La mer 37 : 163–171, 2000
Société franco-japonaise d'océanographie, Tokyo

Influences of concentration, particle-size and kind of inorganic suspended matter on feed caught by Manila clam, *Ruditapes philippinarum*

Akihisa TABATA*,†, Tsutomu MORINAGA* and Hisayuki ARAKAWA*

Abstract : The influences of concentration ,particle-size and kind of inorganic suspended matters on the feed caught by of Manila clam, *Ruditapes philippinarum*, were quantitatively analyzed using a Coulter Counter. Total of 250 samples under shell-length 40 mm (±1.0 mm) were examined. Inorganic particles such as porcelain clay, kaolinite (average size 4.2 μm and 15.3 μm) and red-yellow soil (average size 4.5 μm) were suspended in filtered seawater. Phytoplankton, *Pavlova lutheri* (average size 5.6 μm) constituted the simulated feed suspension. The percent catch rate was based on the proportion of feed particles reduced from the initial number. As the particle-size distribution of phytoplankton followed a normal mode, the catch rate's was expressed as the average in the range from 4.0 to 6.3 μm.

When the kaolinite particles of size 4.2 μm were added at the concentration of 2.0×10^5 ml^{-1} to the phytoplankton suspension of 1.0×10^5 cells・ml^{-1} containing one clam, the catch-rate of phytoplankton by the clam was 74.5%・h^{-1}, revealing that the rate remained almost constant, compared to the pre-addition figure of 70.4%・h^{-1}. However, the catch-rate decreased strikingly to 48.7%・h^{-1} when the kaolinite concentration increased to 5.0×10^5 particles・ml^{-1}. In case of the experiment mentioned above, the very fine kaolinite particles were found adhering to the tip of the clam's incurrent siphon. Furthermore, the phytoplankton cell catch-rates were almost constant when kaolinite was replaced with red-yellow soil. When kaolinite particles of sizes 4.2 and 15.3 μm respectively were added at the concentration of 0.5×10^5 particles・ml^{-1} to a feed suspension of identical concentrati wadicating, the cell catch-rates were 77.8%・h^{-1} in the former and 24.1%・h^{-1} in the latter size, indicating a wide variation in the performance of the clam. Thus it is considered that the influence of inorganic suspended matter on the feed caught by Manila clam depends heavily on inorganic particle's concentration and size, but little on its kind.

Key words : *inorganic suspended matter, feeding, Manila clam, catch rate*

1. Introduction

Recently, a great deal of clay and sand are found dispersed in the coastal waters owing to reclamation works, dredging operations and river transports. Thus it is considered that these particles suspended in seawater have a direct influence on tidal flat inhabiting benthic suspension feeders, for instance, the bivalve Manila clam which is one of the important species from the view-point of fishery resources.

GRIZZLE *et al.* (1989) and NUMAGUCHI (1990) reported the profound influence of concentration of particulate organic matter (POM) and suspended solids (SS) on the bivalve's growth and survival rate. With respect to studies on the influence of particle-size on filtration performance, there are the reports of KUWATANI (1965), KUSUNOKI (1977a, b), HANS (1988), and ARAKAWA *et al.* (1997). KUSUNOKI (1977a, b) investigated the quantities of suspended particles caught by oyster according to particle-size. ARAKAWA *et al.* (1997) examined the size of captured particles for different shell-lengths of the

* Department of Ocean Sciences, Tokyo University of Fisheries, 5–7 Konan-4, Manato-ku, Tokyo 108–8477, Japan.
† Present address: Department of Urban Environmental Engineering, Faculty of Engineering, Hokkaido University, Kita-Ku, Sapporo-city, Hokkaido 060–8628, Japan.

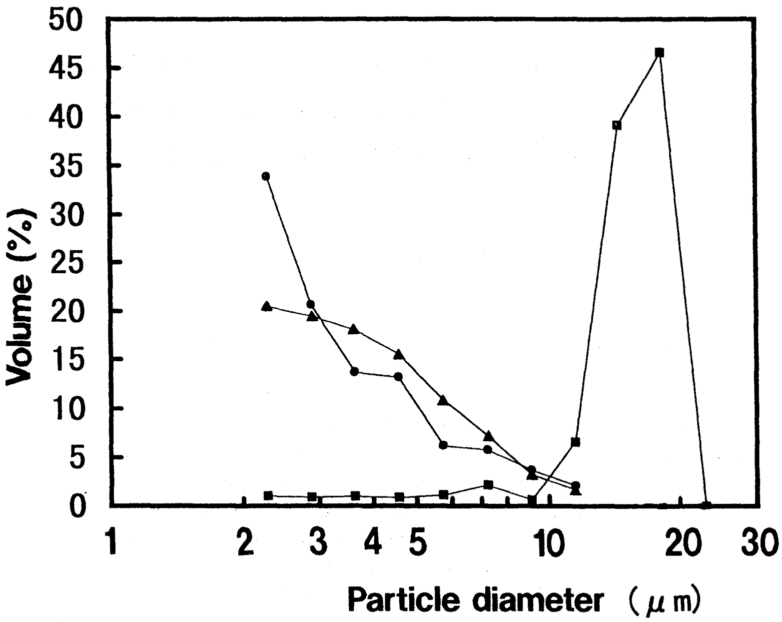

Fig. 1. Particle size distribution of kaolinite and typic red-yellow soil. Symbols ● and ■ indicate kaolinite suspension with average particle-sizes of 4.2 μm and 15.3 μm, respectively, and ▲ indicate red-yellow soil.

clam, supposing that the particle-size of feed greatly influenced the clam's growth in the early stages.

In an earlier related research, FUJIYA *et al.* (1958) studied the influences of waste water and industrial drainage on the feed and filtration of Manila clam with references to their concentrations and the opening and shutting movement of incurrent siphon. CHIBA and OSHIMA (1957) examined the effect of oragnic and inorganic suspended particles on the amount fed and the filtration speed of Manila clam and blue mussel, and found that the speed were approximately constant, irrespective of the quantities of bentonite particles. Apart from this, there is very few information on the influence of inorganic matter suspended in seawater on the feed caught by bivalves.

This study attempts to examine the influences of concentration, particle-size and kind of the inorganic particulate matter on the feed capture of Manila clam.

2. Materials and Method

2.1 Samples and Materials

The bivalve Manila clam, *Raditapes philippinarum* , collected from the tidal flat at Futtsu, Chiba Prefecture were used in this study. A total of 250 clams of shell-length 40 mm (±1.0 mm), were used for the experiment. Each sample was kept from one to eight weeks in basins with filtered seawater maintained at 21±3 ℃.

The inorganic particles employed in this experiment were porcelain clay, kaolinite and typic red-yellow soil. The powdered kaolinite was mixed with seawater filtered through millipore HA (pore-size 0.45 μm), and after one hour, the resulting kaolinite suspension was divided into two kinds; one was the supernatant fluid of suspension, and the other was the suspension filtering through a net of mesh size 20 μm, and not through that of mesh size 10 μm. Fig. 1 shows the particle-size distributions of the supernatant and filterate fractions of the kaolinite suspension obtained. The average particle-size was 4.2μm for the supernatant and 15.3 μm for the filtrate. Considering the particle range from 2.3 to 11.5 μm in the supernatant suspension, kaolinite particles less than 4.0 μm, constituted nearly 70% of it. On the other hand, the suspension of the filtrate was constituted more than 60% by particles in the range from

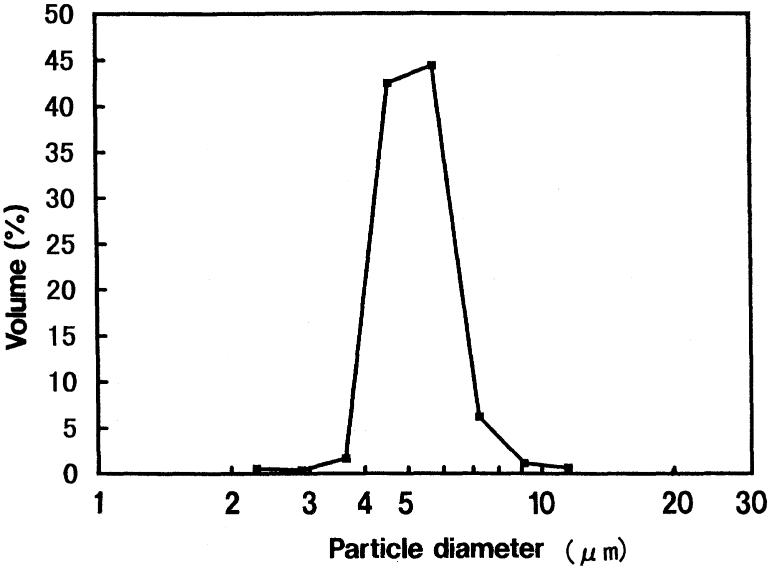

Fig. 2. Particle size distribution of the phytoplankton, *Pavlova lutheri*.

14.5 to 18.3 μm. The red-yellow soil embeded in the Kunigami marge located at Nago, Okinawa Prefecture was also studied. This soil consists of Illite, Halloysite, and etc. (Aoki , 1973) The red-yellow soil was mixed with sea water, filtered through millipore HA (pore-size 0.45 μm), and after one hour, the supernatant fluid of the resulting soil suspension was used as an experimental sample. The particle-size distribution of soil suspension is also shown in Fig. 1, the average size being 4.5 μm. In the case of soil, there were also fewer particles of larger size in the suspension, and those below 4.0 μm, occupied approximately 60% of the total. This distribution is similar to that of the supernatant suspension of kaolinite particles mentioned above.

The feed suspension was the phytoplankton, *Pavlova lutheri* monocultured in a constant temperature room, and it was allowed to emigrate into the seawater. The particle-size distribution of phytoplankton cells is shown in Fig. 2. They ranged in size from 2.3 to 11.5 μm, the maximum numbers (90% of the total) falling in the range from 4.6 to 5.7 μm. The average cell-size of the phytoplankton was 5.6 μm. This value is a little larger than that of Arakawa *et al.* (1997).

2.2. Method

The experiments were conducted at the Banda Marine laboratory of Tokyo University of Fisheries during the period from June to December in 1995. An outline of experimental system is illustrated in Fig. 3. The experimental tank was cylindrical in shape and had a diameter of 18 cm, and a depth of 10cm. this tank was set in the constant temperature water-tank. Also, the experimental tank contained yet another cylindrical inner container, 6 cm each in diameter and depth, which retained the experimental bivalve, and a aerator to facilitate water circulation. Such an experimental system enables the pseudo faeces to keep in an inner container, and is similar to that in the previous paper (Arakawa *et al.*, 1997).

The experiments intended to examine the effect of, (1) concentration of inorganic particle, (2) it's size, and (3) it's kind on the feed caught by Manila clam. Under the first aspect, kaolinite particles were added to phytoplankton suspension, and the mixture had the concentration of 1.0×10^5 particles · ml^{-1}. At this fixed concentration, we tried four ratios of phytoplankton to kaolinite mix; 10 : 0, 5 : 5, 2 : 8, and 0 : 10. Further, keeping the concenration of phytoplankton at 1.0×10^5 cells · ml^{-1} we added kaolinite at concentrations of 2.0×10^5 particles ·

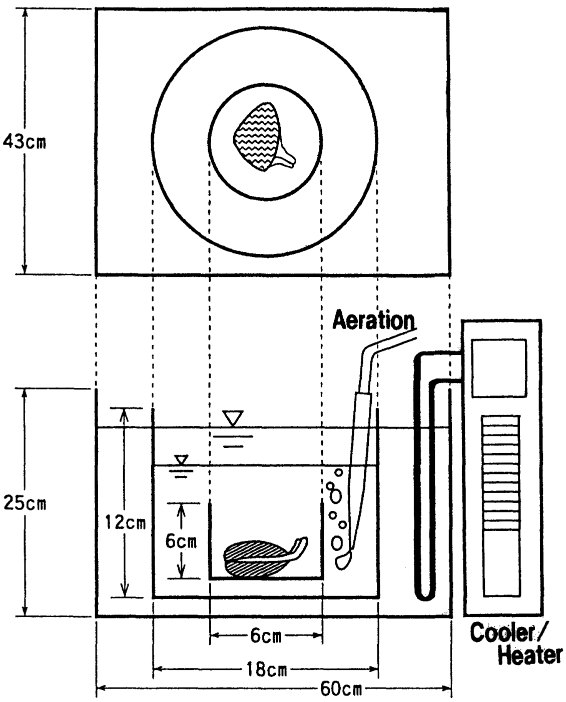

Fig. 3. An outline of experimental system.

ml^{-1} and 5.0×10^5 particles $\cdot ml^{-1}$. In the second aspect examining the size, kaolinite particles of sizes 4.5 and 15.3 μm, at a concentration of 0.5 $\times10^5$ particles $\cdot ml^{-1}$, was added to the phytoplankton suspension at an identical concentration. In the third study in this series, evaluating the kind of inorganic particle, the red-yellow soil at a concentration of 5.0×10^5 particles $\cdot ml^{-1}$ was added to the phytoplank-ton suspension having the concentration of 1.0×10^5 cells $\cdot ml^{-1}$. The suspensions mentioned above were maintained in a dispersed state with weak air-pumping in order to avoid sedimentation, thereby producing uniform mixtures.

From about five to ten minutes after introducing a sample clam in the vessel, we observed the vigorous filtration activity with incurrent siphon, and after one hour, we collected 200ml of the water from the vessel with a whole-pipet. The number of particles in the sampled water was measured with a Coulter Counter (Model ZM; aperture size of 100 μm). The objective particles for the study were those in the range from 2.0 to 25 μm. A control was employed simultaneously, using the vessel without the experimental animals, and determining the particle numbers from a similar sample as mentioned earlier.

The catch rate, $C_{r(i)}$ is obtained using the following formula(ARAKAWA *et al.*, 1997);

$$C_{r(i)} = \frac{1}{n\cdot t}\,\frac{C_{c(i)}-C_{e(i)}}{C_{c(i)}}\cdot 100 \quad (\%\cdot h^{-1}) \quad (1)$$

where, $C_{c(i)}$ is the concentration of particles without the clam, $C_{e(i)}$ denotes the concentration of particles(diameter at i - class: di) contained in the water with the clam, t (hour) stands for the experimental period, and n is the number of clams.

Besides, the average diameter of captured-particle $\bar{D}$ is based on the following formula:

$$\bar{D} = \frac{\Sigma\, d_i\cdot Nd_i}{\Sigma\, Nd_i} \quad (2)$$

Where, d_i stands for the diameter of particle-size at i-class, and Nd_i stands for the number of particles at the diameter d_i.

In this study, each of the values of n and t mentioned above was one piece and one hour, respectively. Also, the value of catch rate was

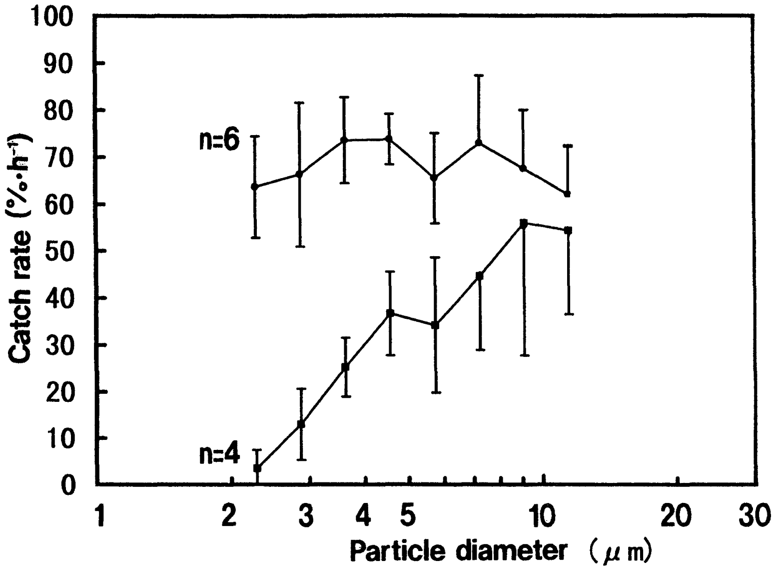

Fig. 4. Changes in the catch-rates of clams when offered two different suspension. Symbols ● and ■ represent phytoplankton and kaolinite with particle-sizes of 4.2 μ m, respectively.

expressed as the average for the size range from 4.0 to 6.3 μm as the particle-size of phytoplankton had a normal mode in distribution.

3. Rusults

3.1. Quantity of inorganic matter

3.1.1. Constant concentration

Figure 4 shows the relationship between catch rates of phytoplankton cells and kaolinite particles on the clam and particle-size when it was kept for 60 minutes in filtered seawater. Circle and square symbols denote the phytoplankton, *Pavlova lutheri* and the kaolinite with particle-size of 4.2 μm, respectively. Both had a concentration of 1.0×10^5 particles · ml^{-1}. In the former, the catch rates of phytoplankton cells were 63.6% · h^{-1} corresponding to the particle-size of 2.3 μm, 65.4% · h^{-1} for 5.7 μm, and 62.1% · h^{-1} for 11.5 μm. Accordingly, their catch rates were about 60–70% · h^{-1} for the size range from 2.3 to 11.5 μm. On the other hand, the catch rates of kaolinite were 3.5% · h^{-1} corresponding to 2.3 μm particle-size, 34.1 % · h^{-1} for 5.7 μm, and 54.3% · h^{-1} for 11.5 μm, respectively. The noticeable difference for kaolinite particles was the high catch rates for the size range from 9.1 to 11.5 μm. These facts suggest that the feeding pattern of clam on the phytoplankton cell distinctly differs from that with the kaolinite particle.

The kaolinite with particle-size of 4.2 μm was added to the phytoplankton suspension, and the concentration of resulting suspension was 1.0×10^5 particles · ml^{-1}. Table 1 exhibits the number of particles caught by clam in relation to the phytoplankton: kaolinite ratio. The number of particles was 1.4×10^8 cells · $piece^{-1}$ · h^{-1} corresponding to the ratio 10 : 0, 1.6×10^8 particles · $piece^{-1}$ · h^{-1} for 5 : 5, 6.2×10^7 particles · $piece^{-1}$ · h^{-1} for 2 : 8, and 1.8×10^7 particles · $piece^{-1}$ · h^{-1} for 0 : 10, respectively. The efficiency of particle-capture decreased with an increase in the proportion of kaolinite. In particular, when the ratio of phytoplankton to kaolinite was 0 : 10, the capture rate was only 1.8×10^7 particles · $piece^{-1}$ · h^{-1}, and this was just one-tenth that of the suspension containing only phytoplankton cells.

3.1.2. Increase of particle concentration

In the particle-size distribution of phytoplankton cells caught, about 87.9% of the total was constituted by those in the range from 4.0 to 6.3 μm. Table 2 shows the changes in catch

Table 1. Relationships between mix ratio and actual number of particle captured by the clam.

Mix ratio (phytoplankton: kaolinite)	Number of sample	Number of particle (particles・piece^{-1}・h^{-1})
10 : 0	6	1.4 ±0.13×10^{8}
5 : 5	6	1.6 ±0.08×10^{8}
2 : 8	8	6.2 ±0.29×10^{7}
0 : 10	4	1.8 ±0.06×10^{7}

Table 2. Results of different experimental conditions on the catch-rate of phytoplankton cells by the clam.

Initial condition of experiment	Number of sample	Catch rate(%・h^{-1})
I Kaolinite concentration		
(particles・ml^{-1})		
0	6	70.4±6.7
2.0 ×10^{5}	5	74.5±4.2
5.0 ×10^{5}	5	48.7±4.7
II Kaolinite-size		
(μm)1		
4.2	6	77.8±4.2
15.3	8	24.1±4.7
III Particle types		
Kaolinite (4.2μm)	5	48.7±5.2
Red-yellow soil	4	48.8±1.5

* Remarks : Phytoplankton concentrations of condition I and III, and condition II are 1.0×10^{5} cells・ml^{-1}, and 0.5×10^{5} cells・ml^{-1}, respectively.

rate depending on the concentrations of kaolinite particles introduced. Here, the feed suspension of phytoplankton was at a concentration of 1.0×10^{5} cells・ml^{-1}. With respect to this suspension, kaolinite particles at the concentrations of 2.0×10^{5} and 5.0×10^{5} particles・ml^{-1} were added.

In case of the phytoplankton suspension having no kaolinite, the catch rates of clam was 70.4%・h^{-1} for the size range from 4.0 to 6.3 μm. However when kaolinite particles were added at 2.0×10^{5} and 5.0×10^{5} particles・ml^{-1}, the catch rates of phytoplankton cell were 74.5%・h^{-1} and 48.7%・h^{-1}, respectively. At the higher kaolinite concentration, the drop in catch rate was quite evident. The fine kaolinite particles were found adhering to the tip of the clam's incurrent siphon.

3.2. Particle-size of inorganic matter

Table 2 expresses the changes in catch rates of phytoplankton cells in the size range from 4.0 to 6.3 μm by the clam when two different sizes of kaolinite were added. The concentration of feed suspension was 0.5×10^{5} cells・ml^{-1}, and a similar concentration of kaolinite particles at sizes 4.2 and 15.3 μm were introduced. The catch rates of phytoplankton cells were 77.8%・h^{-1} for the particle-size of 4.2 μm and 24.1%・h^{-1} for 15.3 μm, respectively. It is clear throughout the experiments that when the particle-size of the added kaolinite was larger, the catch rate of feed particles was extremely low.

3.3. Kind of inorganic matter

Figure 5 shows the catch rates of clam in relation to particle-size when it was exposed for 60 minutes in seawater containing red-yellow soil at the concentration of 1.0×10^{5} particles・ml^{-1}. The catch rate of red-yellow soil was 21.6 %・h^{-1} corresponding to the particle-size of 2.3 μm, 57.8%・h^{-1}for 5.7 μm, and 41.2%・h^{-1} for 11.5 μm. The catch rates(65 to 68%・h^{-1}) were

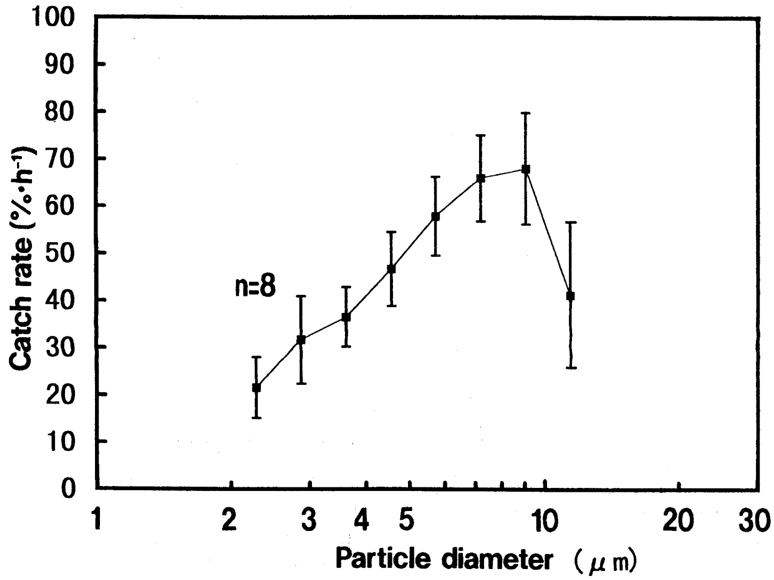

Fig. 5. Changes in the catch-rates of clams exposed to red-yellow soil suspension.

higher for the size range 7.2 to 9.1 μm. Comparing these rates with those for phytoplankton (Fig. 4), we found that the values for the phytoplankton were nearly equal (62 to 74% · h^{-1}) for a wide particle size range from 2.3 to 11.5 μm; as against very similar catch rates (65 to 68% · h^{-1}) for the soil particles but for a narrower range from 7.2 to 9.1 μm. This result suggests that the capture probability of phytoplankton cells is distinctly different from that of soil and as well as the kaolinite.

Table 2 shows the percent catch rates in the presence of inorganic matter such as kaolinite and red-yellow soil. Here, the value of catch rate was expressed for the size range from 4.0 to 6.3 μm, the concentration of the feed phytoplankton cells being 1.0×10^5 cells · ml^{-1}. Also, the concentrations of added inorganic particles were 5.0×10^5 particles · ml^{-1}. In case of the soil addition, the catch rate of phytoplankton cells was 48.8% · h^{-1} which was approximately the same as that with the 4.2 μm kaolinite particles. This reveals that the type of the inorganic particle has little influence on the catch rate of the Manila clam.

4. Discussion

In order to fully understand the influence of inorganic particle on the feed caught by Manila clam, it is necessary to have some prior basic information on the filtration performance. Hence, some preliminary experiments: (1) the changes in phytoplankton cell catch rate when the clam were either performing active filtration or not, (2) the changes in phytoplankton cell catch rate with lapse of time, and (3) the influence of the concentration of phytoplankton cell on filtration performance were conducted.

In the first item, the catch rate of clam in a state of motion was about three times of that in a state of rest, corresponding to the particle range from 2.3 to 11.5 μm. The clam used in the present experiment performed active filtration with the end of the incurrent siphon opened. (Arakawa *et al.*, 1997)

With respect to the second item, the authors obtained that the number of cells captured was 0.8×10^8 cells · $piece^{-1}$ · h^{-1} in the first half-hour, 1.4×10^8 cells · $piece^{-1}$ · h^{-1} at the end of the first hour and 1.8×10^8 cells · $piece^{-1}$ · h^{-1} by the second hour when the cell concentration was 1.0 $\times 10^5$ cells · ml^{-1}. There was a rapid increase during the first hour and these after the increase was gradual. Throughout these experiments, it is found that the filtration activity of clam continued to an hour.

In case of the third item, the catch rates at different concentrations of phytoplankton cells were 50 to 75% $\cdot h^{-1}$ for the size range from 2.3 to 11.5 μm. The catch rate of phytoplankton cell is little influenced by the wide range in concentration(0.5 to 6.0×10^5 cells $\cdot ml^{-1}$). The catch rates of different particle-sizes and concentrations, in the present study, was almost constant throughout the experiments for cell concentrations between 0.5 to 6.0×10^5 cells $\cdot ml^{-1}$. In an earlier study, ARAKAWA *et al.* (1997) experimenting with pellets, reported that with regard to sizes from 2.0 to 10 μm, the catch rates at the concentration of 6.0×10^5 particles$\cdot ml^{-1}$ were extremely lower than those at 1.0×10^5 and 3.0×10^5 particles $\cdot ml^{-1}$. This does not coincide with the present findings. It could be attributed to the variations in particle-size distribution, particle's kind and shape between the phytoplankton and pellet.

As to the influence of inorganic particle on the filtration performance of Manila clam, the catch rates of phytoplankton cells(size range from 4.0 to 6.3 μm) abruptly decreased with increase in inorganic particles. JøRGENSEN (1966) has reported that the filtration speed of a bivalve decreased corresponding to an increase in the sediment-particle concentration resulting in closure of the incurrent siphon. In our observations too, we found that the adhension and settlement of inorganic particle in the incurrent siphon of clam occurred in the presence of larger amounts of suspended matter, thereby lowering the phytoplankton cell catch rate. Further experiments are necessary to clarify this point.

With regard to the influence of particle-size of inorganic matter on feeding, the catch rate of phytoplankton cell decreased remarkably as the size increased from 4.2 μm to 15.3 μm. SEMURA (1995) reported that the filtration speed of Adult scallop, *Pecten albicans* changed with kind and quantity of the feed phytoplankton, and found some relationship between the phytoplankton cell size and particle of sizes 5 to 7 μm which were effectively caught with the gill or the filtering organ. The remarkable decrease in catch rate observed in this study when the particle-size of kaolinite is larger, might be because the kaolinite particles of size 4.2 μm are more effectively filtered than those of 15.3 μm.

In the present study, the influence of inorganic suspended matter on the feed caught by Manila clam depended heavily on particles concentration and size of inorganic particles, but little on its kind. These influences could either be fluctuated in the clam of smaller shell-lengths, or different benthic suspension feeders. They have to be examined further.

Acknowledgement

The authors would like to thank to Mr. J. KAKINO, Mr. T. SHIBATA, and Ms. M. SAKAI who are the staffs of the Shellfish Laboratory, Futtse Branch Office of Chiba Prefectural Fisheries Experimental Station for the help presented during the conduct of this study.

References

AOKI, S. (1973) : Carbonate and clay minerals in the sediments of Nago Bay, Okinawa Prefecture, Japan. La mer, **11**, 65–69.

ARAKAWA, H., T. YAOITA, T. KOIKE and T. MORINAGA (1997) : Sizes of suspended particles caught by Manila clam, *Ruditapes philippinarum*. La mer, **35**, 149–156.

CHIBA, K. and Y. OSHIMA (1957) : Effect of suspending articles on the pumping and feeding of marine bivalves, especially of Japanese neck–clam. Bull. Japan. Soc. Sci. Fish., **23**, 348–353. (in Japanese)

FUJIYA, M., S. CHIKUNI, and Y. YAMADA (1958) : Study on the effects of industrial drainage upon the bivalves. Bull. Naikai Regi. Fish. Res. Lab., **11**, 25–39. (in Japanese)

GRIZZLE, R.E. and P.J. MORIN(1989) : Effect of tidal currents, seston and bottom sediments on growth of *Mercenaria mercenaria* : results of a field experiment. Mar. Biol., **102**, 85–93.

HANS, U.R. (1988) : Efficiency of particle retention and filtration rate in 6 species of North American bivalves. Mar. Ecol. Prog. Ser., **45**, 217–223.

JøRGENSEN, C.B. (1966) : The biology of suspension feeding. Pergamon Press, Oxford, 337pp.

KUSUNOKI, Y. (1977a) : On measurement of the filtration rates of the Japanese oyster. Bull. Japan. Soc. Sci. Fish., **43**, 1069–1076. (in Japanese)

KUSUNOKI, Y. (1977b) : Retention of small particles by the gills of the Japanese oyster. Bull. Japan. Soc.

Sci. Fish., **43**, 1391–1396. (in Japanese)

KUWATANI, Y. (1965) : A study on feeding mechanism of Japanese pearl oyster, *Pinctada martenisii*, with special reference to passage of charcoal particles in the digestive system. Bull. Japan. Soc. Sci. Fish., **31**, 789–798.

NUMAGUCHI, K. (1990) : Concentrations of chlorophyll *a* phaeo-pigments of bottom sea water, sediment and surface mud in estuary where short necked clam *Ruditapes philippinarum* (Adams et Reeve) inhabited. Bull. Natl. Res. Inst. Aquaculture No. **18**, 39–50. (in Japanese)

SEMURA , H. (1995) : The effect of algal species and concentration on the rates of filtering digestion, and assimilation of the adult Japanese bay scallap *Pecten albicans* . Nippon suisan gakkaishi, **61**, 673–678.

Received August 12, 1998
Accepted January 29, 2000