九州西部平戸島近海におけるヒラメ稚仔の餌料要求とプランクトンの分布様式

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Food Requirement of the Flounder Larvae and Possible Distribution Pattern of the Prey Organisms in the Waters Adjacent to Hirado Island, Kyushu

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A comparison between the food requirement and the turn over rate of stomach full of the larval flounder, *Paralichhtys olivaceus* (TEMMININCK et SCHLEGEL), known as "Hirame" in Japanese, showed that the larvae with vacant stomachs are actually famished in a natural environment. It was deduced from the capability of searching food and feeding success of the larva, that the mean density of prey organisms is too low to fulfill the food demand during 50 days after hatching. Neverthless some of the larvae manage to get enough food. This would mean that the distribution of prey organisms is not uniform. A possible pattern of the spatial micro-distribution of prey organisms was suggested; the volume of the aggregation of the tiny organisms or swarm was estimated to be 3-952 liters.

Quantitative relationship between fish larvae and prey organisms has long been considered to influence the survival and growth of larval fish.[1,2] Food conditions for survival and normal growth were discussed from different view points; physiological approaches,[2,3] feeding experiments,[4-8] and theoretical considerations.[9] From these it was suggested that the larvae require a higher density of food organisms than that found at sea.[2,10] HUNTER,[3] however, stated that the patchy distribution of prey organisms may settle the problem on early larva feeding, and TANAKA[10] stressed the importance of surveying the spatial micro-distribution of larval forms and prey organisms.

The authors observed the high scarcity of contents in the stomachs of pelagic larvae of flounder (*Paralichthys olivaceus* (TEMMINCK et SCHLEGEI), "Hirame" in Japanese) taken from the northernmost area of the East China Sea to the west of Nagasaki Prefecture during spring. Food conditions required by the fish larvae community in the area and season under observation are discussed based on the results obtained and previous physio-ecological works.

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Stomach Content Analyses

Fish larva net oblique tows and plankton nets vertical hauls were carried out in Nagasaki waters in early May from 1982 to 1985. The result of stomach content analyses showed that many larvae of the Hirame flounder had very low contents and it admitted annual variation (Table 1). The advanced stages of copepodite in micro-calanoids such as *Ctenocalanus*, *Paracalanus*, *Clausocalanus* and *Acartia*, copepod nauplii, cladoceren *Penilia*, ova of crustaceans, and sometimes appendicularian *Oikopleura* were observed in some stomachs. In four years of survey individuals with full stomach were hardly observed. The percentage of larvae with vacant stomachs higher during the earlier developmental stages, and exceeded 50% in individuals smaller than 4mm in total length (Fig. 1). The qualification vacant stomach was taken as an entirely empty stomach without any trace of content. The fact above is of interest in finding the food strategy of larvae.

Table 1. Rate of vacant stomachs in Hirame flounder larvae caught by oblique tows with the larva net (130 cm in mouth dia., 0.5mm mesh aperture) upper 50m layer of Nagasaki waters, May 1982-1985.

Date	Day		Twilight		Night		Total	
	N	%	N	%	N	%	N	%
May 6—7, 1982	47	81.5	18	94.4	16	100	81	90.1
May 6—7, 1983	243	56.8	49	98.0	0		292	63.7
May 7—9, 1984	486	35.6	17	31.7	63	35.3	566	35.2
May 12—13, 1985	736	29.8	0		0		736	29.8

N : Number of Hirame larvae examined

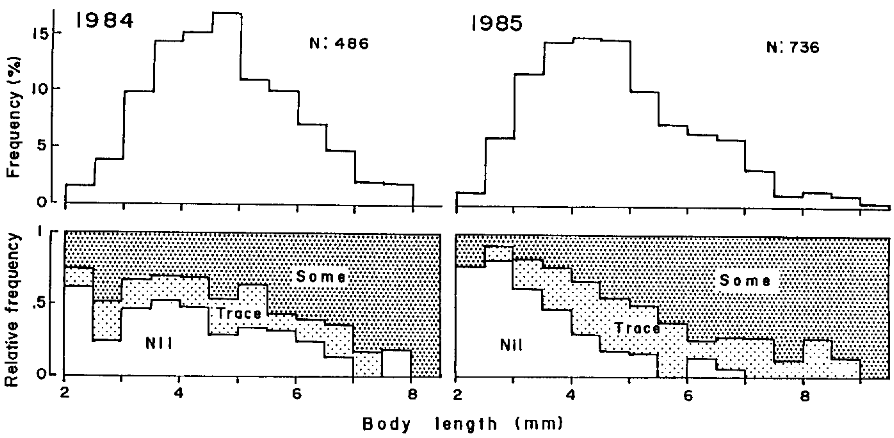

Fig. 1. Frequency distribution of body length (upper) and relative frequency of three grades of amount of stomach contents (lower) in Hirame flounder larvae in Nagasaki waters, May 1984 and 1985.

Food Intake and Stomach Evacuation

Value of stomach full in Hirame larvae ranging from 3 to 40% of body weight was obtained by YASUNAGA[11] in 6-50 days old individuals reared under sufficient food of rotifer *Brachionus plicatilis* and nauplius of brine shrimp *Artemia salina*. These values seem to be scattered in comparison with the ones in the larval forms

Table 2. Stomach full percentages of body weight in the larval stage of various fish from the previous works.

Species	Body size	Food	Tempereature (°C)	Stomach full (%)	Reference
Paralichthys olivaceus	0.3—1.2mg*	Rotifer	14—21	3—21	YASUNAGA[11]
Paralichthys olivaceus	2—49mg*	*Artemia*	14—21	13—40	YASUNAGA[11]
Pagrus major	3—5mm**	Rotifer		4—5	FUSHIMI[12]
Pagrus major	5—7mm**	Copepods		6—7	FUSHIMI[12]
Pagrus major	7—70mg*	*Tigriopus*	21—22	11—14	KITAJIMA[13]
Pagrus major	0.3—14mg*	Rotifer	17—20	7—11	KITAJIMA *et al*[14]

* In wet weight
** In total body length

of red sea bream (Table 2). Here we adopt the value of 10-20% for the flounder larva.

During the pelagic life of 80 days, under some physiological assumptions at the standard metabolism[15] and carbon/dry weight ratio of zooplankton is 0.4[16], the daily food requirement of the larva is 20-45% of the body weight, when active metabolism is 2-3 times the standard one[7,17,18] and assimilation efficiency of food is 0.8.[18] Therefore, to fulfill the daily food requirement, it is needed for the larva to have a turn over rate in the stomach of 1-4.5 (20-45%/10-20%) times a day.

The Hirame larvae smaller than 4mm in body length took 2 hours and half at 14-21°C[11] to digest the rotifers. The red sea bream larvae of 4.2-5.2mm took one hour or more at 17.7-19.2°C (MASUMURA unpublished, cited from FUSHIMI[12]). On the hand, YASUNAGA[11] reported that Hirame larvae required 3-5 hours to digest the *Artemia* nauplii at the age of 20-26 days at 14-25°C. To digest the *Artemia* nauplii herring larvae took 7-8 hours at 9°C.[19] It seems that rotifers and the like, however, are not available for Hirame larva in the natural envrionment. As for copepod nauplius, noting their similarity to *Artemia*, the Hirame larva's digesting time at the present enviroment of temperature 17-18°C can be reasonably assumed to be 3-5 hours. Feeding time in the flat fish larvae is restricted in the day hours (winter flounder,[7] Hirame,[20] Table 1). The turn over rate of the stomach full is computed to be, therefore, 2.4-4.0 a day when they perform continuous feeding on copepod nauplii for 12 hours a day. These values well coincide with those of the daily turn over frequencies of the Hirame stomach to satisfy its food requirement. This means that Hirame larva without stomach contents should be hungry.

Production of Prey Organisms

Table 3 shows the plankton biomass obtained by vertical hauls from the bottom to the surface with 3 mesh sized plankton nets. Among these 100 μm mesh collections are the organisms that most likely represent the Hirame stomachs. The 100

Table 3. Plankton biomass obtained by vertical hauls from the bottom to the surface with 45 cm diameter plankton nets of 3 mesh sizes in Nagasaki waters, May 1982-1985.

Date	335μm			200μm			100μm		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
May 6—7, 1982							18	141.8	55.7
May 6—7, 1983	14	69.3	36.8				14	266.0	138.7
May 7—9, 1984	13	122.7	33.7	19	131.9	68.5	19	223.6	98.7
May 12—13, 1985	19	105.1	42.7	19	156.1	56.5	19	173.5	61.6

N : Number of plankton samples
SD : Standard deviation

μm biomass in wet weight ranged from 150 to 250 mg per 1 m^3 in round number with a variation according to year. This level may somewhat be overestimated because a certain amount of diatoms and detrital material are included in the plankton collections. Assuming that these are negligible and water content of zooplankton is 0.8,[21] zooplankton biomass is calculated to be 30-50 mg in dry weight per 1m^3. Assuming again that the ratio of production to biomass, P/B ratio, of 100 μm plankters is 0.1 a day[22] (slightly underestimated as a value of that in *Paracalanus* and *Acartia* of about 500 μg in dry weight at the ambient temperature of 17-18°C), daily zooplankton production is to be 3-5mg in dry weight per 1m^3.

The harvest of this level is capable to carry 3-12 individuals of Hirame larva in a water mass of 1m^3, because the mean amount of food requirement of the larva during its pelagic stages is 0.4-0.9mg dry weight per day including active metabolism.[15] The distribution density of fish larvae including Hirame in the season and place concerned ranged from 0.1 to 0.5 and 0.3 in average per 1m^3. Assuming that fish larvae other than Hirame require the same amount of food, it is noteworthy that zooplankton production in the present waters far exceeds the food demand of fish larvae.

Availability of Food Organisms

The volume of water needed to supply the daily demand of prey animals by the larva, 0.4-0.9mg in dry weight, is calculated as 8-30 liters ((0.4-0.9mg) × 1,000 l ÷ (30-50mg)), if it does not miss to search and bite the ambient prey organisms. Taking into account its capability of searching the prey and feeding success presented by BLAXTER and STAINES[23] (figs. 6-b, 8), the Hirame larva may be able to sweep the volume sufficiently in its later stages but incompletely in its earlier stages.

For this pourpose the authors try to discuss in detail the relationship between the larva food requirement and the distribution of prey organisms. Table 4 gives

Table 4. Food strategy of Hirame flounder larvae and possible distribution pattern of their prey organisms in Nagasaki waters (weight is on dry basis).

	Days after hatching				Remarks
	10	20	30	50	
(A) Body weight (μg)	84.5	171	345	1410	MORIOKA[15]
(B) Food requirement (μg/day)	17—38	34—77	69—155	282—635	See text
(C) Search volume (l/day (12 hrs))	3	10	17	28	Plaice (BLAXTER & STAINES[23])
(D) Feeding success rate	0.4	0.5	0.6	0.8	Plaice (BLAXTER & STAINES[23])
(E) Neccessary search vol (l/day)	9—19	17—39	35—78	141—318	B/2μg/l
(F) Minimum prey concentration (μg/l)	14—32	7—15	7—15	13—28	B/C/D
(G) Percentages of prey stock to the required	6—14	13—29	13—29	7—15	2μg/l/F×100
(H) Vol (l) of parcel when preys make a single aggregation	208—476	444—952	444—952	238—513	2μg/l×3.33m³/F

ontogenetic variation of the food requirement, feeding ability and feeding conditions in a Hirame larva. Larvae of body length shorter than 5.5mm[20] or 5.9mm[24] depend mainly on copepod nauplii before depending on appendicularians and copepodites[20,24] for their food. The body dry weight of the Hirame of 5.5mm in body length is 1.4mg[11] assuming dry/wet weight ratio is 0.2,[21] and corresponds to a 50 day old specimen.[15] Copepod nauplii are distributed at a mean density of 10 individuals per liter in the area surveyed (NAKASHIMA unpublished). Though the body weight of a single individual of nauplius ranges over two figures, a value of 2.0 μg in dry weight is adopted for *Acartia* nauplii of 200 μm in body length.[25] Therefore, the nauplius biomass is 2 μg dry weight/l.

When the Hirame larvae depend entirely on the copepod nauplii during the pelagic life of 50 days after hatching, the needed volume of water to fulfill the requirement is given in Line E of Table 4. We have no information on the feeding ability of the Hirama, so we apply the approximate values deduced from the figures obtained by BLAXTER and STAINES[23] for the North Sea plaice. The volume is too large compared with the capable search volume (Line C), and the food search capability is only 9-33% of the volume necessary to fulfill the food demand (Line E). These percentages must be lowered with regard to the feeding success ranging from 40 to 80% (Line D). The minimum prey concentration to sustain the demand of the larva is given in Line F, and the standing stock of nauplii, 2 μg dry weight/l, is by far lower than that (6-29%, Line G). However, they are able to satisfy their requirement in stages older than 50 days due to feeding on larger organisms which have a biomass of 30-50 $\mu g/l$ retained by 100 μm meshed plankton net. These explain the high vacancy of stomach during early stages. In spite of the availability of surplus preys in a certain unit volume of water, e. g., $1m^3$, many larvae are not able to catch enough to fulfill the requirement, i. e., assuming that the preys are distributed at random.

Some larvae satisfy their appetite, but many larvae are famished. Let's consider the prey environment for the animals which succeeded in the predation. As mentioned above the density of larvae was $0.3/m^3$. Assuming that they are distributed at random because we have no information on the small scaled spatial distribution of 1 meter scale, a single individual of larva spatially occupies a mean $3.33 m^3$ of water.

Plankton copepods sometimes show an aggregated community, called swarm, in shallow shore waters,[26,27] and this is suggested to be significant in the food supply for fish larvae.[27,28] When prey animals make a single swarm in 3.33 m^3 of water the volume of parcels with the minimum amount of food is illustrated in Line H of Table 4, and the volume of the swarm ranges from 3 to 952 liters (Lines C and H). If these have a spherical aggregation, their radius is distributed at the range of 9-61cm.

As a conclusion the authors would state the importance to elucidate on the small scale spatial distribution pattern of the prey organisms as well as that of the predators.

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九州西部平戸島近海におけるヒラメ稚仔の餌料要求とプランクトンの分布様式

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抄　録

1982年から1985年の毎年5月上旬，平戸島近海，北緯33度10分，東経129度20分を中心とする約400平方海里内の19定点における稚魚網（口径130cm，網目幅0.5mm）の50m以浅層傾斜びき試料から選別された浮遊期ヒラメの消化管内容物を調べたところ，年による違いはあるものの空胃の個体が多かった．

既往の資料によるヒラメをふくむ主に異体類の稚仔の食物要求量（1日あたり体重の20～45%）と体重に対する消化管の最大充満量の比率（10～20%）とから得られる1日あたりの所要回転数（1～4.5）が，1日12時間に食物が消化管を通過すると見込まれる回数（2.4～4.0）とが似ていることから，空胃の稚仔は飢餓状態にあると解釈される．

しかしながら，ヒラメが全浮遊期間の約80日に要する餌料は1日あたり0.4～0.9mg（乾重量），この期間の餌料と目される網目幅 100μm のネットで得られるプランクトンの1㎥あたり1日あたりの生産量は3～5mg（乾重量）と概算され，このことから1㎥あたり3～12尾のヒラメを養うことができることになるのに対し，海洋現場でのヒラメをふくむ全稚仔魚の分布密度は，1㎥あたり0.1～0.5尾にすぎなかった．栄養をおもに橈脚類ノープリアス期幼生に依存する生後50日間においては，北欧産ツノガレイの1種での値を用いるならば，餌料を探索，捕獲できる水量（12時間あたり 3～28 l）は，ノープリアスの平均分布密度（2μg 乾重量/l）のもとで掃破しなければならない水量（12時間あたり 9～318 l，成長とともに増大）に比べてきわめて少ない．すなわち，プランクトンがまばらに分布していたのでは稚仔の生残や正常な発育に要するだけの餌料を捕獲できない．プランクトンはある場所に集中的に分布して濃密な群を成していなければならず，それが塊状であるとしたときその容積は 3～952 l と見積られる．