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Fluxes and Accumulation of Organic Matter Loading from Yellowtail Culture in Yashima Bay, Japan

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ABSTRACT

Vertical fluxes of particulate matter precipitating through the water column and on the surface sediment of the yellowtail culture area were caught by sediment trap monthly for 1 yr from June 1992 to May 1993. The daily fluxes of suspended particulate matter were vary from 22-72 $g/m^2.d$, The annual fluxes of organic matter, organic carbon, and organic nitrogen of newly settling materials were 1,146 $g/m^2.yr$, 284 $gC/m^2.yr$, 34 $gN/m^2.yr$, respectively which were low in winter period and elevated in late spring to summer and early autumn during the period of fish culture (June to February). Thus, yellowtail culture could induce the accumulation of organic matter to the sea bottom.

Key words : yellowtail, organic matter, vertical fluxes

INTRODUCTION

The intensive culture of yellowtail that made its origin in Japan has, today become an important fish for industry. Yellowtail is a predatory fish having a large stomach and short intestine. This means that a large amount of protein (70-80% in dry weight) is required for rearing this fish (Tomiyama and Hibiya, 1979). The deterioration of water quality at culture centers by both leftover feed at the sea bottom and the excrements of the fish itself, is believed to be the cause of inhibited fish growth and the environmental pollution. Sediments have been a rich source of organic geochemical information because they provide large, time-averaged samples of known sequence from a great variety of depositional environments (Hedges *et al.*, 1988a). Most of what is known about the sources of organic matter to ancient and modern aquatic environments has been obtained from the analysis of sedimentary deposits. In the yellowtail culture area, one mean of evaluating the extent to which sedimentary records reflect actual biological sources from cultured fish is to directly compare the compositions of organic materials settling through the water column with those preserved in the underlying sediments.

The objective of this study is to find out the relationship and fluxes of particulate material in the water column and surface sediment in fish (yellowtail) culture area.

MATERIALS AND METHODS

Study area

The study area is illustrated in Figure 1, Yashima Bay is a shallow bay located in the Bisan-Seto inland sea. The average depth is 6.5 m while

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the deepest area is 14 m situated on the mount of the bay. The outer part is the yellowtail fish culture area.

Sediment collector

A sediment trap (Figure 2) consisted of a polyethylene funnel with an inner diameter of 210 mm, the cone angle from vertical was 30 degree. Funnel was modified to alter the hydrodynamic flow across their upper open end with 2 pieces of baffle made from acrylic plastic sheet (210 mm length, 50 mm width) set to fit the upper open end of funnel in x-y direction. The neck of funnel was cut to fit the mouth of a 500 ml polyethylene bottle and connected with vinyl tape to ensure that the funnel and the bottle would not separate during deployment. The trap was set in a tripod holder designed to an axial symmetry to reduce the current resistance. The effect of sediment trap design on collecting efficiency or degradation of deposited material was not considered.

Collection of newly settling materials and surface water sample were carried out monthly throughout the year from June 1992 to May 1993. Two arrays, one consisted of 5 sediment traps, were deployed at the yellowtail culture area. The traps were set at 1 m high above sea bottom (about 8 m from sea surface) to prevent resuspended material and retrived after exposure for one day. A 500 ml bottle filled with newly settling materials was closed with a lip to keep the materials in undisturbed condition until samples were brought to the

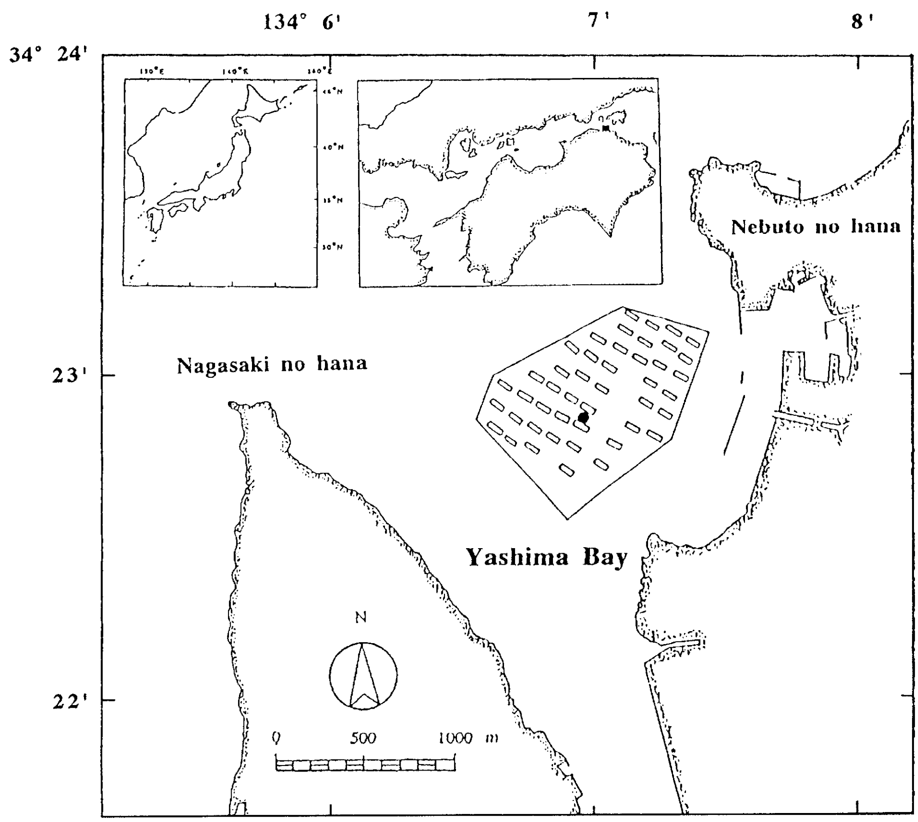

Figure 1 Sampling location in Yashima Bay.

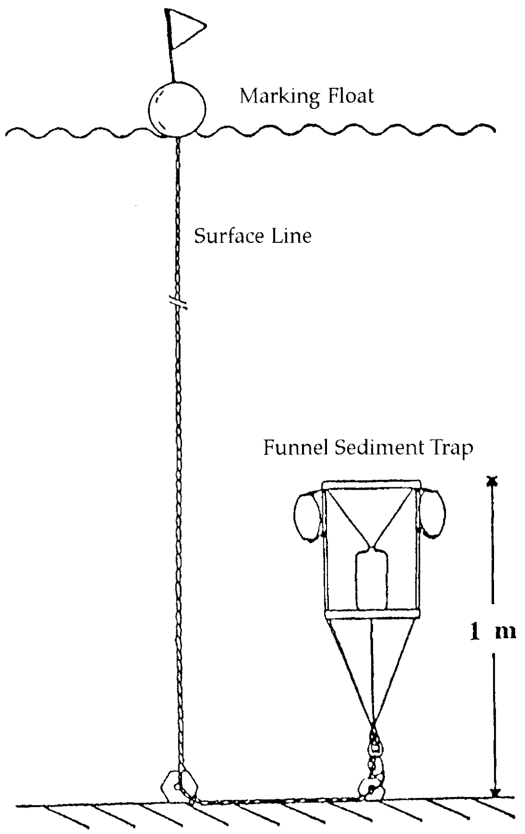

Figure 2 Field arrangement of sediment trap in Yashima Bay.

laboratory for analysis. In order to determine the suspended particulate matter, surface water over the sediment trap were deployed, about 100 litres was collected. Each time water temperature and salinity were also measured.

After returning to the laboratory, the settled materials in 500 ml bottles were centrifuged for 10 mins at 3,000 rpm with centrifugal machine (Kubota Model KR/180). Then, surface water sample was continuously centrifuged to obtain suspended particulate matter. Samples were free of salt by centrifuging in distilled water twice and then freeze dried. Dried samples were ground to small pellets and kept in desiccator for analysis of organic matter, organic carbon, and organic nitrogen content.

Sediment cores were taken bimonthly during June 1992 to April 1993. A diver was required in all case to make sure that the apparatus was placed properly with minimum distortion of the sediment surface. The sediment column was sliced into 1 cm thick each and kept in a small plastic bottle for analysis of water content, total organic matter, total carbon and total nitrogen content.

A part of well mixing sediment in each segment was dried at 60°C for 48 hrs to estimate the percentage of water content from the weight reduction.

Dried sediments after water content measurement were used to determine the total organic matter as loss on ignition at 450°C for 3 hrs.

The dried samples were analyzed for total organic carbon and total organic nitrogen by using a CN corder (Yanaco, Model MT-500) after removal of carbonate by treating with 2 N HCl.

The chlorophyll-a content was determined with the method reported by UNESCO (1966). Nutrients in water sample were measured by Technicon Autoanalyzer II, TC analyzer, and TN analyzer.

RESULTS

The concentration of total suspended particulate matter at surface water around the sediment trap deployment varied from 4.93 to 8.54 g/m^3 with an annual average concentration of 6.47 g/m^3. The two highest peaks were observed in September and October 1992 (8.27 and 8.54 g/m^3) during yellowtail culture period. The small amount of suspended particulate matter was observed in March 1993 (4.93 g/m^3). The concentration of chlorophyll-a (chl-a) ranged from 0.79 to 5.18 mg/m^3 with the annual average of 1.48 mg/m^3. The highest peak was observed in September 1992 (5.18 mg/m^3) and the lowest concentrations were observed in October 1992 and January 1993 (0.79 mg/m^3). As the fact that suspended particulate matter in the sea consists of living organism as phytoplankton and dead material (detritus) which include faecal material and faecal debris, organic aggregates of various types, and other complex organic particle. Thus, it is more suitable to measure suspended particulate matter by separating into two components (Sasaki and Inoue, 1985; Nimsantijaroen, 1993), assuming that dry weight of living phytoplankton equals to δ(chl-a), then the suspended detritus can be obtained from:

$$SS = SS' + SS''$$
$$SS = SS' + \delta(chl\text{-}a)$$

where

SS = suspended particulate matter
SS' = suspended detritus
SS'' = living phytoplankton

Dividing both sides by chl-a, then, we can estimate the value of δ which is the conversion coefficient of dry weight of living phytoplankton with the value of 0.55 mg/g (Figure 3). Then, dry weight of living phytoplankton and dry weight of suspended detritus can be estimated. The

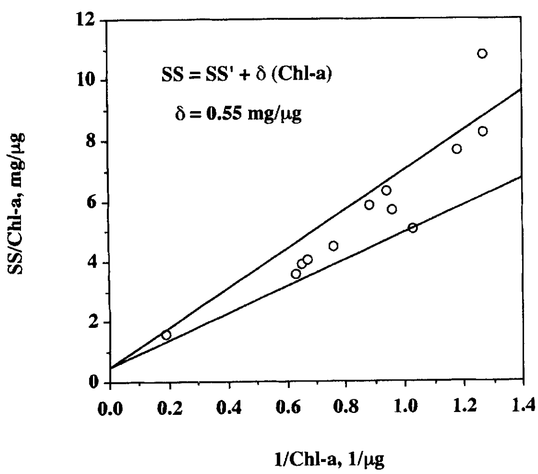

Figure 3 Relationship between SS/Chl-a and 1/Chl-a (r = 0.8507, confident interval 95%).

concentration of suspended detritus ranged from 4.40 to 8.11 mg/m^3 with trend to be high during autumn and winter whereas the concentration of living phytoplankton ranged from 0.43 to 2.85 mg/m^3 with high peak found in summer. Considering the nutrients in surface sea water at the culture area which are summarized in Table 3 PO_4, $NO_2 + NO_3$ showed the same pattern of change which were high in autumn and winter (September to January) and low in spring and summer (February to August) in contrast to the chlorophyll-a content and the bulk of living phytoplankton as described above. During spring and summer, the increase in temperature causes phytoplankton to utilize nutrient in photosynthesis and express the high bulk of chlorophyll-a content. On the other hand, in autumn and winter, temperature seems to be the limiting factor for phytoplankton growth in this area and results in low chlorophyll-a concentration.

From Table 1 the organic matter of suspended particulate matter varied from 104 to 229 mg/g with organic carbon content from 34.0 to 82.6 mgC/g and organic nitrogen content from 4.27 to 14.46 mgN/g. By multiplying these contents with suspensed particulate matter concentration and summation of these values over the year, the annual concentration of organic matter fluxes from surface water could be obtained as 387 g/m^3.yr with 125 gC/m^3.yr and 20 gN/m^3.yr, respectively.

From sediment trap, the bulk of newly settling materials exhibited values in the range of 22.0-72.5 g/m^2.d with an average daily fluxes of 45.8 g/m^2.d. The organic matter, organic carbon and organic nitrogen contents of newly settling materials were in the range of 50.3-82.3 mg/g, 11.5-24.3 mgC/g and 1.35-2.92 mgN/g, respectively. Total fluxes of organic matter, organic carbon, and organic nitrogen were estimated to be in the range of 1.55-5.15 g/m^2.d, 336-1,251 mgC/m^2.d and 93 mgN/m^2.d. The annual fluxes of organic matter, organic carbon, and organic nitrogen

Table 1 Organic matter (Cm), organic carbon (Cc) and organic nitrogen (Cn) of suspended particulate matter (SS) and newly settling material (SI) obtained all year round in Yashima Bay.

Sampling Date	SS g/m^3	$Cm_{(ss)}$ mg/g	$Cc_{(ss)}$ mgC/g	$Cn_{(ss)}$ mgN/g	SI $g/m^2.d$	$Cm_{(si)}$ mg/g	$Cc_{(si)}$ mgC/g	$Cn_{(si)}$ mgN/g
9 JUN 92	6.63	176	49.8	8.25	37.9	82.3	18.0	2.12
7 JUL 92	5.64	188	50.5	7.17	67.3	66.6	15.7	1.94
7 AUG 92	6.11	229	82.6	12.83	51.4	78.6	24.3	2.75
9 SEP 92	8.27	225	82.5	14.46	57.5	74.4	20.1	2.43
13 OCT 92	8.54	118	38.0	5.63	72.5	71.0	17.0	1.92
11 NOV 92	6.70	104	34.0	4.27	66.4	50.3	11.5	1.35
26 DEC 92	6.53	129	40.3	5.67	38.6	62.6	14.1	1.58
13 JAN 93	6.50	144	43.7	7.13	34.0	73.2	15.4	1.74
10 FEB 93	6.07	178	50.2	8.02	22.0	70.5	15.2	1.89
11 MAR 93	4.93	168	56.7	8.32	36.8	70.5	16.9	2.17
13 APR 93	5.87	156	53.0	9.22	28.0	72.8	19.7	2.92
12 MAY 93	5.90	152	52.2	8.60	37.9	53.6	14.8	1.83

contents of newly settling materials were 1,146 $g/m^2.yr$, 284 $gC/m^2.yr$, 34 $gN/m^2.yr$.

Over the study period, the organic carbon content of particulate matter sample were ranged from 3.4 to 8.3% with consistently low values for material collected during autumn and winter (October to February), organic carbon content from sediment trap samples showed the same trend as particulate matter with the range from 1.2 to 2.4% whilst, samples from sediment cores had organic carbon content varied from 0.5 to 0.8% with a little higher in spring. The organic nitrogen content of particulate matter sample ranged from 0.6 to 1.4%, whereas sediment trap sample were 0.1-0.3% and surface sediment sample were in the range of 0.07-0.11%.

The fluxes of organic matter, organic carbon, and organic nitrogen showed similar pattern of changes which were low during winter and higher in late spring, summer and early autumn in the period of fish culture. The vertical fluxes of these components during yellowtail culture period were 944 g/m^2, 238 gC/m^2, and 24 gN/m^2, with 82-84% of organic material deposited for the whole year. The C:N ratio of suspended particulated matter were in the range of 5.7-8.0 which were elevated to the values in the range of 6.8-8.9 in newly settling materials which the high C:N ratio was corresponding to the period of fish culture. These findings indicated that this area was mainly received the organic matter from fish culture.

DISCUSSION

The suspended particulate matter consists of a variety of materials ranging from living organisms and organic detritus to clay minerals. In general, the suspended detritus will sink from the water column to the bottom sediment while the living phytoplankton vertically migrate in the water column. Therefore, most of the newly settling material is the accumulation of the suspended detritus rather than the living phytoplankton. Moreover, in fish culture area the excess fish feed and by-product from cultured fish will increase the bulk of materials deposited to the sea bottom. As the cultured fish is a predominant organism and its food origin is abundant, it is reasonable to expect that the measured particle fluxes in the water column of Yashima Bay is corresponding to the operation of fish culture. The amount of newly settling materials obtained all year-round, indicated that low bulk of material were trapped during February to May 1993 corresponding to the period of non-fish culture. However, in March 1993, fluxes of particulate materials were quite high thus, this input might be resulted from the resuspension of bottom sediments from the shallow perimeter of the bay by tidal current.

The C:N ratios were evaluated to investigate the fractionation processes acting at the bottom. From Table 2 the C:N ratios of suspended particulate matter were ranged from 5.7 to 8.0 comparatively, the C:N ratios of trapped material were ranged from 6.8 to 8.9. The high C:N ratios of suspended particulate matter were obtained in spring and summer coincided with the bulk of phytoplankton. Hedges *et al.* (1988b) suggested that a high C:N ratio indicated the composition of nitrogen-rich organic component. The compositional characteristics of the nitrogen-rich component along with the timing and apparent shallow depth of its introduction in the water column, are all consistent with a planktonic source exclude a primarily allochthonous origin. Redfield *et al.* (1963) reported a C:N ratio value of 6.7 for the average marine plankton, the range of 5.4-6.5 for phytoplankton (64-300 μm) sample collected during the study of Hedges *et al.* (1988a), and the range from 3.5 to 7.0 for phytoplankton (Parsons *et al.*, 1984). However, the newly settling materials in sediment trap consisted of little living organism, incorporated with leftover feed and fish faecal pellets. Moreover, some materials might resuspend from the bottom sediment and decomposition of organic matter by bacteria were found (Hargrave and Taguchi, 1978). These caused the C:N ratios of trapped material to become higher than those found in suspended particulated material. The increase in C:N ratios between suspended particulate matter and sinking particle indicated that suspended particulate matter is remarkably higher in nitrogen than the organic matter at the sediment surface, considering that proteins are more readily utilized than carbohydrates. The result was in agreement with Downs and Lorenzen (1985) who reported an increase in C:N from 7.2 for laboratory-grown *Thalassiosira weissflogii* to 8.8 for the faecal pellets of *Calanus pacificus* fed on this diatom and Chester (1993) who concluded that deep water particulate organic material consisted of two fractions: (a) a small-sized fraction, which made up the bulk of particulated organic material, only a few fraction of the deep water particulate organic material, probably a few percent, was composed of living material, and (b) a large-sized fraction, consisting mainly of faecal pellets and organic debris, which was utilized in the food chain. Iturrioga (1979) found the C:N ratios were increased from 8.1 at 10 m to 8.4 at 18 m of water depth.

Generally, the distribution profile of organic matter in the coastal sediments shows a relatively regular cyclic change with depth. For the input rate at the surface, the assumption of steady state is probably not valid because sedimentation, bioturbation, and decomposition vary seasonally, producing different contents of organic matter in the topmost layer over the year. However, Balzer (1984) suggested that organic matter content by dry weight in sediment decreased exponentially with depth, due to the bacterial decomposition, reaching an asymtotic value below a depth of 10 cm. Thus, it is reasonable to compare the annual

Table 2 Carbon, nitrogen component and comparison of C:N ratio between surface sediment (from sediment core), newly settling material (from sediment trap) and suspended particulated matter (from sea surface) in Yashima Bay.

Sample sources	Sampling date	Carbon mgC/g (dw)	Nitrogen mgN/g (dw)	C:N ratio
Sediment core	JUN 92	5.4	0.67	8.06
	AUG 92	6.4	0.80	8.00
	OCT 92	6.7	0.85	7.88
	DEC 92	5.5	0.71	7.75
	FEB 93	6.3	0.80	7.88
	APR 93	8.5	1.08	7.87
Sediment trap	9 JUN 92	18.0	2.12	8.49
	7 JUL 92	15.7	1.94	8.09
	7 AUG 92	24.3	2.75	8.84
	9 SEP 92	20.1	2.43	8.27
	13 OCT 92	17.0	1.92	8.85
	11 NOV 92	11.5	1.35	8.52
	26 DEC 92	14.1	1.58	8.92
	13 JAN 93	15.4	1.74	8.85
	10 FEB 93	15.2	1.89	8.04
	11 MAR 93	16.9	2.17	7.79
	13 APR 93	19.7	2.92	6.75
	12 MAY 93	14.8	1.83	8.09
Particulate matter	9 JUN 92	49.8	8.25	6.04
	7 JUL 92	50.5	7.17	7.04
	7 AUG 92	82.6	12.83	6.44
	9 SEP 92	82.5	14.46	5.71
	13 OCT 92	38.0	5.63	6.75
	11 NOV 92	34.0	4.27	7.96
	26 DEC 92	40.3	5.67	7.11
	13 JAN 93	43.7	7.13	6.13
	10 FEB 93	50.2	8.02	6.26
	11 MAR 93	56.7	8.32	6.81
	13 APR 93	53.0	9.22	5.75
	12 MAY 93	52.2	8.60	6.07

Table 3 The concentration of nutrients from Yellowtail culture area in Yashima Bay (JUN 92-MAY 93).

Sampling Date	PO_4 µg/l	$NO_2 + NO_3$ µg/l	NH_4 µg/l	TOC µg/l	TN µg/l	DIN µg/l	DON µg/l
9 JUN 92	12.1	41.3	147.9	203×10	204	189	15
24 JUN 92	13.9	49.0	169.9	199×10	268	219	49
7 JUL 92	16.7	75.6	53.0	176×10	257	129	128
21 JUL 92	18.9	81.9	263.8	171×10	378	346	32
7 AUG 92	17.4	43.0	287.7	181×10	343	331	12
27 AUG 92	16.7	75.4	192.2	206×10	287	268	19
9 SEP 92	10.5	16.7	201.0	166×10	241	218	23
25 SEP 92	20.4	110.9	110.4	179×10	373	221	152
13 OCT 92	28.2	118.5	93.1	187×10	340	212	128
27 OCT 92	37.8	144.4	83.1	192×10	347	227	120
11 NOV 92	36.6	182.5	53.5	176×10	409	236	173
25 NOV 92	44.6	218.4	50.6	182×10	407	269	138
13 DEC 92	31.9	135.6	49.7	199×10	352	185	167
26 DEC 92	28.5	125.1	44.3	181×10	284	169	115
13 JAN 93	27.3	134.5	44.8	176×10	324	179	145
25 JAN 93	22.9	109.8	40.8	172×10	249	151	98
10 FEB 93	15.5	47.9	36.3	163×10	235	84	151
26 FEB 93	11.5	14.0	18.6	178×10	257	33	224
11 MAR 93	10.5	8.3	19.2	177×10	270	27	243
26 MAR 93	10.2	16.4	21.6	171×10	266	38	228
13 APR 93	9.6	6.3	10.8	180×10	207	17	190
27 APR 93	10.8	8.5	19.1	156×10	185	27	158
12 MAY 93	11.5	12.5	18.5	137×10	161	31	130
25 MAY 93	9.4	8.0	15.8	157×10	265	24	241

average water column fluxes to the corresponding mean surface sediment (0-10 cm) accumulation rates in order to determine the extent of organic matter degradation at the water-sediment interface (Hedges *et al.*, 1988b). This comparison is illustrated in the form of ratios of water column to sediment accumulation flux (R). The percentages of degradation (%D) corresponding to these ratios is expressed as %D = 100(1-1/R). These calculations showed that 88% organic carbon and 90% organic nitrogen of particulate matter were degraded in the water column before it reached the surface sediment, whilst 62% organic carbon and 60% organic nitrogen of newly settling material, trapped at 1 m above sea bottom was still degraded near water-sediment interface before it was buried through the sediment. Thus, organic matter loading to surface sediment in Yashima Bay is either degraded in the water column or at the water-sediment interface before ultimate burial. This result is in agreement with the average C:N ratio from the surface sediment (0-7 cm) which showed fairly lower than those obtained from the traps. It is indicated that in yellowtail culture area the decomposition of organic matter and nutrient regeneration still occur on the surface sediment. There is a strong evidence that in the open ocean most of the nutrients are regenerated within the water column by *in situ* decomposition of organic matter before it reaches the bottom. On the shelf and in the other shallow water areas, however, regeneration involved the sediment surface because the settling time for organic detritus is relatively short and supply of organic matter is large (Suess, 1976).

Yellowtail culture and organic matter fluxes relationship were studied from the C:N ratio of newly settling materials obtained year-round. The C:N ratio during fish culture period was higher than non-fish culture period thus, it could be implied that in the time of fish culture period organic matter fluxes loading to the sea bottom might be resulted from either primary production from phytoplankton or fish culture activity.

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