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by

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Variation in prey size selectivity of fingerling chum salmon (*Oncorhynchus keta*) in sea life: effects of stomach fullness and prey abundance

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ABSTRACT

Prey size selection by fingerling chum salmon (*Oncorhynchus keta*) was studied with respect to variations related to the stomach fullness of fish and prey abundance in the coastal waters of the Japan Sea off northern Honshu, Japan. Fingerlings mainly fed on zooplankton, and their diets consisted of two size groups of major prey taxa. Fingerlings showed two behavioral patterns: selective foraging for the larger prey and non-selective foraging. The effects of prey abundance on the selectivity of fish were different between the size groups. Fingerlings intensified foraging selectively with a increase in the abundance of the larger prey. On the contrary, the abundance of the small prey did not influence the prey size selectivity. The stomach fullness of fish was also positively correlated with the prey size selectivity. Since the abundance of the larger prey and the stomach fullness of fish varied independently each other, both of which are considered to be an important factor affecting the prey size selection and diet composition of fingerling chum salmon in sea life.

INTRODUCTION

Change in prey selectivity of predators in relation to status of prey and (or) predator are well known in various taxa of animal (see Stephens and Krebs 1986). For teleost fish, prey selection has been studied intensively on visual and particulate feeders, which feed on planktonic or epibenthic prey one at a time or no more than a few at a time (see Durbin 1979, Ringer 1979a, Sahara 1987, Gerking 1994). The previous studies pointed out factors affecting prey selection, such as size and abundance of prey (e.g., Ivlev 1965, Werner and Hall 1974, O'Brien et al. 1976) and size (or developmental stage) and stomach fullness of fish (e.g., Ivlev 1965, Hart and Ison 1991, Hart and Gill 1992).

Salmonids are recognized as a visual and particulate feeder (see Gerking 1994), and juvenile chum salmon (*Oncorhynchus keta*) feeds on zooplankton in their sea life (Salo 1991, Higgs et al. 1995) . Juvenile chum salmon fed opportunistically for prey species (LeBrasseur 1966, Peterson et al. 1982, Brodeur and Pearcy 1990), but fed selectively for a larger prey (LeBrasseur 1969, Bailey et al. 1975, Healey 1980; 1991, Simenstad and Salo 1982, Cordell 1986). On the other hand, the temporal and geographical variations in the size of dominant prey were observed on juvenile chum salmon (Manzar 1969, Kaeriyama 1986). From these reports, it is suggested that the prey size selectivity of juvenile chum salmon would also be variable. Nevertheless, little information is available on variation in the prey size selection by juvenile chum salmon, except for the change with development from the fry stage to the fingerling stage (Suzuki et al. 1994).

Fingerling chum salmon inhibits in the coastal waters of the Japan Sea off northern Honshu, where they feed on zooplankton and fish larvae (Irie 1990).

This paper examines variations in prey size selection of fingerling chum salmon with respect to their stomach fullness and prey abundance from field observation.

MATERIALS AND METHODS

Study area

This study was conducted in the Japan Sea coast off Fukura, northern Honshu, Japan, during March and May in 1993-1995 (Fig. 1). Six stations were located along a southeast-to-northwest trancect in the area in 1993. The distances from the shore line to each station ranged from 1 km to 10 km. In 1994 and 1995, five stations (2-20 km offshore) were located on the trancect. The depth at the staions ranged from 12 m to 120 m. Temperature and salinity of surface water measured at each stations showed 8.5-14.3℃ and 18.5-34.1 in the sampling period in 3 years.

Juvenile chum salmon

Juvenile chum salmon were collected with a surface tow net. The net was 8 m wide and 4 m deep at the mouth and equipped with 25-34 mm (stretched) mesh in the body and 7.5 mm mesh in the cod end. The net was towed parallel to the shore line with the speed of 4 km per hour. The net was towed in thirty minutes at each station in 1993. Three sets of 15 minutes towing in a station were carried out in 1994 and 1995. Most collections were made in the morning. Catches were anaesthetized in MS-222 and preserved in buffered 10% formalin-seawater solution on aboard, following which samples were transferred to 70% ethanol solution in

1994 and 1995.

Fishes were sorted to the species level and measured fork length and wet weight (nearest 0.1 mm and 0.01 g, respectively). We used the data of juvenile chum salmon larger than 50 mm fork length, at which chum salmon change their developmental stage from fry to fingerling (Kaeriyama 1986). Chum salmon developed to the young stage, larger than 120 mm fork length, was not caught in this study.

Zooplankton

Zooplankton samples were collected using a Norpac net (0.45 m diameter, 0.33 mm mesh size) in 2 times (before and after the fish collection) in 1993 and 3 times (after fish collection) in 1994 and 1995 at each staion. The Norpac net was towed vertically from 20 m to the surface. At the stations where depth was less than 20 m, the net was towed from the bottom. Filtered water volume was measured using a flow meter (Rigosha Co. Ltd., Japan). The samples were fixed in 10% buffered formalin-seawater solution.

Zooplankton samples were sorted to the taxonomic level and life history stage as lower as possible, and the number of each taxa was recorded. Zooplankton composition was indicated by percent number. Abundance of zooplankton was defined as density per cubic meter. The composition and abundance of zooplankton at each station were expressed as the mean value of the sets within a staion. Body length and body width of zooplankton were measured to the nearest 0.01 mm on a random sample of 50 individuals in each taxon. Assuming that the form of zooplankton was a cylinder, we caluculate a volume of zooplankton as a size index of each taxon.

We estimated a food environment of fingerlings from zooplankton collections in the daytime. However, juvenile salmon started feeding from dawn (Bailey et al 1975, Godin 1981, Kaeriyama 1986) and diel vertical migration of zooplankton is common in general (see Raymont 1983), suggesting that the food environment would change in temporal. Thus, to compare abundance of prey between dawn and day, we collected zooplankton in dawn at some stations in 1995. The abundance of two prey groups (described in the next section) did not differ significantly in temporal except for a single case (table 1), suggesting that our estimation is reliable in this study.

Diet analyses

Stomach contents were analyzed for the maximum of 30 specimens in each station. Obrebski and Sibert (1977) suggested that the full range of dietary organisms is usually found in a sample of 30.

Stomachs were opened and the entire contents were weighted (wet weight) to the nearest 1 mg. A relative stomach weight (SCI) was used for an index of the stomach fullness of fingerlings:

$SCI=100xSCW/(BW-SCW)$;

where SCW and BW are the weight of stomach contents and fish body weight, respectively.

Food items were identified to the lowest possible taxonomic level and life history stage, and the number of each taxa was recorded. Diet compositions were expressed as percent number by each station. A prey taxon contributed more than 5% to the diet composition in a station were used for the following analysis. However, fish larvae and a amphipod, *Themisto japonica*, were omitted, because they did not collected by the Norpac net. Accordingly, we excluded three stations where fish larvae and *Themisto japonica* were dominated (>50%) in the diet composition.

Prey taxa were divided into two size groups according to their mean sizes (Fig .2). The smaller taxa, such as *Evadne nordmanni*, *Podon leuckarti*, euphausiid calyptopis larvae, and *Oikopleura* spp., are called *small prey*. The larger taxa, such as euphausiid furcilia larvae, polychaetes, *Calanus sinicus*, and *Neocalanus plumchrus* copepodid V stage (*Neocalanus plumchrus* CV, as follows) are said to be *large prey*.

Selectivity for the prey groups by fingerlings was measured by the rank preference index (Johnson 1980) in each station. Following this method, we can compare difference in selectivity among food items without influence of inclusion or exclusion of a specific food item.

RESULTS

Prey size selection

Fingerling chum salmon showed two behavioral patterns, such as selective foraging for a larger prey and non-selective foraging. The large prey was ranked higher in selectivity than the small prey in 17 of the total stations (Table 2). On the other hand, the ranks of selectivity were tie or not significantly different ($F_{1,2}=2.00$, $p=0.293$) between the prey groups in other 7 stations. These variations in the prey size selectivity of fingerlings did not depend on relative abundance of prey, because the ranks of the small prey in zooplankton composition were consistently higher than that of the large prey.

In the following analyses, the rank of selectivity for the small prey was used for an index of prey size selectivity of fingerlings, since this rank of the large prey was constant as rank 1 among stations; the rank 1 and the rank 2 indicated non-selective and selective foraging, respectively.

Factors affecting the prey size selection

We used three factors, such as the abundance of the large prey, that of the small prey, and the stomach fullness of fingerlings (SCI) to evaluate effects on the variation in the prey size selectivity of fingerling chum salmon. These three factors were varied independently one another in this study (table 2). A significant positive relationship between the rank of selectivity for the small prey and the abundance of the large prey indicated that fingerling chum salmon intensified foraging selectively with a increase in the availability of the large prey (r_s=0.616, p<0.001, Fig. 3). On the contrary, the abundance of the small prey did not relate to the variation in the selectivity of the small prey (r_s=-0.331, p>0.05, Fig. 4). The SCI was positively correlated with the rank of selectivity for the smaller prey (r_s=0.556, p<0.01, Fig. 5), showing a tendency that fingerling got to foraging selectively as they became satiation.

DISCUSSION

Estimation of prey abundance

We assumed that fingerling chum salmon inhibit in near-surface waters shallower than 20 m in depth. There has been little research directed at determining vertical distribution of juvenile salmon at sea. However, Burgner (1991) concluded that salmon generally occur in near-surface waters by reviewing information from research and from the operation of commercial high-seas salmon fisheries. For chum salmon, young and adult fish mostly swam above 20-24 m layer in the north Pacific Ocean from spring to autumn (Manzer 1964, Machidori 1967, French et al. 1971, Ogura and Ishida 1995).

The prey abundance was not significantly different between dawn and day in most stations. This result would be supported by the following studies on the diel vertical distribution of major prey taxa in this study. Euphausiid calyputopis larvae did not show diel vertical migration (Iguti 1995). *Evadne nordmanni* and *Podon leuckarti* inhibited in near-surface water trough a day (Onbe 1974). This distribution pattern was also observed on *Neocalanus plumchrus* CV in spring season (Fulton 1973, Taka et al. 1982). *Calanus sincus* and euphausiid furcilia larvae migrated down below the range of our zooplankton sampling, but they descended to a day habitat before dawn (Hirakawa et al. 1990, Uye et al. 1990, Taki et al. 1996). For *Oikopleura* spp., there is little information on diel vertical migration, however, Shiga (1985) reported that their vertical distribution were governed by hydrographic condition and that they inhibited homogeneously when water column was vertically mixed. Since the water column had not stratified yet throughout this study period (Suzuki and Fukuwaka, unpublished data), the vertical distribution *Oikopleura* spp. would not change greatly within a day.

Factors affecting to prey size selectivity

Fingerling chum salmon showed two behavioral patterns: selective foraging for the large prey and non-selective foraging. Selection for a larger prey has been observed in various fishes of particulate planktivore, including chum salmon (see Sahara 1987, Salo 1991, Gerking 1994, Higgs et al. 1995). Size is recognized as one of the most important characters of prey affecting prey selection of particulate planktivore fish (Kislarioglu and Gibson 1976) . It is considered that selection for a larger prey is attributed to it's higher visibility (Ware 1972, Confer and Blades 1975) and a higher rate of energy intake for fish (Werner and Hall 1974, Ringler 1979b).

Indices for measurment of foraging selectivity, in general, can change depending on the relative number of food items in the environment and on that in diet. A change in selectivity for a prey with it's relative number in the environment was stated as 'switching' by Murdoch (1969). In this study, the small prey was consistently abundant than the large prey. Consequently, the observed variation in prey size selection of fingerling chum salmon dose not imply the switching, but resulted from the variation in diet composition. The selective foraging for the large prey was due to their dominance in the diets. Fingerlings got to forage selectively for the large prey with a increase in abandance of the large prey, but irrespective of that of the small prey. This result reflects a foraging behaviour of particulate planktivore fishes, that is, frequency of predation on a smaller prey was higher where a large prey was relatively rare and did not depend on the abundance of a small prey itself (Sunaga 1970; 1971, Eggers 1982).

Selective foraging was indicated by fingerling chum salmon that contained relatively large amount of food in stomaches. Ivlev (1965), Hart and Ison (1991) and Hart and Gill (1992) examined an effect of stomach fullness on prey selection of particulate feeding fishes by observing their foraging behaviour directly until fish reach satiation. They demonstrated that as fish approached satiation, they became highly selective and ate only their favorite prey. Although we could not clarify the level of hunger when the fingerlings started feeding in a day, the previous studies suggest that stomach contents of fish fed relatively large amount of food would consist with a preferred prey in higher proportion.

Sahara (1987) suggested that change in prey selection with prey abundance may only refrect the change with fish stomach fullness, since he speculated that the best index that fish can use to evaluate prey abundance would be their stomach fullness and that feeding intensity would relate positively to prey availability in general. Contrary to this hypothesis, we demonstrated that prey abundance and stomach fullness affect independently on prey selection, which result consistents with the experimental study by Hart and Ison (1991).

Although we could not clarify a ecological and physiological background of the variation in prey size selectivity of fingerling chum salmon from this empirical study, some quantitative experiments have succeeded in explaining the prey selection of particulate planktivore fishes functionally or causally (e.g., Wener and Hall 1974, O'Brien et al 1976, Ringler 1979b, Hart and Gill 1992). Such a study is needed in a further understanding of prey selection of fingerling chum salmon.

CONCLUSION

The present study indicated that the prey size selectivity of fingerling chum salmon in sea life is variable. We pointed out both extrinsic and intrinsic factors, such as abundance of a larger prey and stomach fullness of fish as an important factor affecting the variation. These two factors were positively related to the selectivity for a larger prey.

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Table 1. Comparisons between abundance of prey (average±s.e., N=3) collected in dawn and that collected in day at each stations by one-way ANOVA. The values of abundance were transformed to logarithm.

Date	Station[a]	Large prey			Small prey		
		Dawn	Day	*p*	Dawn	Day	*p*
1995.4.12	10	4.13±0.17	3.27±0.26	*	6.05±0.21	5.94±0.29	NS
1995.4.28	10	2.36±0.47	3.34±0.12	NS	5.58±0.60	6.59±0.36	NS
1995.4.28	20	4.65±1.22	6.04±1.15	NS	7.38±1.05	5.84±0.61	NS
1995.5. 9	10	2.00±0.34	1.14±0.29	NS	6.73±0.23	6.75±0.41	NS
1995.5.10	20	1.95±0.09	2.50±0.39	NS	6.07±0.29	6.74±0.26	NS

a: The numbers indicate distance (km) from the shore to the stations.
*: $p<0.05$, NS: $p>=0.05$

Table 2. Ranks of the large prey (LP) and the small prey (SP) in the zooplanktor compositions (percent by number), in the diet compositions (percent by number) and in selectivity of fingerling chum salmon in each sampling station.

Year	Date		Station[a]	Zooplankton composition		Diet composition[b]		Selectivity[c]		N[d]
				LP	SP	LP	SP	LP	SP	
1993	Apr.	28	1	2	1	1.4	1.6	1	2	7
1993	Apr.	28	2	2	1	1.0	2.0	1	2	28
1993	Apr.	28	4	2	1	1.0	2.0	1	2	4
1993	Apr.	28	8	2	1	1.0	2.0	1	2	30
1993	May	18	2	2	1	2.0	1.0	1	1	3
1993	May	18	6	2	1	2.0	1.0	1	1	3
1994	Mar.	22	2	2	1	2.0	1.0	1	1	3
1994	Apr.	7	2	2	1	1.8	1.2	1	2	28
1994	Apr.	7	5	2	1	1.0	2.0	1	2	4
1994	Apr.	21	2	2	1	2.0	1.0	1	1	15
1994	Apr.	21	5	2	1	2.0	1.0	1	1	15
1994	Apr.	21	10	2	1	1.8	1.2	1	2	26
1994	Apr.	21	15	2	1	1.0	2.0	1	2	6
1994	Apr.	21	20	2	1	1.0	2.0	1	2	5
1995	Apr.	12	2	2	1	1.0	2.0	1	2	12
1995	Apr.	12	10	2	1	1.0	2.0	1	2	2
1995	Apr.	28	2	2	1	1.0	2.0	1	2	22
1995	Apr.	28	10	2	1	1.3	1.8	1	2	4
1995	Apr.	29	15	2	1	2.0	1.0	1	1	3
1995	May	9	10	2	1	1.5	1.5	1*	2*	2
1995	May	9	15	2	1	1.0	2.0	1	2	11
1995	May	9	20	2	1	1.0	2.0	1	2	30
1995	May	10	2	2	1	1.1	1.9	1	2	8
1995	May	10	5	2	1	1.1	1.9	1	2	27

a: The numbers indicate distance (km) from the shore to the stations.
b: The rank of prey item is indicated by mean value of fingerlings in each station.
c: The rank of selectivity is indicated by the rank preference index (Johnson 1980).
d: The number of fish examined in each station.
*: Ranks are not significantly different using ANOVA ($p>=0.05$).

Table 3. Relationship between the abundance of the large prey (LP), that of the small prey(SP), and the satiation level (SCI) of fingerling chum salmon among the sampling stations (n=24). The abundances of prey were transformed to logarithm.

Variables		*r*	*p*
LP	SP	-0.083	0.702
LP	SCI	0.150	0.485
SP	SCI	0.248	0.243

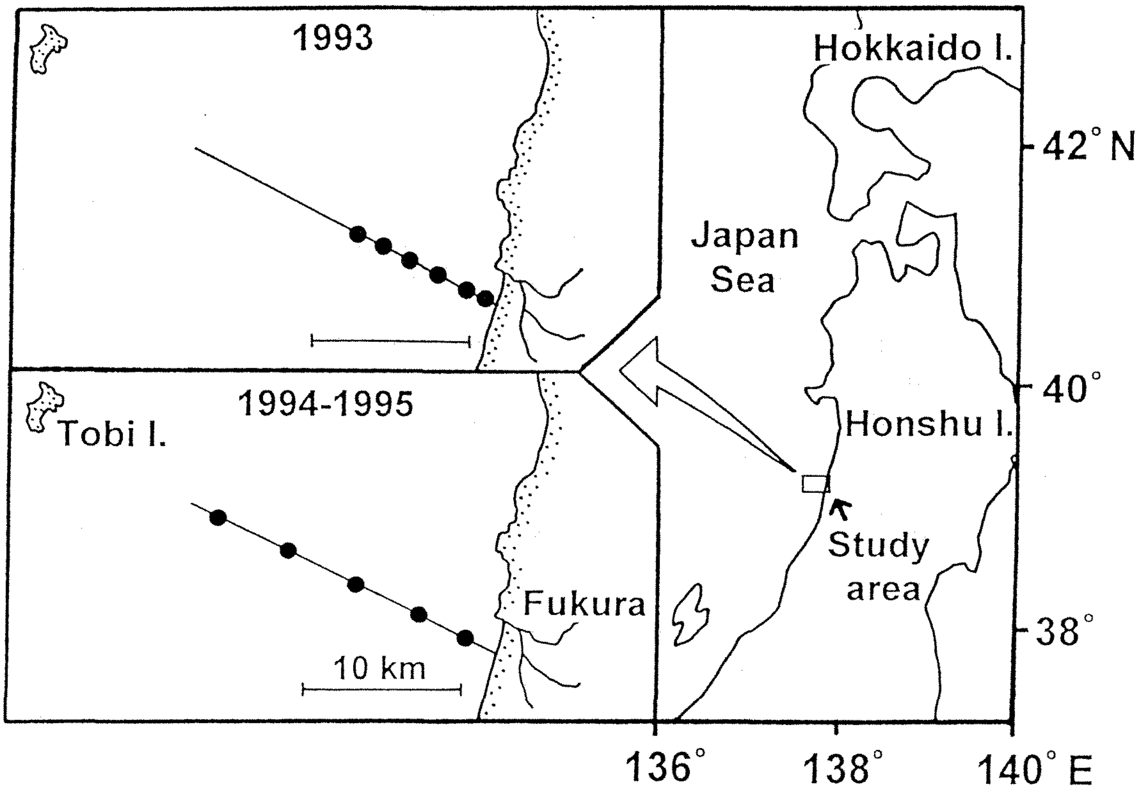

Fig. 1. Location of the study area and the sampling stations (dots) in 1993 and 1994-1995 in coastal water of the Japan Sea off Fukura, Japan.

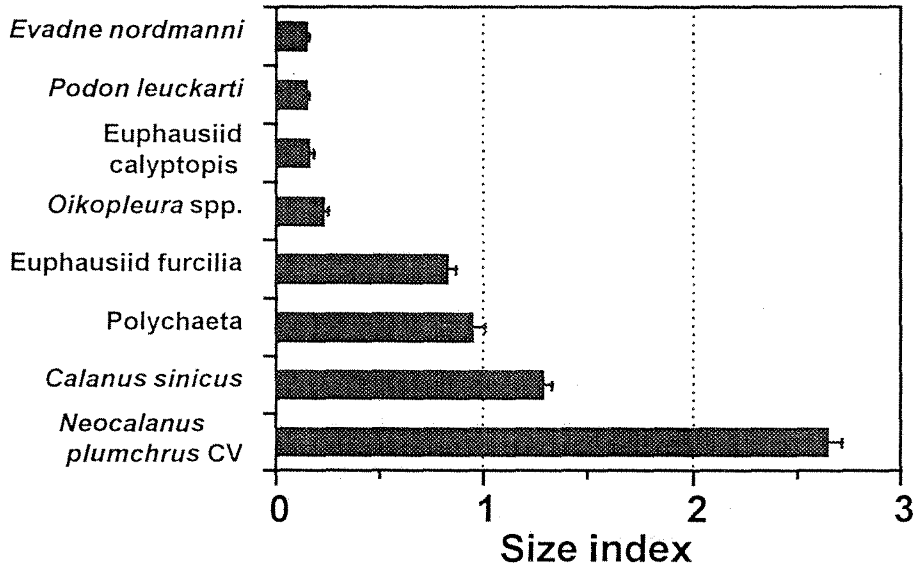

Fig. 2. Average body size of major prey taxa of fingerling chum salmon. The horizontal lines indicate standard errors. The size index is indicated as volume of prey, whose shape is assumed to be a cylinder.

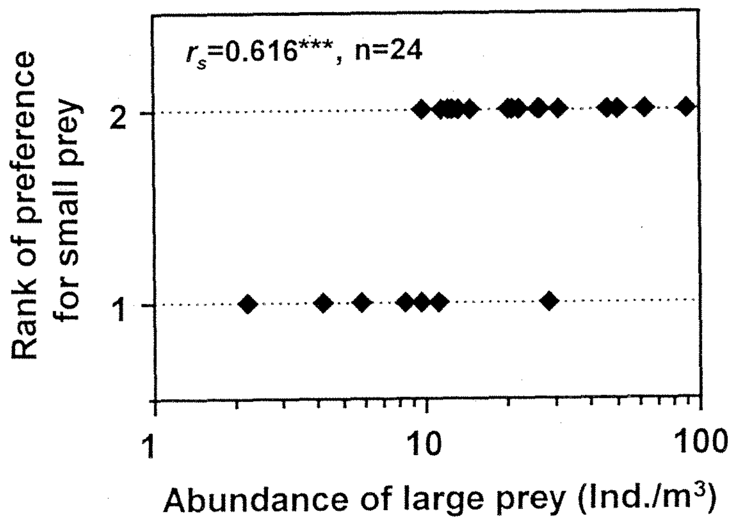

Fig. 3. Relationship between abundance of the large prey and the rank preference index of the small prey. r_s indicates a Spearman's rank correlation coefficient. ***: $p<0.001$.

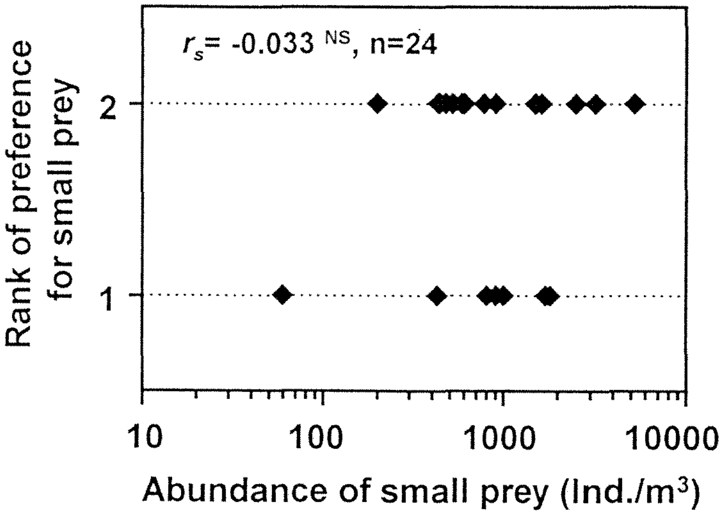

Fig. 4. Relationship between abundance of the small prey and the rank preference index of the small prey. r_s indicates a Spearman's rank correlation coefficient. NS: p>=0.05.

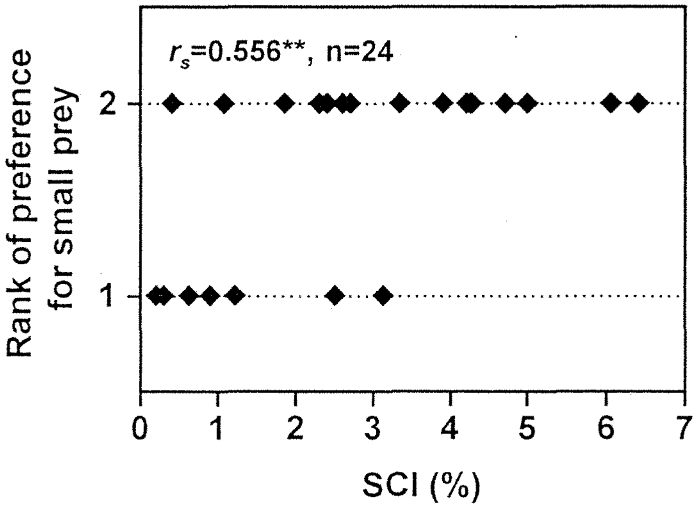

Fig. 5. Relationship between satiation level of fingerling chum salmon and the rank preference index of the small prey. The satiation level is indicated by SCI (relative weight of stomach contents per body weight). r_s indicates a Spearman's rank correlation coefficient. **: p<0.01.