Estimation of the sediment flux from the cultured Japanese oyster in Ofunato Estuary and its annual variation - Calculation by incorporating the monthly mean environmental data for ten years -

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Abstract : As the first step of obtaining an optimal culture-density of oysters in a farm, the magnitude of sediment flux from Japanese oyster *Crassostrea gigas* was examined in Ofunato Estuary. By applying monthly averages of observed environmental data such as water temperature, salinity and chlorophyll-*a* concentration from 1985 to 1994 to a population dynamics model, the fluxes of sediments discharged by oysters were calculated, and the calculated values of sediment fluxes were compared with observed ones. The results of our simulation qualitatively reflect the patterns of seasonal variation of the fluxes. Also, in quantity, our results are not contradictory to observed values when the dispersion by the flow in the bay is taken into account. In conclusion, the population dynamics model we adopted is applicable to estimate the fluxes of sediments discharged by oysters in Ofunato Estuary. Moreover, by using the environmental data obtained from respective years instead of the averaged values, it is suggested that environmental characteristics of each year are reflected in the sediment fluxes.

Keywords : Crassostrea gigas, Ofunato Estuary, population dynamics model, sediment flux.

1. Introduction

The Japanese oyster *Crassostrea gigas* is a typical bivalve cultured commercially. In Japan, the cultivation of this species is done mostly by the suspended culture using rafts. In 2003 the oyster harvest in Japan yielded 224,861 t in live weight (Japanese Ministry of Agriculture, Forestry and Fisheries, 2005), corresponding to 46% of the total cultivated shellfish production in the nation. Since oysters take in a large amount of seawater in respiration and ingestion, they purify seawater by filtering suspended materials. For example, filtration rate of an oyster is estimated about 2.5 L h^{-1} in 80 mm shell length (Kobayashi *et al.*, 1997). However, oyster excretions also increase organic material in the bottom

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sediment. Therefore, the bottom environmental conditions in oyster farming areas were pointed out as the important factor of sustaining the high productivity of oyster (Kusuki, 1977a, b). Especially, in France where oysters are cultivated in the bottom culture system, the bottom condition is one of the most important factors for oyster culture. Effects of the oyster cultivation on the ecosystem of an intertidal mudflat were investigated and estimated by the model (Leguerrier *et al.*, 2004). Kusuki (1977a) estimated that the amount of faecal materials was about 19.3 t per a raft during the period from June to next April using experimental data. He directly measured faecal materials of oysters only four times in the farming areas of Hiroshima Bay, western Japan. However, the direct measurements of oyster's faecal materials in the farming areas of northern Japan were not carried out although the environmental conditions of seawater were investigated and

compared between western and northern Japan (KAMIYAMA *et al.*, 2005). How many organic materials do oysters remove from seawater and how many suspended materials do they add to seawater as excrements in northern oyster farming area? What is the optimal value of culture-density of oysters in a farm? In the present paper, as the first step to solve these problems, we calculate the fluxes of sediments excreted by oysters in Ofunato Estuary, by applying observed environmental properties to a population dynamics model.

By comparing the calculated values of sediment flux with observed ones, we examine whether the model is applicable to *C. gigas* in Ofunato Estuary and how much oyster excretion is observed as sediment in the farm. The population dynamics model we adopt was developed by one of the authors (MK) and his co-workers and successfully applied to *C. gigas* in mariculture fields in Hinase waters of the Okayama Prefecture, Japan (KOBAYASHI *et al.*, 1997). The significant feature of this model is in that it includes the effects of time-evolutional size variance of oysters.

In addition, by using the environmental data obtained from respective years instead of the averaged ones, we examine annual fluctuations in the sediment flux due to the differences in the environmental condition.

2. Methods
2.1 Description of the study site

Ofunato Estuary is located on the northeastern Pacific coast of Japan (Fig.1). It is a typical semi-closed bay where Sakari River flows in with an average flow rate of 2.80 m^3s^{-1}. The size of this Estuary is 6km in length and 1.5km in width with a maximum depth of 38m. It has 7.89km^2 in area and 1.24×10^8 km^3 in volume. In Ofunato Estuary, the Japanese oyster is commercially cultured and its annual landing is about 300 t in wet weight in the 1980s (MIYAZAWA and HAYAKAWA, 1994).

2.2 Simulation model

To examine the growth of *C. gigas*, we use a population dynamics model composed by KOBAYASHI *et al.* (1997) which is based on a series of papers (POWELL *et al.*, 1992; HOFMANN *et al.*, 1992; HOFMANN *et al.*, 1994; POWELL *et al.*, 1994; POWELL *et al.*, 1995). This model was applied to *C. gigas* in Hinase waters, Okayama Japan. Fundamental equations, coefficients and biological factors used in the model are shown in Table 1. In the present paper, this model is used without modification except the forms of reproductive efficiency, R_{eff} (Eq.17).
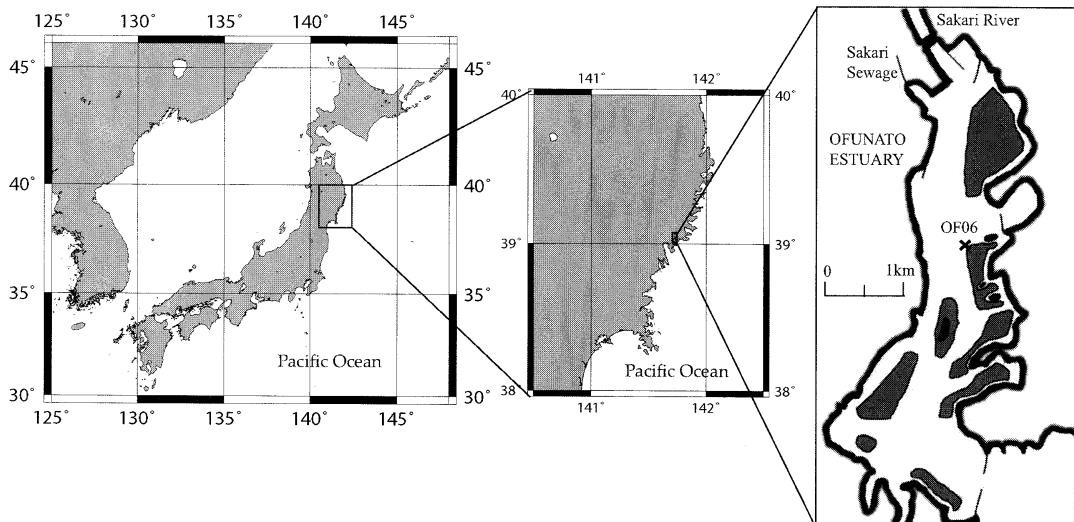

Fig. 1. A map of study site, Ofunato Estuary. The surfaces occupied by oyster rafts are indicated by gray. Black-painted regions in the Estuary indicate small islands. Environmental data are observed at Station OF06.

Table 1 Fundamental equations, coefficients and biological factors used in our population dynamics model

Fundamental equations

Time-evolution equation

(1) $dO_j/dt = P_{gj} + P_{rj} +$ (gain of O_j from O_{j-1}) $-$ (loss of O_j to O_{j+1})
$+$ (gain of O_j from O_{j+1}) $-$ (loss of O_j to O_{j-1})

The constitution of net production

(2)* $NP_j = P_{gj} + P_{rj} = A_j - R_j$

Reproductive efficiency $R_{\text{eff}\,j}$

(3) $P_{rj} = R_{\text{eff}\,j} NP_j$

Formulations of production rates (by (2) and (3))

(4)* $P_{gj} = (1 - R_{\text{eff}\,j}) (A_j - R_j)$

(5)* $P_{rj} = R_{\text{eff}\,j} (A_j - R_j)$

$j\ (=1,2,-10)$: suffix indicating each size class

O_j : oyster standing stock in each size class

t : time

P_{gj} : somatic production rate

P_{rj} : reproductive tissue production rate

NP_j : net production

A_j : assimilation rate

R_j : respiration rate

Concrete forms of the rates

Respiration rate (per mass)

(6)* $R_j / W_{dj} = r_s (69.7 + 12.6T)\ W_{dj}^{-0.25}$

Modification factor by salinity

(7) $r_s = 1$ at $20 \leqq S$

     $r_s = 1 + (r_t - 1)\ (20 - S)/ 5$ at $15 < S < 20$

     $r_s = r_t$ at $S \leqq 15$

Temperature-dependent factor

(8)** $r_t = 0.0915\ T + 1.324$ at $20\text{℃} \leqq T$

     $r_t = 0.007\ T + 2.099$ at $T < 20\ \text{℃}$

Assimilation rate

(9) $A_j = a_{\text{eff}} I_j$

Ingestion rate

(10) $I_j = FR_j \times$ Food

Assimilation efficiency

(11) $a_{\text{eff}} = 0.75$

Filtration rate

(12)*** $FR_j = f_s f_\tau FR_{wj}\ T^{0.5}/4.47$

Size-dependent factor

(13) $FR_{wj} = 2.51\,W_{dj}^{0.279}$ at $2.0\ \text{g} < W_{dj}$

     $FR_{wj} = 0.117\,W_{dj}^3 - 1.05\,W_{dj}^2 + 3.09\,W_{dj} + 0.133$ at $W_{dj} \leqq 2.0\ \text{g}$

Modification factor by salinity

(14) $f_s = 1$　　　　　　　at $20 \leqq S$

　　$f_s = (S-10) / 10$　at $10 < S < 20$

　　$f_s = 0$　　　　　　　at $S \leqq 10$

Modification factor by the concentration of suspended material

(15) $f_\tau = 1 - 0.01 (\log_{10} \tau + 3.38) / 0.0418$

Ambient food concentration

(16) Food $= 0.088$ Chl-$a + 0.520$

Reproductive efficiency (for size classes j=4 to 10)

(17) $R_{eff} = 0.8$　　　　　　at $21°C \leqq T$

　　$R_{eff} = 0.073T - 0.73$　at $10°C < T < 21°C$

　　$R_{eff} = 0$　　　　　　at $T \leqq 10°C$

　　(between May and August)

　　$R_{eff} = 0.8$　　　　　　at $21°C \leqq T$

　　$R_{eff} = 0.27T - 4.86$　at $18°C < T < 21°C$

　　$R_{eff} = 0$　　　　　　at $T \leqq 18°C$

　　(between September and April)

(18) $R_{eff} = 0$ (for size classes $j = 1$ to 3)

　a_{eff} : assimilation efficiency

　R_j : respiration rate (μL O_2 consumed h^{-1})

　W_{dj} : dry meat weight (g)

　T : water temperature (°C)

　S : salinity

　FR_j (FR_{wj}) : filtration rates (L filtered per individual h^{-1})

　τ : total particulate content (g L^{-1})

　Food : ambient food concentration (mg dry wt L^{-1})

　Chl-a : chlorophyll-a concentration (μg L^{-1})

Caloric conversions

　Oysters : 5210 cal g dry wt^{-1} ($= 21809$ J g dry wt^{-1})

　Food : 5168 cal g dry wt^{-1} ($= 21634$ J g dry wt^{-1})

　Energy consumption of oysters by respiration : 4.83 cal mL^{-1} O_2 ($= 452928$ J mol^{-1} O_2)

Spawning

　Trigger condition : when the gonadal fraction reaches 50% of total meat weight

　Result : all of the reproductive tissue is lost

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* In the previous papers such as KOBAYASHI *et al.* (1997) and POWELL *et al.* (1992), both respiration rate used in (2), (4) and (5), R_j and respiration rate per mass used in (6), R_j / W_{dj} were written as R_j.

** The values of r_t at 20°C derived from two equations in (8) are not corresponding to each of them. However, we used these equations, which are based on the experimental data of SHUMWAY and KOEHN (1982), in the same manner as POWELL *et al.* (1992) did.

*** The effect of temperature on relative filtration rate of *C. gigas* was examined experimentally by WALNE (1972) and found to be of the form:

　FR (at 20°C) $= 2$ FR (at 5°C),

where FR is the filtration rate (L filtered per individual h^{-1}). Thus, the influence of temperature on filtration rate can be obtained as Eq. 12.

Table 2　Biomass and length dimensions of the oyster size classes used in this model.

Model size class	Biomass (g dry wt)	Length (mm)
1	0.507×10^{-8}–0.202×10^{-1}	0.3–25
2	0.202×10^{-1}–0.642×10^{-1}	25–35
3	0.642×10^{-1}–0.219	35–50
4	0.219–0.409	50–60
5	0.409–0.695	60–70
6	0.695–1.10	70–80
7	1.10–1.65	80–90
8	1.65–2.37	90–100
9	2.37–3.83	100–115
10	3.83–5.84	115–130

We summarize the model used in this study as below.

Oysters are divided into 10 size classes ($j=1,2,-10$) according to the shell length. To examine the biomass of oysters, we need to convert the size class into biomass. The biomass and length dimensions of the oyster size classes are shown in Table 2. Owing to this classification of mass, the effect of time-evolutional size variance of oysters in the process of growth is included through time-evolution, which is explained as follows: After a time-step, total energy (biomass) of oysters belonging to a class is changed by biological processes. This increase/decrease of energy transfers a part of the oysters to the next upper/lower class because the energies (biomasses) are fixed in each class. As a result, non-single mass distribution is obtained through time-evolution from single initial mass, which is very unique character of this model.

The time-evolution equation of oyster standing stock Eq.1 represents that net production changes biomass of individual oysters in quantity and that individuals which evolve from the former size classification after a time step are classed into a new size class thereafter. Moreover, the net production is determined by the environmental parameters such as temperature, salinity and chlorophyll-a concentration through two rates A_j (Eq.4) and R_j (Eq.5), whose concrete forms are represented by Eqs.6–18. Table 1 also mentions the conditions of spawning. Equation 18 represents that oysters with size classes $j = 1$ to 3 are too young to spawn. One of the important points in our calculation is that the assimilation rate is obtained from the ingestion rate using an assimilation efficiency of 0.75 (Eqs.9–11), an average value obtained from GERDES (1983) (0.724–0.760). In reality, all calculations are done in terms of energy, which is not explicitly shown in the equations described above. Caloric conversions are also mentioned in Table 1.

As above-mentioned, we do not use the reproductive efficiency, R_{eff} of KOBAYASHI *et al.* (1997). The function of R_{eff} used in Hinase waters by KOBAYASHI *et al.* (1997) represents that reproductive tissue is not produced for $T < 23\,°C$. If we apply the function used in Hinase waters to Ofunato Estuary, oysters cannot spawn since water temperature of Ofunato Estuary is lower than that of Hinase waters. Therefore, at first, we had used the following function:

(17a)　$R_{eff} = 0.8$　　　　　at $21\,°C \leqq T$;
　　　　$R_{eff} = 0.073T - 0.73$　at $10\,°C < T < 21\,°C$;
　　　　$R_{eff} = 0$　　　　　at $T \leqq 10\,°C$;
　　　　　　　　　　　　　(in all seasons).

This function is different from that in Hinase waters, only in numerical values. However, our simulation using Eq.17a showed an unnatural result that spawning lasts from June to December, which was dependent on depth. In fact, the decline of water temperature in autumn induces that energy share to reproductive tissues sharply decreases, which is really observed for the Japanese oysters (KUSAKA *et al.*, 1991). Thus, we use Eq.17, which represents that for $T \leqq 18\,°C$, $R_{eff} = 0$

between September and April. By the use of Eq.17, the end of spawning came earlier, namely in October. Therefore, the natural conditions are reflected.

2.3 Calculation of sediment fluxes

In Ofunato Estuary, starting from May, individual oysters are cultivated over 2 years. In the present work, the growth of oysters from May 15 is simulated. Namely, all oysters are put into size class 2 on May 15. Then, the development of oysters for a 2-year period is simulated by the methods described in the previous subsection. We take 1 day as a time-step in our numerical simulation. In the farm, oysters are bound to ropes. In our simulation, oysters are bound at six depths of 0, 5, 10, 15, 20 and 25m, and the surface density of oysters at each depth is set to 100 ind.m^{-2} for the convenience of calculation. In other words, oysters at depths between 0 and 2.5m are represented by those at 0m, and oysters between 2.5 and 7.5m are represented by those at 5m and so on. Environmental properties at each depth which are necessary for our simulation, water temperature, salinity and chlorophyll-a concentration, were observed in Ofunato Estuary between 1985 and 1994 (HAYAKAWA et al., 2001; HAYAKAWA et al., 2002).

We run two types of simulations. At first, we calculate the growth of oysters by using the monthly averaged values of the environmental properties to examine whether the population dynamics model we adopted is applicable to oysters in Ofunato Estuary. Next, by simulations using the monthly values obtained from respective years, we investigate the effects of the environmental characteristics on the growth of oysters. Especially, we use two 2-year data, namely, the data between May 1986 and April 1988 and those between May 1990 and April 1992. In the period between May 1987 and April 1988, lower chlorophyll-a concentration was observed, while it was higher between May 1991 and April 1992. Thus, we can obtain the fluxes of sediments excreted by oysters in the two typical periods. Note that calculation from one year before is necessary to see the effects of the environmental characteristics of a year

because individual oysters are cultivated over 2 years and both first-year oysters and second-year ones are simultaneously cultivated.

The fluxes of the oyster excretion are calculated as follows. The materials ingested but not assimilated are excreted. Assuming an assimilation efficiency of 0.75, 0.25 is the excretion rate of oyster. In Ofunato Estuary, the depth of the cultivation is shallower than 12m. At three depths of 5, 10 and 15m, the fluxes of sediments are calculated as the sum of excretions of oysters at upper levels. Namely, 50 ind.m^{-2} at 0m and 50 ind.m^{-2} at 5m contribute to the flux of sediments at 5m. And, 50 ind.m^{-2} at 0m, 100 ind.m^{-2} at 5m and 50 ind.m^{-2} at 10m contribute to the flux of sediments at 10m. Moreover, 50 ind.m^{-2} at 0m, 100 ind.m^{-2} at 5m and 100 ind.m^{-2} at 10m contribute to the fluxes of sediments at 15m and deeper levels.

3. Environmental data

In our simulation, we use the environmental properties at the middle of Ofunato Estuary, named as Station OF06. This station is located near a raft (the culture facilities of oysters). Our simulation needs observations of water temperature, salinity and chlorophyll-a concentration at each depth. Moreover, observed values of sediment fluxes are also necessary to compare them with the results of our simulation. These environmental data were obtained from 1985 to 1994 and were reported in HAYAKAWA et al. (2001) and HAYAKAWA et al. (2002). We summarize the characteristics of their average data as below.

Chlorophyll-a concentrations are high in early spring (February-March; 4μg L^{-1} at 5m and 10m). For the surface layer (0m), higher chlorophyll-a concentrations are observed between May and October (3–9μg L^{-1}), showing a maximum (9μg L^{-1}) in September.

The sea surface temperature is highest (23℃) in August. At deeper depths, it reaches a maximum later (17℃; in October at 25m).

Salinity of sea surface fluctuates between 20 and 33, which do not affect the growth of oysters, because of the higher optimal salinity of C. gigas (MANN et al., 1991).

Between May 1987 and April 1988, lower

chlorophyll-a concentration was observed. Especially, the maximum value at surface layer was $2\mu g$ L^{-1} and that at 5m was $3\mu g$ L^{-1}. Meanwhile, in the period between May 1991 and April 1992, higher chlorophyll-a concentration was observed. At 0m, it exceeded $10\mu g$ L^{-1} between July and September 1991, especially $20\mu g$ L^{-1} in September 1991. Extremely low salinities had occasionally been observed (6.6 at July 1986 and 12.3 at October 1991).

4. Results of simulations and comparison with observational data
4.1 Simulation using 10 years' averaged data

At first, we describe the results of the simulation using monthly averaged environmental data from 1985 to 1994.

Individual oysters are cultivated over 2 years. We show the simulated growth of oysters at the depth of 0m as an example (Fig. 2), showing that oyster size increases with time. As in Fig. 3, sediment fluxes at three depths of 5, 10 and 15m over 2 years show monotonic increases until September of the first year and thereafter remain nearly stable until January of the second year. The fluxes then nearly monotonically increase again until September and thereafter nearly monotonically decrease until landing, May of the third year. However, the fluxes have small peaks at each March. The peaks of September are probably
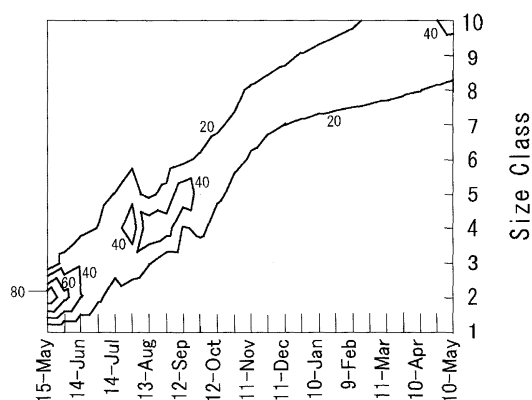

Fig. 2. The growth of oysters at the depth of 0m from May 15, when the initial condition that all oysters are put into size class 2 is set, to May 10 of the next year

ascribed to the growth of oysters in summer season. That is because the highest chlorophyll-a concentration at surface layer appears from June to September. The secondary peaks of March are also probably ascribed to higher chlorophyll-a concentration. Our simulation shows that, at deeper levels, oysters grow later and the spawning is weaker because of lower temperature.

The oysters are cultivated over 2 years from May, but, in each farm, oysters are planted every spring. Namely, oysters of first-year and oysters of second-year are of the same number in each raft. Then, the oysters of age-1 and age-2 equally contribute to the sediment fluxes. The seasonal variation of the sediment fluxes is obtained by averaging the contributions by oysters of age-1 and age-2. As shown in Fig.4, the sediment fluxes have a maximum in September and a secondary peak in March. Figure 5 shows contour lines of the calculated sediment fluxes, which must be compared with the average values of observational results. The observation shows that the sediment (total carbon) fluxes reach a maximum in September (22 g $m^{-2}day^{-1}$ at deeper levels than 15m) and March (16 g $m^{-2}day^{-1}$) and a minimum in January (12 g $m^{-2}day^{-1}$) (HAYAKAWA et al., 2001; HAYAKAWA et al., 2002). Both the calculated values and the observed ones have similar properties of having a maximum at September and a secondary peak in March and a minimum in January.

Next, quantitatively sediment fluxes are considered. To this end, the surface density of oysters in our calculation, 250 ind.m^{-2} (50 ind.m^{-2} at 0m, 100 ind.m^{-2} at 5m and 100 ind. m^{-2} at 10m), must be converted to real density in Ofunato Estuary. The production of oysters in Ofunato Estuary is about 100 kg year^{-1} per 1km rope (wet weight) (MIYAZAWA and HAYAKAWA, 1994). An oyster is estimated about 1-2.5g dry meat weight. This is converted to 5.3-12.0g wet meat weight (KOBAYASHI et al., 1997). So, the density of oyster in Ofunato Estuary is about 0.8×10^4-1.9×10^4 ind.km^{-1} year^{-1}. A raft of oyster cultivation has 112 ropes of 12m long. Thus, the surface density of oysters immediately below the raft is estimated as 600-1300 ind.m^{-2}. Then,
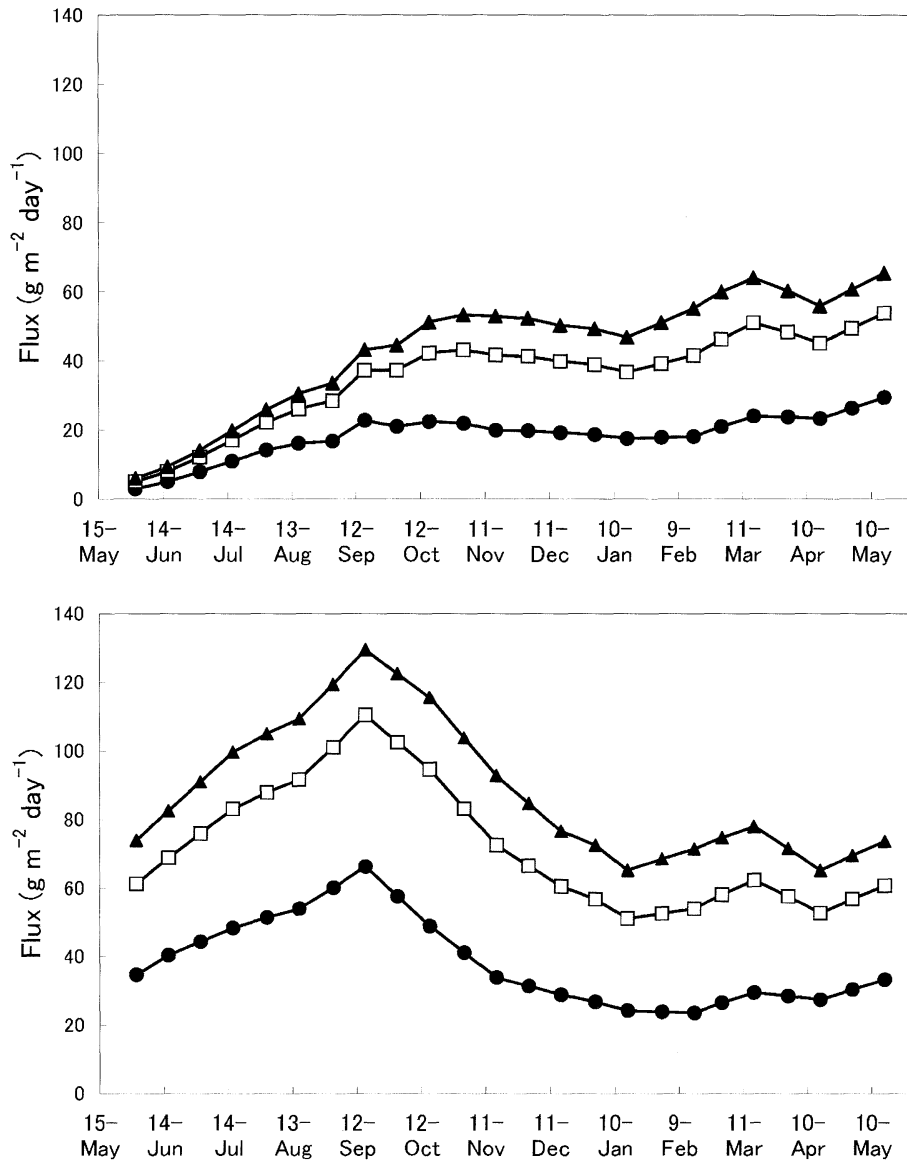
Fig. 3. The time-evolution of sediment fluxes over 2 years at three depths of 5, 10 and 15m. The values at each depth are indicated by symbols; ●: 5m, □: 10m and ▲: 15m. (a) for first one-year period (upper); (b) for second one-year period (lower).

Table 3　The sediment fluxes under an oyster-cultivation raft (in unit of g $m^{-2}day^{-1}$)

Season	Simulated values	Observed values
September (maximum)	170–430	22
March (secondary peak)	140–350	16
January (local minimum)	110–270	12

The respective supposed surface densities of oysters are different. (See Text.)
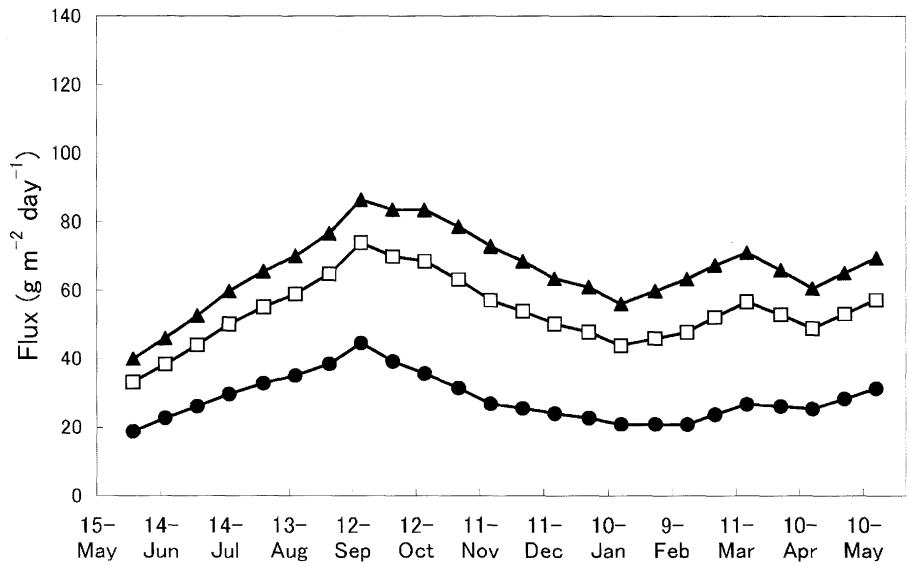

Fig. 4. The seasonal variation of the sediment fluxes obtained by using average data. Symbols are same as in Fig.3.
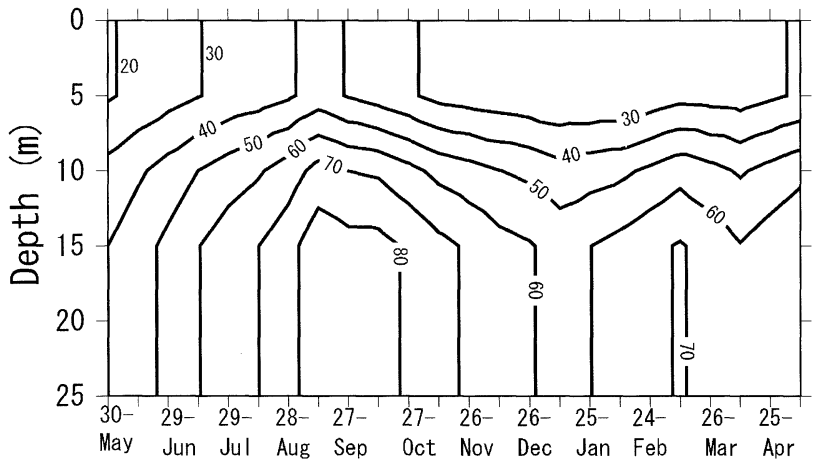

Fig. 5. The seasonal variation of the vertical distribution of sediment flux (calculated values). Numerals attached to curves represent the values of fluxes (g m^{-2} day^{-1}).

the calculated sediment fluxes multiplied by 2–5 must be compared with observed ones. In Table 3, both values of the sediment fluxes are shown. The calculated values are 10–20 times larger than observed ones. However, this does not defeat our model but only indicates that the assumption that sediments discharged by oysters remain just under a cultivation raft is oversimplified. In practice, the tidal flow disperses sediments and reduces the fluxes. The

area occupied by rafts is 8×10^4 m^2, and its fraction to the total area of Ofunato Estuary (8×10^6 m^2) is 0.01. If the sediments spread over the bay, the fluxes are rarefied to the level of 1/100. The results of our simulation suggest the rate of rarefaction with 1/10–1/20. They are comparable to observational data.

4.2 The case using two 2-year data
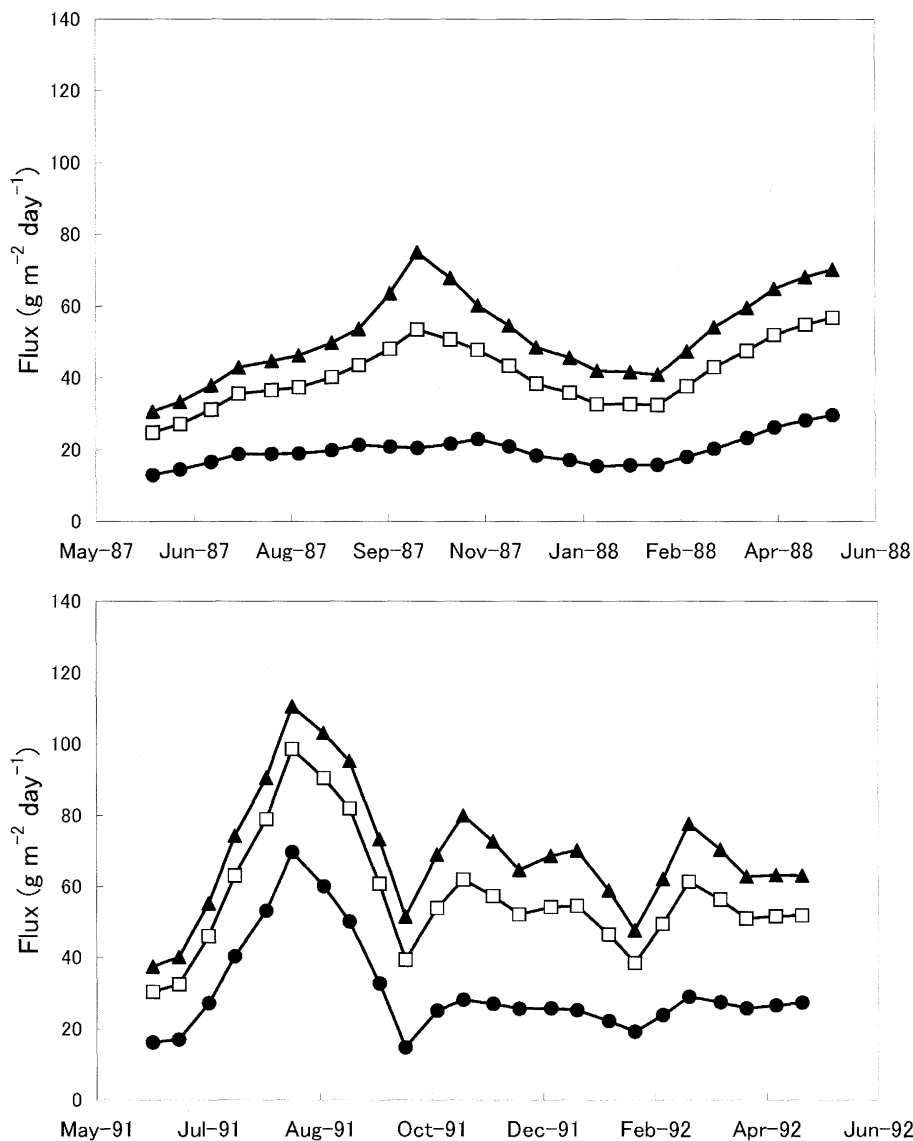In this subsection, we describe the results of

Fig. 6. Temporal changes in the sediment fluxes by using the monthly values obtained from respective years.
Symbols are same as in Fig. 3. (a), the period between May 1987 and April 1988 (upper); (b), between
May 1991 and April 1992 (lower).

our simulations for the case of two periods, when extremal chlorophyll-a concentrations were observed. In the period between May 1987 and April 1988, lower chlorophyll-a concentration was observed, while between May 1991 and April 1992 higher one was observed. The temporal changes of the sediment fluxes between May 1987 and April 1988 shown in Fig. 6 (a) were obtained by calculation using environ-

mental data between May 1986 and April 1988. Likewise, those between May 1991 and April 1992 shown in Fig. 6 (b) were obtained by the data between May 1990 and April 1992. Figures 6 and 4 show that for 250 ind.m^{-2}, the maximal values of the sediment fluxes in each calculation are 110 g m^{-2}day^{-1} for 1991–1992, 86 g m^{-2} day^{-1} for the averaged data and 75 g m^{-2}day^{-1} for 1987–1988, which suggests that

the sediment fluxes have a positive correlation with chlorophyll-*a* concentration. Both for the averaged data and in the period between 1987 and 1988, maximal values are reached in October, while in the period between 1991 and 1992, the maximum is in August and the value in October was a minimum, which is ascribed to the extremely low salinity at surface layer in October. Without this low salinity, the growth of oysters would not be hindered and the fluxes after October 1991 would be larger. But, in reality, the values of fluxes are not larger than those for the averaged data. This can be because such high chlorophyll-*a* concentration causes a rapid growth and strong spawning, making the oysters lighter in their weight (KUSAKA *et al.*, 1991). Finally, the fluxes in the period between 1987 and 1988 are larger than those for the averaged data but the difference is not large. This may suggest importance of other foods than phytoplankton.

5. Concluding remarks

We have used a population dynamics model by KOBAYASHI *et al.* (1997) and environmental data in Ofunato Estuary obtained between 1985 and 1994 (HAYAKAWA *et al.*, 2001; HAYAKAWA *et al.*, 2002), and simulated sediment fluxes by oysters. Our simulation of using the monthly averaged values obtained from this observation has been able to qualitatively reflect the patterns of seasonal variation of the fluxes. Quantitatively, our results are not contradictory to observational data when we take into account the dispersion over the bay. Thus, we conclude that the population dynamics model we have adopted is applicable to oysters in Ofunato Estuary and that the sediments observed in the farm originate from oysters. As to the environmental data, by using the values obtained from respective years instead of the averaged values, we have understood how the environmental characteristics of each year are reflected in the sediment fluxes. Namely, the fluxes have a positive correlation with chlorophyll-*a* concentration. But, it is also suggested that food of oysters is not only phytoplankton (SONIAT *et al.*, 1984; SONIAT and ROY, 1985), which has been considered in our model, in the

second term of the right-hand side of 0.520 in Eq.16. It has been noted that the fluxes decrease rapidly probably because the *C. gigas* growth is hindered when the salinity is low (12.3). The composition of foods of oysters is a next subject in our study.

Acknowledgements

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