The Attractive Effect of Food Based on the Behavioral Responses of Juvenile Yellowtail *Seriola quinqueradiata**^{1,2}

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(Received December 16, 1981)

An index for the attractive effect of food was sought from three behavioral responses of active juvenile yellowtail, which entered, left and remained in the test compartment containing food. The attractive effect based on the main locomotive activity as observable attractive criteria could be represented as the product of the coefficients g and r of a logistic curve, $y=g/\{1+\exp[-r(j-a)]\}$ in the entering or the leaving time-course.

The attractive effect of various kinds of food, either the whole or the tissue of the organisms macerated, was examined by using the method mentioned above. Among seven classes of seawater organisms tested as food, polychaets, cephalopods, crustaceans and teleosts were found to be effective attractants. Blood worm *Marphysa sanguinea*, squid *Loligo edulis edulis*, whiskered velvet shrimp *Metapenaeopsis barbata* and flying fish *Prognichthys agoo* were the food that provoked remarkable exploratory and feeding behavior. Among three classes of freshwater organisms, strong attractants were only two kinds of crustaceans, sawtooth caridina *Caridina denticulata* and lake prawn *Palaemon paucidens*. None of the terrestrial organisms examined were effective.

It has been acknowledged, based on morphology, physiology and ecology, that olfaction in fishes plays an important role in the orientation of food.^{1,2)} In the ecological study of seventy-two Japanese teleosts in relation to the brain morphology, they were separated into five types according to the fissure and projecting part of *Bulbous olfactorius*.³⁾ It has been pointed out that the yellowtail behaves in a visual rather than an olfactory manner in the orientation of food. Field and laboratory experiments of yellowtail, however, reveal the importance of olfaction in the exploratory and feeding behavior of the fish.^{4,5)}

Behavioral studies on fish attractants have revealed that amino acids,⁶⁻¹⁸⁾ protein,^{14,15)} amine,¹⁶⁾ ammonia,¹⁷⁾ betaine,^{9,10)} lactic acid⁷⁾ and vitamin B₁₂.^{6,13)} strongly influence the exploratory and feeding behavior of fish. In 1975, SANGSTER *et al.*¹⁷⁾ showed that two dipeptides, hypotauryl-2-carboxyglycine(arcamine) and C-methyl-imino-diacetic acid(strombine) are active in grunts *Bathystoma rimator* and display exploratory and feeding behavior.

In series of the studies on the feeding attractants for fishes and shells, the attractive effect based on the main remaining time as observable attractive criteria for oriental weatherfish and black abalone,

which are comparatively low in the locomotive activity, could be represented as the coefficient a of logistic curve, $y=g/\{1+\exp[-r(j-a)]\}$ in the remaining time-course.^{18,19)} The present study was selected the juvenile yellowtail which is very high in the activity and investigated on the fitness of logistic curve to the three behavioral time-courses in order to find the attractive index of food. If the entering or the leaving time-course fits to a logistic curve, $gr/4$ is the tangent of the curve at coefficient a in reaching to $g/2$. The gr , i.e., the attractive index, accorded with the observable general evaluation which was employed the locomotive activity of yellowtail as the main attractive criteria. The attractive effect was examined by using the attractive index on a variety of aquatic and terrestrial organisms from different classes that might evoke the exploratory and feeding behavior of juvenile yellowtail, with an aim to determine whether these organisms would have the attractive properties.

Materials and Methods

One hundred specimens of juvenile yellowtail, 4.9 cm in average fork length were obtained from the Sea of Japan with a small roundhaul net.

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Fig. 1. An experimental aquarium.

They were transported to the experimental aquarium⁸⁾ modified as shown in Fig. 1 and fed to satiation only once at 16:00 daily with the commercial feeding stuff composed mainly of fish meal manufactured in Nihonhaigoshiryo Co. Seawater was introduced continuously into the aquarium through each inlet of delivery tube I at the rate of 1 liter per minute. h_1 and h_2 are elliptical holes ($a=5$ cm, $b=10$ cm) provided on the septa. Test food consisted of 57 specimens of terrestrial and aquatic organisms containing

eight classes of aquatic animals. All aquatic animals used were fresh.

The experiments for food attractiveness were conducted as follows. A 1.5 g sample of macerated tissue or organisms was wrapped in a double gauze (5×5 cm). The wrapped gauze was hung on a wire in the right side S of the test compartment A. A double gauze with no sample in it was used as a dummy. The experiments were carried out twice a day, at 10:00 and 15:00. A series of the experiments were done four times in a similar manner with the Latin Square method. The number of yellowtail that entered B from C, remained in B or left B for C was counted for each compartment at 1 minute interval for a period of 10 minutes after three samples of attractants and the dummy were suspended and the perforated screen P lifted. Four numbers counted a minute in each behavior of each sample were summed up. The number summed was successively integrated with time.

Results and Discussion

Decision Method for an Attractive Effect

Fig. 2. Time-course of the number of juvenile yellowtail respondent to food in using 10, 30 and 50 individuals. Circle, triangle and square indicate the number of yellowtail which entered, left and remained in the test compartment, respectively.

In order to establish a decision method for the attractive effect of food, observations for each behavior and its time-courses were made with the number of different individuals of yellowtail, using as attractants the muscle tissues of flying

fish, silver whiting and horse mackerel. Among the behavioral attractive criteria, the remaining time, the exploratory and feeding, and the locomotive activity that may be involved in the attraction, the remaining time in the yellowtail was

Fig. 3. Time-course of the number of juvenile yellowtail respondent to food in using 70 and 80 individuals. Notations are the same as the legends in Fig. 2.

Table 1. General evaluation of the three kinds of food as fish attractant through the observations of exploratory and feeding behavior

Food*	Behavior		General evaluation
	Locomotive activity	Exploratory and feeding	
Dummy	Weak	None	None
Flying fish-"Hontobi"- <i>Prognichthys agoo</i>	Strong	Strong and ceaseless	High
Silver whiting-"Kisu"- <i>Sillago sihama</i>	Weak	Weak	Low
Horse mackerel-"Maaji"- <i>Trachurus japonicus</i>	Moderate	Strong and ceaseless	Moderate

* English name-Japanese name-Scientific name.

Table 2. Estimation of logistic curve from the results of observations

Individuals used	$Y_{i,j}$	Method	Dummy					Flying fish					Silver whiting					Horse mackerel				
			g	r	a	χ^2	d.f.	g	r	a	χ^2	d.f.	g	r	a	χ^2	d.f.	g	r	a	χ^2	d.f.
10	$Y_{1,j}$	1	—	—	—	—	—	9	0.9	6.5	1.7†	2	—	—	—	—	—	7	1.0	2.4	0.3†	4
		2	—	—	—	—	—	17	0.8	6.3	1.0†	2	—	—	—	—	—	7	1.4	2.3	0.5†	4
	$Y_{2,j}$	1	—	—	—	—	—	473	0.6	14.4	20.9	1	—	—	—	—	—	7	1.0	2.4	0.3†	4
		2	—	—	—	—	—	25	0.7	8.0	4.6†	2	—	—	—	—	—	7	1.4	2.3	0.5†	4
	$Y_{8,j}$	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	$Y_{1,j}$	1	9	0.4	4.9	1.7†	2	18	1.4	7.6	2.0†	1	19	0.2	9.2	1.2†	3	55	0.3	13.6	9.8	2
		2	15	0.3	8.5	1.0†	3	19	1.3	7.6	1.8†	1	6	1.0	2.9	5.6†	4	—	—	—	—	—
	$Y_{2,j}$	1	9	0.4	4.9	1.7†	2	15	1.5	7.3	0.3†	1	13	0.3	6.8	1.0†	3	45	0.3	13.0	7.9	2
		2	7	0.6	3.9	2.6†	3	15	1.5	7.3	0.3†	1	7	1.0	2.7	4.3†	4	—	—	—	—	—
	$Y_{8,j}$	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50	$Y_{1,j}$	1	18	0.3	7.2	1.1†	3	48	1.2	5.3	10.5	3	29	0.4	10.0	3.9†	2	—	—	—	—	—
		2	16	0.4	6.2	1.2†	3	44	1.2	5.1	7.5†	3	21	0.4	9.1	7.7	3	—	—	—	—	—
	$Y_{2,j}$	1	18	0.3	7.2	1.1†	3	47	1.2	5.2	9.4	3	29	0.4	10.0	3.9†	2	—	—	—	—	—
		2	16	0.4	6.2	1.2†	3	42	1.2	5.1	5.7†	3	21	0.4	9.1	7.7	3	—	—	—	—	—
	$Y_{8,j}$	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70	$Y_{1,j}$	1	—	—	—	—	—	124	0.9	4.0	6.2†	5	42	0.9	4.3	6.1†	5	117	0.7	9.3	16.4	3
		2	—	—	—	—	—	130	0.8	4.1	3.6†	6	64	0.6	6.1	1.5†	5	226	0.6	10.4	24.8	3
	$Y_{2,j}$	1	—	—	—	—	—	87	0.8	3.9	4.9†	5	38	0.9	4.3	3.3†	4	23	0.6	7.2	68.3	2
		2	—	—	—	—	—	89	0.8	4.0	4.2†	6	58	0.5	6.3	2.2†	5	57	0.6	9.4	17.3	2
	$Y_{8,j}$	1	—	—	—	—	—	32	1.4	3.7	14.1	4	46	0.8	3.9	2.9†	2	67	0.9	8.8	27.9	1
		2	—	—	—	—	—	37	1.2	4.1	5.1†	4	46	0.7	4.5	1.6†	2	38	0.9	7.9	12.0	1
90	$Y_{1,j}$	1	—	—	—	—	—	146	0.8	3.5	9.1†	5	50	0.7	3.0	7.0†	5	152	0.6	7.1	13.1	5
		2	—	—	—	—	—	158	0.7	3.9	4.4†	6	57	0.5	3.7	3.6†	6	94	0.8	5.1	3.9†	5
	$Y_{2,j}$	1	—	—	—	—	—	115	0.7	4.3	6.7†	5	39	0.6	3.0	3.4†	5	16	0.4	11.5	39.3	5
		2	—	—	—	—	—	132	0.6	4.9	2.4†	6	37	0.9	2.7	6.5†	6	51	1.3	3.5	55.8	5
	$Y_{8,j}$	1	11	0.9	4.7	3.6†	3	35	1.2	2.2	1.0†	5	10	1.2	2.7	7.7†	4	16	1.6	3.7	10.1	3
		2	15	0.5	6.3	2.4†	2	36	1.0	2.3	0.7†	6	10	0.8	1.9	7.6†	5	14	0.9	3.7	19.3	4

† $\Pr(\chi^2 > \chi^2_{0.100}) > 0.010$; $Y = g / \{1 + \exp[-r(j-a)]\}$, where $Y_{1,j} = \sum y_{1,j}$. The $y_{1,j}$, $y_{2,j}$ and $y_{8,j}$ show the number of yellowtail which entered, left and remained in the test compartment respectively $j-1$ to j (one minute interval) after the start of experiment. $r \dots$ estimated from the coefficient of the regression of reciprocal of $Y_{i,j}$ on reciprocal of $Y_{i,(j-1)}$, a and $g \dots$ estimated from the coefficient and constant of the regression line of reciprocal of $Y_{i,j}$ on $\exp(-rj)$, Method 1... estimated from the relation between $1/Y_{i,j}$ and $1/Y_{i,(j-1)}$ ($j=2$ to 10), Method 2... estimated from the relation between $1/Y_{i,j}$ and $1/Y_{i,(j-1)}$ (weight by j) ($j=1$ to 10).

difficult in observing as judging from the remaining time-courses shown in Figs. 2 and 3, as opposed to that in the oriental weatherfish and the abalone.^{18,19)} This discrepancy may be caused by the fact that the former is vigorous in locomotion,

whereas the latter are not so active. In this context, the locomotion was employed as the main attractive criterion in the behavioral observations of yellowtail. The results of the observations are shown in Table 1. As Table 1

Table 3. The attractive effect of various kinds of food on juvenile yellowtail

No.	Food		Attractive effect*2
	Species*1	Tissues	
(Aquatic animals and plants)			
Seawater			
Polychaets			
	Dummy	—	40†
1	Sand worm—"Isogokai"— <i>Perinereisnuntia vallata</i>	Entire animal	101†
2	Blood worm—"Iwamushi"— <i>Marphysa sanguinea</i>	Ditto	163†
3	Sand worm—"Kankokusanisogokai"— <i>Perinereis vancaurica tetradenta</i>	Ditto	88†
Cephalopods			
	Dummy	—	6
4	Cuttlefish—"Koika"— <i>Sepia esculenta</i>	Muscle	—
5	Squid—"Kensakiika"— <i>Loligo edulis edulis</i>	Ditto	17
6	Cuttlefish—"Kaminariika"— <i>Sepia lycidas</i>	Ditto	22†
	Dummy	—	12
7	Cuttlefish—"Koika"— <i>Sepia esculenta</i>	Mid-gut gland	102†
8	Squid—"Kensakiika"— <i>Loligo edulis edulis</i>	Ditto	208†
9	Cuttlefish—"Kaminariika"— <i>Sepia lycidas</i>	Ditto	73†
Bivalves			
	Dummy	—	17
10	Blue mussel—"Murasakiigai"— <i>Mytilus edulis</i>	Muscle & Viscera	6
11	Short-necked clam—"Asari"— <i>Tapes philippinarum</i>	Ditto	26†
12	Blue mussel—"Murasakiinkogai"— <i>Septifer virgatus</i>	Ditto	7†
Gastropods			
	Dummy	—	—
13	Top shell—"Sazae"— <i>Batillus cornutus</i>	Muscle	2
14	Abalone—"Tokobushi"— <i>Sulculus diversicolor aquatilis</i>	Ditto	2
15	Limpet—"Matsubagai"— <i>Cellana virgatus</i>	Ditto	—
	Dummy	—	4
16	Top shell—"Sazae"— <i>Batillus cornutus</i>	Viscera	4
17	Abalone—"Tokobushi"— <i>Sulculus diversicolor aquatilis</i>	Ditto	4
18	Limpet—"Matsubagai"— <i>Cellana virgatus</i>	Ditto	2
Crustaceans			
	Dummy	—	10†
19	Barnacle—"Kamenote"— <i>Mitella mitella</i>	Muscle	35†
20	Whiskered velvet shrimp—"Akaebi"— <i>Metapenaeopsis barbata</i>	Ditto	139†
21	Krill—"Okiami"— <i>Euphausia superba</i>	Ditto	76†
	Dummy	—	24†
22	Whiskered velvet shrimp—"Akaebi"— <i>Metapenaeopsis barbata</i>	Muscle	59†
23	Whiskered velvet shrimp—"Akaebi"— <i>Metapenaeopsis barbata</i>	Viscera	56†
24	Whiskered velvet shrimp—"Akaebi"— <i>Metapenaeopsis barbata</i>	Shell	139†
Echinoids			
	Dummy	—	4
25	Purple sea urchin—"Murasakiuni"— <i>Anthocidaris crassipina</i>	Muscle & Viscera	—
26	Red sea urchin—"Akauni"— <i>Pseudocentrotus depressus</i>	Ditto	—
27	Green sea urchin—"Bafununi"— <i>Hemicentrotus pulcherrimus</i>	Ditto	—

Table 3.—(contd)

No.	Species* ¹	Food	Tissues	Attractive effect* ²
Teleosts				
	Dummy	—	—	16†
28	Flying fish—"Hontobi"— <i>Prognichtys agoo</i>	Muscle	—	78†
29	Silver whiting—"Kisu"— <i>Sillago sihama</i>	Ditto	—	34†
30	Horse mackerel—"Maaji"— <i>Trachurus japonicus</i>	Ditto	—	40†
Seaweeds				
	Dummy	—	—	7
31	Japanese pilchard—"Maiwashi"— <i>Sardinops melanosticta</i>	Muscle	—	102†
32	Chub mackerel—"Masaba"— <i>Scomber japonicus</i>	Ditto	—	20†
33	Grunt—"Isaki"— <i>Parapristipoma trilineatum</i>	Ditto	—	11†
Freshwater				
Oligochaets, Bivalves and Crustaceans				
	Dummy	—	—	1
37	Tubificid—"Itomimizu"— <i>Tubifex</i> sp.	Entire animal	—	8†
38	Freshwater mussel—"Mashijimi"— <i>Corbiculina leana</i>	Muscle & viscera	—	1†
39	Water flea—"Ohmijinko"— <i>Daphnia magna</i>	Entire animal	—	3†
Crustaceans				
	Dummy	—	—	31†
40	Sawtooth caridina—"Minaminumaebi"— <i>Caridina denticulata</i>	Entire animal	—	158†
41	Marsh crab—"Akategani"— <i>Sesarma haematocheir</i>	Muscle	—	21†
42	Water flea—"Kebukamijinko"— <i>Macrothrix hosea</i>	Entire animal	—	30†
	Dummy	—	—	8†
43	Lake prawn—"Sujiebi"— <i>Palaemon paucidens</i>	Entire animal	—	109†
44	River crab—"Sawagani"— <i>Potamon dehaani</i>	Muscle & viscera	—	26†
45	Water flea—"Kebukamijinko"— <i>Macrothrix hosea</i>	Entire animal	—	22†
(Terrestrial animals and plants)				
Animals				
	Dummy	—	—	1
46	Chicken—"Niwatori"— <i>Gallus</i> sp.	Muscle	—	11†
47	Cow—"Ushi"— <i>Bos</i> sp.	Ditto	—	2
48	Pig—"Buta"— <i>Sus</i> sp.	Ditto	—	5†
	Dummy	—	—	—
49	Chicken—"Niwatori"— <i>Gallus</i> sp.	Liver	—	—
50	Cow—"Ushi"— <i>Bos</i> sp.	Ditto	—	24†
51	Pig—"Buta"— <i>Sus</i> sp.	Ditto	—	6†
Plants				
	Dummy	—	—	22†
52	Barley—"Mugi"— <i>Hordeum vulgare</i>	Albumen	—	22†
53	Rice—"Kome"— <i>Oryza sativa</i>	Ditto	—	13†
54	Parched rice bran—"Baishokomenuka"— <i>Oryza sativa</i>	Testa	—	30†
	Dummy	—	—	6
55	Azuki bean—"Azuki"— <i>Phaseolus angularis</i>	Entire bean	—	6
56	Mottled kidney bean—"Uzura"— <i>Dolichos lablab</i>	Ditto	—	11†
57	Soy bean—"Daizu"— <i>Glycine max</i>	Ditto	—	11†

*¹ English name-Japanese name-Scientific name; *² The product of *g* and *r* in either the entering or the leaving time-courses;

*² † $\Pr(\chi^2 > \chi^2_{0.100}) > 0.100$.

Fig. 4. Relation of coefficients g and r of logistic curve in the entering and the leaving time-courses. The numbers 1 and 2 on each symbol, open and close symbols show Methods 1 and 2, and the batch of entering and leaving time-courses respectively. The coefficient g was converted into 100 individuals series.

showed, it was evaluated that the attractive effect of flying fish is high, that of silver whiting is low and of horse mackerel moderate.

Table 2 shows the fitness and the coefficients of logistic curve to the three behavioral time-courses as shown in Figs. 2 and 3. The entering and the leaving time-courses fitted fairly well to the curve, the remaining one not so. These results can be inferred from the observations mentioned above and the time-courses in Figs. 2 and 3. The attractive index could hence not be obtained from the coefficients of the curve in the remaining time-course as the similar manner to the previous papers.^{18,19)}

In this context, the attractive index was sought from the coefficients in the entering or the leaving time-course fitted. The attractive index could not be represented with one of the six coefficients, but the combination of g and r for either the entering or the leaving time-course. The results are shown in Fig. 4. As judging from Fig. 4, the product of g and r completely accorded with the general evaluation (cf. Table 1 and Table 2). The locomotive activity, the main attractive criterion of the evaluation, may be represented by the product, because g is maximum of number at sufficient long observation and r indicates the process of altering g in the present case. And gr is thought to be showed the real activity at the coefficient a (minute) as gr is obtained from $y'_{j=a} = gr/4$ which is the maximal number of y' . The content of

apparent locomotive activity is practically thought to be g in the entering or the leaving time-course. As shown in Fig. 4, however, g in the strong attractive food, for example, flying fish muscle, correlates negatively with r . The attractive effect might not hence be judged from only g .

Attractive Effect of Food

Table 3 shows the attractive effect of various kinds of food, i.e., the product of the coefficients g and r in the entering or the leaving time-course, when 80 individuals of yellowtail were used. Among the marine animals and seaweeds, polychaets, cephalopods, crustaceans and teleosts strongly provoked the exploratory and feeding behavior, but gastropods and echinoids elicited almost no attractive effect. Bivalves and seaweeds were found to be only weakly effective. Among the freshwater and terrestrial animals and plants only two species inhabiting in freshwater, sawtooth caridina and lake prawn were found to be as effective as a food attractants as polychaets, cephalopods, crustaceans and teleosts.

There are two behavioral studies on the attractive effect of food on yellowtail. KANEDA *et al.*⁴⁾ have revealed that the chum prepared, using squid mid-gut gland oil, apparently enables fishermen to catch a greater amount of fish at a low cost than the chum not containing the oil. Three kinds of mid-gut gland of cephalopods shown in Table 3 were found to be effective in attracting in a striking contrast with their muscle. These findings may show the possibility that the squid oil plays an important role in the exploratory and feeding behavior of yellowtail. TAKEI⁵⁾ examined the preference effect of marine fish and other organisms. Among the fish examined, the macerated muscle of horse mackerel and chub mackerel were found to be preferred. In my study, as shown in Table 3, horse mackerel was fairly effective in attracting and chub mackerel weakly effective.

Polychaets and crustaceans are widely used at home and abroad as live or dead prey for fishing. All the examined species belonging to these classes were favorite food for yellowtail. It is especially very interesting to note that the shell of whiskered velvet shrimp is effectual in attracting yellowtail. It should be also noted that sawtooth caridina and lake prawn inhabiting in freshwater are also attractants. In Japan these prawn are said to be quite efficient for attracting marine fish. Live or dead organisms will not be as effective chemically as the macerated tissue. Amine isolated from the water that bathed trouts, however, attracts sea

lamprey.¹⁰⁾ In this context, there will be co-substances in attracting between live or dead prey and macerated tissue or organisms.

Gastropods and echinoids might be effective in repelling yellowtail rather than in attracting them because the fish did not enter the test compartment, and gathered around the outlet of the test aquarium when these animals were used as food.

Acknowledgements

The author is very grateful to Dr. H. MAÉDA, Dept. Fish. Sci. Technol., Shimonoseki Univ. Fish., for his help in the calculation of logistic curve and his valuable advices, and Drs T. TAKAI, A. TSURUTA, Z. KUBOTA, M. AMIO, O. TABETA, and K. HAYASHI, Dept. Biol. Aquacul., Shimonoseki Univ. Fish., for the identification of species.

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