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## **An Adaptive Modeling Technique for Instream Fish Habitat Preference of Japanese Medaka (*Oryzias latipes*)**

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It is widely known that habitat selections of riverine fish differ within and between rivers. In our past study, the preference intensity of Japanese Medaka (*Oryzias latipes*) to three environmental factors of water depth, current velocity and cover ratio was quantified on laboratory open-channel experiments for developing a general habitat preference model. A simplified fuzzy reasoning method was introduced in consideration of essential vagueness of fish behaviors. The fuzzy preference intensity model was then optimally searched with a simple genetic algorithm and was successfully verified by both laboratory water tank experiments and on-the-spot examination. The results indicated that this general model showed agreement between predicted and observed spatial distribution of target fish, but the habitat preference models are still desired to be developed through field studies. In this study, we propose an adaptive modeling technique for instream fish habitat preference by conjugating the fish preference intensity model developed in laboratory experiments. The adaptive prediction model was also determined by simple genetic algorithm, which enabled us to model the habitat preference of instream resident fish even with insufficient data.

### INTRODUCTION

The demand for ecological restoration is generally recognized, and several guidelines for assessing environmental changes have been proposed (Hayes and Jowett, 1994; Lamouroux and Capra, 2002; Lamouroux and Souchon, 2002). The microhabitat models of each method are now facing the problem of transferability of fish habitat selection. In the past, human activities such as urbanization, reclamation and settlement reduced both availability and quality of fish habitat. Agricultural canals also have increasingly altered into artificial flume with a view to water management, although these canals play an important role for living things as spawning and nursery sites. Many species reside in habitats surrounding paddy fields during their life cycles. For example, loaches (*Misgurnus anguillicaudatus*) winter in permanent creeks, enter paddy fields via temporary creeks, and spawn and reproduce in paddy fields (Tanaka, 1999). Hata (2002) evaluated the important role of agricultural water channels and paddy fields in the life of

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fish: three-spined stickleback (*Gasterosteus aculeatus aculeatus*), carp (*Cyprinus carpio*), Prussian carp (*Carassius carassius* subsp.), catfish (*Silurus asotus*), Japanese Medaka (*Oryzias latipes*), loach and Miyako-tanago (*Tanakia tanago*). With understanding their value in nature, applicable techniques for ecological restoration are urgently needed in waterfront development. Several models, e. g., IFIM (Instream Flow Incremental Methodology: Stalnaker *et al.*, 1995), have been proposed and applied for assessing the impact of human activities (e. g., Reiser *et al.*, 1989; Van Winkle *et al.*, 1998; Spence and Hickley, 2000; Holms *et al.*, 2001; Lamouroux and Capra, 2002; Lamouroux and Souchon, 2002), but, in the application, it was found that fish had site-specificity in their habitat selection.

In the past study, we quantified the preference intensity of Japanese Medaka to three environmental factors: water depth, current velocity, and cover, using laboratory open channel experiment for the purpose of development of a general habitat preference model (Hiramatsu and Shikasho, 2002). A simplified fuzzy reasoning was introduced in order to take essential vagueness of fish behavior into consideration (Hiramatsu *et al.*, 2003). We utilized a simple genetic algorithm (Hiramatsu and Shikasho, 2004) to search for an optimal model structure, and then the fuzzy preference intensity model was constructed. The result showed a sound agreement between predicted and observed fish distribution of Japanese Medaka in both the laboratory water tank experiment and on-the-spot examination. The site-specificity of microhabitat preferences of fish, however, was implied in the verification, which induced us to develop the habitat preference model in the field studies.

From the observation in the past study (Hiramatsu *et al.*, 2003), we have found it difficult to obtain data sufficient to construct fuzzy preference intensity models in agricultural canals. This difficulty may result from its even distribution of physical environments of water depth and current velocity. The present study proposes an adaptive modeling technique for fish habitat preference of Japanese Medaka by conjugating the fuzzy preference intensity model developed in laboratory experiments. An artificial intelligence technique of simple genetic algorithm was introduced to develop the fuzzy preference intensity model even with insufficient data of on-the-spot examination.

## MATERIALS AND METHODS

### Study site

The agricultural canal for the study site is located in Kurume city, Fukuoka, Japan (Fig. 1). The chosen canal has a low gradient, almost unlined and is used as a dual-purpose canal. It is originating in the spring so that water runs throughout the year and thus fish population of Japanese Medaka is supported during the non-irrigation period in the canal. The observation point is located at midpoint in the canal, whose length is about 50 m and width ranging from 1.6 m to 2.0 m. A concrete agricultural facility is located about 31 m up from the downstream end. Topminnow (*Gambusia affinis*), a competitive species to Japanese Medaka, is not found in the canal.

### Data sampling

During the irrigation period, agricultural canals are stemmed by weirs; almost all the

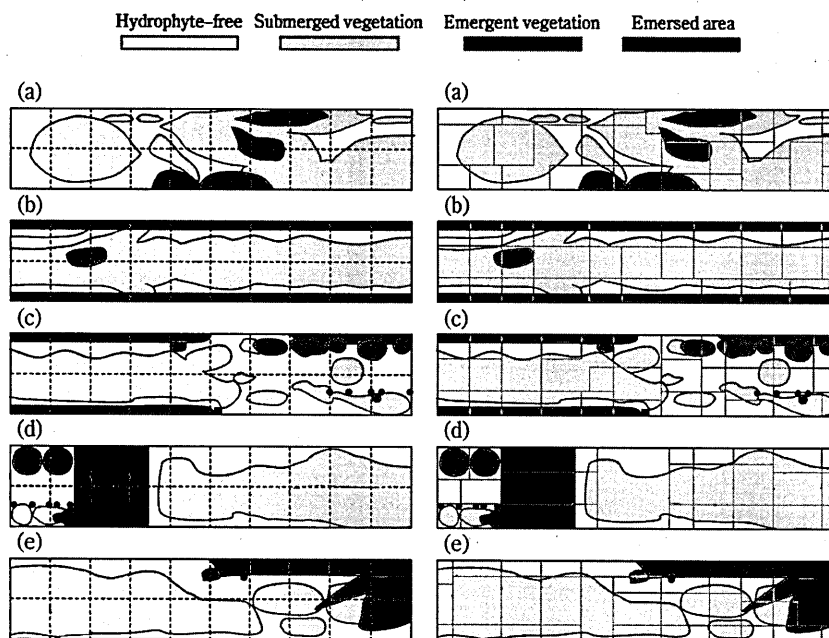


Fig. 1. Schematic of overview (left) and water bodies (right) of the study site.

area has similar habitat characteristics such as deep water and low current velocity. For this reason, it becomes difficult to develop habitat preference models. Multiplicity in distribution of physical environments is necessary for model construction, so the on-the-spot examination was carried out during the non-irrigation period. The census was taken on a sunny day, November 5. Mean water temperature was 17.5°C (16.1–18.5°C). First, we observed fish distribution (11:00–13:30) and then measured spatial habitat characteristics.

### Fish observation

We observed fish from the upstream end toward downstream so as to minimize fish disturbance. The distribution of Japanese Medaka was counted by sight every five fish, according to previous studies. Iwamatsu (1997) pointed out that attractive fish schools of Medaka increased proportionately with the number of fish up to five. Kanda and Itazawa (1986) represented that grouped Medaka showed more stability in locomotor activity and less consumption of oxygen compared to individual fish. A series of fish observations was repeated eight times, and the results were averaged to avoid observation variance.

### Spatial habitat characteristics

Spatial habitat characteristics of water depth, current velocity, and cover ratio were measured to quantify the habitat preference of Japanese Medaka. Water depth was sur-

veyed with a stainless steel ruler, and current velocity with a portable propeller current meter (KENEK V-303) at intervals of 1 m. In order to determine similarity in the physical environmental factor, the study site was divided into water bodies by measuring water depth and current velocity. Fish population density was calculated from the obtained information.

We estimated cover ratio from the schematic of water bodies (Fig. 1) according to the following definition.

### Definition of cover ratio

The definition of cover ratio follows, with reference to the authors' experiment (Hiramatsu *et al.*, 2003):

$$\text{Cover ratio (\%)} = \text{LR-cover (\%)} + \text{TB-cover (\%)} \quad (1)$$

where "LR" is abbreviation of left and right, and "TB" of top and bottom. Both LR-cover and TB-cover becomes up to 50%. LR-cover is valued the maximum of 50% when four lateral sides (backward, forward, left and right which is equally evaluated at 12.5% each) of water body are covered with water's edge or emergent vegetation. TB-cover consists of upper and bottom cover of 25% each. We give 25% to TB-cover for streambed since we do not consider upper cover into the calculation for its obstruction to fish observation. Therefore, cover ratio is estimated to be the maximum of 75%.

### Existing fuzzy preference intensity model

The preference intensity model (subsequently called source model) was developed upon two laboratory open channel experiments. A single-factor experiment was undertaken to quantify preference intensity for a single environmental factor, and a composite-factor experiment to relate preference intensities between three environmental factors. A simplified fuzzy reasoning was introduced to explicitly take the essential vagueness of fish behavior. Singletons for the consequence part of fuzzy if-then rule were optimally searched by a simple genetic algorithm (Table 1). The source model was thus constructed and then successfully verified by both laboratory water tank experiment and on-the-spot examination.

**Table 1.** Consequence parts for the fuzzy preference intensity models developed using the laboratory open channel experiment and on-the-spot examination data, respectively.

Laboratory experiment	Weight	Singletons for consequence part					
		1	2	3	4	5	6
Depth	0.46	–	0.0952	0.1429	0.2698	1	0.6984
Velocity	1	0.5873	1	0.9365	0.3175	0.1429	0.0635
Cover	0.49	0.1270	0.2222	1	–	–	–
5-Nov-04	Weight	Singletons for consequence part					
		1	2	3	4	5	6
Depth	0.46	0	0.0159	0.0159	0.2540	0.4286	1
Velocity	1	1	0.5079	0.1746	0	0	0
Cover	0.49	0	0.2222	1	–	–	–

### Adaptive fuzzy preference intensity model

The present chapter describes how adaptive modeling technique works with insufficient data. The concept of the adaptive fuzzy preference intensity model is almost the same as the source model, while several improvements have been added. The procedure is as follows. First, the premise part for the fuzzy if-then rule is defined (Fig. 2). In the present study, the premise part for the water depth has changed with a view to take the ecological factor into consideration for the model. The fuzzy set for the depth of 2 cm has been added. The adjoined membership function represents a shallower limit for inhabitancy of Japanese Medaka so that the singleton corresponding to that fuzzy set is assumed to be zero. Morishita and Morishita (1997) pointed out that fish require a depth of at least three-fold body length in order to inhabit in a stream, which supports the above ecological hypothesis. Second, determinable fuzzy relations are searched because not all the fuzzy relations can be determined in the case of shortage of data. To solve the problem of insufficiency, fuzzy relations of the source model are substituted into the adaptive model instead of the indeterminable one. Third, the singletons for the consequence part are determined by the use of the simple genetic algorithm. In the optimization, the codes for singletons are given six bits each for the singletons. The fitness function is defined by the multiplicative inverse of square error between observed and predicted fish population density ( $\rho_{oi}$  and  $\rho_{ci}$  respectively) as follows. To start with, we composite preference intensities to a single environmental factor of water depth, current velocity, and cover ratio using the Sekine's expression (Sekine *et al.*, 1997),

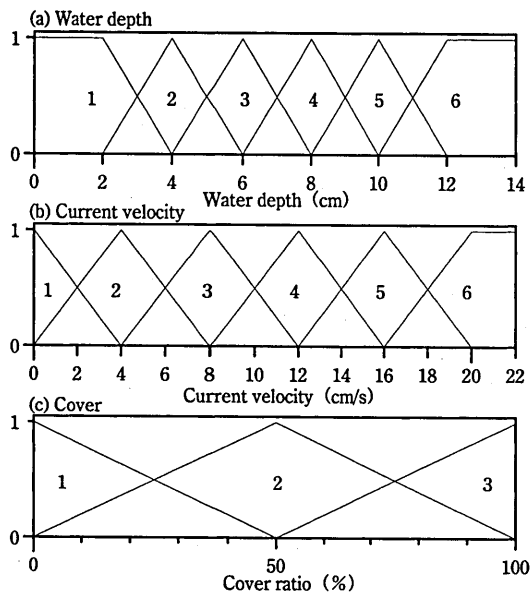


Fig. 2. Premise part for the fuzzy preference intensity model.

$$P_i = \prod (P_{i,j})^{\frac{W_j}{W_{\max}}} \quad (2)$$

where  $P_i$  denotes preference intensity for the  $i$ th water body,  $i$  ( $=1, 2, \dots, n$ ) the number of water bodies,  $W_j$  the weight of  $P_{i,j}$ , and  $j$  ( $=$ depth, velocity and cover) environmental factor. This equation (2) is newly introduced in the model so that the weight  $W_j$  has been recalculated (Table 1). Subsequently, fish population density  $\rho_{c,i}$  is predicted with preference intensity and following equation

$$\rho_{c,i} = \left( P_i / \sum_{i=1}^n P_i \right) \sum_{i=1}^n \rho_{o,i} \quad (3)$$

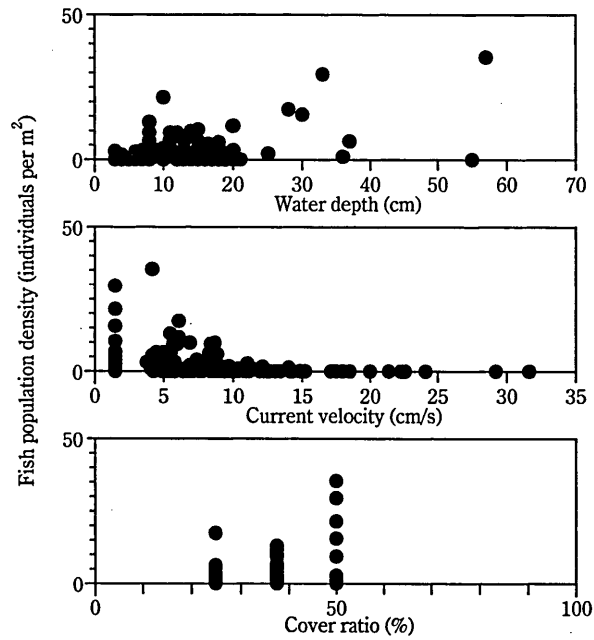
where  $\rho_{o,i}$  is observed fish population density. Thereupon, the fitness function  $F_i$  is given as

$$F_i = 1 / \sum_{i=1}^n (\rho_{o,i} - \rho_{c,i})^2. \quad (4)$$

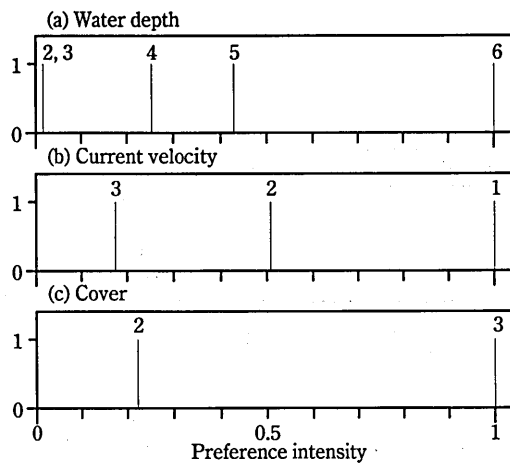
Altogether with the above calculation, the computation is conducted under the following conditions: at least one of the singletons for each environmental factor becomes the maximum of unity, and the singletons subsequent from the maximum singleton have values with the tendency of steady, decreasing, or increasing. In the case that the condition cannot be satisfied, the penalty of  $10^{-3}$  is forcedly given as fitness. It is widely known that fish have an optima or threshold in habitat preference, which permits us to introduce these calculative restrictions. Finally, the fuzzy preference intensity model is constructed and verified with the on-the-spot examination data using Spearman's rank correlation test.

## RESULTS

The result of the on-the-spot examination is shown in Fig. 3. Water depth ranges from 3 cm to 57 cm, current velocity from 1.5 cm/s to 31.6 cm/s, and cover ratio from 25% to 50%, which reveals the sufficiency in both water depth and current velocity for the model construction, and its lack in cover ratio. Therefore, the singleton for the 100% of cover ratio has been substituted from the source model into the adaptive model. The optimally searched consequence part is shown in Fig. 4, and preference intensity distribution calculated by the model is in Fig. 5. Maximum habitat preference is found from calculation to be over 12 cm of water depth, 0 cm/s of current velocity, and 100% of cover ratio. The preference for water depth and cover ratio increases in keeping with environmental value, but for current velocity decreases. Fish population density calculated using the fuzzy preference intensity model and equation (3) is shown in Fig. 6 in comparison to observed data of the on-the-spot examination. The adaptive model explained fish distribution well. The predicted and observed fish population data correlated significantly ( $r_s=0.668$ ,  $p<0.001$ ). The square error between predicted and observed fish population density decreases from 23.33 to 18.42 (individuals per  $m^2$ ).

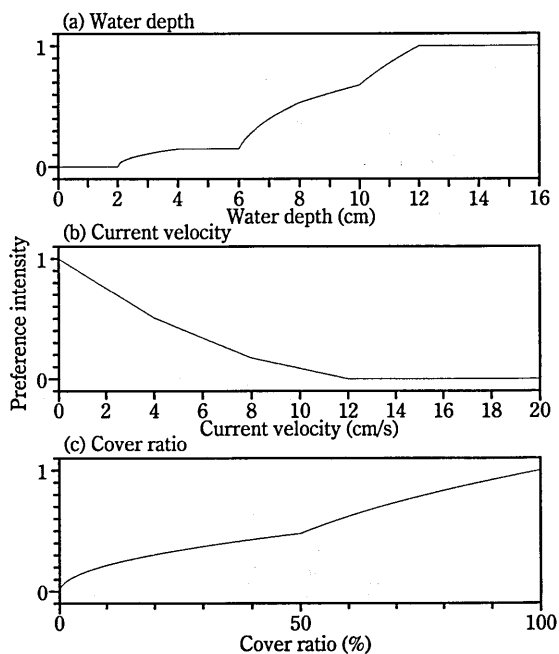


**Fig. 3.** Fish population density and physical habitat characteristics.

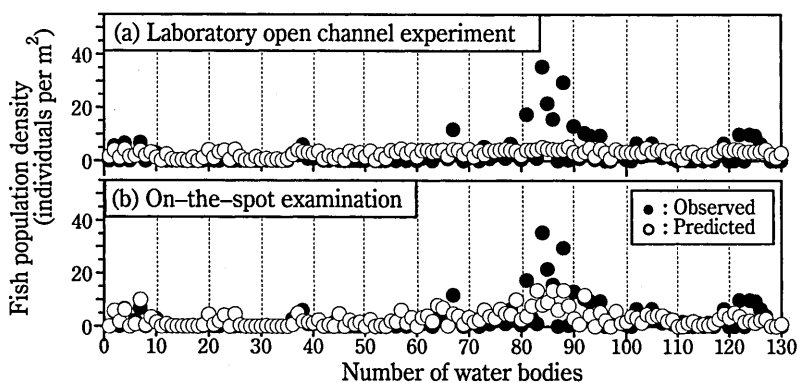


**Fig. 4.** Consequence part for the fuzzy preference intensity model developed using on-the-spot examination data.





**Fig. 5.** Preference intensity distribution calculated by the fuzzy preference intensity model.



**Fig. 6.** Comparison between observed and predicted fish population density calculated by fuzzy preference intensity models developed using the laboratory open channel experiment and on-the-spot examination data, respectively.

## DISCUSSION

The result of the field examination (Fig. 3) indicates the avoidance in depths shallower than 8 cm, velocity faster than 10 cm/s, and less than 50% of cover. The obtained fuzzy preference intensity model describes a similar tendency in the prediction (Figs. 4, 5 and Table 1). The preference for deeper water is generally recognized as a shelter in a stream channel that provides aquatic organisms protection from avian or terrestrial predators in the force of visual isolation and so on (Power, 1985; Stalnaker *et al.*, 1995). Although the Japanese Medaka is often found swimming near the surface in a stream, Yokota and Oishi (1992) reported that Medaka, in their experiment under natural condition, showed diurnal activity at the lower layer in autumn and winter, which supports the result of our observation. Slower velocity is preferred among fish larvae because of their limitation in swimming ability. In general, swimming ability of stream fish is assumed to increase in correlation to body length. Vincent (1960) demonstrated that wild-stock fish had greater stamina than domesticated fish. The major difference in consequence part between the two models (Table 1) can be explained as a difference in swimming ability between wild and domestic. Some riverine fish change their habitat from lower to faster velocity according to increased body length (Suzuki, 1998). Adult Medaka becomes only 20 mm to 30 mm of body length, and, hence, dwells in slow flowing areas. The present result shows preference for larger cover ratio. In other microhabitat models (e. g., Bovee *et al.*, 1998), definition of cover differs in each model while we defined the term consistent with the laboratory open channel experiment. We focused on the existence of water's edge, emergent vegetation and a dike surrounding the body of water. This includes the concept of distance from shore (Wolter and Bischoff, 2001) and showed similar results. Medaka preferred the near-the-shoreline habitats rather than mid-channel.

From the comparison between observed and predicted fish population density (Fig. 6), it is apparent that the present modeling technique can be widely applicable, and gives us a better prediction than the model developed using only laboratory experiments. The prediction becomes more precise, and the fish distribution was well represented. For site-specific environmental condition including fish density, stream productivity, physical habitat characteristics, and fish community structure (Johnson, 2002), the microhabitat models should be developed through field studies. The present study describes an adaptive modeling technique that can quantify fish habitat preference in a definite procedure. Further application of the present model to both different rivers and seasons will be necessary for validation and for assessment.

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