A Fish Habitat Evaluation Model Based on the Behavioral Mode

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Abstract: We propose a new evaluation procedure of fish habitats by considering the environmental preference with four behavioral modes (feeding, resting, hiding, and spawning) and considering the fish home range. We examined the behavioral mode of feeding and resting through continuous experiments that last for several days. Then, we decided the values of preference parameter for velocity, depth, and cover for each behavioral mode. We have already proposed a fish preference model in multiplication form, in which parameter values for the environmental preference equations and weight values among the environmental factors can be determined separately, and the environmental factors can be added anytime without affecting other parameter values. In this paper, we propose a model that combines the preference equations for each behavioral mode using an addition formula. We applied the model to Furukou River at Yamaguchi Prefecture, Japan, in which restoration work is going on. Parameter values for feeding and resting modes are determined through experiments, and those for hiding and spawning through literature survey. The fish home range is determined by Minns' formula or through field surveys. The calculated fish distribution using this model reproduces successfully the observed fish distribution, whereas a method without behavioral modes fails to reproduce it. Using this procedure, we can evaluate the importance of the combination of pools and rapids, which we could not previously evaluate properly.

Keywords: Fish habitat in rivers; Preference for environment; Behavioral modes; Evaluation model

1. INTRODUCTION

PHABSIM [Stalnaker et al., 1994] is one of the most popular methods of evaluating river fish habitats. In PHABSIM, the value of fish habitat is expressed as *WUA* (Weighted Usable Area) using preference value for velocity $f(v_i)$, depth $g(d_i)$, and river bed condition $h(s_i)$ as:

$$WUA = \sum f(v_i) \times g(d_i) \times h(s_i) \times a_i \qquad (1)$$

where a_i is an area for a "cell" i in a river segment in which velocity, depth, river bed condition are relatively uniform.

Estimations of $f(v_i)$, $g(d_i)$ and $h(s_i)$ are the key part in calculating *WUA*. Usually, $f(v_i)$, $g(d_i)$ and $h(s_i)$ are determined through field observation. If fish have been observed twice as often at a velocity of one meter per second than at two meter per second, it means $f(1\text{m/s}) = 2f(2\text{m/s})$. Thus, by conducting many observations, we can determine the preference curve for $f(v_i)$, $g(d_i)$ and $h(s_i)$. Although *WUA* shows very good coincidence with observed fish distribution in the river where the preference curve has determined, it sometimes fails to explain the fish distribution in different rivers.

In the field observation, several environmental conditions affect the immediate fish distribution. When fish numbers are compared at different velocities, the depth and the bottom conditions also have some difference in the field. Preference curves obtained through field observation are not independent of other unaccounted conditions and this is the one reason, why preference curves obtained thorough field observations cannot be applied to different rivers.

Independent of PHABSIM, we have reported a method to determine preference curves based of laboratory experiments [Sekine et al. 1997]. Although our preference curves did not show a perfect coincidence with observed fish distributions, they showed reasonable similarity to different rivers [Kawamoto et al., 1999]. From laboratory experiments, we can obtain a "pure" preference curve independent from other unaccounted conditions.

In spite of robust preference curves based on laboratory experiments, we found cases in which fish distribution could not be reproduced. For example, in a river segment with monotonous rapid continues, the calculation shows that the segment is a good habitat for fish, whereas the observed fish number is small. We thought the reason for the disagreement is the existence of diurnal fluctuation in fish behavior.

Kawanabe [1956] observed the behavior of Ayu (*Plecoglossus altivelis*) for a whole day. He found that when a pool was abundant in feed, Ayu stayed in the pool for the whole day, whereas when a pool was not abundant in feed, Ayu went out to an adjoining rapid for feeding during day time and came back to the pool during night time. Although it is widely recognized that Ayu prefers rapids, it also prefers pools during the night. This is the reason why the combination of rapids and pools is very important.

Although the importance of the combination is well known among ecologists, it has not been modeled properly for habitat evaluation purpose. This may be why our preference curves could not reproduce the observed fish distribution in the monotonous rapid segment. The purpose of this study is to show the existence of behavioral modes by laboratory experiments, then to determine the preference curves for each behavioral mode, and lastly, to construct a model to express the habitat value based on the behavioral modes.

2. EXPERIMENTAL ANALYSIS OF FISH BEHAVIORAL MODES

The experimental apparatus is similar to that used by Sekine et al. [1997, Figures.1 and 2]. A narrow junction of 5 cm connects two parallel white tanks to each other. The observation area is surrounded by 150 cm high, 60 cm wide, and 60 cm long frame box with grey blackout curtains to avoid any visual stimulus to the fish. Inside the curtain, a 300 W halogen bulb is lighted during the day, and a 10 W electric bulb is used during the night. The illumination on the surface of the tank is 4000 lx for a simulated day. and 12 lx for a simulated night. Minnows (*Zacco platypus*) of the size of about 8 to 10 cm were used in the experiment.

Figure 3 shows that the fluctuation of distribution ratio in a tank where high velocity (30 cm/s) is set, whereas the velocity in a tank where velocity is not set is 3 cm/s. The minnows tend to stay in high velocity during the day and in low velocity during the night.

Figure 4 shows the preference for velocity changes not only diurnally, but also seasonally.

From those observations, we define the two behavioral modes, feeding mode and resting mode. During the feeding mode, minnows stay mainly in the high velocity tank, whereas, during the resting mode, they stay mainly in the low velocity tank. The preference curves for feed amount, depth and cover for each behavioral mode were obtained by conducting experiments for 24 hours and averaging the fish distribution during the day and the night.

In our previous study, we proposed new equations to express preferences as:

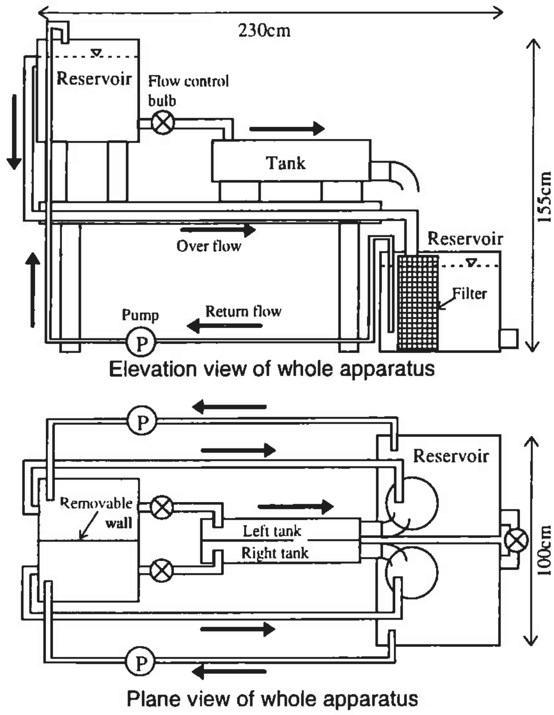

Figure 1. Experimental setup to test fish preference.

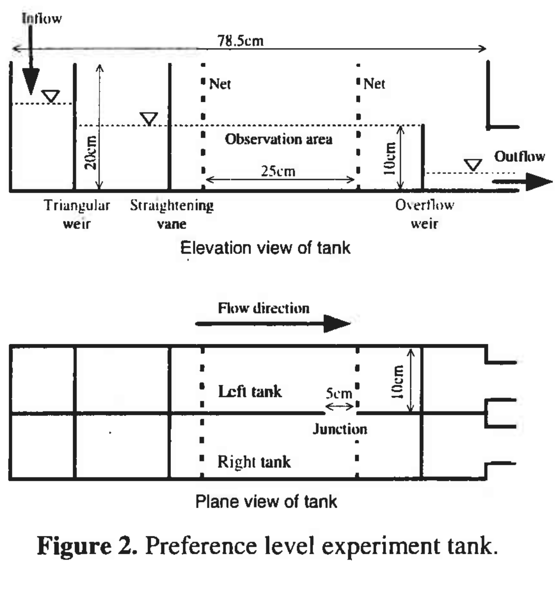

Figure 2. Preference level experiment tank.

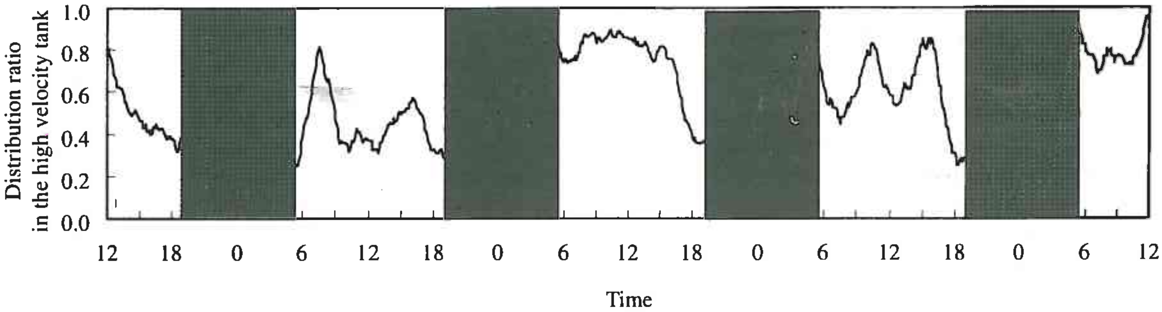

Figure 3. Fluctuation of distribution ratio in the high velocity tank.

$$P^* = \prod_{j=1}^{J} (P_j)^{\frac{W_j}{W_{\max}}} \tag{2}$$

$$W_{\max} = \begin{cases} \max\limits_{j \in V}(W_j) & V \neq \phi \\ \infty & V = \phi \end{cases} \tag{3}$$

$$V = \left\{ j \middle| (\exists i, i')\left(P_{j,i} \neq P_{j,i'}\right) \right\} \tag{4}$$

where ϕ represented the null set, $\exists$ was an existential quantifier, and $W_{\max}$ was the maximum weight among the weight sets that have different preference levels in different tanks [Sekine et al., 1997]. Table 1 shows the obtained preference curves expressed by this formula.

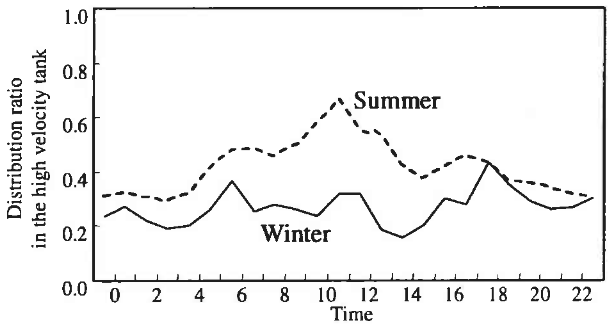

Figure 4. Difference of the distribution ratio during a day in the high velocity tank between summer and winter.

Table 1. Preference curves for Feeding and Resting mode.

Behavioral mode	Environmental factors	Preference curves	Weight
Feeding mode	Feed amount (mg-N/100cm²)	$P_{F_f} = \begin{cases} 0.25 & f \in [0, 0.34] \\ 0.75 \cdot \frac{f-0.34}{0.47} + 0.25 & f \in [0.34, 0.81] \\ 1.0 & f \in [0.81, \infty) \end{cases}$	0.58
	Velocity (cm/s)	$P_{F_v} = \frac{1}{\sqrt{2\pi} \cdot 12.54} e^{-\frac{(v_i-19.01)^2}{2 \cdot 12.54^2}}$	1.00
	Depth (cm)	$P_{F_h} = \frac{1}{\sqrt{2\pi} \cdot 9.98} e^{-\frac{(h_i-15.1)^2}{2 \cdot 9.98^2}}$	0.67
Resting mode	Cover (%)	$P_{R_c} = \left\{ 0.64 \cdot \frac{c}{100} + 0.36 \quad c \in [0, 100] \right.$	1.00
	Depth (cm)	$P_{R_h} = \begin{cases} 0.12 & h \in [0, 7] \\ 0.88 \cdot \frac{h-7}{35} + 0.12 & h \in [7, 42] \\ 1.0 & h \in [42, \infty) \end{cases}$	0.65
	Velocity (cm/s)	$P_{R_v} = \frac{1}{\sqrt{2\pi} \cdot 7.55} e^{-\frac{v_i^2}{2 \cdot 7.55^2}}$	0.50

3. COMBINED PREFERENCE MODEL BY CONSIDERING FISH HOME RANGE

To express the value of the combination of pools and rapids, we need a new formula that can treat not only the preference for a target cell but also looking into the preferences for adjoining cells. Here we introduce *Home Range*, which is an area where fish move around to obtain their living energy. Based on Minns' study [Minns, 1995], *Home Range* is described as a function of fish weight *WT* as:

$$Log_e[Home\ range(m^2)] = 3.43 + 0.53 * Log_e WT \quad (5)$$

In this study, we convert *Home Range* into *Sensible Distance* because we treat rivers as one dimensional which can be expressed as:

$$Sensible\ Distance = Home\ Range / River\ Width / 2 \quad (6)$$

A fish has a chance to "sense" the preference for a cell *Sensible Distance* apart from the current location of the fish. Based on this idea, *Sensible Weight* $M_{i,k}$ is defined as:

$$M_{i,k} = \max\left(1 - \frac{dist_{i,k}}{Sensible\ Distance},\ 0\right) \quad (7)$$

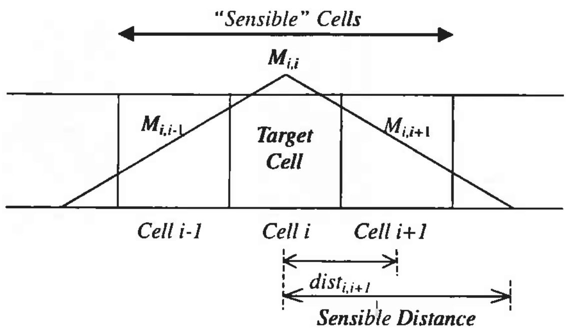

Fig. 5. Sensible Weight and Sensible Distance.

where max(a, b) is a function that returns the larger value between a and b, and $dist_{i,k}$ is a distance from the center of the cell i to the center of the cell j. Figure 5 illustrates the *Sensible Weight* and *Sensible Distance*. By using *Sensible Weight* $M_{i,k}$ and preference curves for each behavioral modes Pm_k, the total preference for a cell i, P_i, is expressed as:

$$P_i = \sum_m \left\{ Wm \left(\frac{\sum_k M_{i,k} \times Pm_k \times A_k}{\sum_k M_{i,k} \times A_k} \right) \right\} \quad (8)$$

Table 2. Preference curves for Hiding and Spawning mode.

Behavioral mode	Environmental factors	Preference curves	Weight
Hiding mode	Bank protection work	$P_{H_g} = \begin{cases} 1.0 & porous\ revetment \\ 0.1 & concrete\ revetment \end{cases}$	1.00
	Cover (%)	$P_{H_c} = \left\{ 0.64 \cdot \frac{c}{100} + 0.36 \quad c \in [0,100] \right.$	0.75
	Depth (cm)	$P_{H_h} = \begin{cases} 0.12 & h \in [0,7] \\ 0.88 \cdot \frac{h-7}{35} + 0.12 & h \in [7,42] \\ 1.0 & h \in [42,\infty) \end{cases}$	0.49
Spawning mode	Bottom condition	$Ps_s = \begin{cases} 0.01 & mud \\ 0.5 & sand \\ 1.0 & fine\_gravel \\ 0.5 & gravel \\ 0.01 & large\_gravel \end{cases}$	1.00
	Velocity (cm/s)	$Ps_v = \frac{1}{\sqrt{2\pi} \cdot 6.38} e^{-\frac{(v_i - 17.5)^2}{2 \cdot 6.38^2}}$	0.80
	Depth (cm)	$Ps_h = \frac{1}{\sqrt{2\pi} \cdot 3.83} e^{-\frac{(h_i - 12.5)^2}{2 \cdot 3.83^2}}$	0.80

$$\sum_m Wm = 1 \quad (9)$$

m is a suffix representing behavioral modes. Here $m = \{F, R\}$ for feeding and resting. Wm is a weight for behavioral modes, which represents the ratio of the length of time when a fish is in the mode m. From the laboratory observations, we estimate $W_F = 0.33$, $W_R = 0.67$ for summer, and $W_F = 0.23$, $W_R = 0.77$ for winter.

4. APPLICATION OF THE MODEL

We apply the model to Forukou River at Yamaguchi prefecture, Japan. Observed fish distribution is shown in Figure 6, with some calculated results mentioned later. In this river segment, 0m to 80m is a newly constructed and completely flat reach, and 90m to 290m is a diverse reaches with succession of pools and rapids, and a monotonous rapid continues from the 300m to the 570m, except a small pool around 400m. Because of this monotonousness, observed fish distribution is rather small in the upper half part of the segment. In spite of this fact, the calculated habitat potential by using the traditional formula is almost the same level in upper part and lower part of the segment, as previously mentioned.

Due to technical difficulty in the experiment, we discussed only two behavioral modes in the former sections. Moreover, we have already constructed preference curves for the other two behavioral modes (hiding mode and spawning mode) based on the literature survey. Table 2 shows the preference curves for these two modes.

When using our new formula, Figure 6 shows that the calculated habitat potential is much closer to the observed fish distribution than the traditional one. The calculated habitat potential with all four behavioral modes showed better fit than that of two behavioral modes. It shows that the better understanding of the behavioral modes will be very important to evaluate fish habitat properly.

5. CONCLUSION

In this study, we revealed the existence of two behavioral modes for minnows in laboratory experiments. We, then, determined preference curves for each behavioral mode. Based on these experimental results, we constructed a new

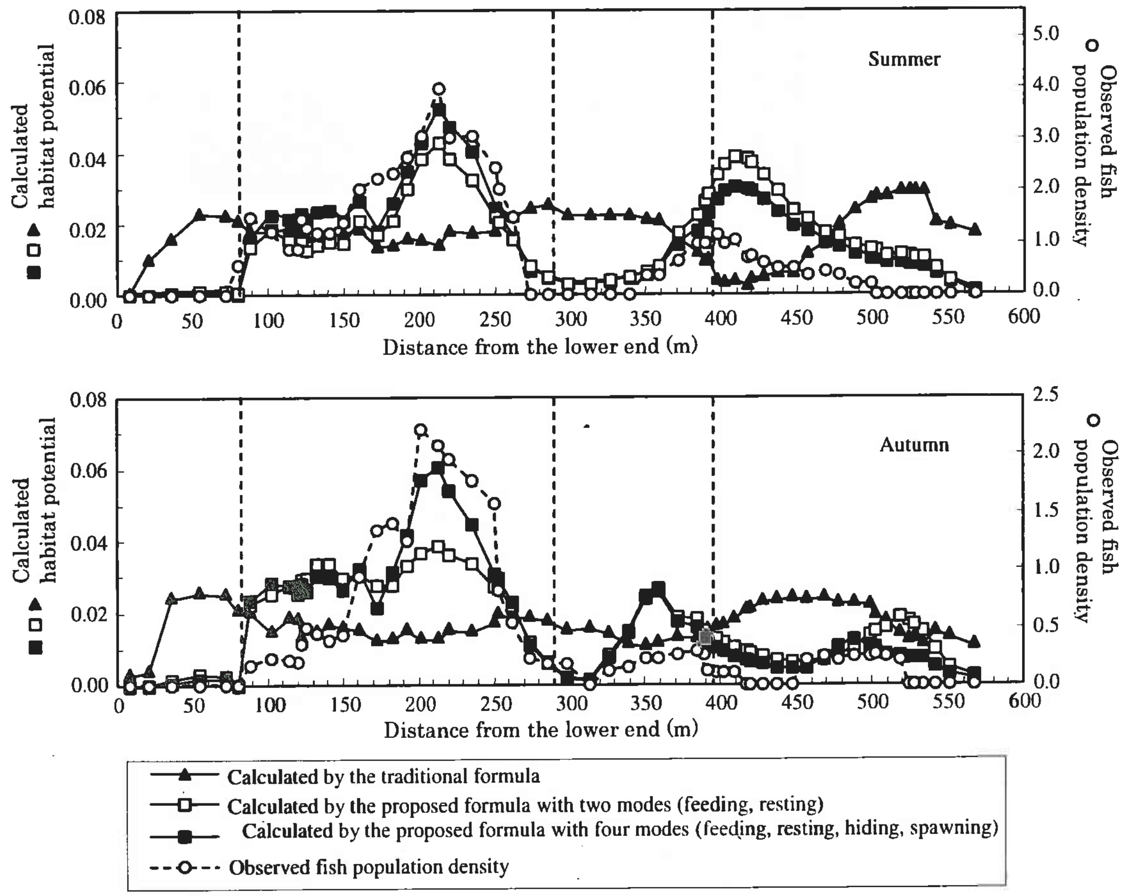

Figure 6. Observed fish population density and calculated habitat potential in Furukou river.

preference model that can express the importance of the combination of rapids and pools. The model showed a good accordance with observed fish distribution in a river.

We are currently constructing a computer program PHERM (a Physical Habitat Evaluation model with home Range and behavioral Mode; Figure 7), which can be a "skin" over the PHABSIM program. PHERM receives preference calculation results for each behavioral mode from PHABSIM, and combines them into one habitat evaluation result. We believe this will help to evaluate fish habitat in river environments more effectively.

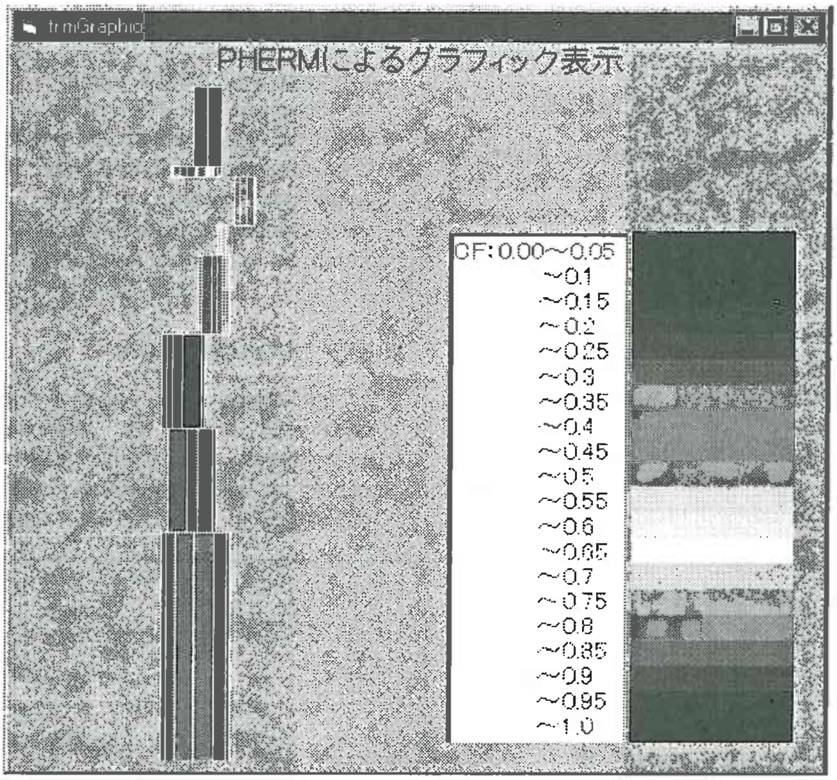

Figure 7. Screen shot of PHERM (beta version).

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