水研センター研報，第19号，69－77，平成19年
Bull. Fish. Res. Agen. No. 19, 69-77, 2007

Effect of effluents from a new fish farming site on the benthic environment

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Abstract : In relation to improvement of the environment around fish (red seabream and yellowtail) farms in Shitaba Bay, Uwajima, Ehime Prefecture (Japan), about half of fish cages were shifted from the inside (ca. 20-50 m depth) to the outside (60 m depth) of the bay during May-November 2001. The spatio-temporal variability of the benthic environment at the newly established fish farm site was investigated, by analyzing the sediments at both the new (outside) and the old (inside) farm sites before and after the shift of fish cages. For example, the organic matter load from the new farm was measured to determine the assimilative capacity of the benthic ecosystem.

Acid volatile sulfides (AVS-S) of sediment at the center of the new farm were 0.03 mg/g dry weight in February 2001 without fish cages. As soon as the fish cages were set, AVS-S drastically increased (0.11 mg/g dry weight in July) and reached 0.26 mg/g dry weight in November when the fish cage shift had been completed. Moreover, AVS-S continued to increase and reached its maximum (0.46 mg/g dry weight) in April 2002. However, it remained at ca. 0.3-0.4 mg/g dry weight thereafter. Although AVS-S increased also at the edges and surrounding areas of the new site, concentrations were lower than those at its center. AVS-S increased slightly at areas over 50 m distance from the edges. Total phosphorus (TP) was about 2 times higher in the old farm site than that of the new farm site, while no marked differences of total organic carbon (TOC) and total nitrogen (TN) were detected between the two sites. TN and TP of sediment at the new farm site were slightly higher than concentrations observed in a pearl farm and a non-farming site (as reference sites).

From data on the amount of feed sold, production and feeding amount to cultured fish for some cages, about 50% (5,000 ton in dry weight) of the total amount of feeds sold by the fisheries cooperative association was consumed in the new farm site in 2002. These feeds may be reflected in the TOC, TN and TP flux caught using sediment traps set at 5 m depth above the bottom, which were equivalent to or more than the concentrations at the old farm site.

Thus, it was suggested that the AVS-S increase was largely due to effluent of organic matter (uneaten food and fecal) from fish farming activities closely linked with the shift of fish cages, and that the effect of the loaded organic matter on the benthic ecosystem was low in areas more than 50 m away from fish farming site.

Key words : New fish farming site, Organic matter lord, Benthic environment, AVS-S, TP

Recently, the impacts of coastal aquaculture on the environment become serious problems, and attentions on environmentally sustainable aquaculture production are increasing at local, national and international levels. So it is necessary to clarify the load processes of effluents from aquaculture for evaluating the effects of newly established fish farm sites on the benthic environments. However, few studies have been made so far on this subject in Japan.

In 2001, new fish farming site was established out of Shitaba bay, Uwajima, Ehime, for ensuring and

2006年６月26日受理（Received. June 26, 2006）
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promoting sustainable production of cultured fish by avoidance of environmental impact on a limited area. And also, it was estimated that organic matter lord would reduce inside the bay but the benthic environment would change at outside of the bay by increase of organic matter lord. It was expected to work out the environmental control plan of fish farming site, from quantitative relationship between organic matter lord and pollution in fish farming site by investigation of this process of change in detail.

So, the spatio-temporal variability in organic matters loaded from the new fish farm site was investigated, by the analysis of sediments and settling flux at both the new and the old farming sites before and after the shift of fish cages.

Materials and Methods

Shitaba bay is located at western coast of Shikoku Island, Uwajima and characterized by the intermittent inflows of warm water from the "Kuroshio" and cold water from the shelf slope (Takeoka and Yoshimura, 1988; Hashimoto *et al.*, 1995).

Fish farming in this bay started in 1960's, and at first, yellowtail *Seriola quinqueradiata* was the farming fish. Then aquaculture in this bay became more active and now beside yellowtail, red seabream *Pagrus major* and pearl oyster *Pinctada fucata martensii* are the common fish farmed here.

Before the shift of cages, all of them were situated inside the bay, about 20 to 50 m depth and total area of cages were about 43,000 m^2, maximum in regulation. After the shift, about half of cages (21,600 m^2) were set to the new site, which has a depth of about 60 m and other cages (21,382 m^2) were remained inside the bay, and rearranged.

Sampling and data analysis

The changes in benthic environment were investigated at 21 stations in and around of the new fish farming site, the old fish farming site and pearl oyster farming site (Fig. 1). Stn. 6 to 10 were located about 50 m, and stn. 11 to 15 were located about 200 m from edges of the new site.

At the 20 stations among them, sediment samples were obtained using gravity core sampler, for the analysis of acid volatile sulfide (AVS-S). Surface layer (0-1 cm) of AVS-S in sediment was measured with a H_2S absorbent columns (GASTEC, Kanagawa, Japan). Sediment were collected monthly at the stn. 1, 17 and 18 from February 2001 to September 2003 and at the other stations, February, July, September, November in 2001, January, May, July, September, November in 2002 and February, May, August in 2003.

Total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP) contents in sediment were analyzed. Sediment samples were obtained in the same way with AVS-S in August and September 2002, at the 5 stations in the new site and 2 stations in the old site. And 2 stations in pearl farming site (Stn. 19, 20) and 1 station outside of the farm sites as a reference site (Stn. 21) were added. Sediments were dried in 60℃ until it became constant weight and sieved with 0.25 mm mesh. After removal of carbonate with HCl (1N), TOC and TN contents were measured with CN coder. TP contents in sediment was measured with the following method. The sediment samples were autoclaved for an hour in a closed bottle with 4% potassium peroxodisulfate solution. The filtrate through GF/F was measured with auto analyzer (BRAN + LUEBBE, Germany).

And also, settling flux of particulate matter was measured with sediment traps (type Montani : Montani *et al*, 1988) set at 5 m above the bottom. At 1 station in the new site (Stn. 16), 1 station in the old site (Stn. 17) and 1 station in the pearl site (Stn. 20) from April 2002 to January 2003 almost monthly. Traps were set in the water during 24 hrs, then taken to the laboratory and settling flux of particulate matter was collected on GF/F filter which was combusted in 450℃ during 2 hrs. The filters were dried in 60℃ until it became constant weight, then weighed. On a part of samples, TOC, TN, TP contents were measured with the same method as the sediment samples.

Feeds consumed to the new and old fish farm site in 2001 and 2002 were calculated from the feed sold data of fishermen's cooperative association, stock number of farming fish and feeding amount to cultured fish for some cages. The monthly amount of feeds to the each sites were calculated from below method.

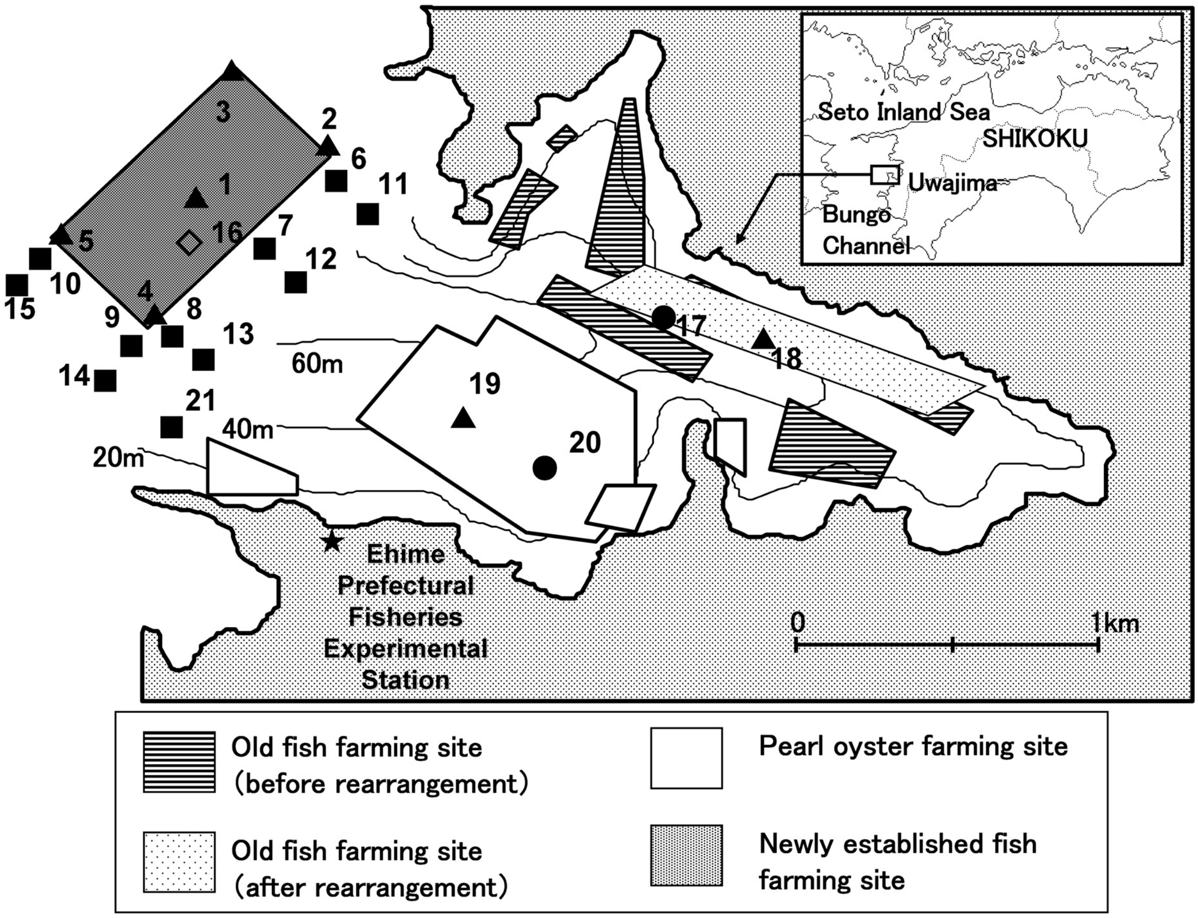

Fig. 1. Map showing sampling stations and farming sites. Stations were shown with following simbols by investigated parametersthere.
● : AVS, TOC, TN, TP and settling flux. ▲ : AVS, TOC, TN and TP
■ : AVS ◇ : Settling flux

$Xn = A \times \Sigma (Bij \times Cij) / (\Sigma (Bij \times Cij) + \Sigma (Bij \times Dij))$

$Xo = A \times \Sigma (Bij \times Dij) / (\Sigma (Bij \times Cij) + \Sigma (Bij \times Dij))$

Xn: Monthly amount of feeds consumed in the new fish farming site.

Xo: Monthly amount of feeds consumed in the old fish farming site.

A: Monthly amount of feeds sold by the fishermen's cooperative association. It was converted to dry weight.

Bij: Monthly feeds consumption by fish kind and age per thousand fish, from some cages. They were converted to dry weight. (Yellow tail was cultured from 2000 to 2002 and red seabream was cultured from 2001 to 2003)

i, yellow tail, red seabream

j, age0, age1+

Cij: Regulation maximum number of fish per cage decided by fishermen's cooperative association × number of cages by fish kind and age in the new fish farming site in September 2002.

i, yellow tail, red seabream

j, age0, age1+

Dij: Regulationary maximum number of fish per cage decided by fishermen's cooperative association × number of cages by fish kind and age in the old fish farming site in September 2002.

i, yellow tail, red seabream

j, age0, age1+

The shift of cages was carried out from May to November in 2001 and it was assumed the cages were shifted in a fixed pace for this period. And the feeds to the new site were calculated by multiplying below number to the monthly feeds with above method.

Mn/7

Mn = progress months number from April (from Jan. to Apr. is 0 ; Nov. and Dec. is 7)

Feeds consumed in the old site for this period were calcultated taking feeds to the new site from monthly feed sold data.

Results

Organic matter lords and AVS-S

Fig. 2 shows the change in AVS-S content of sediment at the newly established fish farming site and surrounding areas from February 2001 to December 2003. At the center of the new site (Stn.1), AVS-S content was 0.03 mg/g dry weight in February 2001 when there was no fish cages. As soon as the fish cages were set in May, AVS-S drastically increased and it reached 0.26 mg/g dry weight in November when the fish cage shift had been completed. Moreover, AVS-S continued to increase and topped in 0.46 mg/g dry weight in April 2002 and after that, it kept about 0.3-0.4 mg/g dry weight until August 2003. AVS-S contents increased in the similar way at the edges and surrounding areas of the new site. But the contents were lower than the center.

Feeds to the new and old fish farming site were estimated for 2001 and 2002. Amount of feeds sold by fishermen's cooperative association were 8,742 dry ton in 2001 and 9,776 dry ton in 2002. But in 2001, when the shift of cages was carried out, there is no data for exactly number of fish cages for calculation of organic matter lord. Monthly feed consumption in the both fish farming sites became minimum in April, then increased until September, and it became almost constant until December, thereafter. This quantitative change of feeds shows similar tendency every year. Moreover, it was estimated about 5,000 ton in dry weight of feeds were consumed in the new site in 2002 after the completion of the shift, this number was nealy equal to the it in the old site in this year. Estimated organic matter lords to the new fish farming site were gradualy increased from May to November in 2001 and AVS-S at Stn. 1 also increased in the similar way of feeds consumption (Fig.3).

Fig. 4 shows a comparison of AVS-S between the center of the new fish farming site and the old site. In the old site AVS-S content was about 0.3-0.5 mg/g dry weight before the shift of cages. Even though after the shift, AVS-S content remained constant for about 3 years in the similar value, it didn't decrease.

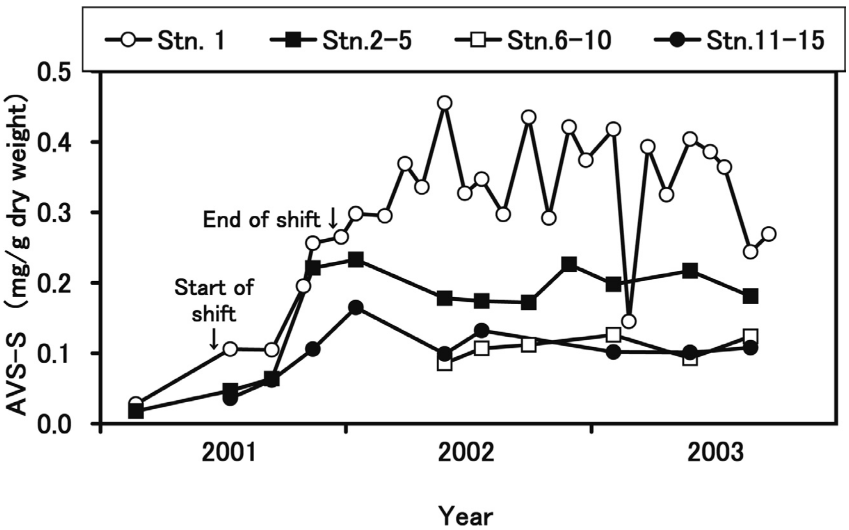

Fig. 2. Change of AVS-S in and around new fish farming site out of Shitaba bay

-○-: Stn. 1 (Center of new fish farming site)

-■-: Average of Stns. 2-5 (Edges of new fish farming site)

-□-: Average of Stns. 6-10 (50m away from the edge of new fish farming site)

-●-: Average of Stns. 11-15 (200m away from the edge of new fish farming site)

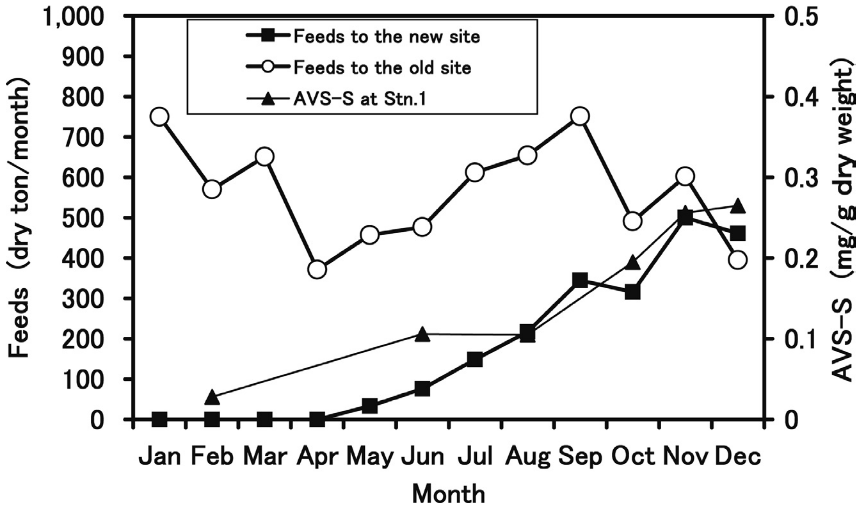

Fig. 3. Change in feeds used to new and former fish farming sites in 2001 Value were converted to dry weight for each site per month.

■ : Feeds used to new fish farming site per month
○ : Feeds used to former fish farming site per month
▲ : Monthly change of AVS-S at Stn. 1

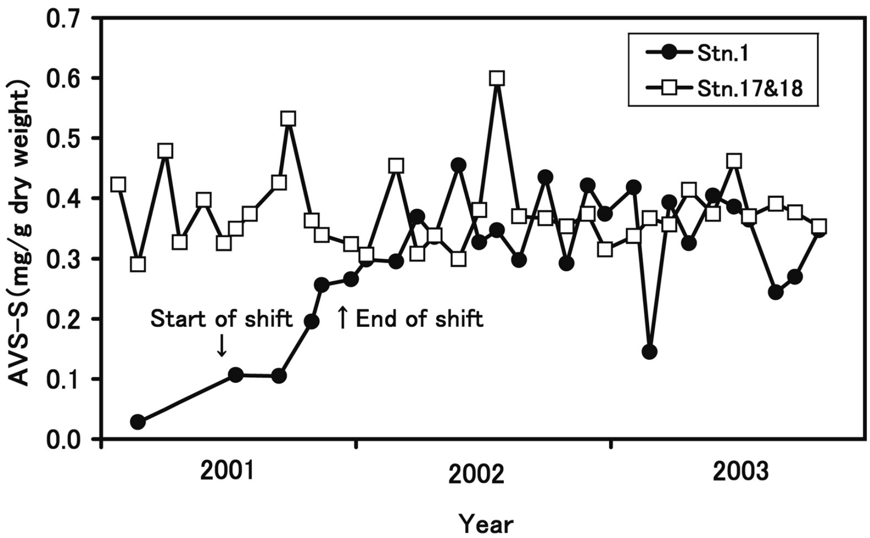

Fig. 4. Change of AVS-S in new and former fish farming sites from january 2001 to August in 2003

● : Stn. 1 (Center of new fish farming site)
□ : Average of Stns. 17 and 18

TOC, TN and TP content in sediment and settling flux

TOC, TN and TP content in sediment have been used for the indicators of artificial effect to benthic environment similarly to AVS-S. TOC content was 14.1-14.5 mg/g dry weight in the new fish farming site, 12.2 mg/g dry weight in the pearl farming site, 13.5 mg/g dry weight in the non-farming site and 15.1 mg/g dry weight in the old fish farming site (Fig. 5). TN content was 1.7-1.8 mg/g dry weight in the new site, 1.5 mg/g dry weight in the pearl site, 1.5 mg/g dry weight in the non-farming site and 2.0 mg/g dry weight in the old site. TP content was 0.6-0.7 mg/g dry weight in the new site, 0.5 mg/g dry weight in the pearl farming site, 0.5 mg/g dry weight in the non-farming site and 1.5 mg/g dry weight in the old site. TP was about two times higher in the old site than the new site. Although, TOC and TN content were slightly higher in the old site, no marked differences were detected between all the sites. In contrast, TP content is remarkably high in only the old site.

The settling flux of TOC, TN and TP was measured from April 2002 to January 2003. Fig. 6 shows TP content among them. TP content in the settling flux was 91-263 mg/m^2/day in the new fish farming site. It increased from April to October, similarly to the trend of feeds amount. In the old fish farming site, TP content in the settling flux topped in 299 mg/m^2/day in December, but it varied widely compared to the new site. And also, the TP content in the settling flux in the new site was higher than in the old site, except for December. On the other hand, TP content in the settling flux in the pearl oyster farming site was lower compared to both fish farming sites, except for May and June. And it was 12-50 mg/m^2/day for the investigation period. TP was higher in the both fish farming sites than the pearl oyster farming site.

Fig. 7 shows the change of TP content in sediment in the old fish, new fish and pearl oyster farming sites from February 2001 to February in 2003. In the old site, though sediment TP was remarkably higher than the other sites in all investigations, it continued to decrease from July 2001. At first, there was no difference between stations in and around the new fish farming site, but at the center of new site, it increased slightly, in contrast to the other stations.

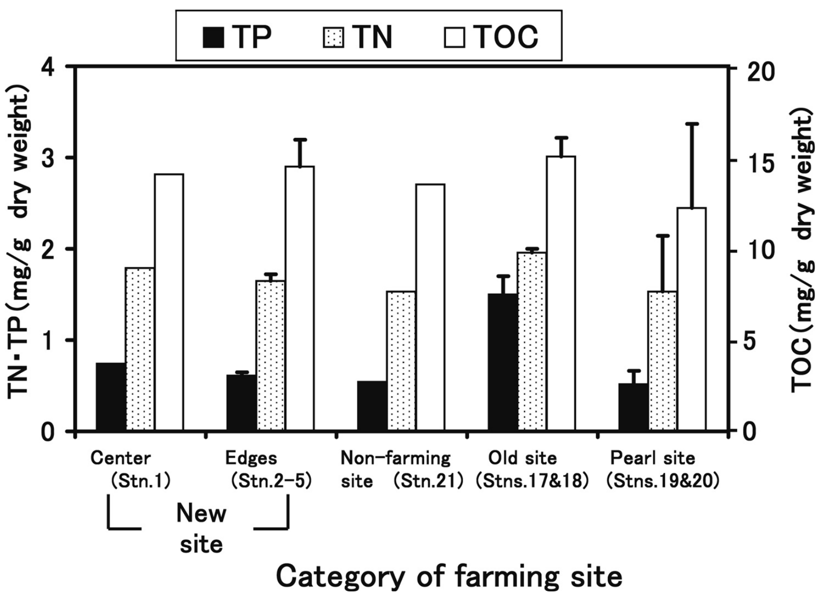

Fig. 5. TOC, TN and TP concentrations in sediment in new fish, former fish and pearl oyster farming sites.

Vertical lines indicate the standard deviations. Samples were collected in August and September in 2002

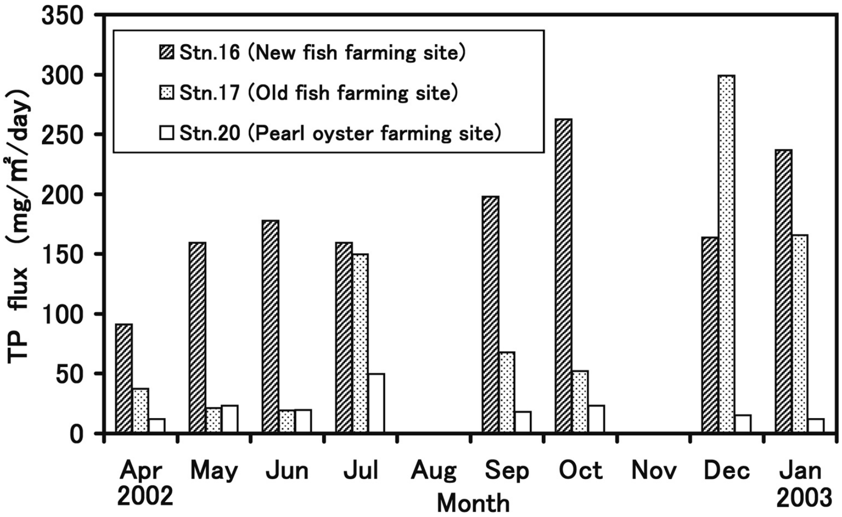

Fig. 6. TP concentration in settling flux to bottom in new fish, former fish and pearl oyster farming sites.

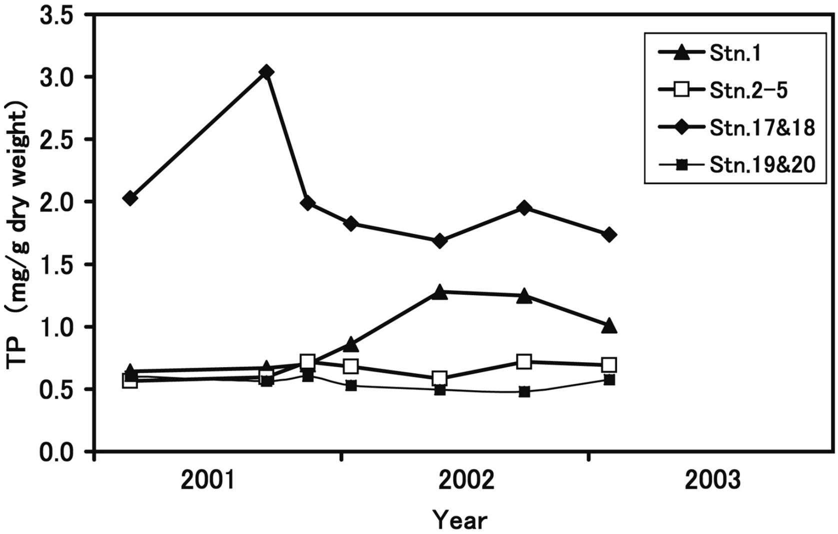

Fig. 7. Change of TP concentrations in sediment from February 2001 to February 2003

▲ : Stn. 1 (Center of new fish farming site)

□ : Average of Stns. 2-5 (Edges of new fish farming site)

◆ : Average of Stns. 17 and 18 (Former fish farming site)

■ : Average of Stns. 19 and 20 (Pearl oyster farming site)

Discussion

It is necessary to keep balance between organic matter lord and it's decomposition for sustainable production of aquaculture. So, the environment of fish farming site should be monitored with appropriate method. Until now, many indicators were proposed to evaluate the impact of aquaculture on the environment (Yokoyama, 2000). Among them, AVS-S is one of the most common parameter, used to many investigations in Japan, from it's easiness to measure and unnecessary expensive tools (ex. Tsutsumi and Inoue, 1995; Pawar *et al.,* 2001; Yokoyama, 2002 etc.). On the other hand, most of these investigations were carried out in the old fish farming sites established many years ago, there was not so much examples of investigations of AVS-S against to increasing of organic matter lord by establishment of new fish farming site. And it was insufficient to clarify quantitative relationship between organic matter lord and change of benthic environment. So, it was expected to establish the method to control benthic environment in and around fish farming sites, by examination of AVS-S and organic matter lord in 2001.

The shift of fish farming cages to the new fish farming site was carried out from May to November 2001. AVS-S in the new site were very low before the shift of fish farming cages, but AVS-S drastically increased at the same time with the start of shift of cages to the new site. This rise of AVS-S in the new site suggest increase of organic matter lord with the shift of cages. Usually in this investigation area, fish seeds for aquaculture were introduced in Spring and begun to take from the next Autumn. In the new site, it seems that organic matter lord increased due to shift of fish cages, rise of feed consumption with growth and high water temperature more than 19.6℃ from May to September in 2001. Artificial organic matter lord to the new site increased from 0 to the level shown in Fig. 3 in November in 2001, when cage's shift was completed. It was obviously that AVS-S increased consistently with increasing feeds used from April to November. This result indicates that AVS-S of sediment is one of the most appropriate indicators.

On the other hand, rise of AVS-S were recognized at the edge of the new fish farming site but at the stations from the edge more than 50m, the rise was slight. It was indicated that the effect to benthic environment from fish farming cages was limited within 50m from the cages (Kubota, 1977). This agree with the investigation of the new fish farm site of Shitaba bay.

Before this investigation, it was expected that the sediment AVS-S would decrease in the old site after the shift. The effect of shift of fish cages on the benthic environment has not been found yet. As mentioned above, the effect from the new fish farming site was limited within about 50 m. In this investigation, the stations in the old fish farming site were situated just under the fish cages, it was thought that there was not major change of organic matter lord from cages. For the estimation of removal of fish cages from inside the bay, it is needed to continue the investigations added other stations far from fish cages more than 50 m.

Not only AVS-S but also TOC, TN and TP contents are often used for the indicators of benthic environment. There were not large difference about TOC and TN contents in the sediment between the new and the old fish farming sites. But, only TP content in sediment among these three parameters was always 2 times higher in the old site than that of the new site in this investigation. Though, the amounts of the feeds consumed in the new and the old sites were nearly equal in 2002.

To clarify the reason for this difference, the settling flux of particulate was measured, near the bottom in the new, old and pearl oyster farming site. TP content in the settling flux was higher in the both fish farm sites than that of the pearl oyster farm site. But TP content in the settling flux in the new site was higher than in the old site, except for one month. This result show that though the sediment TP in the old site was quit high compare to the other sites, the settling flux of TP in the new and old sites are almost equal or higher in the new site.

The main material of fish feeds is fish meal, including large amount of phosphorus derived from fish bones (Satoh, 2003). Decomposition of phosphorus derived from fish bone would occur slowly, so they would remain in the sediment for a long time. Most of it is the poor solubility (Satoh, 2003), and the possibility of the storage to the sediment has been indicated. So, it was estimated that the TP concentration of sediment will keep increasing in the new fish farming site during the fish culture was continued.

AVS-S in sediment is an appropriate indicator for monitoring the quick response of the benthic environment to the organic matter lords from fish farming. The response of the sediment TP concentration to the influent from fish farm is quite slow compared to AVS-S. So, TP in sediment is an appropriate indicator of long time influent from fish farming.

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Acknowledgements

We are gratefully acknowledges Dr. Kazumasa Hirakawa, Hokkaido National Fisheries Research Institute Fisheries Research Agency, for his many helpful comments.

We are grateful to Dr. Yuichi Hayami, Center for Marine Environmental Studies (CMES), Ehime University, for his comments and suggestion.

The research presented in this paper was made possible by grant from the Japanese Fisheries Agency.