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Water and Sediment Characteristics in the Shellfish Farms of the Western Part of Jinhae Bay

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The environmental characteristics in shellfish farms were investigated in the western part of Jinhae Bay, 1996. During summer, anoxia and high nutrient concentrations were found in the bottom waters of shellfish farms. The concentrations of particulate organic species in seawaters were enriched, showing an average 57.44 μM for POC, an average 5.45 μM for PON, and an average 0.42 μM for PP. The sediments environment in the farms was very polluted. The concentrations of COD and AVS were more than 20 mg/g.dry and 0.5 mg/g.dry, respectively. The total sedimentation rate was high as an average 7.81 g/m²/day with organic matter contents of 26%. Oxygen consumption rate was similar to polluted area as an average of 439 mg/m²/day. Nutrient release rates were an average of 8.25 mg/m²/day for nitrogen and an average of 1.38 mg/m²/day for phosphorous. The cluster analysis through environmental data in summer indicated that DO, nutrient in the bottom water, and AVS in the sediment were important factors to characterize the polluted environmental site.

Key words: environmental characteristics, shellfish farms

Introduction

The western part of Jinhae Bay is a typical semi-enclosed bay in Korean coast. This bay is one of the most productive areas for filter feeding mollusks such as oyster, ark shell, and mussel which grow by uptake of suspended particles in the seawaters. However, recently, eutrophication progressing in this area has caused frequent outbreaks of red tide and formation of oxygen deficient water in the bottom layer. Consequently marine environment has been deteriorated and production has decreased. Domestic and industrial wastes have played an important role in marine pollution occurred in Jinhae Bay and self-pollution by culture organism also have been determined to be secondary cause of marine pollution.

A substantial amount of organic materials, mainly in the form of faeces from the shellfish farms, is released into the environment. These organic materials accelerated the eutrophication in the bay. In several cases, this organic enrichment has caused serious environmental problems such as outbreaks of red tides and oxygen deficient water mass and deteriorated the sediment environment (Uyeno et al., 1970; JFRPA, 1977; Takimoto, 1984; Hall et al., 1990; Johnsen et al., 1993; Tanimoto, 1997). Eutrophication related effects have been reported in many coastal environments (Yamada et al., 1981; Kadowaki et al., 1984; Seiki et al., 1985; Joh, 1989; Johnsen et al., 1993; Kim et al., 1996). In fact, Jindong Bay and Goangdo Bay which belong to the western part of Jinhae Bay have been affected by eutrophication and oxygen deficient water in the bottom water (Hong, 1987; Lee et al., 1993). Due to the deteriorated environment, the productivity of farms was lowered and mortality of the cultivated organisms increased. In this paper, the environmental impact on the shellfish farms induced by organic matters such as faeces was investigated by the analysis of water and sediment quality including phsico-chemical parameters, sedimentation rate, oxygen consumption rate, and nutrient release rate.

Materials and Methods

Study area and sampling scheme

Monthly samplings were taken at seven stations of the shellfish farms of Jindong Bay (St. 1~5)

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and Goangdo Bay (St. 6~7) which are located in the western part of Jinhae Bay from February to October, 1996 (Fig. 1). Jindong and Goangdo Bay show very weak current velocities of <0.1 kn (Hydrographic Office, 1982). The depths are 10~15 m for Jindong Bay and 18~20 m for Goangdo Bay.

On each sampling occasion the vertical profiles of water temperature, salinity, pH, and dissolved oxygen (DO) were recorded by Water Analyzer (HydroLab Surveyor III).

Water parameters and the suspended particles

Water parameters: Seawater samples from surface, middle, and bottom layers were filtered through 0.7 μm GF/F filter for nutrients and 0.45 μm membrane filter for chlorophyll-a. Nitrite, nitrate, ammonia, phosphorous, and chlorophyll-a were analyzed according to Parsons et al. (1984). Chemical oxygen demand (COD) was determined using the permanganate method.

Particulate organic matter: Particulate organic carbon (POC) and particulate organic nitrogen (PON) were analyzed according to Gasshölf et al. (1983) with a CHN analyzer (Perkin-Elmer model 2400). Particulate organic phosphorous (PP) was analyzed using acid digestion.

Sediment parameters and organic matters

Sediment parameters: Chemical oxygen demand (COD) and ignition loss (IL) were measured according to Park et al. (1985). Acid volatile sulfide (AVS) was detected in a Gastec after the addition of acid.

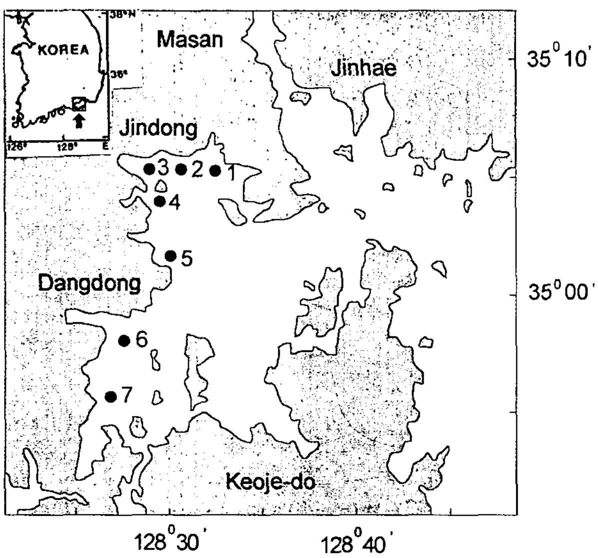

Fig. 1. Location of sampling stations in the western part of Jinhae Bay

Total organic matter: Total organic carbon and nitrogen were analyzed according to Gassholf et al. (1983) with a CHN analyzer (Perkin-Elmer model 2400).

Sedimentation rate, oxygen consumption rate, and nutrient release rate

Sedimentation rate (SR): To measure SR, a sediment trap, which consisted of 4 individual trap-tubes (inner diameter: 70 mm, height: 600 mm), was deployed at 3 m above sea bed during 10~14 days. Particulate organic matter (POM) was determined using the IL method. The sedimentation rates of POC and PON were measured in CHN analyzer and PP was analyzed using acid digestion method.

Oxygen consumption rate (OCR) and nutrient release rate (NRR): In Jindong Bay (St. 3), OCR was calculated by dividing the difference between the initial DO concentration and the DO concentration at the elapsed time into the area of *in situ* chamber and NRR was also calculated on nutrient change during 5 days. DO was measured daily using DO meter (YSI 55) and nutrients was analyzed on subsamples pumped from *in situ* chamber (length: 500 mm, width: 500 mm, height: 500 mm) in sea bed.

Cluster analysis

The environmental characteristics between farms were estimated through cluster analysis with data of the DO concentrations in the surface, middle and bottom waters, nutrient concentrations in the bottom water, and COD, IL and AVS concentrations in the sediments during summer. Cluster analysis was performed with SPSS program (Version 7.5). Standardization of the data by z scores was performed automatically in the program.

Results and Discussion

Seawater environment

anoxic water mass and nutrient

Water temperature and salinity differences between surface and bottom water layer, and the DO concentrations in the bottom water measured monthly are shown in Fig. 2. Thermocline appeared at St. 1~7 in May with the water temperature

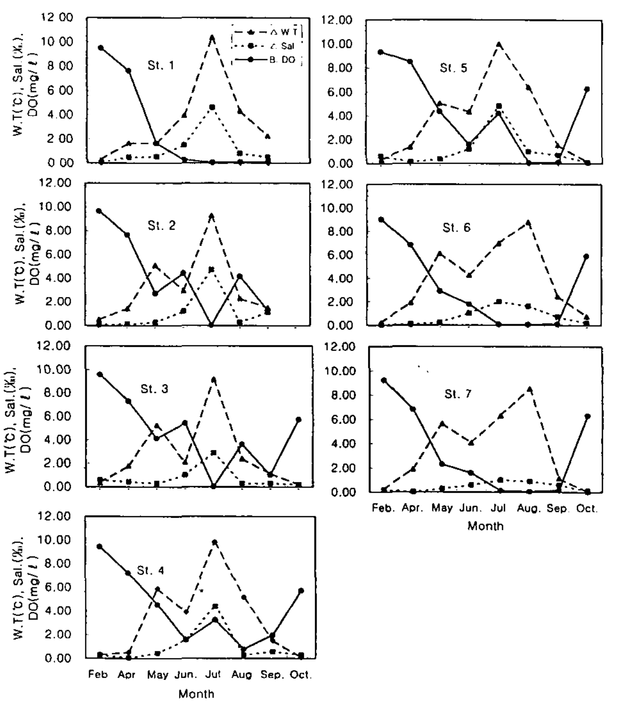

Fig. 2. Monthly variation of water temerature and salinity difference between the surface and the bottom (△ W.T and △ Sal.) and DO concentration in the bottom layer (B. DO) in the shellfish farms.

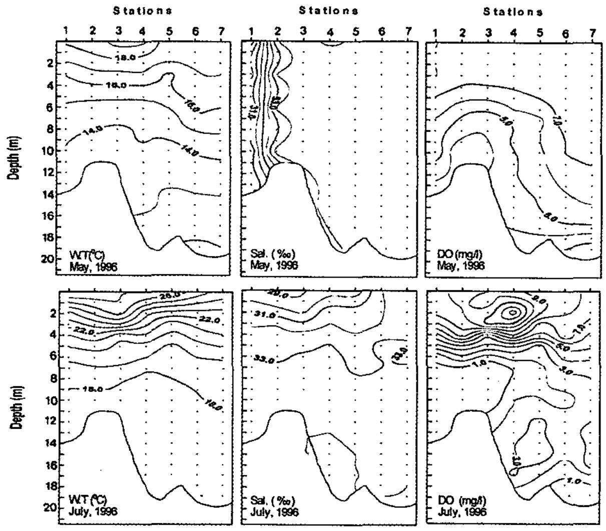

Fig. 3. Vertical distribution of water temperature, salinity and dissolved oxygen with station.

differences of 4.68~6.11℃, and became stronger in July with those of 6.31~10.37℃. Salinity showed a difference of only less than 1‰ at all stations except for July with a difference of about 4‰ at St. 1, 2, 4 and 5. Oxygen deficient water occurred in May and existed until September. During the period of strong stratification, DO concentrations in the bottom water of St. 1, 2, 3, 6 and 7 indicated anoxia close to zero. In St. 4 and 5, the low DO concentrations of about 1 mg/l appeared in the middle layer. According to the vertical distribution profile of water temperature, salinity, and DO in May and July (Fig. 3), the water temperature of about 18℃ in the surface layer decreased rapidly to about 14℃ at 5~6 m in May and about 27℃ to about 23℃ at 3~6 m in July. Salinity with depth showed a constant level of more than 31.00‰ at all stations in May, while the salinity of below 30.00 ‰ in the surface increased to about 33.00‰ at 5~6 m of St. 1, 2, 3 and 4 in July. Oxygen deficient water was formed at 1~2 m upper surface sediment in May and extended to 6~7 m depth in July. Particularly, anoxia appeared in overlying water of sediment at St. 1, 2, 3, 6 and 7 in July. These results suggest that oxygen deficient waters formed at St. 1~7 depends on mainly by water temperature. Joh (1989) also reported similar data in Osaka Bay. Development of the oxygen deficient water mass in Osaka Bay was closely related to the temperature difference between the surface and the bottom water.

One factor of environmental impacts caused by oxygen depletion in the bottom water layer is the change of nutrient in the bottom. During the summer anoxia, 70% of the hypolimnetic accumulation of NH_4^+ is accounted for by diffusion from the sediments. This proportion is comparable to 54% for total P (Carignna and Lean, 1991). Distribution of phosphorous and ammonia concentrations in seawaters are given in Fig. 4. During vertical mixing periods, the concentration of phosphorous and ammonia were low at all layers in all stations, showing below 0.50 μM and 5.00 μM, respectively. However, when a strong stratification was formed in July, concentration of nutrients in the middle and the bottom layers increased. Particularly, at St. 1, 2 and 3, phosphorous and ammonia in the bottom layer of showed high values more than 2.00 μM and 25.00 μM, respectively. Handa and Takeo (1981) reported the similar results that concentration of phosphorous and ammonia reached to a maximum below DO concentration of 2.00 mg/ℓ, decreasing toward surface layer.

Variation of particulate organic matter

Fig. 5 presents the distribution of POC, PON, PP, and chlorophyll-a concentrations in seawaters.

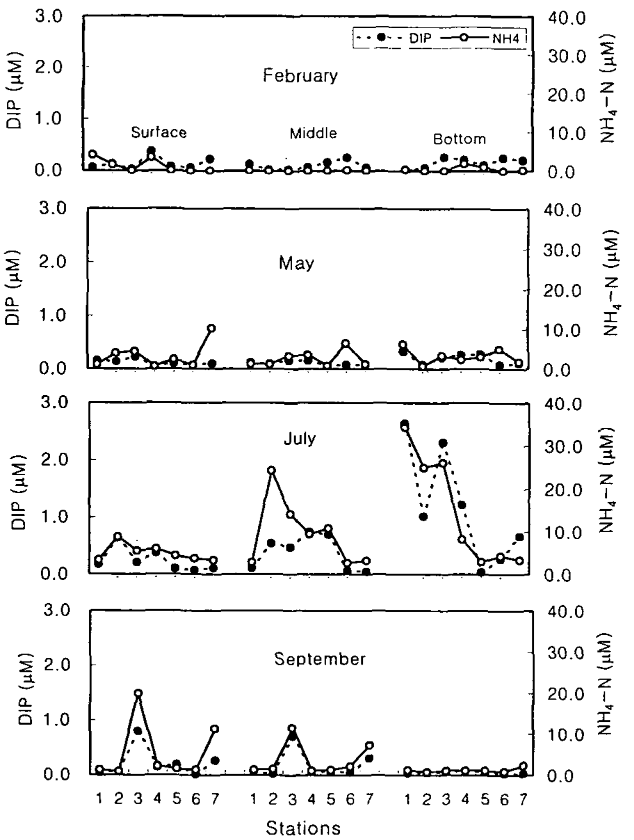

Fig. 4. Distribution of dissolved inorganic phosphorous (DIP) and ammonia (NH_4-N) concentrations in the seawaters of the shellfish farms.

Particulate organic components were in the range of 22.33~189.95 μM (mean 57.44 μM) for POC, 2.29~12.77 μM (mean 5.45 μM) for PON, and 0.18~1.02 μM (mean 0.42 μM) for PP. High values of those components were found in July, while low values in September and October. In distribution of POC and PP, St. 1, which was the inner-most site of all stations as shown in the map, was recored the highest concentrations, while St. 4 the lowest concentrations. PON concentration was similar at all the stations.

Generally POC concentration varies over a wide range in the ocean. Particularly high concentration between 43.33~209.16 μM were observed in the coastal and estuarine waters of Goa (Verlencar and Qasim, 1985). The POC and PON concentrations of Asan Bay which is a highly polluted area in Korea were also in the range of 16.68~174.25 μM and 0.57~26.54 μM, respectively (Moon et al., 1993). The Nakdong estuary with an excessive input of terrestrial organic matters showed that POC and PON concentrations were in range of 4.58~54.00 μM and 2.14~11.07 μM, respectively (Choe and Chung, 1972). Therefore these results indicated that the particulate matter values of these aquaculture farms were similar to or close to those of the above-mentioned polluted areas. Chlorophyll-a concentration ranged from 0.50 to 18.46 μg/ℓ, increasing in summer at all the stations. Particulate material contains both living and non-living organic matter. To estimate each of the living and non-living fractions in terms of the total POC, POC/Chl.a ratio was estimated (Fig. 6). A linear relationship between POC and chlorophyll-a was evident from data treated irrespective of the season at all the stations. POC/chlorophyll-a ratio was 61.62. This value was higher than the mean ratio of 47.2 in estuarine region reported by Verlencar and Qasim

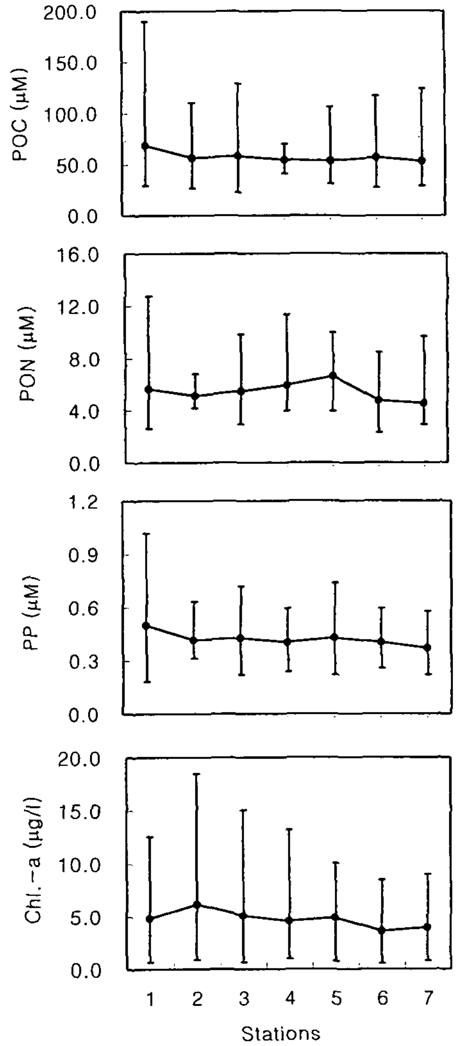

Fig. 5. Distribution of particulate organic carbon (POC), nitrogen (PON), phosphorous (PP), and chlorophyll-a (chl.-a) concentrations in the seawaters from the shellfish farms.

(1985). The carbon content in phytoplankton will be a variable fraction of the total POC and that fraction is roughly proportional to POC. The phytoplankton carbon/chlorophyll-a ratio will vary as a function of isolation and ambient nutrient levels, as well as with the temperature.

It is well known that ratio of POC/Chl.a was 42 for the diatom bloom and 78~209 for the dinoflagellate blooms (Epply et al., 1977). Fig. 7 shows that C/N ratio of 10.84 was higher than that of Redfield's ratio of 6.6 (Redfield et al., 1963) for living matter. Particulate organic matter can be brought by terrestrial organic matters through rivers or by atmospheric inputs to the oceans, but the major part seems to originate from *in situ* production of living organisms. C/N ratio in the phytoplankton generally ranged from 3 to 7 (Antia et al., 1963) and high C/N ratios over about 10 resulted from an influx of terrigenous material (Flemer and Biggs, 1971). Increased detrial organic matter also resulted in high C/N ratios (Kang et al., 1993)

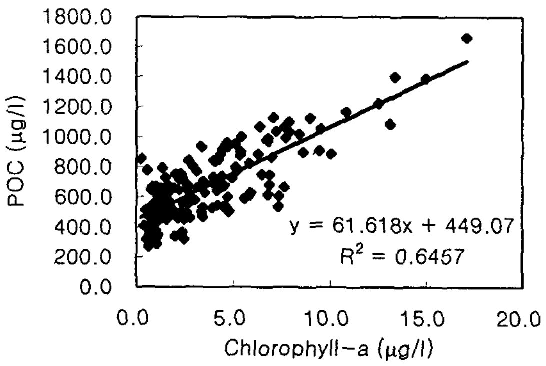

Fig. 6. Correlation between particulate organic carbon and chlorophyll-a concentrations in the surface water of the shellfish farms.

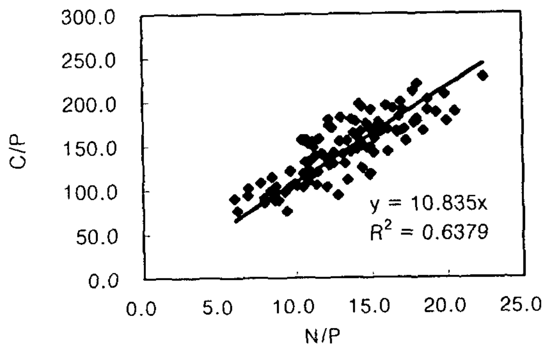

Fig. 7. Correlation among particulate organic carbon, nitrogen and phosphorous in the seawaters of the aquaculture farms.

Sediment environment

Distribution of ignition loss, chemical oxygen demand, and acid volatile sulphide values are given in Fig. 8. Organic components concentrations were in the range of 7.10~25.00% for IL, 3.11~48.08 mg /g.dry for COD and 0.07~2.12 mg/g.dry for AVS. The maximum values of COD were observed at St. 1. Mean value of COD at all the stations exceeded 20.00 mg/g.dry of Japanese sediment standard (JFRPA, 1972). IL contents had levels of more than 10% at seven stations. The AVS concentrations of indicative component of the polluted sediment were an average more than 1.00 mg/g.dry at St. 2, 3, 4 and 6. St. 1, 5 and 7 also exceeded 0.20 mg/g.dry of Japanese sediment standard (JFRPA, 1972). Murakami (1975) pointed out that abundant organic matters in sediments are responsible for forming the anoxia in the bottom of the aquaculture farms. His conclusion is supported by our observation that almost all stations in shellfish farms were observed to have oxygen deficient water during summer. It is clear that the sediment derived from the farm is extremely organic-rich, highly

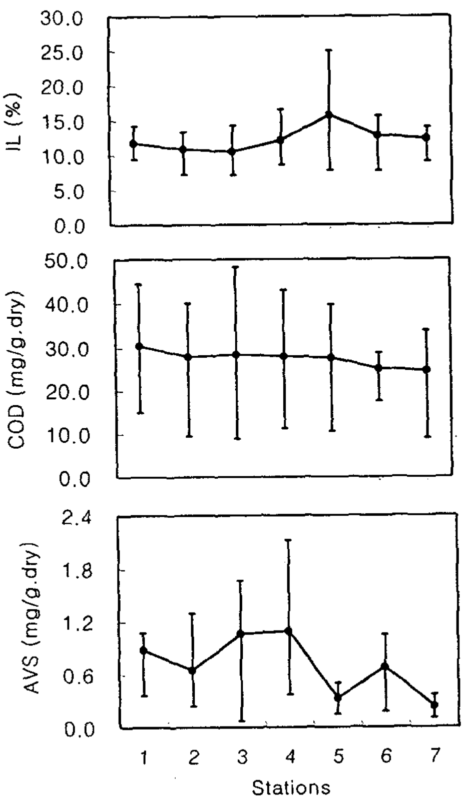

Fig. 8. Distribution of contents of ignition loss (IL), chemical oxygen demand (COD) and acid volatile sulfide (AVS) in the sediments of the shellfish farms.

Table 1. Sedimentation rates of POM, POC, PON and PP measured using sediment trap at 3 m above sea bed in the shellfish farms

Month	Site	Sedimentation rate				
		Total	POM	POC	PON	PP
		(g/m²/day)		(mg/m²/day)		
May	St. 4	4.26	1.15	295	56	14.70
	St. 6	3.27	1.16	272	44	13.20
July	St. 4	8.29	2.93	1,054	187	18.21
	St. 6	3.95	1.69	657	108	10.23
August	St. 4	9.16	2.70	993	167	6.94
	St. 6	7.58	2.58	801	80	13.59
September	St. 4	4.43	2.60	529	133	3.08
	St. 6	5.10	1.18	934	139	16.20
November	St. 4	21.29	2.55	1,009	125	–
	St. 6	10.73	1.99	1,487	195	–

reducing and very sulfidic (Hall et al., 1990). C/N ratio by atoms was 4.23 (Fig. 9). A similar ratio also was reported in yellowtail farms by JFS (1977). According to JFS (1977), C/N ratios were low as 4~5 in the sediment below the net due to undegradable matters and high as 8~9 in 100 m outside from nets.

Sedimentation

Sedimentation rate of POM, POC, PON, and PP are given in Table 1. The total sedimentation rates were in the range of 3.27~21.29 g/m²/day (mean 7.81 g/m²/day) with organic matter contents of 26%. A high total sedimentation rate was remarked in November. However, the POM sedimentation rates were similar during survey period. Sedimentation rates were higher at St. 4 of Jindong bay than at St. 6 of Goangdo Bay. Sedimentation rates with components were an average of 803.10 mg/m²/day for carbon, 123.40 mg/m²/day for nitrogen, and 12.02 mg m²/day for phosphorous. POC sedimentation rate varied over a wide range, showing a high level in November, while PON and PP sedimentation rates had a similar level during the survey period.

Total sedimentation rate of the shellfish farms in this area was close to that of Hiroshima Bay which was highly eutrophicated with rate, ranging from 3.29 to 10.14 g/m²/day. However, it is noted that sedimentation rates of POC, PON and PP were higher than those of Hiroshima Bay as shown by Seiki et al. (1985).

Oxygen consumption rate and nutrient release rate

Fig. 10 shows the oxygen consumption rate and nutrient release rate measured using *in situ* chamber at St. 3. Oxygen was depleted in the chamber within the first day after the experiment and oxygen fluxes were constant from the third day after the installation. Nutrient fluxes were strongly

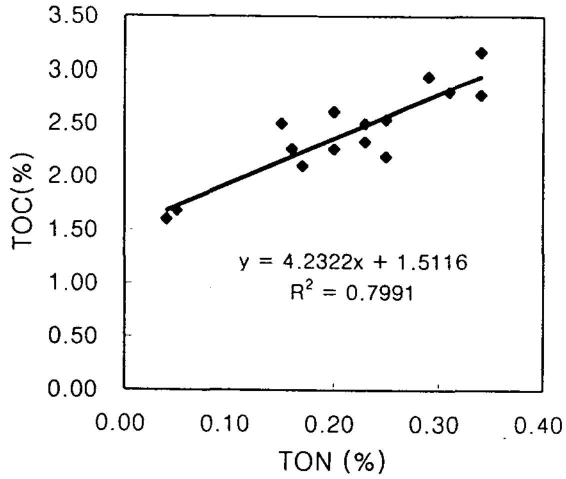

Fig. 9. Correlation between total organic carbon and nitrogen in the sediments in April.

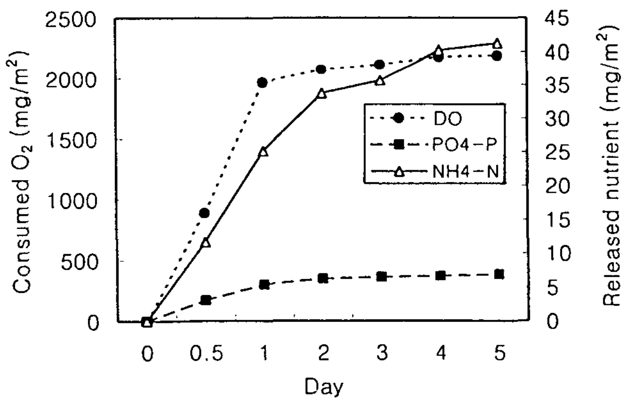

Fig. 10. Oxygen consumption rate and nutrient release rate measured using *in situ* chamber at St. 3 during 5 days (Sep. 16 - Sep. 20).

Table 2. Mean and standard deviation among clustered areas by the compare mean

Average Linkage		Bottom water					Sediment		
		May DO	June DO	July DO	NH_4^+	DIP	IL	COD	AVS
		(mg/ℓ)			(μM)		(%)	(mg/g.dry)	
Area 1 (St. 1~3)	Mean	3.55	3.71	0.05	28.76	1.99	13.25	11.03	1.34
	N	3	3	3	3	3	3	3	3
	Std. Deviation	0.74	2.17	0.02	5.68	0.85	1.66	3.36	0.29
Area 2 (St. 4~5)	Mean	4.45	1.58	3.74	6.98	0.86	20.77	10.78	1.31
	N	2	2	2	2	2	2	2	2
	Std. Deviation	0.12	0.02	0.68	1.76	0.50	5.98	0.46	1.14
Area 3 (St. 6~7)	Mean	2.61	1.68	0.10	5.37	0.32	14.83	13.19	0.71
	N	2	2	2	2	2	2	2	2
	Std. Deviation	0.41	0.13	0.03	0.02	0.07	1.11	6.02	0.48
Total	Mean	3.53	2.52	1.11	15.86	1.19	15.85	11.57	1.27
	N	7	7	7	7	7	7	7	7
	Std. Deviation	0.88	1.67	1.81	12.54	0.95	4.34	3.32	0.58

influenced by oxygen. The phosphorous concentration reached a maximum during the first day. However, nitrogen was released continuously from sediment for five days, showing the maximum values in the second days. Oxygen consumption rate of average 439 mg/m²/day was similar to 410~650 mg/m²/day of Hiuchi-Nada where has progressed anoxia in the bottom water during summer (Hoshika et al., 1989). The northern part of eutrophicated Hiroshima Bay showed a high level of 753 mg/m²/day compared with this result (Kusuki, 1981). Nitrogen and phosphorous release rates were an average of 8.25 mg/m²/day and 1.38 mg/m²/day, respectively. These rates were comparable to 6% and 14% compared to the sedimentation rates of PON and PP in the shellfish farms.

Environmental characteristics between farms

Dendrogram from cluster analysis of the sampling stations is shown in Fig. 11. All stations were graped into three clustered areas. According to the compare means (Table 2), cluster 1 (St. 1~3) was characterized by high nutrients concentration

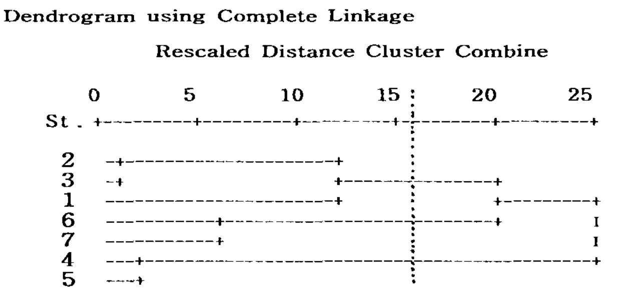

Fig. 11. Dendrogram by cluster analysis of enviromental characteristics in the shellfish farms.

and anoxia in the bottom layer, cluster 2 (St. 4~5) was characterized by oxygen deficient water in the middle layer in July. Cluster 3 (St. 6~7) showed a low AVS concentrations in the sediment and the lowest value of nutrient in bottom water (Fig. 12). Therefore the results indicated that the DO, nutrient in the bottom water, and AVS in the sediment were important factors to characterize the polluted environmental site in summer.

Conclusions

The environmental characteristics in the shellfish farms were investigated in the western part of Jinhae Bay, 1996. During summer, anoxia appeared

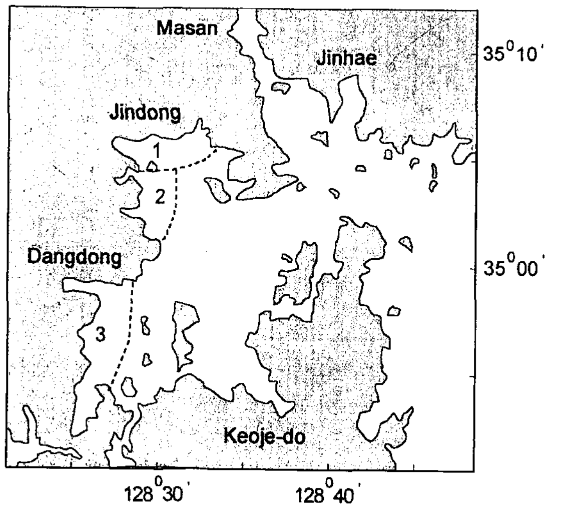

Fig. 12. Clustered areas in the western part of Jinhae Bay.

in overlying water of sediment at St. 1, 2, 3, 6 and 7, and phosphorous and ammonia in the bottom of St. 1, 2 and 3 showed high values of more than 2.00 μM and 25.00 μM, respectively. Particulate organic carbon, nitrogen and phosphorous concentrations in the seawaters were a high level as 57.44, 5.45, 0.42 μM, respectively in summer. C/N ratios of 10.85 indicated the input of terrigenous materials into the study areas and POC/Chl.a ratio of 61.62 also supported this result. The sediments in the aquaculture farms were very polluted with more than 20 mg/g.dry for COD and 0.5 mg/g.dry for AVS at all the stations. C/N ratio in the sediment was 4.23 due to a rapid degradation of nitrogen compounds.

Sedimentation rates were an average of 7.81 g/m²/day for POM, 803.10 mg/m²/day for POC, 123.40 mg/m²/day for PON and 12.02 mg/m²/day for PP in the aquaculture farms. In the shellfish farm of Jindong Bay, the oxygen consumption rate was an average of 439 mg/m²/day and the nutrient release rates were an average of 8.25 mg/m²/day for nitrogen and an average of 1.38 mg/m²/day for phosphorous.

According to cluster analysis, cluster 1 (St. 1~3) was characterized by high nutrients concentration and anoxia in the bottom layer, cluster 2 (St. 4~5) was characterized by oxygen deficient water in the middle layer in July. Cluster 3 (St. 6~7) showed a low AVS concentrations in the sediment and the lowest value of nutrient in bottom water. Therefore, the results indicated that the DO, nutrient in the bottom water and AVS in the sediment were important factors to characterize the polluted environmental site in summer.

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