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# Daily Variation of Particulate Organic Carbon in Wonmun Bay on the South Coast of Korea in Late Summer

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Daily variation of particulate organic carbon(POC) and some factors controlling its level were examined for a semi-enclosed bay(Wonmun Bay, south coast of Korea), in which a lot of suspended oyster culture farms existed, in September, 1992.

Observations were made at hourly interval. In spite of the relatively short survey period, strong short-term variation of POC concentration could be observed. Concentrations of POC were the range of 58~582 $\mu g/l$(average 272 $\mu g/l$) and their variation pattern was similar to those of chlorophyll *a* with the range of 0.90~7.25 $\mu g/l$(average 3.35 $\mu g/l$). The low C/N ratios also suggested that marine microalgae was a major component of POC for Wonmun Bay.

Primary production, average 1.97 $gC/m^2/day$, was the main source of POC beacuse the supply of POC via freshwater input and exchange with the outer part of the bay was little. Oyster population also excreted a small amount of POC. About 40% of produced POC was decomposed heterotrophically. Another important cause for the fluctuation of observed POC was tidal cycle. Considerable POC, which amounted 37% of produced POC, was lost from the bay due to flushing by tidal cycle. It was also calculated that about 16% was transported onto the sediment. It seemed that a part of POC was consumed by oyster and other heterotrophs.

## Introduction

The oyster absorbs either directly dissolved substances present in the sea water or through the ingestion of particles in suspension. However, the absorption of dissolved substance was equivalent to 5% of particulate energy actually absorbed(Heral, 1987). So commercial cultivation of filter feeding molluscs such as oyster requires the adequate supply of particulate food. Particulate organic matter and chlorophyll *a* concentration are the most likely indicators of food supply as recorded in previous oceanographic surveys of intrest because of good correlations with Pacific oyster growth(Brown and hartwick, 1988).

Particulate organic matter consists of living organisms and non-living particles, and plays a significant role in producing organisms of higher trophic levels. Particulate organic matter is usually estimated by its carbon content. In general, the concentration of particulate organic carbon(POC) in coastal water is higher than that in open ocean on account of higher productivity and terrestrial influence(Parsons, 1975). POC in the bay system may be produced by primary production and supplied by terrestrial input. While the loss of POC from water column may occur from the uptake of organisms, decomposition and sedimentation. Tidal process can also act to vary POC levels through exchange of sea water with the outer part of the bay.

Many investigators have studied on the relation between environmental condition and growth rate in the suspended culture of oyster *Crossostrea gigas* in the Korean coastal waters. The oyster suspended in March like the Wonmun Bay showed higher growth rate than the samples suspended in July (Yoo *et al.,* 1980). The growth of oyster suspended in July was increased exponentially and consisted of two lines: a curved line during the first half culture period(July~November) and a linear line in the later half period(December~April)(Kim, 1980). That is, the growth was much higher during the former period than during the latter period. The meat weight was increased rapidly in September(Bae *et al.,* 1978). Accordingly POC level in September may be a major energy source for the growth of suspended oyster. Despite the fact that the important role of POC in the oyster culture is well known, we have little information on the processes of POC flux in the culture farm.

This paper presents observation on daily variation in POC level in Wonmun Bay, a small semi-enclosed bay with a lot of oyster culture farms on the South coast of Korea, in September. We also describe the influence of the processes on POC level and budget.

## Discription of Wonmun Bay

Wonmun Bay, located at the southwestern part of Chinhae Bay on the southeastern coast of Korea, is a small bay which has an area of about $8.3\times10^6$ $m^2$ and a maximum depth of about 16 *m*(mean 8.3 *m*). The area developed for suspended oyster culture was about $1\times10^6$ $m^2$. According to the study on the water conditions of the bay by Lee(1992), the stratification of water column began being developed in spring, showed its strong formation with oxygen-deficent water mass in the bottom layer in summer and disappeared in autumn.

For the tidal pattern Park *et al.*(1992) reported that it was semi-diurnal type. Tidal range is 1.9 *m* in the spring tide and 0.7 *m* in the neap tide. Tidal exchange volume is $16.5\times10^6$ $m^3$ in the spring tide and $5.8\times10^6$ $m^3$ in the neap tide with average 11.1 $\times10^6$ $m^3$. The circulation of seawater is weak as the mean velocity of 9.2 *cm/sec* showing that of 9.9 *cm/sec* in flood tide and that of 8.4 *cm/sec* in ebb tide. The circulation pattern is characterized by reversing current through channel. Flood current is stronger than ebb current even though both the velocity of flood and ebb current decrease by depth. The tidal residual current shows a pattern like slack water in each depth. In particular a weak gyre which has counterclockwise flow in the inner part of the bay is generated in bottom water.

## Materials and Methods

Sampling stations were shown in Fig. 1. For POC, PON and Chlorophyll *a* measurement, the hourly sampling was carried out at Station 2 and 4-hour interval sampling at Station 1, 3 and 4 during a 26-h period from September 15 to September 16, 1992. All samples were collected using a 2 *l* Van Dorn type water sampler and filtered through a plankton net(0.35 *mm* mesh size) to remove large zooplankton. Samples were only obtained at surface and bottom water owing to the shallow depth of the bay.

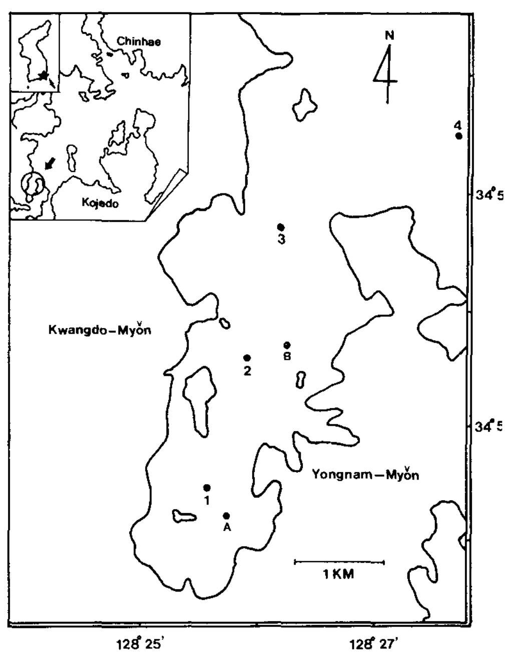


Fig. 1. Locations of observed stations in Wonmun Bay.
(A and B: oyster culture farm; 1, 2, 3 and 4: non-cultured area).

To estimate the sedimentation rate of settling matter, U type sediment traps(Noriki and Tsunogai, 1986) were placed at three stations(A, 2 and B) for 48 *h* as reported by Park *et al.*(1992). The traps consisted of polyvinyl chloride tubes 22 *cm* tall and 7.2 *cm* internal diameter. Four tubes were clamped in a metal bracket at 1 *m* above the bottom. Oyster excretion materials at Station A and B were trapped *in situ* using the phytoplankton net with mesh size 50 *μm* for 24 hours as reported by Kim(1980). Experimental net was filled with a rope of oysters cleaned, while an empty net was used as control for natural settling matter.

The filtered water were filtered again using 24 *mm* glass fiber filter(Whatman GF/C) ignited for 3 hours at 450℃ previously for the analysis of particulate organic carbon and nitrogen(PON). POC and PON were analysed using a Perkin Elmer CHN analyser model 2400. 2 glycine standards showed a percent error of ±0.5% for the organic carbon and nitrogen determinations.

Primary production was measured *in situ* using the $C^{14}$ standard method of Steemann-Nielsen(1952) at 3 stations. Water samples were collected with Van Dorn type water sampler at three vertical depths(0, 4~5 and 7~9 *m*). Each sample was treated with carbon-14 and incubated *in situ* for less than 2 hours. Cap test tube(100 *ml*) was used as the incubation vessels. Primary production was integrated with depth. Daily isolation was measured for the estimation of daily primary production.
Chlorophyll *a* was calculated according to the method of Holm-Hansen *et al.*(1965) after measuring fluorescence using spectroflourometer(Simatzu model). Light and dark bottles for measuring heterotrophic activity were incubated *in situ* in duplicate at 0, 5 and 9 *m* for 48 hours. The titration procedure of dissolved oxygen to calculate the rate of decomposition used Winkler's method modified by Strickland and Parsons(1968). Heterotrophic activity was also integrated with depth in the same method as primary production.

## Results and Discussion

*Daily variation and C/N ratio*

Variations of POC, chlorophyll *a* concentration and C/N ratio analysed during a 26-*h* period in the body of water at Station 2 are presented in Fig. 2. The POC concentration at the surface water was maximum 565 *μg/l* during ebb tide on the sfternoon of September 16 and minimum 58 *μg/l* during flood tide on the evenning of September 15. The POC concentration at the bottom water ranged from 82 to 582 *μg/l*, showing similar curve pattern with that of the surface water. Whereas differences in POC level with tide comprised one order of magnitude, differences with depth were not pronounced. The PON concentration ranged from 11.5 to 111.3 *μg/l* and highest in the afternoon. With the exception of a short time after high tide, C/N ratio by weight ranged from 3.1 to 7.7 close to Refield's ratio of 5.6(Redfield *et al.*, 1963) for living matter. C/N ratio in the phytoplankton generally ranged from 3 to 7(Antia *et al.*, 1963; Banse, 1974) and high C/N ratios over about 10 resulted from an influx of terrigenous material(Flemer and Biggs, 1972; Pocklington and Leonard, 1979). Increased detrital organic matter also reulted in high C/N rations(Cauwet, 1981; Lenz, 1977). Chlorophyll *a* concentration with the range of 0.90 to 7.25 *μg/l* also showed the similar variation curve to POC. These results suggested that planktonic algae was acted as a major component on POC for Wonmun Bay.

*Production of POC*

Primary production is an important factor for the increase of POC. The daily primary productivity measured at three stations(1, 2 and 3) in Wonmun Bay was average 1.97 $gC/m^2/day$ and increased from the mouth to the inner part of the bay(Table 1). Maximun primary productivity was found at the middle layer and minimum at the bottom water.

The main source of POC for Wonmun Bay was the contribution of primary production within the system. In general, main sources of POC in the coastal region are the supply from freshwater and the contribution from primary production. In Wonmun Bay the terrestrial supply of POC could be neglected because of its little input from stream. Park *et al.*(1992) also reported that the supply of suspended materials from freshwater was very little. The primary productivity was 1.97 $gC/m^2/day$

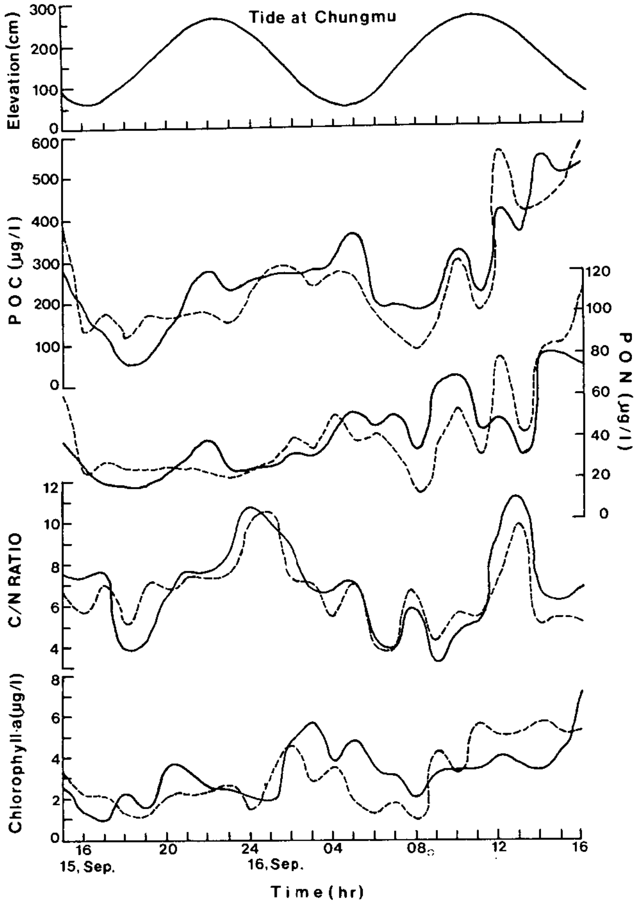


Fig. 2. Variations of POC, PON, Chlorophyll-*a* concentration and C/N ratio during 26-h period in Wonmun Bay in September(——: surface layer; ----; bottom layer).

Table 1. Primary production in Wonmun Bay September

| Layer\Station | Primary productivity($gC/m^2/day$) 1 | 2 | 3 |
|---|---|---|---|
| Surface | 366 | 229 | 229 |
| Middle | 371 | 256 | 237 |
| Bottom | 94 | 54 | 45 |
| Depth-integrated | 2,172 | 1,910 | 1,817 |

higher than 0.62 $gC/m^2/day$ in Hansan-Koje Bay and similar to 2.11 $gC/m^2/day$ in Kamagyang Bay, the oyster-farming bay, in summer(Lee *et al.*, 1991). From the surface area of $8.3\times10^6$ m$^2$, the daily total mass of POC fixed by primary production for Wonmun Bay was estimated in 16.3 ton. In particular, maximum values of POC in the afternoon seemed to depend on the relatively high primary productivity in the daytime.

*Heterotrophic decomposition*

Heterotrophic activity, as measured by dark bottle oxygen uptake, was calculated in similar way to primary productivity. Decomposition with depth in the water column is shown in Fig. 3. A marked difference in oxygen consumption was observed with the highest value at the surface water and the lowest value at the bottom water. The daily decomposition of organic material was equivalent to 2.71 $gO_2/m^2/day$. Gocke(1977) reported that the turnover time of organic matter was shorter at 2 *m* de-

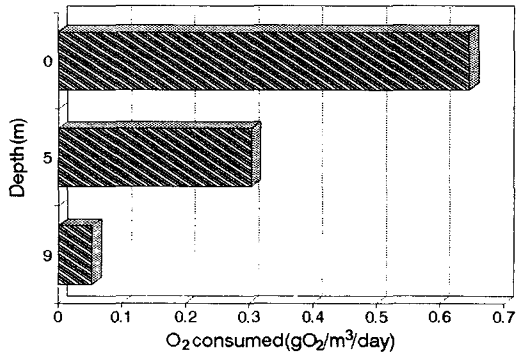


Fig. 3. Vertical structure of heterotrophic activity in September.

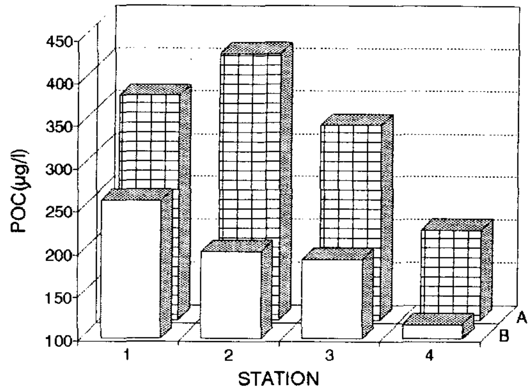


Fig. 4. Distribution of POC concentration at the surface water after 3 hours from high(A) and low (B) tide.

pth that at 10 *m* depth in Kiel Fjord and Kiel Bay in summer. Yanada and Maita(1978) also showed higher decomposition rates of POC in the productive layer than in decomposition layer in Funka Bay, Japan. In general, the marked variation of heterotrophic activity has a close association with primary production. By the Redfield's ratio, 276 to 106 (Redfield *et al.*, 1963), for oxygen utilization to carbon mineralization, the daily water column decomposition of POC was calculated as 0.78 *gC/m²/day*. From this, it was estimated that POC of 6.5 tonC, which corresponded to 40% of produced POC, was lost by heterotrophic decomposition within the bay.

*Flushing*

Fig. 4 shows the distribution of POC concentration at the surface water after 3 hours from low and high tide. POC concentration, which showed relatively high difference with tidal cycle, was higher in ebb tide with the range of 205 to 412 *μg/l* than in flood tide with the range of 116 to 261 *μg/l*. Its distribution was also higher in the inner part of the bay(between 192 and 412 *μg/l*) than in the outer part(between 116 and 205 *μg/l*) in ebb and flood tide. Therefore, it may be said that there was the flushing of considerable POC from the inner part to the outer part of the bay.

The loss of POC due to flushing was calculated in Table 2. Water volume exchanged with tidal cycle was calculated by using the difference of tidal level and the surface area($8.3\times10^6$ $m^2$). Then the daily flux of POC was estimated by using average POC concentration during each tide. At the first tidal cycle average values of POC were 118 and 254 *μg/l* in flood and ebb tide. At the second cycle the values were 228 *μg/l* in flood tide and 481 *μg/l* in ebb tide. There were the import of 5.9 tonC/day and the export of 11.9 tonC/day due to tidal cycle.

Table 2. Calculated external loss and gain of particulate organic carbon in Wonmun Bay from September 15 to 16, 1992

| Tidal cycle | Difference of tidal level (*m*) | Exchanged water volume($m^3$) | Average POC concentration (*μg/l*) | Import(+) or Export(−) (tonC) | Net gain(+) or loss(−) (tonC) |
|---|---|---|---|---|---|
| The first | | | | | −2.4 |
| flood tide | 1.93 | $16.02\times10^6$ | 118 | +1.9 | |
| ebb tide | 2.05 | $17.02\times10^6$ | 254 | −4.3 | |
| The second | | | | | −3.6 |
| flood tide | 2.11 | $17.51\times10^6$ | 228 | +4.0 | |
| ebb tide | 1.90 | $15.77\times10^6$ | 481 | −7.6 | |

The total daily export was thus estimated as 6.0 tonC/day. This corresponded to 37% of the total primary production for Wonmun Bay. McMahon and Patching(1984) estimated that 35% of POC produced by the phytoplankton production was lost from a fjord, Killary Harbour, due to flushing and this value accounted for 25% of the calculated annual gross input(by both influx and *in situ* productivity).

*Sedimentation*

Sediment traps were placed at two sites of the oyster culture farm and a site of non-cultured bed. Total catch of sediment at the oyster culture farms was 8.9 and 12.4 $g/m^2/day$(Table 3). Of this, the organic matter content was the range of 21.8 to 32.8%. The daily sedimentation rate of POC was about 0.94 $gC/m^2/day$ while that of PON was 0.13 $gN/m^2/day$ at all sites. At the non-cultured area, total sediment catch was about 1.2 $g/m^2/day$. The organic matter content of 32.6% was similar to Trap A. Sedimentation rates of POC and PON were 0.23 $gC/m^2/day$ and 0.04 $gN/m^2/day$, respectively. C/N ratio of 5.7 at the non-cultured area was lower than about 7.2 at the oyster culture farms. Kusuki(1977) reported that C/N ratios of feacal material were between 6 and 10. Accordingly, high C/N ratio at oyster culture farms indicated that a lot of oyster feacal material sank fastly to the bottom because its size resulted in high sinking velocity at the culture farms.

Organic matter content of total catch was higher than 20% in St. Margaret's Bay, Nova Scotia(Webster *et al.*, 1975). Taking $1\times10^6$ $m^2$ for the cultured area and $7.3\times10^6$ $m^2$ for the non-cultured area into consideration, the daily sedimentation rate was estimated as 2.6 tonC, 16% of produced POC, for Wonmun Bay. Yanada and Maita(1978) reported that the amount of POC transported into the deep layer, or to the sediment, was 26% of the produced organic constitutions in Funka Bay, Japan. Davies (1975) demonstrated that 30% of the organic carbon production of a shallow Scottish sea loch settled to the sediment. Hartwig(1976) calculated that 25% reached the sediment. 16% in Wonmun Bay was more or less lower than that in shallow others.

*Excretion by oyster population*

Oyster population excretes considerable amount of food consumed(Kim, 1980 and Heral *et al.*, 1983). Faeces and pseudofaeces is the quantity of biological wastes excerted by the molluscs determined *in situ*, using traps arranged around the culture farms. The technique used for excretion rate of oyster in the suspended culture farms was given by Kim(1980). Excretion rate, value of oyster-contained net minus that of empty net in which oyster was not contained, was 1.76 *gC* rope/day(Table 4). C/N ratio of the materials excreted was 8.7 in the oyster population higher than 6.2 in the empty net.

In Wonmun Bay the number of suspended oyster was total 1988 raft with 142 rope a raft(Park *et al.*, 1992). From the excretion rate of 1.76 *gC/rope/day*, it was calculated that 0.5 tonC was excreted from oyster population for the Bay.

Table 4. Excretion rate of particulate organic matter from the oyster-culture rope in Wonmun Bay in September

| | POC *gC/rope/day* | PON *gN/rope/day* | C/N ratio by weight |
|---|---|---|---|
| Oyster-contained net | 2.01 | 0.23 | 8.7 |
| Empty net | 0.25 | 0.04 | 6.2 |

Table 3. Settling rates of particulate organic matter measured by sediment trap in Wonmun Bay in September, Trap A and B, Culture farm; Trap 2, Non-cultured area

| | Total flux $gC/m^2/day$ | POM % | POC $gC/m^2/day$ | PON $gN/m^2/day$ | C/N ratio (by weight) |
|---|---|---|---|---|---|
| Trap A | 8.9 | 32.8 | 0.95 | 0.13 | 7.3 |
| Trap B | 12.4 | 21.8 | 0.93 | 0.13 | 7.1 |
| Trap 2 | 1.2 | 32.6 | 0.23 | 0.04 | 5.7 |

*Consumption by organisms*

It was obvious in Wonmun Bay that the variation of POC was affected by production, decomposition, flushing, sedimentation and excretion.

Another possible loss of POC was a consumption by the cultured organisms. We have no data on the consumption of organism in Wonmun Bay. Kim(1980) directly estimated that 44.5% of the filtered food material expressed by value for oyster population had been rejected as pseudofaeces and faeces at suspended culture farms in Geoje-Hansan Bay, Korea. Kusuki(1977) reported that 40~50% of the suspended matter contained in the inhalent current was founded to be ratained by the gills. The culturing density and the size of oyster may play an important role on the consumption rate. Consumption rate obtained from oyster excretion data, which was calculated in this survey, was estimated at around 1 tonC/day. A lot of fouling organisms attached on the culture rope of oyster(Park *et al.,* 1992). Arakawa *et al.*(1971) reported that excrection by the attached organisms corresponded to about 20% of that of oyster. In addition to oyster population, consumption by the fouling organisms and/or other heterotrophs might have accounted for the rest.

As a conclusion, POC in Wonmun Bay was affected by various factors and showed large daily variation. When a quantitative knowledge of the availability of particulate organic material during all cultured period is provided, it is possible to decide the maximum commercial yield in an area. Hence contineuous survey for the factors controlling the POC variation is required. From the viewpoint of time scale of variation, it may be suggested that sampling with tidal process is appropriate.

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# 늦여름 원문만 굴양식장 입자유기탄소의 일변동

강창근 · 이필용 · 김평중 · 최희구
국립수산진흥원 환경과

진해만의 서남단에 위치하고 수하식 굴 양식의 주산지로서 널리 알려진 반폐쇄성 내만 해역인 원문만에서 굴의 성장기인 9월에 주요 성장에너지원인 입자유기탄소의 일변동 양상과 농도분포에 영향을 미치는 몇몇 요인을 조사하였다. 1시간 간격으로 측정된 입자유기탄소의 농도는 비교적 짧은 조사기간에도 불구하고 큰 변동을 보였는데 최저 58 *μg/l*에서 최고 582 *μg/l*범위(평균 272 *μg/l*)였고, 유사한 일변동 양상을 보인 Chlorophyll *a*의 농도는 0.90에서 7.25 *μg/l*(평균 3.25 *μg/l*)범위였다. 또한 낮은 C/N비(3.1~7.7)는 만내의 미세조류가 입자유기탄소의 주요 구성요소임을 시사하였다.

조사수역에서 입자유기탄소의 양은 외부로부터의 유입을 거의 기대할 수 없어 비교적 높은 미세조류의 기초생산(평균 1.97 *gC/m²/day*)에 크게 의존하며 양식굴의 배설도 일부분을 차지하였다. 생산된 입자유기탄소의 약 40% 정도가 분해과정으로 제거되고 간조시 36%에 달하는 입자유기탄소가 만외측으로 흘러나가는 것으로 나타났다. 또한 약 16%의 입자유기탄소는 저질중으로 퇴적되는 것으로 추산되었고 일부는 양식굴과 그외 타가영양생물에 의한 섭이로 소모될 것으로 사료된다.