The Attractive Effect of Seaweeds Based on the Behavioral Responses of Young Herbivorous Abalone *Haliotis discus**1,2

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It has been clarified that the attractive effect of seaweeds on young herbivorous abalone could be presented as the coefficient a of a logistic curve, $y=g/(1+\exp[-r(j-a)])$ in the time-course of abalone that remained in the test compartment. The attractive effect of three phyla of seaweeds was examined on the basis of behavioral responses of abalone. Among six specimens tested in the green algae, *Chaetomorpha spiralis*-“Hosojuzumo” in Japanese, *Ulva pertusa*-“Anaaosa” and *Caulerpa okamura*-“Fusaiwazuta” were found to be effective in attracting abalone. Among twelve specimens in the brown algae, strong attractants were *Sargassum hemiphyllum*-“Isomoku”, *Pachydictyon coriaceum*-“Sanadagusa”, *Ishige okamura*-“Ishige” and *Padina arborescens*-“Umiuchiwa”. Amongst fourteen specimens in the red algae, only two species, *Gelidium amansii*-“Makusa” and *Gelidium divaricatum*-“Himetengusa” provoked exploratory and feeding behavior.

Gastropods have been acknowledged to possess an acute sense of smell. This reputation is based partly on anecdote and partly on their prominent olfactory system.¹⁾ Behavioral studies have demonstrated that osphradium in gastropod plays an important role as a smell or distant chemoreception in extirpation or cauterization.²⁻⁵⁾

VAN DONGEN,⁶⁾ employing pulmonate *Littorina obtusata* in a series of food preference experiments, showed the role of smell or distant chemoreception in the herbivorous gastropod. In the Hawaiian sea-hare *Aplysia juliana* feeding exclusively on green larver *Ulva lactuca*, FRINGS *et al.*⁷⁾ reported that the herbivorous sea-hare was oriented toward both the algae and the seawater in which *Ulva* was kept for a few minutes. Smell or distant chemoreception appears to have been demonstrated in the herbivorous pulmonate *Australorbis glabratus*.⁴⁾ The importance of olfaction in the feeding behavior of herbivorous abalone *Haliotis* spp. may also be considered.⁸⁻¹¹⁾ In contrast, BOVBJERK¹²⁾ pointed out that taste or contact chemoreception is of significance rather than smell or distant chemoreception in the herbivorous pulmonate *Stagnicola reflexa* which will feed on various algae, but exhibit a marked preference for *Spirogyra*.

Gastropods are strongly attracted by amino acids^{13, 14)} and protein.¹⁵⁾ Oyster drill *Urosalpinx*

cinerea gives a positive response to oxaloacetic acid.¹⁶⁾ BROWN¹⁷⁾ has shown that sandybeach snail *Bullia digitalis* and *Bullia laevissima* are particularly sensitive to trimethylamine at concentrations as low as 0.00001%. Tetramethylammonium hydroxide is also highly attractive, as are certain betaines. Other substances, propionic acid,¹⁸⁾ and starch and glycogen¹⁹⁾ are effective in attracting gastropod.

The present paper describes the attractive effect of various seaweeds from different phyla on young herbivorous abalone in order to determine whether these seaweeds would have the attractive properties.

Materials and Methods

One hundred specimens of young abalone of 2.4 cm in average shell length were kindly supplied by Mr. Y. YURANO, Yamaguchi Prefecture Gaikai Fisheries Experiment Station. These abalones had been fed on three seaweeds *Ulva pertusa*, *Ecklonia cava* and *Eisenia bicyclis* in the Station. They were transported to the depot aquarium. Being used to an experiment, definite number of abalone was taken from the aquarium and re-transported to the experimental aquarium shown in Fig. 1. The abalone in both the aquaria were fed at the intervals of four days with green larver *Ulva pertusa* or the commercial feeding stuff manufactured in

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Hayashikane Sangyo Co.. Seawater was introduced continuously into the experimental aquarium through each inlet of delivery tube I at the rate of 150 ml per minute. In this case, when methylene blue was placed at S in the test compartment A,

Fig. 1. An experimental aquarium.

the dye reached to the edge of the compartment for about two minutes.

The attractive effect of seaweeds were examined by the following method. A 1.5 g algae cut finely as test material was wrapped in a double gauze (5×5 cm) and placed at S in the compartment A. A double gauze with no test material within was used as a dummy. The experiments were carried out twice a day at 10:00 and 15:00 in a similar manner with the Latin Square method. Each batch of abalone which entered A from C, left A and remained in A, after three test materials and a dummy were placed at each S and a perforated screen P was immediately lifted, was counted for twenty minutes at two minutes intervals. Four numbers counted every two minutes in each behavior of each test material were summed up. The number summed was successively integrated with

Table 1. General evaluation of the three kinds of seaweeds as shell attractants through the observations of exploratory and feeding

Seaweeds*	Behavior		General evaluation
	Remaining time	Exploratory and feeding	
Dummy	Medium	None	None
<i>Undaria pinnatifida</i> -“Wakame”	Long	Weak	Low
<i>Hijikia fusiforme</i> -“Hijiki”	Long	Strong and ceaseless	Moderate
<i>Ulva pertusa</i> -“Anaososa”	Long	Strong and ceaseless	High

* Scientific name-Japanese name.

Fig. 2. Time-course of the number of young abalone respondent to food in using 20, 50 and 100 individuals.

Circle, triangle and square indicate the number of abalone that entered, left and remained in the test compartment respectively.

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

Individuals used	$Y_{i,j}$	Method	Dummy						"Wakame"						"Hijiki"						"Anaosa"					
			g	r	a	x^2	$d.f.$	g	r	a	x^2	$d.f.$	g	r	a	x^2	$d.f.$	g	r	a	x^2	$d.f.$				
20	$Y_{1,j}$	2	14	0.5	1.8	5.5*	6	8	0.9	3.3	1.6*	5	18	0.3	4.7	2.9*	6	11	0.8	4.9	1.7*	4				
	$Y_{2,j}$	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
	$Y_{3,j}$	2	9	0.7	0.4	7.4*	6	5	1.1	2.3	0.4*	1	12	0.5	2.6	2.3*	6	7	0.9	3.9	1.3*	3				
50	$Y_{1,j}$	2	23	0.8	4.5	2.2*	5	27	0.6	4.3	2.9*	6	23	1.2	3.9	6.6*	5	23	0.6	4.7	1.4*	6				
	$Y_{2,j}$	2	9	1.8	5.2	0.7*	2	6	0.7	4.8	0.7*	2	9	0.5	4.7	0.4*	4	6	0.7	4.2	0.3*	3				
	$Y_{3,j}$	2	13	0.9	3.3	1.7*	5	22	0.6	4.1	3.8*	6	17	1.2	4.3	4.4*	4	18	0.5	4.9	0.5*	5				
100	$Y_{1,j}$	2	30	0.8	4.3	2.7*	6	29	0.5	2.6	4.5*	6	32	0.6	6.0	1.0*	5	35	0.7	5.9	3.7*	5				
	$Y_{2,j}$	2	16	0.7	5.9	5.0*	2	8	0.6	6.2	2.2*	4	—	—	—	—	—	42	0.4	12.2	2.9*	2				
	$Y_{3,j}$	2	15	1.1	3.3	1.5*	6	20	0.5	3.9	3.6*	5	13	1.2	4.1	1.9*	4	22	0.9	5.8	3.5*	4				

* $Pr(x^2 > x^2_{0.100}) > 0.100$; $y = g/(1 + \exp[-r(U - a)])$, where $Y_{i,j}$, $Y_{2,j}$ and $Y_{3,j}$ show the number of abalone which entered, left and remained in the test compartment respectively $j=1$ to j (two minutes interval) after the start of experiment. r , ... estimated from the coefficient of the regression of reciprocal of $Y_{i,j}$ on reciprocal of $Y_{i,j(j-1)}$, a and g , ... estimated from the coefficient and constant of the regression line of reciprocal of $Y_{i,j}$ on $\exp[-rj]$, Method 2 ... estimated from the relation between $1/Y_{i,j}$ and $1/Y_{i,j(j-1)}$ ($j=1$ to 10) (weight by j). The coefficient a multiplied by two makes real value of a .

time. The number which was subtracted number during two minutes from number during each minute was used as the data of time-courses. The majority of seaweeds were used immediately after being gathered, with a few algae being collected and kept at -80°C . Fifty individuals of abalone were most frequently used and otherwise stated.

Results and Discussion

Decision Method for Attractive Effect

In order to get an index for the attractive effect of seaweeds, the observations of each behavior and its time-course were done with different individuals of abalone, 20, 50 and 100 individuals, according to the previous paper.²⁰⁾ The test materials used were three kinds of algae, *Undaria pinatifida*-“Wakame” in Japanese, *Hijikia fusiforme*-“Hijiki” and *Ulva pertusa*-“Anaaosa” which are the preferable food of abalone. The results of the observations and the time-course are shown in Table 1 and Fig. 2 respectively. Table 1 presents the general evaluation: the attractive effect of “Anaaosa” is high, that of “Hijiki” is moderate and of “Wakame” low.

The fitness and the coefficient of a logistic curve in the time-course for each behavior are shown in Table 2. The time-course for both the entering and the remaining abalone fitted to the curve. The coefficient a of the curve in the remaining abalone adequately accorded with the evaluation shown in Table 1, that is, this coefficient a can be used as a single index for the attractive effect. This holds for the decision method of the attractive effect in the oriental weatherfish *Misgurnus anguillicaudatus*.²⁰⁾ In contrast, as 85% of the remaining time-course in using yellowtail *Seriola quinqueradiata* did not fit the logistic curve, the coefficient a could not be used as an index for the attractive effect.²¹⁾ This difference may be to the locomotive activity of the aquatic animals used. Because yellowtail was by far the most active in locomotion amongst these three aquatic animals, whereas oriental weather fish and abalone were not so active on the basis of observations.

Attractive Effect of Seaweeds

Table 3 shows the attractive effect of 32 species comprised of six green, twelve brown and fourteen red algae, i.e., the value of coefficient a in the time-course of remaining abalone. The attraction was high in two green algae *Chaetomorpha crassa*-“Hosojuzumo” and *Caulerpa okamura*-“Fusai-

Table 3. The attractive effect of various kinds of seaweeds on young abalone

No.	Seaweeds* ¹	Attractive effect* ²
(Green algae)		
	Dummy	6.1
1	<i>Ulva congrobata</i> -“Botanaosa”	3.3
2	<i>Enteromorpha intestinalis</i> -“Bouaonori”	6.2
3	<i>Chaetomorpha crassa</i> -“Hosogyuzumo”	11.4
	Dummy	6.3
4	<i>Codium fragile</i> -“Miru”	7.2
5	<i>Bryopsis plumosa</i> -“Hanemo”	4.9
6	<i>Caulerpa okamurai</i> -“Fusaiwazuta”	12.3
(Brown algae)		
	Dummy	9.1
7	<i>Sargassum horneri</i> -“Akamoku”	5.1
8	<i>Sargassum hemiphylum</i> -“Isomoku”	13.9
9	<i>Sargassum serratifolium</i> -“Nokogirimoku”	8.4
	Dummy	6.0
10	<i>Sargassum muticum</i> -“Tamahahakimoku”	5.4
11	<i>Sargassum thunbergii</i> -“Umitoranoo”	5.8
12	<i>Sargassum patens</i> -“Yatsumatamoku”	7.5
	Dummy	5.2
13	<i>Pachydictyon cariaceum</i> -“Sanadagusa”	11.2
14	<i>Colpomenia sinuosa</i> -“Fukuronori”	5.2
15	<i>Scytosiphon lomentaria</i> -“Kayamonori”	7.9
	Dummy	4.8
16	<i>Ishige okamurai</i> -“Ishige”	11.4
17	<i>Padina arborescens</i> -“Umiuchiwa”	13.9
18	<i>Dictyopteris undulata</i> -“Shiwayahazu”	5.4
(Red algae)		
	Dummy	5.4
19	<i>Schizymenia dubyi</i> -“Benisunago”	5.8
20	<i>Grateloupia filicina</i> -“Mukadenori”	7.2
21	<i>Gelidium amansii</i> -“Makusa”	15.8
	Dummy	6.4
22	<i>Chondrus ocellatus</i> -“Tsunomata”	6.7
23	<i>Grateloupia turturu</i> -“Tsurutsuru”	8.3
24	<i>Grateloupia filicina</i> -“Mukadenori”	7.1
	Dummy	8.6
25	<i>Garpopeltis affinis</i> -“Matsunori”	5.9
26	<i>Laurencia okamurai</i> -“Mitsudesozo”	6.2
27	<i>Plocamium telfairiae</i> -“Yukari”	6.2
	Dummy	4.6
28	<i>Champia parvula</i> -“Watsunagisou”	5.9
29	<i>Gelidium divaricatum</i> -“Himetengusa”	10.3
30	<i>Hypnea charoides</i> -“Ibaranori”	7.6
	Dummy	9.2
31	<i>Polysiphonia</i> sp.-“Itogusa”	6.6
32	<i>Centroceras clavulatum</i> -“Togeigisu”* ³	3.5
33	<i>Gracilaria verrucosa</i> -“Ogonori”	8.3

*¹ Scientific name-Japanese name.*² The coefficient *a* of logistic curve in the time-course of abalone that remained in the test compartment.*³ Contained a small amount of *Polysiphonia urceolata* and *Symphocladia marchantioides*.

wazuta”, four brown algae *Sargassum hemiphylum*-“Isomoku”, *Pachydictyon coriaceum*-“Sanadagusa”, *Ishige okamurai*-“Ishige” and *Padina arborescens*-“Umiuchiwa”, and two red algae *Gelidium amansii*-“Makusa” and *Gelidium divaricatum*-“Himetengusa”. Brown algae were inclined to be generally effective in attracting abalone.

There is no literature which is examined on the attractive effect of seaweeds on herbivorous abalone *Haliotis discus* and its akin species. The stomach contents and the seaweeds choice of abalone, however, were investigated by many Japanese researchers.^{8-11, 22, 23)} These studies show the fact that the feeding habits of abalone are mainly brown algae. Possibly this fact could be applied to the results that brown algae are more attractive than green and red algae, as shown in Table 3. KIKUCHI *et al.*¹⁰⁾ suggests that the choice of food in abalone depends on preferable or repellent substance in seaweeds. In contrast, foreign abalone *Haliotis* spp. feed mainly on red algae.^{24, 25)} The difference in the feeding habits between Japanese and foreign abalone is of much interested in chemoreception on the ecology and the physiology of these abalone.

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