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Evaluation of Habitat Potential for Field Gudgeon in Drainage Canals Using Habitat Suitability Indexes: a Case Study of Yatsu Paddy Fields, Chiba Prefecture, Japan

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Abstract

To recover fish habitats and restore rich biota in rural areas, we evaluated the habitat potential for field gudgeon *Gnathopogon elongatus elongatus*, a representative species in rural areas, in non-improved drainage canals with soil and improved drainage canals having concrete walls but with a soil bottom in Yatsu paddy fields of the Shitada-gawa River basin, Chiba Prefecture, Japan, using habitat suitability indexes (SI). SI relations for water depth, water velocity, water width, substrate, and vegetation covering for life stages of the fish were developed using field research data collected from July 2002 to June 2004. The composite suitability indexes $SI_{depth} \times SI_{substrate} \times SI_{width}$ (larvae), $SI_{depth} \times SI_{velocity} \times SI_{width}$ (juvenile) and $SI_{depth} \times SI_{substrate} \times SI_{vegetation}$ (adult) were adopted statistically for calculation of the habitat potential (HP), expressed by a dimensionless weighted usable area. The values of HP varied monthly, but did not show significant differences between non-improved and improved canals for all life stages. This result showed that the improved canals were not inferior in producing fish habitats when compared with the non-improved canals. Also, it was clarified that the improved canals could even be used as alternative habitats to give temporary refuge to the fish, when a canal in this basin was being modified.

Discipline: Agricultural engineering
Additional key words: physical environmental factors, the Shitada-gawa River

Introduction

Since the 1960's, numerous land consolidation projects have been performed in rural areas of Japan[1,8]. Typically dual-purpose canals around paddy fields have been separated into irrigation and drainage canals, and concrete has been used for the canal lining material. Diversion weirs and many drops were installed in these canals, and as a result many fish have lost their canal habitat[8]. However, due to revision of the Land Improvement Act in 2001, consideration to the regional ecosystem has become essential for execution of land consolidation and construction of water use facilities at present. Various types of habitat devices, such as fishways and fish-nest blocks, have been installed in many drainage canals, and also fundamental information about the distribution and habitat properties of fish has been accumulated gradually for rural areas of Japan.

In the Kanto Plain, previous studies of fish in drainage canals have been performed mainly in paddy fields of hilly and mountainous areas in Nagano and Tochigi Prefectures[2,3,10] and on the plain in the Tokyo Metropolitan area[11,12]. Although there are numerous Yatsu paddy fields in the Kanto Plain, fish researches in those fields have not been carried out sufficiently[5,6]. Yatsu paddy fields were reclaimed 2,000–3,000 years ago, and most of them are formed in swamps in the valleys[1]. Land consolidation of Yatsu paddy fields has been delayed in comparison to other areas, and some of these fields still seem to support a specific and rich biota. Therefore, fish researches in Yatsu paddy fields are valuable for considering strategies to conserve and maintain fish habitats in rural areas.

To recover fish habitats in drainage canals and restore

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rich biota in rural areas, we have investigated the relationship between morphological and physical environmental properties and fish distribution in Yatsu paddy field canals, of the Shitada-gawa River basin, Chiba Prefecture, Japan, as a case study for several years[5,6]. In this paper, for quantitatively assessing fish habitats, habitat suitability indexes of physical environmental factors for the field gudgeon *Gnathopogon elongatus elongatus* were developed using this field research data[6]. Also, physical habitat potential for the fish in non-improved drainage canals with soil and improved drainage canals having concrete walls but with a soil bottom, hereinafter referred to as non-improved and improved canals, respectively, was evaluated in this basin with the habitat suitability indexes. The field gudgeon is a representative fish species in rural areas, and is distributed widely in drainage canals in the Kanto Plain including this basin. Most individuals inhabit intermediate and bottom layers of stagnant water in drainage canals, and grow to be adults at about 10 cm in total body length in two years[4,9].

Materials and methods

1. Study site

The Shitada-gawa River basin (catchment area: 10 km^2, length of main stream: 5.1 km) in Chiba Prefecture is composed of ten or more Yatsu paddy fields (Fig. 1). Based on the degree of land consolidation, canals in this basin were classified mainly into non-improved canals (Fig. 2A) and improved canals (Fig. 2B). We investigated four non-improved canals (canals 20, 23, 25, and 27) with lengths from 368 to 1,245 m and four improved canals (canals 1, 14, 18, and 24) with lengths from 580 to 1,882 m out of canals with relatively long lengths in this basin (Fig. 1 and Table 1).

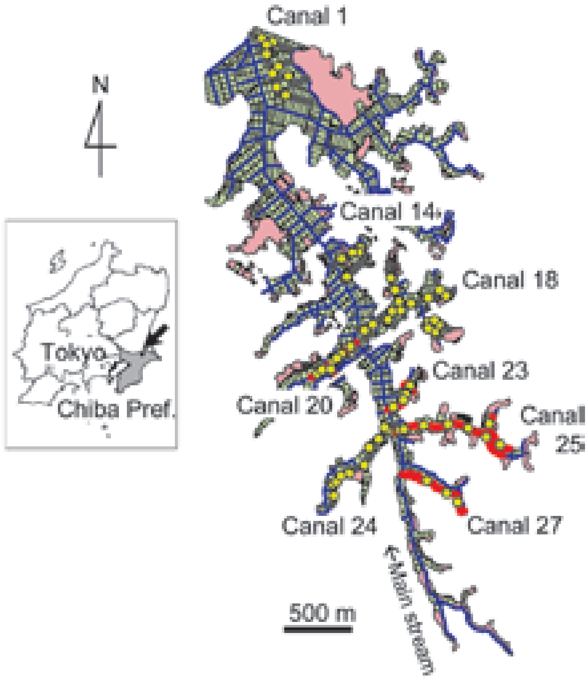

Fig. 1. Location of drainage canals in the Shitada-gawa River basin, Chiba Prefecture
: Non-improved canal, : Improved canal,
: Monitoring site, : Paddy field, : Others.

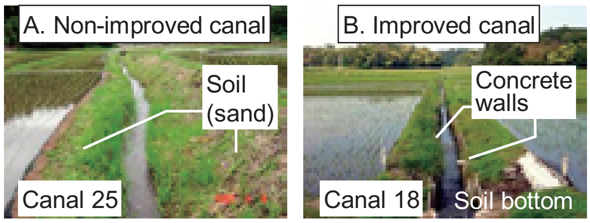

Fig. 2. Non-improved drainage canal with soil walls (A) and improved drainage canal having concrete walls but with a soil bottom (B)

Table 1. Outline of the field research data for five physical environmental factors and population density for life stages of field gudgeon in drainage canals from Koizumi et al.[6]

Canal No.	Length (m)	No. of Segments	Physical factor					Population density[a)]		
			Depth[b)] (cm)	Velocity[c)] (cm/s)	Width[b)] (cm)	Substrate[c)]	Vegetation[c)] (%)	Larvae[b)]	Juvenile[b)]	Adult[b)]
20[d)]	467	7	12±6	10–20	90±28	sand	0	0.76±2.19	0.35±0.96	0.16±0.68
23[d)]	368	5	9±7	10–20	51±22	sand	0–25	0	0.01±0.06	0.02±0.17
25[d)]	1,245	8	11±5	20–30	87±27	sand	0	0.22±0.70	0.54±1.62	0.30±0.92
27[d)]	641	3	8±3	20–30	46±13	sand	0	0	0	0
1	1,406	9	17±14	10–20	87±16	sand	0–25	0.12±0.36	0.47±1.07	0.09±0.29
14	580	5	6±3	10–20	63±8	sand	0	0	0	0
18	1,882	17	9±8	10–20	86±54	sand	0–25	0	0	0
24	968	10	11±7	10–20	102±41	sand	0	0	0	0

a): Number of individuals per unit water surface area (m^2). b): Average ± standard deviation among monitoring sites during the field research. c): Mode among monitoring sites during the field research. d): Non-improved canal.

2. Field research data

In this paper, field research data from Koizumi et al.[6] was adopted to develop habitat suitability indexes for the field gudgeon, and to evaluate habitat potential in canals. According to the original field research protocol for canals, the length of canals was divided longitudinally into three to 17 segments with lengths from 32 to 292 m, having homogenous physical environmental conditions. Five physical factors; water depth, water velocity, water width, substrate, and vegetation covering were measured at a monitoring site set up in each segment (Fig. 1 and Table 1). Also, individuals of the fish were collected simultaneously with electro-fishing gear and hand nets. After the number and total body length of individuals were recorded, the collected fish were released immediately in the monitoring site. The field research was carried out from July 2002 to June 2004 at monthly intervals.

3. Development of habitat suitability indexes

(1) Properties of the physical environment and distribution of individuals in canals

Table 1 shows the outline for the physical environmental conditions and distribution of individuals for the field gudgeon in canals from the field research data[6]. Averages of water depth, water width and population density for life stages of the fish, and modes of water velocity, substrate and vegetation covering were described among monitoring sites in the canals during the field research. Individuals of the fish were classified into larval stage for those less than 2 cm, juvenile stage from 2 cm to less than 5 cm, and adult stage for those more than 5 cm in total body length. Also, population density was denoted as the number of individuals per unit water surface area (m^2).

Water depth, water velocity and water width ranged from 6 to 17 cm, from 10 to 30 cm/s and from 51 to 102 cm, respectively in all canals (Table 1). In comparison to the minimum allowable velocity at 45 to 90 cm/s for designing canals, velocity of the improved canals appeared to be relatively low. The substrate consisted mainly of sand and vegetation covered from 0 to 25% of the water surface. The fish were found to inhabit three non-improved canals (canals 20, 23 and 25) and an improved canal (canal 1). Population density for larval, juvenile and adult stages for the four canals varied from 0 to 0.76, from 0.01 to 0.54 and from 0.02 to 0.30 during the research, respectively (Table 1). There were four canals (canals 14, 18, 24, and 27) where the fish did not occur.

(2) Procedure for development of habitat suitability indexes

Habitat suitability indexes (SI) of five physical environmental factors for life stages of the field gudgeon were developed using the field research data[6]. To obtain a common SI among the canals and the four seasons, the data were used without separating by these terms. The following three steps were adopted as a procedure for development of SI in this paper.

In step one values of population density (y-axis) for a life stage against measurements of an environmental factor (x-axis) were plotted as in Fig. 3. An envelope curve with some turning points and surrounding the plotted points was fit temporarily as the values of SI were 1 and 0 at the high and low population densities, namely the best and worst preference, respectively. In step two using this curve, measurements of an environmental factor were translated to values of SI with a range from 1 to 0. The population densities were divided into six SI classes at 0.2

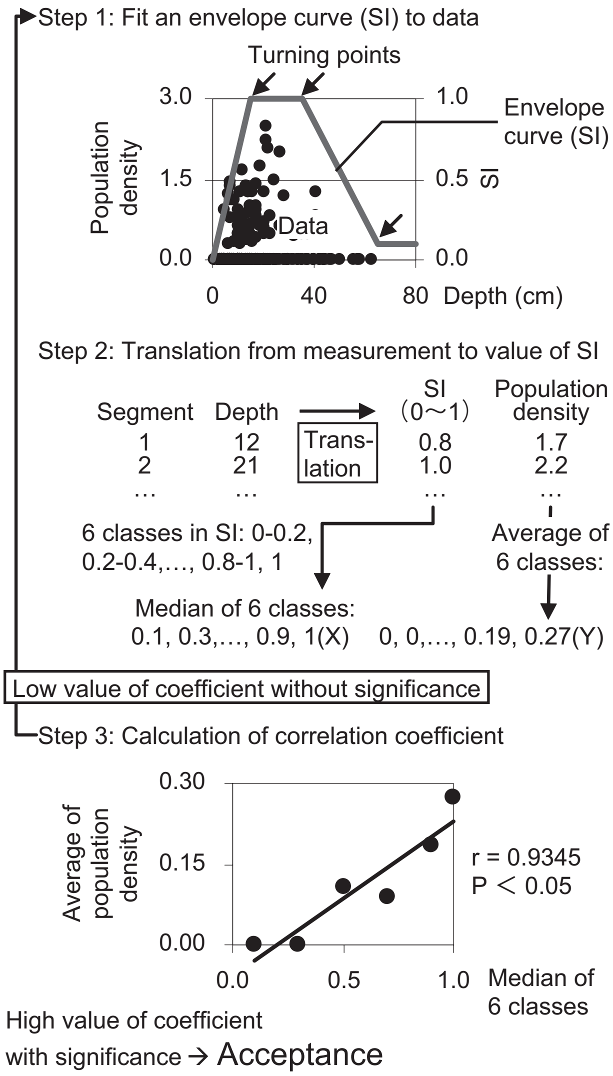

Fig. 3. Procedure for development of habitat suitability indexes

An example of water depth for the adult life stage is shown.

intervals, and average population density was calculated for each class. In step three a correlation coefficient was calculated between medians in classes (x-axis) and averages of population density (y-axis), and the xy-locations of turning points were modified in the envelope curve, until the coefficient became as significantly high a value as possible (Fig. 3).

Results and discussion

1. Habitat suitability indexes of physical environmental factors for life stages of the fish

Fig. 4 shows SI of five physical environmental factors for life stages of the field gudgeon. Correlation coefficients for most of the SI were significantly high values that ranged from the 0.8's to the 0.9's ($p < 0.05$) between medians of the SI classes and averages of population density. The SI for juvenile and adult stages were similar to each other for the physical environmental factors. The best preference, namely SI = 1, of both life stages for each factor occurred when water depth, water velocity and water width ranged from 15 to 30 cm, from 5 to 20 cm/s and from 45 to 120 cm, respectively; substrate ranged from gravel to sand; and vegetation covered from 0 to 75% of water surface area (Fig. 4).

On the other hand, the SI for the larval stage differed from the SI for juvenile and adult stages (Fig. 4). These differences appeared to be related to a part of their ecological and habitat properties. Namely, larvae have a weak swimming power in general. It is known that their habitat is often formed in shallow water with slow velocity and vegetation growth which helps to fix their bodies in a water column, and to escape from attacks of predators[11]. These properties for the larval stage seem to be reflected in the SI for this stage. The best preference of the larval stage in each factor occurred when water depth, water velocity and water width ranged from 15 to 20 cm, 0 cm/s and from 90 to 120 cm, respectively; substrate was sand; and vegetation covered 75% of water surface (Fig. 4).

2. Equation for calculating habitat potential in canals

Habitat potential (HP) in non-improved and improved canals was calculated for each life stage during the field research, using the SI for physical environmental factors. HP in this paper almost equaled a dimensionless weighed usable area (WUA) in the physical habitat simulation model (PHABSIM)[7] and habitat unit (HU) in habitat evaluation procedures (HEP)[14]. The following equation (1) was used basically to calculate $HP_{i,j,k}$ in canal i (i = canal no.), of j month (j = July 2002, … , June 2004) for k stage (k = larval, juvenile and adult stages).

$$HP_{i,j,k} = \frac{\sum_{l=1}^{n}\left(CSI_{i,j,k,l} \times \text{water surface area}_{i,j,l}\right)}{\sum_{l=1}^{n}\text{water surface area}_{i,j,l}} \quad (1)$$

Where l is number of segments in canals and CSI is composite suitability index, which is composed of various SI (i.e. $SI_{depth} \times SI_{velocity}$, $SI_{depth} \times SI_{velocity} \times SI_{width}$,..., $SI_{depth} \times SI_{velocity} \times SI_{width} \times SI_{substrate} \times SI_{vegetation}$, etc.). Water surface area is denoted by water width × length of a segment.

3. Selection of composite suitability indexes for life stages

CSI that was composed of all SI was used in most of the previous PHBSIM studies (e.g. Orth & Leonard, 1990[13]). CSI, however, seems to be a kind of statistical multiple factors model, and performance of variable selection can be considered to possess the robustness of such a model. Therefore, concerning CSI in this paper, an essential CSI for a life stage was selected from a set of CSI, which was composed of two to five SI, before calculation of HP. Correlation coefficients between values of CSI and population densities were calculated, and the CSI that gave the highest score of the correlation coefficients was

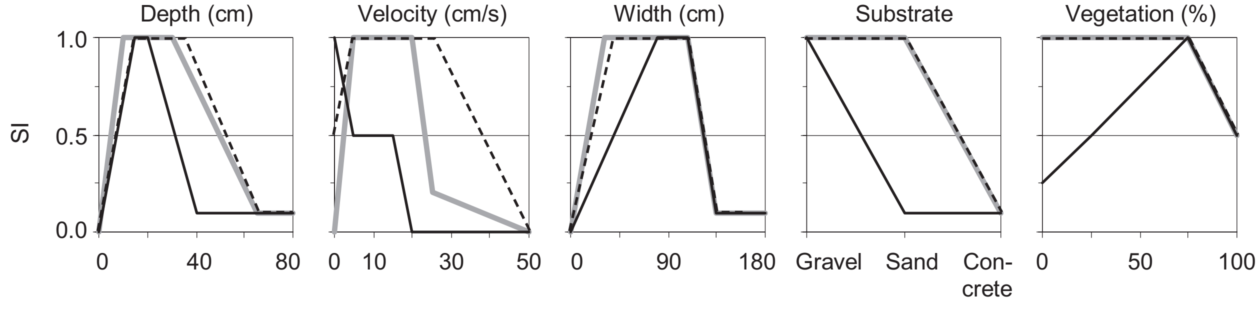

Fig. 4. Habitat suitability indexes of water depth, water velocity, water width, substrate, and vegetation covering for larval, juvenile and adult stages of the field gudgeon
—: Larvae, ▬: Juvenile, ---: Adult.

used to estimate HP.

Consequently the following equation (2) of CSI with correlation coefficients, of which the high values were significantly in the 0.9's ($p < 0.01$), was used for life stages.

$$\left.\begin{aligned} CSI_{\text{larval stage}} &= SI_{\text{depth}} \times SI_{\text{width}} \times SI_{\text{substrate}} \\ CSI_{\text{juvenile stage}} &= SI_{\text{depth}} \times SI_{\text{velocity}} \times SI_{\text{width}} \\ CSI_{\text{adult stage}} &= SI_{\text{depth}} \times SI_{\text{substrate}} \times SI_{\text{vegetation}} \end{aligned}\right\} \quad (2)$$

Water depth at 15 to 20 cm, water width at 90 to 120 cm and substrate with gravel formed the optimal habitat (CSI = 1) for the larval stage. Water depth at 15 to 30 cm, water velocity at 5 to 20 cm/s and water width at 45 to 120 cm formed the optimal habitat for the juvenile stage (Fig. 4). The optimal habitat condition for the adult stage occurred at water depth of 15 to 30 cm, substrate with gravel to sand and vegetation cover of 0 to 75%.

4. Habitat potential in canals for life stages of the fish

Fig. 5 shows examples of monthly variation of cumulative population density of the field gudgeon and HP in non-improved and improved canals (canals 20 and 1, respectively) during the field research. Population density in both canals varied seasonally, and suggested that the high density from July to December was related to recruitment of larvae with spawning, growth of individuals, etc. Also, HP in each canal varied monthly, but the trends of their variation seemed to be random rather than seasonal. Therefore, the averages of HP during the research were calculated in the canals, and they were used for comparing among canals.

Although the fish did not occur in four canals, HP of these canals was also calculated to verify any possible fish habitat, as well as for canals where fish lived. Fig. 6 shows the cumulative averages of HP for larval, juvenile and adult stages in all canals. These averages ranged from 0.08 to 0.53, from 0.29 to 0.80 and from 0.36 to 0.77 for larval, juvenile and adult stages, respectively. T-test results indicated that differences of averages among non-improved and improved canals were not significant for each life stage (d.f. = 5, t = 0.520, $p > 0.05$ for larval stage, d.f. = 5, t = 1.745, $p > 0.05$ for juvenile stage and d.f. = 5, t = 0.173, $p > 0.05$ for adult stage). This result showed that the improved canals were not inferior in producing physical habitats for the field gudgeon when compared with the non-improved canals. Improving canals with concrete lining has often been criticized as damaging to fish habitats[8]. However, if only concrete walls are installed

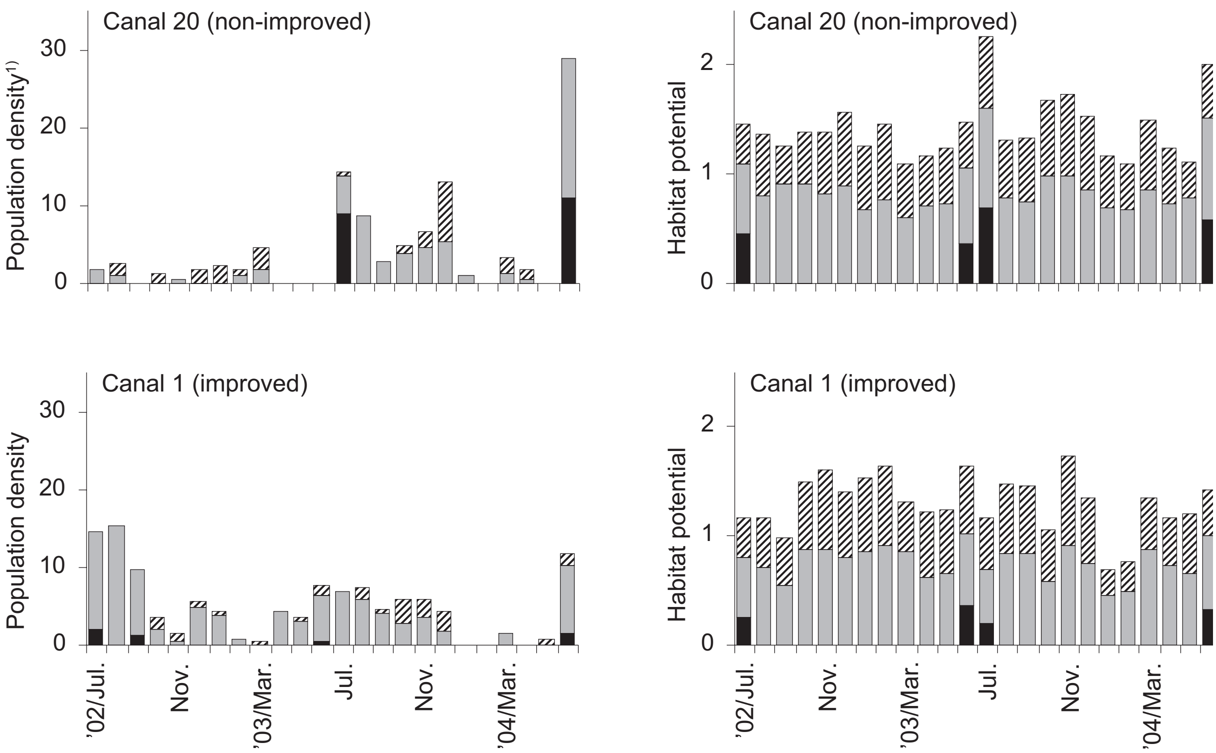

Fig. 5. Monthly variation of cumulative population density and habitat potential for life stages of the field gudgeon in non-improved and improved canals (canals 20 and 1, respectively) during the field research

■: Larvae, ▒: Juvenile, ▨: Adult.

1): Number of individuals/water surface area, m^2.

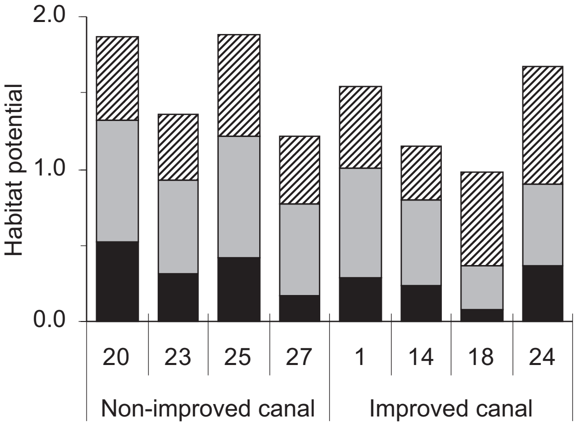

Fig. 6. Cumulative averages of habitat potential for larval, juvenile and adult stages in canals during field research
■: Larvae, ▒: Juvenile, ▨: Adult.

in canals, it seems possible that fish habitats in the improved canals could approach to the condition existing before improvement.

Also, the cumulative averages of HP for all stages in Fig. 6 were high in each of two non-improved canals (1.88 and 1.86 in canals 25 and 20, respectively) and improved canals (1.67 and 1.54 in canals 24 and 1, respectively). Although the field gudgeon did not actually occur in canal 24 during the research, these canals can be used as alternative habitats to give temporary refuge to the fish, when a canal in this basin is being improved. Thus evaluation of habitat potential is available for conservation designs in rural areas. SI of various organisms including fish are developed as well in this paper and it is expected that they would be utilized for planning land consolidation in the future.

Acknowledgments

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