春季の五島灘における魚類稚仔,動物プランクトンおよびクロロフィル量の微細分布

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Small-scale Spatial Distribution of Fish Larvae, Mesoplankton and Plant Pigment in an Area to the West of Kyushu in Spring

Yasuhiro MORIOKA,* Junko NAKASHIMA* and Katsunori KIMOTO*

To resolve a discrepancy that even mean standing stock of zooplankton is far in excess of the food requirement of fish larva, and the fact that many fish larvae are famished, a unit of 0.2 miles towing of the larva net, 100μm mesh net plankton collection and chlorophyll *a* observations were made in an area of 1.2 miles × 1.0 mile in the northernmost area of the East China Sea, May 1985, March-May 1986. The area was selected because of the relative uniformity of watermass. Spatial distribution of many elements showed contagious distribution with a center diameter less than one or two units of tow. A trial estimation showed that food requirement of fish larva is 0.15-1.5% of zooplankton production, and food demand of zooplankters is 2.7-34.8% of primary production in mean. It is concluded that the spatial distributions of fish larvae, net plankton, and chlorophyll *a* have no quantitative relationship with each other, and is also not governed by the property of sea water in terms of salinity.

INTRODUCTION

High scarcity of contents in the stomachs of pelagic larvae was observed in flounder, *Paralichthys olivaceus*, in the Goto-nada waters to the west of Kyushu, the northernmost area of the East China Sea during May 1982-1985.[1] The same authors induced that the larvae with vacant stomachs are actually famished, by comparing the previous data on food requirement with value of those on stomach full and turn over rate of food in the stomach for the flounder larvae. On the other hand, they reported that the distribution density of prey organisms for the larvae is far enough to fulfill their food requirement. Patchy distribution of prey organisms may resolve the discrepancy between the two phenomena: many larvae fail in catching the prey and some succeed. Plankton animals show certain non-random, patchy distribution in some spatial scales, i. e., less than 1 m, from 1 to 100 m, and more than 100 m.[2] Many eye-observations on board[3,4] and detailed submergible sampling operations[5-7]

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*Seikai Regional Fisheries Research Laboratory, Kokubu-machi, Nagasaki 850, Japan (森岡泰啓・中嶋純子・木元克則, 西海区水産研究所 〒850 長崎市国分町49)

documented the presence of the patchiness.

In the present paper particular interest is focussed on comparing the spatial distribution pattern in fish larvae, net plankton and phytoplankton pigment, and some quantitative relationships between them are considered basing on the estimations of the food requirement of the predator and productivity of prey organisms.

MATERIAL AND METHOD

Continuous surface layer horizontal tows with the larva net (130 cm in mouth dia., 450 cm in side length, 500 μm mesh aperture) were carried out alternately from port and starboard of the research ship "*Yōkō Maru*" of the Laboratory on 6 lines of 1.2 miles set at an interval of 0.2 miles in the central part of the Goto-nada waters, May 1985, March-May 1986 (Fig. 1). The grid of rectangle was set not on the geographical position but on the plane of watermass with a correction de-

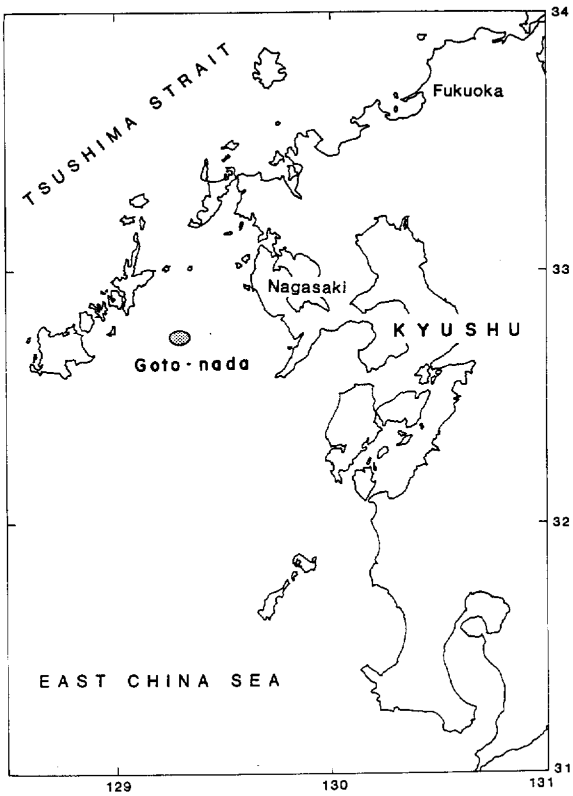

Fig. 1. Location of gird survey area for small-scale spatial distribution of plankton in the Goto-nada waters, May 1985, March-May 1986.

pending on the direction and speed of the water current measurement. The area was decided according to its uniformity of oceanographical properties of the water mass (Table 1), and relatively slow currents.*

Table 1. Temperature and salinity duiring the grid survey of fish larva net tow and plankton samplings in the Goto-nada waters, to the west of Kyushu, May 1985, March-May 1986

Date	Hour	Temperature(°C)	Salinity
May 14-15, 1985	1959-0103	19.4-19.5	
March 15, 1986	1121-1438	14.3-14.3	34.63-34.66
April 12, 1986	1200-1657	16.1*	34.69-34.72
May 15, 1986	0810-1316	18.4-18.5	34.21-34.31

* At Stn., 32°47′N, 129°16′E, April 13, 1986 (NAGASAKI PREF. INST. FISH., unpublished)

The distance of tow, 0.2 miles, was decided to fulfill the minimum level for the quantitative study of fish larva distribution with the fish larva net. Hour given in Table 1 is the interval of fish larva net towing. Temperature was measured at the bottom of the ship at 5 minute intervals. It varied horizontally so little its distribution was left out of consideration in later discussions.

Sea water was drawn with a pump system through the duct which opened at the bottom of the ship (depth of 5 m) on the midway of the fish larva net tow. Net plankton was collected by sieving with 100 μm meshed small plankton net. Crude sea water was processed for fluorometric chlorophyll *a* determination and salinity conductivity measurement. Volume of water sampled for study of each element is shown in Table 2.

Table 2. Volume of water sampled for quantitative study of fish larva and other plankton in the Goto-nada waters, May 1985, March-May 1986

	Fish larva (m^3)	500μm plankton (m^3)	100μm plankton (ℓ)	Chlorophyll *a* (mℓ)
May 1985	451±46	451±46	375	300
March 1986	417±56	417±56	332	300
April 1986	414±53	414±53	335	300
May 1986	441±26	441±26	337	300

± number : Standard deviation

Fish larvae were sorted from the fish larva net samples and divided into 2 groups by expedient category, i. e., "Shirasu" form of clupeid larva and the others. The specimens with body longer than 15 mm in Shirasu and 10 mm in the

* K. TSUKIYAMA, personal communication

other fish were excluded. The number of individuals was counted and wet weight for the batch of a sample was measured at 0.01 mg. Wet weight of specimen other than fish larva in the larva net samples and 100 μm net plankton sample was also determined. The position of the plot on the figures for the horizontal distribution of organisms is the middle point on the segment of the fish larva net tow.

ESTIMATION OF FOOD REQUIREMENT AND PRODUCTION

1. Food Requirement of Fish Larvae

Shirasu: For food requirement estimation on Shirasu form, data on Californian anchovy, *Engraulis mordax* are used here. Food requirement (F) is given from the knowledge of rates of growth (net production, Pn), metabolism loss (respiration, R) and assimilation efficiency of food (A) as follows[8]:

$$F = (Pn + R) / A \quad (1)$$

Respiration rate for the anchovy is given as $R = 4.5\,\mu l$ O_2/mg dry weight/hr by HUNTER.[9] This formula is rewritten on basis of dry weight as follows when 1 μl O_2 is equivalent to 0.00477 cal[8] and 1 cal is 0.2 mg dry weight of body tissue[10]:

$$R \text{ (mg dry wt./mg body dry wt./day)} = 0.103 \quad (2)$$

KRAMER and ZWEIFEL[11] described a growth trend of *E. mordax* in terms of body length (L, mm) at t-th day after hatching:

$$L = 3.24\, e^{0.0555t} \quad (3)$$

The length(mm)-body weight (wet ?, mg) relationship in *E. mordax* is given by LASKER et al.[12] as

$$\log W = 3.3237 \log L - 3.8205 \quad (4)$$

Substituting Eq. 3 into Eq. 4.

$$W = 7.523 \times 10^{-3} \times e^{0.1845t} \quad (5)$$

This means that daily weight specific growth is 0.1845. When the assimilation efficiency of food is 0.8,[8,13] daily body weight specific food requirement of Shirasu is given as follows:

$$F = (0.103 + 0.1845) / 0.8 = 0.359 \quad (6)$$

Miscellaneous fish larvae: The respiration rate (μl O_2/animal/hr) of flounder, *Paralichthys olivaceus* of weight of W (mg dry weight/animal) at the temperature of T°C is given by MORIOKA[13]: $R = 1.09 \times 2^{T/10} \times W^{0.795}$. When the mean ambient temperature in the sea is 17℃, the respiration (mg dry wt./animal/day) is expressed as:

$$R = 0.0811 W^{0.795} \quad (7)$$

We get daily weight specific respiration from Eq. 7 as:

$$R / W = 0.0811 W^{-0.205} \quad (8)$$

The growth rate (*Pn*) of the flounder at temperature of *T*℃ at *t*-th day after hatching is given by MORIOKA [13]:

$$Pn = 0.514 \times 2^{T/10} \times e^{0.0657t} \quad (9)$$

Eq. 9 means that the daily weight specific growth rate is 0.0657. The weight specific daily food requirement (mg dry weight) is derived from substituting these into Eq. 1 under the same assupmtion as in the Shirasu as follows:

$$F = (0.0657 + 0.0811 W^{-0.205}) / 0.8$$
$$= 0.0821 + 0.101 W^{-0.205} \quad (10)$$

Food requirements of Shirasu and the others are obtained from the mean wet body weight of larva (Table 3) and Eqs. 6 and 10. Dry basis is available to convert from wet one by multiplying 0.2 as an approximate value for Japanese anchovy and Evermann's lantern fish larvae.[14]

Table 3. Mean weight (Wet, mg/animal) of 2 categories of fish larvae in a tow in the Goto-nada waters, May 1985, March-May 1986

	Shirasu			Miscellaneous		
	Number	Mean	SD	Number	Mean	SD
May 1985	36	5.526	2.525	36	2.775	2.021
March 1986	24	0.528	0.267	17	0.631	0.536
April 1986	36	0.281	0.259	34	1.869	1.173
May 1986	16	0.742	0.230	36	1.097	0.423

SD : Standard deviation

2. Production of Prey Animals

100 μm net plankton: Material collected with 100 μm mesh net may not be always the food of fish larvae, because it sometimes contains certain amount of phytoplankton cells and non-living substance, etc. But the majority is zooplankters with body length of less than 1 mm (Fig. 2), which consisted of nauplii and copepodite stages of copepod genera such as *Paracalanus*, *Clausocalanus*, *Acartia* and *Oithona*. These appear in the stomachs of flounder[1,15,16] and anchovy larvae.[17,18] Ratio of produc-

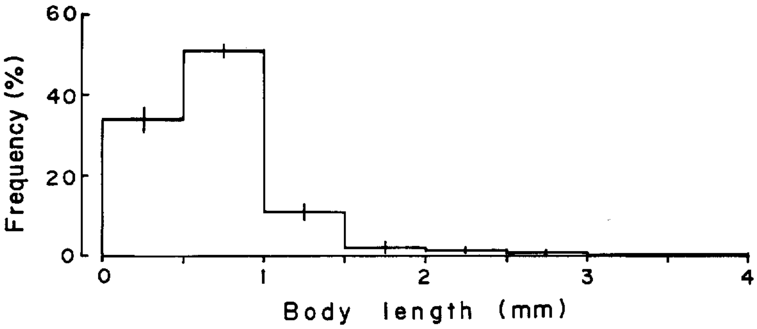

Fig. 2. Body size distribution of zooplanktonin 11 samples obtained with 100 μm mesh net in the Goto-nada waters (pump system, May 1985 grid survey). Vertical bar shows 95% confidence limit.

tion to biomass, P/B ratio, of copepod *Acartia omorii* as a representative species which has similar body size to the above copepods[19] is 0.1 per day* in Shijiki Bay with the oceanographic conditions like that of the present area.

500 μm net plankton: *Calanus sinicus* was tentatively elected as the representative of the organisms collected with the larva net of 500 μm mesh aperture because it was abundant in May for two years. Zooplankters were meager in the earlier months (abundant diatoms in March and scarce fish eggs and so on in April). An individual of *Calanus* weigh 110 μg in dry weight,[19] and its daily productivity to the biomass shows 0.06 at the temperature of 17℃ reading the body weight-P/B ratio diagram by MORIOKA.[20]

3. Food Requirement of Zooplankton

IKEDA and MOTODA[21] chose a value of 0.3 for K_1, the gross growth efficiency, ratio of production (Pn) to the food requirement (F), compiling the results of laboratory experiments by the previous workers. Therefore, F is given as:

$$F = 3.33\,Pn \quad \cdots\cdots \quad (11)$$

Since one miligram wet weight of animal tissue is equivalent to 0.2 mg dry weight in general zooplankton[14] and carbon/dry weight ratio is 0.4 (from the text figure of IKEDA[22]), daily weight specific food requirement on carbon basis is given as: for 100 μm net plankton,

$$F\ (\text{mg C/day}) = 0.0267 \times \text{Biomass (mg, wet wt.)} \quad \cdots \quad (12)$$

and for 500 μm net plankton.

* K. KIMOTO, unpublished

$$F\,(\text{mg C/day}) = 0.0160 \times \text{Biomass (mg, wet wt.)} \cdots \quad (13)$$

4. Phytoplankton Production

Primary production measured by ^{13}C method at 2 stations located ca. 30 miles north of the present area amounted to 0.15-2.2 gC/m^2/day during 12 months.[23] The monthly mean assimilation number (mgC/mg Chl. *a*/day) obtained from the above values and standing crop of chlorophyll *a* at the two stations was 31.2 (range: 10-60, standard deviation: 14.9) excluding an extraordinary high value. A daily assimilation number of 30 was here adopted to calculated the primary production from the standing crop of chlorophyll *a* in the present area.

RESULTS AND DISCUSSION

The number of fish larvae varied according to month. Clupeid larva, Shirasu, ranged from 2 to 130 individuals per 1,000 m^3 of water in monthly mean and the larvae other than Shirasu 5 to 200. Biomass in wet weight accordingly varied too: that of Shirasu amounted to 2-500 mg per 1,000 m^3 of water and miscellaneous fishes 3-480 mg. The highest values in both larvae were observed in May 1985, in which the towing were made at night (Table 4). Fig. 3-a gives their horizontal distribution by month. They performed no uniform pattern, and the amount of each varied even in the narrow area. One or two patchiness of distribution was observed in the area showing a contagious distribution with a center of scale with a diameter of 0.2 miles. Its biomass was 2-9 times the mean amount in the whole area. Each

Table 4. The number and biomass of 2 categories of fish larva in the Goto-nada waters, May 1985, March-May 1986 (number in parentheses is range)

	Number per 1000m^3						Biomass wet wt. μg per m^3					
	Shirasu			Miscellaneous			Shirasu			Miscellaneous		
	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD
May 1985	35	97.8	48.9	35	203.3	71.3	36	496.9	290.6	36	480.2	201.8
		(24.1-273.8)			(69.4-404.7)			(72.3-1554.5)			(131.3-891.8)	
March 1986	24	88.2	143.5	24	4.8	7.1	24	48.8	90.0	24	3.1	4.8
		(2.4-693.6)			(0 - 28.6)			(0.2-450.2)			(0 - 19.4)	
April 1986	36	132.7	141.6	36	13.8	10.3	36	30.7	33.3	36	23.6	23.4
		(2.6-588.1)			(0 - 37.0)			(0.2-167.4)			(0 -131.0)	
May 1986	36	1.9	3.4	36	49.1	16.9	36	1.7	2.7	36	51.4	22.1
		(0 - 17.2)			(19.1- 81.7)			(0 - 13.4)			(10.8- 97.6)	

No.: The number of samples
SD : Standard deviation

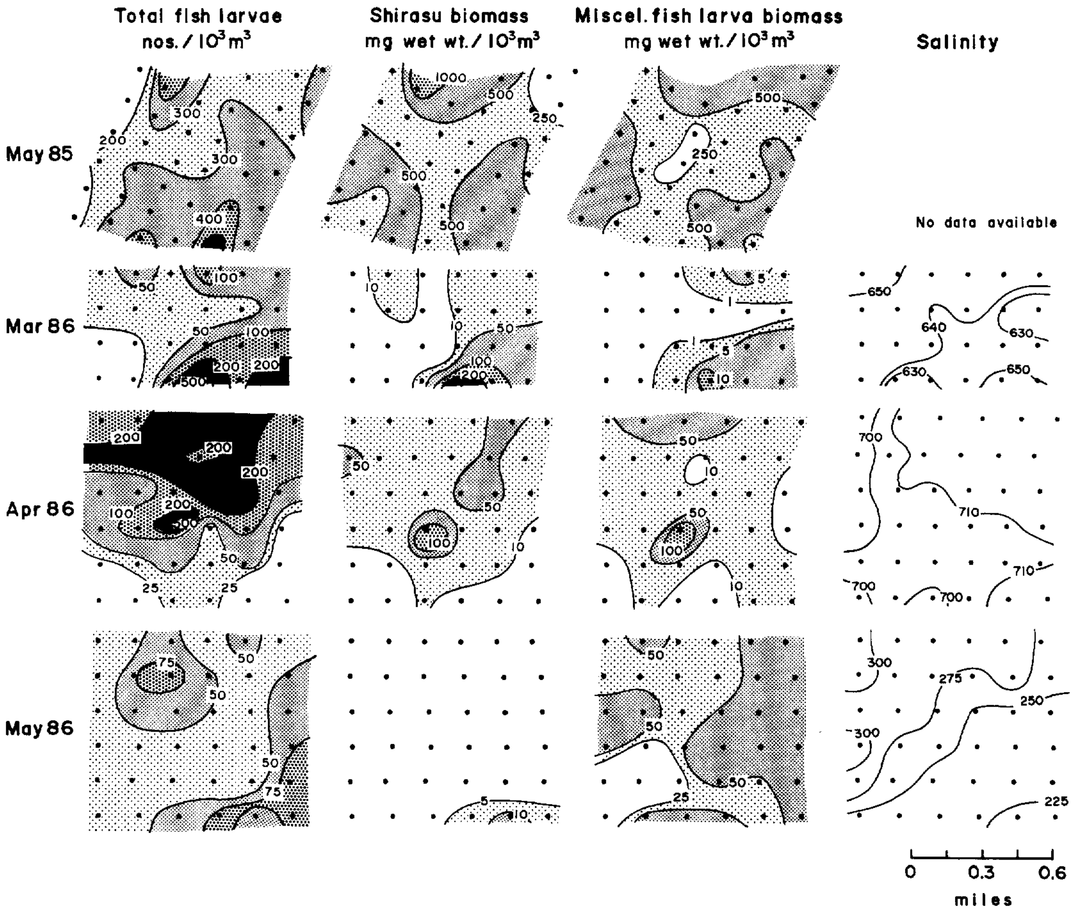

Fig. 3-a. Horizontal distribution of fish larvae and salinity ((-33)×1000) in grid survey in the Goto-nada waters, May 1985, March-May 1986.

pattern does not correspond to that of water mass in terms of salinity (Fig. 3-a).

Biomass of plankton caught with 500 μm mesh fish larva net ranged 1-100 mg wet weight per m^3 of water in mean, and that with 100 μm mesh ranged 50-200 mg. They also showd maximum value in nocturnal sampling in May 1985 (Table 5). A contagious horizontal distribution was also observed in the area surveyed, and scale of diameter of the high density population does not exceed 0.2 miles. The pattern does not correspond only to fish larva distributions but also to salinity distribution in the same manner as in the fish larva distribution (Fig. 3-b). Chlorophyll *a* content amounted to 0.3-2 mg per m^3 in monthly mean, showing a maximum in April 1986 (Table 5). The horizontal distribution pattern does is not coincide with the areal figures of zooplankton and salinity (Fig. 3-b).

To sum up, all elements observed have their own distribution pattern regard-

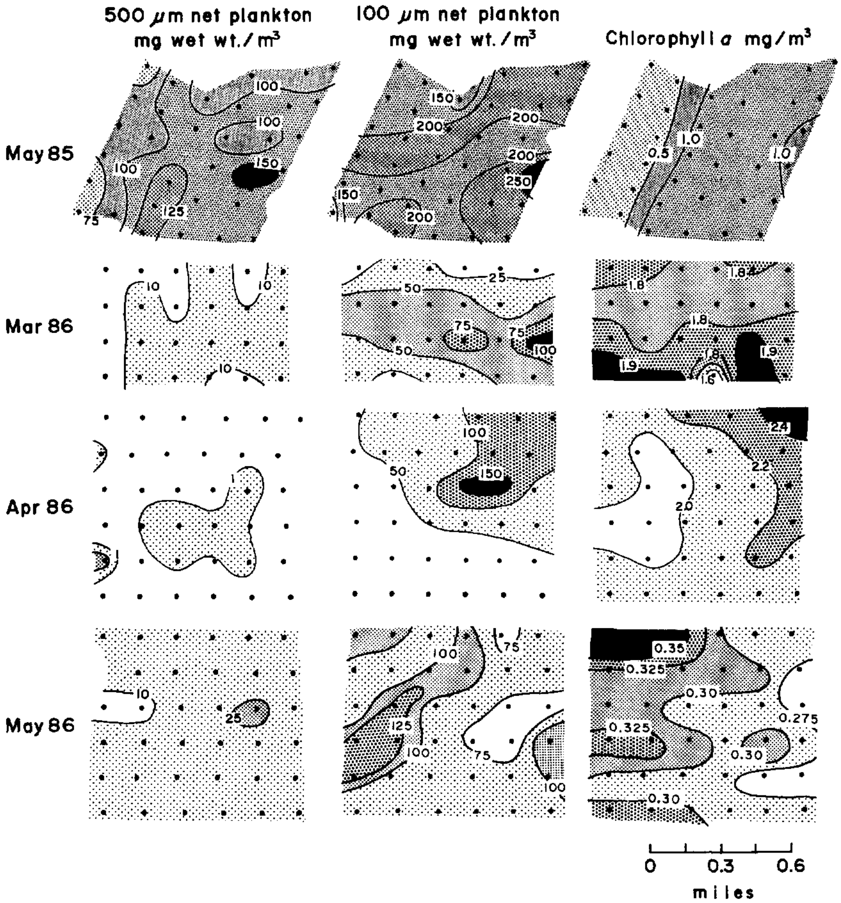

Fig. 3-b. Horizontal distribution of net plankton and phytoplankton pigment in grid survey in the Goto-nada waters, May 1985, March-May 1986.

less the interrelationship among them and may not be governed by salinity gradient. The spatial scale of patchiness of each element never exceed 0.2 or 0.4 miles in diameter of a units of tow. Exact scale may sometimes be smaller than these.

As it is considered generally that fish larvae, zooplankton, and phytoplankton are linked together by food relationship, quantitative considerations must also be discussed. Table 6 gives food requirement of predator and productivety of its food. The sum of daily food requirement of Shirasu and other fish larvae is 0.15-1.5% of daily productivity of 100 μm mesh net plankton. Similarly, plankters caught with 500 μm and 100 μm mesh net require 2.7-34.8% of primary production. Even in the segment of maximum food requirement of fish larvae and zooplankton it does not exceed 5% of prey animal production and 70% of primary production, respectively. It is concluded from these that areal abundance of fish larvae, zooplankton and

Table 5. Net plankton biomass (wet wt., mg/m³) and amount of chlorophyll *a* (mg/m³) in the Goto-nada waters, May 1985, March-May 1986 (number in parentheses is range)

	500 μm net plankton			100 μm net plankton			Chlorophyll *a*		
	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD
May 1985	34	102.5 (58.0-141.4)	19.8	35	198.8 (56.1-259.2)	35.7	36	0.87 (0.33-1.22)	0.37
March 1986	24	10.9 (2.1- 17.1)	3.8	24	48.2 (14.7-112.1)	22.8	24	1.82 (1.54-1.98)	0.10
April 1986	36	0.8 (0.4- 2.9)	0.4	36	66.2 (23.9-167.2)	38.8	36	2.12 (1.91-2.60)	0.16
May 1986	35	16.2 (6.1- 30.3)	5.8	36	90.5 (47.5-151.3)	28.2	36	0.30 (0.22-0.36)	0.03

No. : The number of samples
SD : Standard deviation

Table 6. Percentages of food requirement of total fish larvae (Fl) to 100 μm net plankton production (P_{100}), and food requirement of 500 μm and 100 μm net plankton ($F_{500 \cdot 100}$) to primary production (P_p)

	$Fl/P_{100} \times 100$			$F_{500 \cdot 100}/P_p \times 100$		
	Mean	SD	Range	Mean	SD	Range
May 1985	1.49	0.84	0.64-4.61	34.8	19.5	14.4-69.0
March 1986	0.92	0.96	0.00-4.69	2.7	1.1	0.8- 5.6
April 1986	0.27	0.30	0.00-1.68	2.8	1.6	1.0- 7.2
May 1986	0.15	0.08	0.04-0.39	30.2	8.3	16.4-47.0

SD : Standard deviation

phytoplankton are entirely independent. Rather, manner of spawning eggs in organisms, weak movement of watermass and anything else including social behavior of organisms are interesting for the factors governing the spatial distribution of planktonic organisms.

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春季の五島灘における魚類稚仔，動物プランクトンおよびクロロフィル量の微細分布

森岡泰啓・中嶋純子・木元克則

抄　録

海洋現場で採集された魚類稚仔の食物要求量が餌料プランクトン生産量のほんのわずかな部分にしかあたらないにもかかわらず，多くの稚仔の消化管が空であることから，稚仔や餌料プランクトンが均一ではなくパッチ状の分布をしているとの想定のもとに，それらの水平分布の対応状態を調査した．

1985年5月，1986年3，4，5月の4回（1985年は夜間，1986年はいずれも昼間），五島灘の中央部海域において調査船陽光丸（499トン）によって稚魚ネットの表層曳と船底（水深5 m）に開口する管を通じてのポンプ揚水を行なった．海域は物理・化学的になるべく均質なところとして選ばれた．0.2マイル間隔に相並ぶ1.2マイル長の6線上で網目0.5㎜の稚魚ネットによる船速2ノット，6分間ずつの左右両舷交互の連続採集を反復し（1網約0.2マイル，1線上で6回），都合36対の標本を得た．6本の航路は地理上にではなく，潮の流向，流速を実測のうえ水塊上にできるだけ方形になるよう配置された．

測定項目は，稚魚ネット採集物からはイワシ類等のシラスとその他の魚類稚仔の個体数密度と生物量，それに魚類以外の動物プランクトン生物量，ポンプ採水試料からは0.1㎜のネットでこし取ったプランクトンの生物量とクロロフィルa量とである．

間隔5分間で測定された表面水温は各月とも調査海域内でほぼ一様といってよく，最大の幅は0.1℃であった．

稚仔，ネットプランクトン，クロロフィルともに1網（0.2マイル長）または2網を1単位とする濃密な

パッチを中心とした伝幡的な分布を呈した．パッチは海域内に概ね1個存在した．ただ，おのおのの要素の分布の"模様"はそれぞれ異っていて，そのいずれにも塩分の分布型との一致がなかった．稚魚，ネットプランクトン，そして植物プランクトンが食物環によって直接につながっているとして，それぞれの食物要求量と生産量を既往資料を用いて試算すると，稚仔の食物要求量は0.1㎜ネットプランクトンの0.15〜1.5%，0.5㎜と0.1㎜ネット分画のプランクトンの食物要求量は基礎生産量の 3〜35%に あたることになった．すなわち，プランクトン各要素の分布量はわずかな塩分の傾斜に左右されることなく，食物段階において一段階下位にある生きものの分布量に影響を及ぼす程の摂食圧を捕食者は有しない．さらに小さな空間的尺度での検討を要する．