for recreational use by the residents: (1) the irrigation plan was modified to maintain open canals; (2) diversion parks were developed utilizing the pipeline discharge and diversion points; (3) the open irrigation canals were environmentally protected by masonry revetments; (4) sands and gravels were added to the irrigation canal beds; and (5) landscape facilities such as flower beds were installed

Data Collection

Based on the characteristics of the waterway network in this area, a total of 26 canal sections containing a variety of environmental conditions were selected as survey sites (Fig. 2). Each of the survey sites was 20 m in length and the width was the canal width. We conducted a biological and environmental survey on 10-18 August 2018.

As the physical environment varies depending on the type of canal, the survey sites were categorized into four canal types: diversion park (No. 1 to No. 6, Fig. 3a); drainage canal (No. 7 to No. 11, Fig. 3b); irrigation canal A (No. 12 to No. 20, Fig. 3c); and irrigation canal B (No. 21 to No. 26, Fig. 3d).

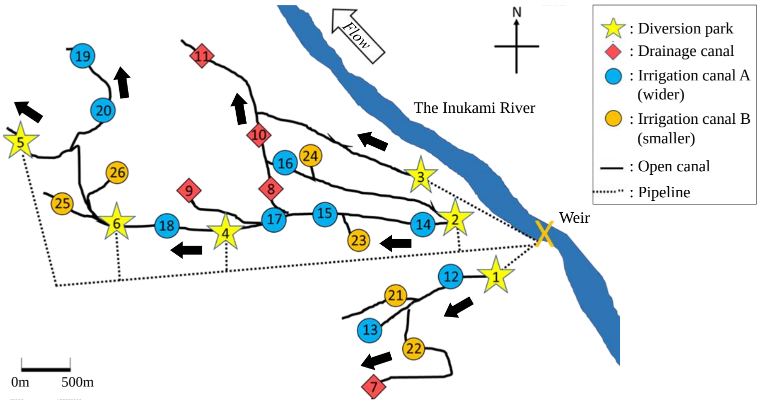

Fig. 2 Location of survey sites with canal type

a) Diversion Park

b) Drainage Canal

c) Irrigation Canal A

d) Irrigation Canal B

Fig. 3 Example of four canal types in the study area
a) diversion park; b) drainage canal; c) irrigation canal A; and d) irrigation canal B

In this waterway network, irrigation water is introduced from the Inukami River, after that, water is distributed into diversion works of each village through pipelines. The diversion park as the water park was developed in diversion points and the associated canals. The survey sites of diversion parks were located in one of the associated canals to compare other canal sites. The Irrigation Canal A is the main canal and has a wider canal width for carrying water to areas of paddy fields. Irrigation Canal B is a small canal that branches off from Canal A and supplies water directly to each paddy field. In diversion parks the environmental improvement commonly modified the canal structure for recreational use: the canal width was widened; gravel was laid on the streambed; the slope of the revetment was made gentler; and emergent plants were planted. In this waterway network, vertical drops were constructed between irrigation canals and drainage canals. However, fish migration was thought to mainly come from the Inukami River through pipelines. Thus, we did not consider the effects of barriers to fish migration.

To measure physical characteristics, cross sections were placed at 5 m intervals in each site. We conducted a field survey including both physical characteristics and biological sampling. To examine the hydraulic conditions of survey sites, water depth, water velocity, canal width, and wetted width were measured. The difference between canal width and wetted width was used as land width across the canal. Water depth and water velocity were measured across cross sections, and the points were divided into quarters. A uniaxial electromagnetic anemometer (Kenek, LP40) was used to measure water velocity. The percentage of streambed material (concrete, large gravel (cobble, > 64 mm), small gravel (pebble and granule, 2-64 mm), sand and silt (< 2 mm)) and vegetation cover were measured visually. We also measured water temperature, electric conductivity, and pH at the same time as those samples. However, the remarkable differences among sites were not shown.

We conducted biological sampling for fish and crustaceans. Two fyke-nets (mesh size: 5 mm) were set at both ends of the sampling section and hand nets (2 mm) were used to collect fish and crustaceans inside the survey site. The sampling effort of each site was fundamentally ten minutes by three persons. However, areas of the survey site (i.e., canal width) differed among sites. Thus, the sampling effort was adjusted to the area of the survey site to ensure an equivalent sampling effort among survey sites. After collecting fish and crustaceans, we identified species and counted individuals of each species. After that, we released sampled fish and crustaceans to the sampling site.

Analysis

To evaluate aquatic habitat, the "Evaluation Program for Fish Habitats in Agricultural Canals" (Watabe et al., 2018; 2020) (hereafter referred to as the "EPFH"), which was developed as a simple evaluation method by non-specialists, was applied. EPFH was developed and published free of charge by the National Agriculture and Food Research Organization (NARO, 2018). In ecosystem-friendly measures, it is important to conduct continuous monitoring surveys and adaptive management, such as updating and modifying facilities, to prevent habitat degradation. However, there are issues such as the significant cost of continuing monitoring surveys and the difficulty of interpreting the results of environmental assessments without specialists. EPFH was developed as a simple evaluation tool to address these issues. In this study, the EPFH was selected based on the assumption that it would be operated by non-specialists (local residents) who are the maintenance managers of the agricultural waterways.

In this program, the evaluation score is calculated using Eq. (1). This is a regression equation, which is positively correlated with both the number of species and the number of individuals identified and is explained by the physical environmental conditions such as water depth and water velocity (Watabe et al., 2018).

$$y=a_0+a_1x_1+a_2x_2+a_3x_3+a_4x_4+a_5x_5 \tag{1}$$

Where y is the evaluation score, a_0 is the constant term, a_1 to a_5 are the coefficients of each variable, and x_1 to x_5 are environmental indices. The values of a_0 and a_1 to a_5 are determined so that both the correlation coefficient r_1 between the evaluation score y and the number of species and the correlation coefficient r_2 between the evaluation score y and the number of individuals are high. The goodness of fit of the model F is defined by the following Eq. (2);

$$F = \frac{r_1 + r_2}{2} \tag{2}$$

where r_1 represents the correlation coefficient between the evaluation score and the number of species, and r_2 represents the correlation coefficient between the evaluation score and the number of individuals. The goodness of fit ranges from values of -1 to 1. In this study, to confirm the reliability of the accuracy of this program, a correlation test of the correlation between the evaluation score and Shannon-Wiener's diversity index H' (Whittaker, 1972) was also conducted.

The Kruskal-Wallis's test was conducted to analyze differences in scores of habitat evaluation among canal types. If the test showed significant differences, multiple comparisons were made using the Steel-Dwass method to determine a pair of canal types with significant differences among the four canal types. All of the statistical analyses were performed using R version 4.0.5 (R Core Team, 2021). The results of this analysis were shown for biological data but not for physical environments. Because the variations were very large depending on the site characteristics. Thus, we focused on the numerical difference of the physical environments.

RESULTS AND DISCUSSION

Status of Physical Environments of Waterways and Aquatic Organisms

The physical environmental conditions of canal type are shown in Fig. 4. Average canal width of survey sites ranged from 50.0 to 446.5 cm, and the land width ranged from 0 to 146.0 cm. Water depth ranged from 3.2 to 43.7 cm, and water velocity ranged from 1.7 to 38.7 cm/s. Vegetation cover ranged from 0 to 51%. Streambed materials were largely varied.

Diversion parks tended to have relatively wider canal widths and deeper water depths. Only the diversion park contained canals with a water depth of more than 30 cm. This is because the diversion park includes the canals through which pipeline water flows before it is diverted, and thus has abundant water flow. As for water velocity, the drainage canals tended to be slower. Vegetation cover tended to be higher in diversion parks and drainage canals. This is because aquatic plants were planted in the diversion park at the time of environmental improvement for landscaping, and also because sediments were deposited in the drainage canals due to the slow water velocity and vegetation growth. Comparing canal bed materials, there was no concrete in the diversion park. The percentage of small gravel tended to be lower in the drainage canal than in the diversion park. Irrigation canals A and B showed similar trends.

The results of the aquatic organism survey are shown in Table 1. In total, 657 individuals of 13 fish species and 4,039 individuals of 4 crustacean species were observed. Among the fish species, dark chub *Nipponocypris sieboldii* was most abundant (351 individuals at 12 sites), followed by Amur goby *Rhinogobius* sp. (153 individuals at 10 sites). Among crustaceans, the number of freshwater shrimps *Paratya compressa* was largely abundant (3,630 individuals at 21 sites). Japanese freshwater crab *Geothelphusa dehaani*, which is an indicator species for good water quality (Ministry of the Environment, 2017), was found at 15 sites (57.7%) with 211 individuals so water quality in the study area was suggested to be relatively good. Among fish species, Japanese medaka *Oryzias* sp. (59 individuals at 3 sites) and weather loach *Misgurnus anguillicaudatus* (14 individuals at 4 sites), which were listed as endangered species on the Red List 2020 (Ministry of the Environment, 2020), were included.

Aquatic Habitat Evaluation

1) Fitness of the model

Based on the data of physical conditions and aquatic organisms, the EPFH was performed to evaluate the habitat quality of the survey sites. As a result, the goodness-of-fit of the model F was 0.80 for fish and 0.74 for crustaceans (Table 2). The correlation between the model score and Shannon-Wiener's diversity index H' showed a strong correlation for fish ($r = 0.63$, $p < 0.01$). On the other hand, no significant correlation was detected for crustaceans ($r = 0.37$, $p = 0.90$). This is thought to be that the extremely large number of freshwater shrimps compared to other crustacean species skewed the results of the analysis, resulting in a low correlation with Shannon-Wiener's diversity index H', which takes into account the evenness of the number of individuals of each species.

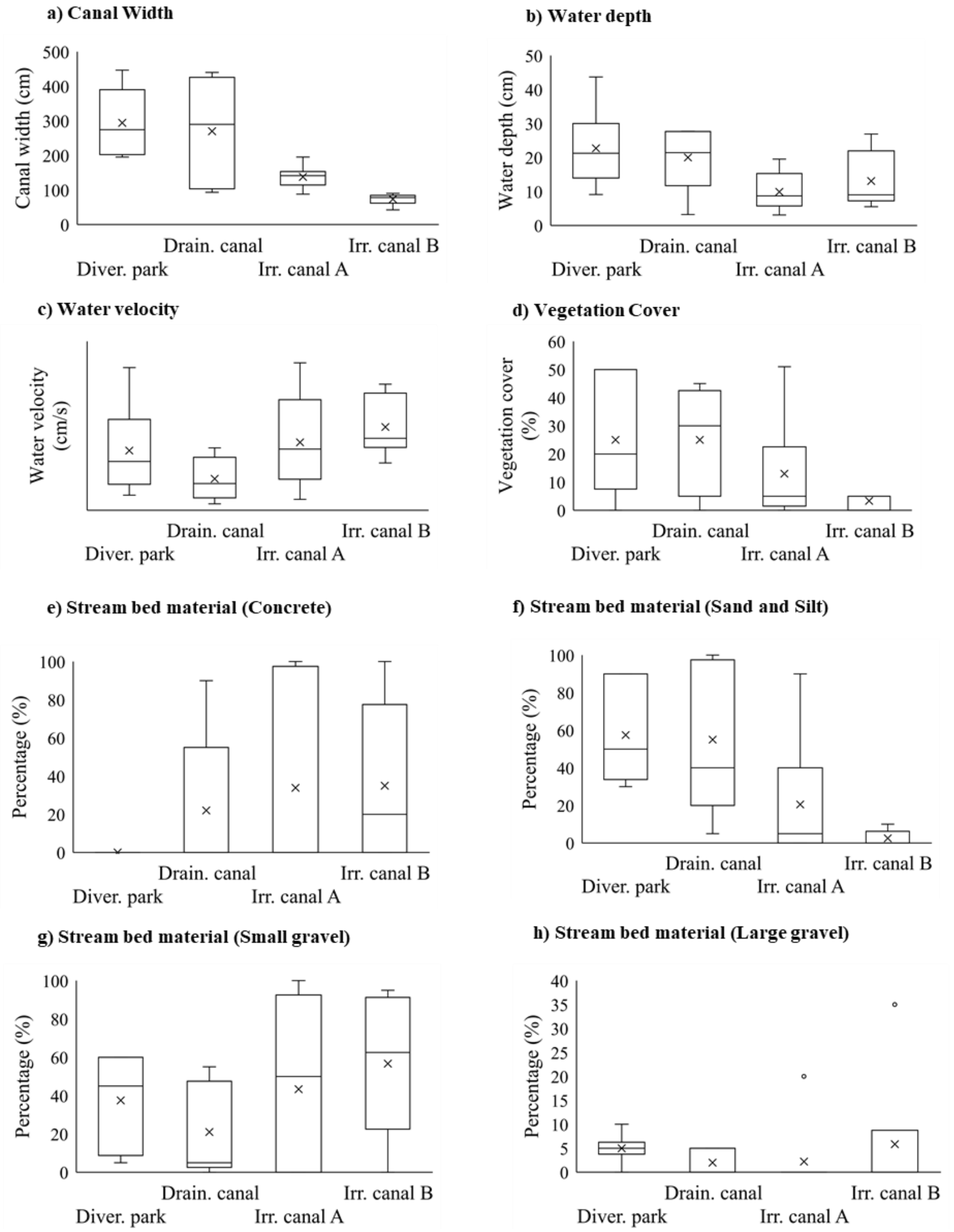

Fig. 4 Boxplots of physical environmental conditions of survey sites by canal type

a) canal width; b) water depth; c) water velocity; d) vegetation cover; and percentage of streambed materials: e) concrete, f) sand and silt, g) small gravel and large gravel. Crosses in each figure indicate the average value.

The goodness-of-fit of the model in this study was higher than that of the previous study (0.71, Watabe et al., 2018), which supports that the EPFH applies to waterway networks containing different canal types such as size, structure, and role for irrigation. On the other hand, though the goodness-of-fit of the model for crustaceans was not low, the correlation with Shannon-Wiener's diversity index was weak. Thus, the model score as an indicator of habitat quality might be useful for habitat evaluation for this taxon.

Table 1 Results of biological survey (fish and crustaceans)

Taxon	Species	Number of individuals	Observed sites		Standard length
			Number	Ratio (%)	Mean ± S.D. (cm)
Fish	*Nipponocypris sieboldii*	351	12	46.2	5.8 ± 2.7
	Rhynchocypris lagowskii steindachneri	22	5	19.2	4.7 ± 1.8
	Oryzias sp.	59	3	11.5	2.5 ± 0.6
	Rhinogobius sp.	153	10	38.5	3.5 ± 0.7
	Cobitis sp. BIWAE type B	1	1	3.8	7.0 ± 0.0
	Odontobutis obscura	3	3	11.5	3.1 ± 1.1
	Opsariichthys platypus	22	3	11.5	5.9 ± 2.1
	Plecoglossus altivelis	24	7	26.9	11.8 ± 1.3
	Misgurnus anguillicaudatus	14	4	15.4	8.0 ± 0.7
	Nipponocypris temminckii	3	2	7.7	7.8 ± 2.3
	Rhynchocypris oxycephalus jouyi	1	1	3.8	4.7 ± 0.0
	Pseudogobio esocinus	3	1	3.8	9.3 ± 1.5
	Tribolodon hakonensis	1	1	3.8	9.7 ± 0.0
Crustaceans	*Geothelphusa dehaani*	211	15	57.7	1.5 ± 0.6
	Procambarus clarkii	163	10	38.5	5.8 ± 2.2
	Paratya compressa	3,630	21	80.8	2.0 ± 0.4
	Palaemon paucidens	35	7	26.9	4.3 ± 0.4

Table 2 Fitness of the EPFH model (fish and crustaceans)

	Goodness of fit of the model *F* calculated by EPFH	Correlation coefficient of the model and Shannon-Wiener's diversity index *H'*
Fish	0.80	0.63**
Crustaceans	0.74	0.37

*Significant difference is indicated by *p < 0.05, **p < 0.01, and ***p < 0.001, if detected*

2) Environmental factors identified by the EPFH model

Based on the EPFH model for fish, five factors were identified as effective factors on fish habitat: water depth, water velocity, land width, vegetation cover, and percentage of sand in the streambed material (Table 3). Four of the factors, except land width, had a positive effect on habitat. Thus, the results indicated that good fish habitat had the following characteristics: (1) deeper water depth; (2) higher water velocity; (3) narrower land width; (4) higher vegetation cover; and (5) a greater proportion of small gravel in the streambed material.

As effective environmental factors on crustacean habitat identified by the EPFH model, five factors were identified: water depth, water velocity, land width, vegetation cover, and percentage of concrete in the streambed material. Among these factors, only vegetation cover had a positive effect on crustacean habitat, while the other four factors had negative effects. Thus, the results indicated that good crustacean habitat had the following characteristics: (1) shallower water depth; (2) lower water velocity; (3) narrower land width; (4) higher vegetation cover, and (5) a smaller proportion of concrete in the streambed material.

Table 3 Environmental factors and coefficients comprising the fish habitat model

	Water depth	Water velocity	Land width	Vegetation cover	Streambed material (small gravel)
Coefficients	0.034	0.021	-0.018	0.014	0.02

Table 4 Environmental factors and coefficients comprising the crustacean habitat model

	Water depth	Water velocity	Land width	Vegetation cover	Streambed material (concrete)
Coefficients	-0.046	-0.049	-0.005	0.022	-0.015

3) Habitat score estimated by the model and its comparison by canal type

Figure 5 shows the habitat score for fish and crustaceans of each survey site, which was calculated by the model. The score ranges from 1 to 5, with higher scores indicating better habitat at that site. The site with a score of 5 for fish habitat was only No. 2 (Diversion Park), and the sites that scored 5 for crustacean habitat were No. 1 (Diversion Park) and No. 13 (Irrigation Canal A).

To examine differences in habitat quality among channel types, the mean habitat scores and the mean Shannon-Wiener's diversity index *H'* are compared. Comparing the habitat scores, the diversion park was the highest (3.3 score), followed by the drainage canal (3.0 score), irrigation canal A (1.9 score), and irrigation canal B (1.7 score) in order of highest to lowest (Table 5). As a result of the Kruskal-Wallis's test, significant differences were detected for the fish score ($p < 0.01$), while no significant differences were detected for crustaceans ($p = 0.075$). Multiple comparisons for fish model scores suggested the scores significantly differ between the diversion park and irrigation canal A ($p = 0.029$, < 0.05, Table 6) and between the diversion park and irrigation canal B ($p = 0.012$, < 0.05, Table 6). The drainage canal was not significantly different from irrigation canals A and B, although the mean habitat score was high.

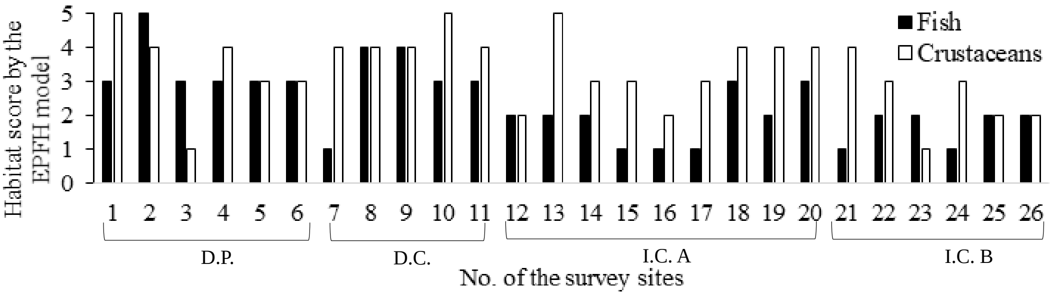

Fig. 5 Habitat score for fish and crustaceans at each survey site

D.P. indicates Diversion Park, D.C. indicates Drainage Canal,
I.C.A indicates Irrigation Canal A, and I.C.B indicates Irrigation Canal B.

Table 5 Habitat score and Shannon Weiner's diversity index *H'* by canal type

Canal type	Fish		Crustaceans	
	Habitat score (Mean ± S.D.)	*H* (Mean ± S.D.)′	Habitat score (Mean ± S.D.)	*H'* (Mean ± S.D.)
Diversion park	3.3 ± 0.8	1.2 ± 0.9	3.5 ± 1.4	0.8 ± 0.5
Drainage canal	3.0 ± 1.2	1.0 ± 0.6	3.8 ± 0.4	0.4 ± 0.4
Irrigation canal A	1.9 ± 0.8	0.3 ± 0.5	3.2 ± 1.0	0.3 ± 0.3
Irrigation canal B	1.7 ± 0.5	0.3 ± 0.6	2.7 ± 1.0	0.2 ± 0.5

Table 6 Results of multiple comparisons using the Steel-Dwass method to fish habitat score

Combination of comparison			*t*-value	*p*-value
Drainage canal	vs	Diversion park	0	1
Drainage canal	vs	Irrigation canal A	1.796	0.275
Drainage canal	vs	Irrigation canal B	1.896	0.230
Diversion park	vs	Irrigation canal A	2.772	0.029
Diversion park	vs	Irrigation canal B	3.052	0.012
Irrigation canal A	vs	Irrigation canal B	0.523	0.954

The canals in the diversion park have the highest discharge among canal types. These canals are located upstream of the irrigation system and thus carry water before being diverted to canals A and B. Thus, the conservation practice would benefit from ensuring such habitat property. In addition, the environmental improvements in the canals of the diversion parks created habitat structure as follows: the canal width was widened; gravel was laid on the canal ed; the slope of the revetment was made gentler; and emergent plants were planted. Such habitat modification might support to conservation of functional habitat characteristics for fish such as higher vegetation cover (Nishida et al., 2011) and coverage of natural material on canal beds (Katano et al., 2003) among factors of fish habitat characteristics. The average habitat score (and Shannon-Wiener index) of the diversion park was higher than drainage canal, although the difference was not significant. Those environmental modifications for recreation, such as gravel beds against concrete lying, may positively affect such higher habitat value. However, the higher scores in drainage canals might not be negligible because of their greater canal width, water depth, and vegetation cover**.**

On the other hand, high scores of crustaceans were found in shallow canals, though we did not conduct a detailed analysis per canal type because of the unconfident model score. Further, their distribution was tended to different from fish. Thus, branched irrigation canals might have habitat value for crustaceans, and considering the effects of preservation of those canals as open canal and their availability for recreational use has remained a future challenge of this study.

CONCLUSION

The canals in diversion parks developed by environmental improvement had higher habitat value for fish. This habitat is characterized by the following conditions: (1) deeper water depth, (2) higher water velocity, (3) greater vegetation cover, and (4) a higher proportion of gravel in the canal bed material. Among these variables, canal bed materials in diversion parks were different from drainage canals, though both canals have higher discharge in an agricultural waterway network (i.e. higher availability for fish). Irrigation canals are generally modified into pipelines with the current modernization of irrigation systems. Our result suggested that conserving and improving the environment of irrigation canals for recreation, particularly in water diversion canals, benefits ensuring higher value of fish habitat. Therefore, our findings demonstrated a way to evaluate the multi-functionality of agricultural waterways from the aspect of recreational use and habitat conservation as green infrastructure.

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