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Environmental conditions relevant to aggregative distribution of macrobenthos below coho salmon culture cage

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Abstract Actual changes in environmental conditions relevant to aggregative distribution of the macrobenthos below coho salmon culture cage were examined by diving observation at Onagawa Bay in 1990s. Organic sediment derived from leftovers of moisture food pellets and fish feces were 15 cm in height at the center below culture cage. Dominant species of macrobenthos were identified *Nebalia bipes*, *Schistomeringos japonica*, *Melita* sp. and *Capitella spp*. Highest density of *Nebalia bipes* was found ca. 40,000 inds./m^2 and that of *Schistomeringos japonica* was ca. 5,000 inds./m^2 from enriched sediment on the bottom surface. Aggregative distribution of *Nebalia bipes* and *Schistomeringos japonica* were monitored at 10-m distance zone from the center point in summer, and that of *Nebalia bipes* and *Melita* sp. were monitored within 5-m distance from the center in winter. From the ecological viewpoint for these external distributions, aggregative position of macrobenthos was correlated to the marginal zone of enriched sediment. Biological activities so-called bioturbation were recognized in conjunction with synchronous patterns of the distribution between macrobenthos and organic sediment below culture cage.

Key words: coho salmon, macrobenthos, environmental condition

The work described here has the aim of obtaining information on the ecological relationship between decomposition of organic sediment and distribution of macrobenthos below coho salmon culture cage. To assess the impacts of fish farming and to prevent self-induced deterioration, several criteria for the protection of the environment around aquaculture farms have been proposed and summarized (Yokoyama, 2000). In order to establish the most prudential plan to prevent environmental deterioration around fish farm site, we need to understand the following ecological basis. Firstly, promotion of circulated nutrient linkage converted by mineralization from the loaded organic sediment decomposed through bacteria and macrobenthos toward ongrowing of sedentary fish, which is regarded as a part role of the cyclic processes in natural ecosystem. Secondary, retrieval of economical materials such as a sedentary fish which converted by macrobenthos with enriched sediment in the course of fishing is a removal step for discharging the organic loads to outside of ecosystem through food chain in the benthic community (Tamai, 1990).

Ohmori *et al.* (1995) has already estimated on the organic loads derived from coho salmon culture by analyzing culture records of fisherman's annual diary, and pointed out that low oxygen levels were yearly correspondent to the increasing production of coho salmon at Onagawa Bay during early 1990s. Key problem to study actual changes in environmental

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conditions below fish culture cage lies in improving the methods for monitoring organic sediment and macrobenthos, which sample was indirectly obtained with Ekman-Birge grab conducted by surrounding researcher on the boat. This lack of understanding is mainly due to underwater research activity and also due to difficulty in sampling methods for macrobenthos below culture cage where environmental conditions are dark, dirty and dangerous for research diver.

In addition to the finding on the nitrogen loads to the environmental water caused by the feeding (Ohmori *et al.*, 1995), we tried to find out the correlationship between the aggregative distribution of macrobenthos and loaded organic sediment that needed to establish the actual contribution for preventing the deterioration. Furthermore, effects of shell-collector as a habitat for macrobenthos were investigated to promote the decomposition of organic sediment and artificial improvement for a bio-monitoring function of environmental condition on the bottom surface below culture cage.

Materials and Methods

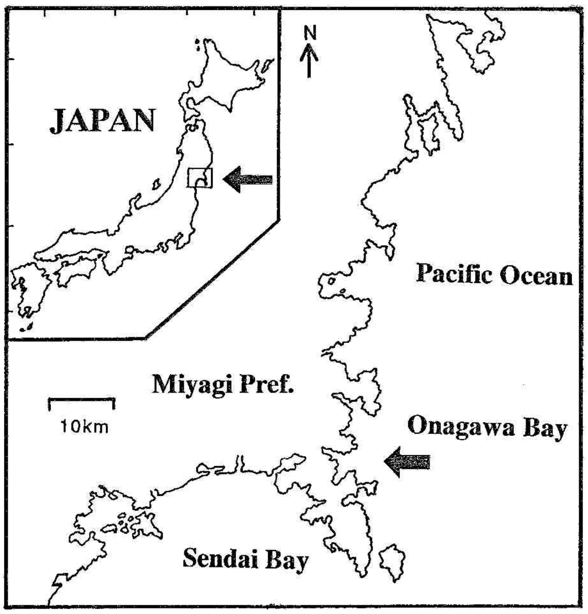

Fig. 1. Location of northern part of Japan and coast map of Miyagi Prefecture showing the study site

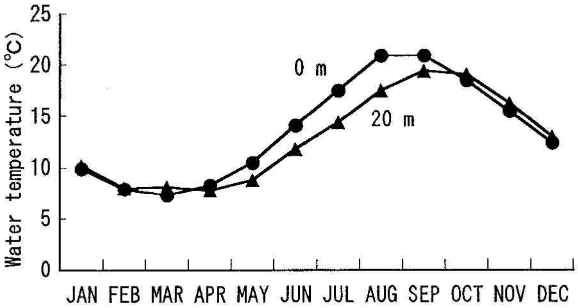

Fig. 2. Monthly changes in water temperature of surface and 20-m depth layer in Onagawa bay

Onagawa Bay (38 °24'N, 141 °29'E), which has an area of 12 km^2 and a mean depth of 19 m, is a typical embayment where mariculture farms, e.g. oyster, scallop, and coho salmon, are densely distributed (Fig. 1) . Water temperature of surface ranged from 21 ℃ in August and to 7 ℃ in February, and that of 20-m depth ranged from 19 ℃ in September to 8 ℃ in March, respectively. Depth of the study site was 20 m and bottom water temperature between August and October during post harvest time were more than 18 ℃ (Fig. 2).

Coho salmon culture is generally started from November with 150 g of body weight for a juvenile and continued until following July with 3 kg body weight for a harvest size, so that absent periods for culture attains 3 months from August through October. Initial density of juveniles in a cage was approximately 15,000 and harvest time 10,000 individuals. The size of culture cage was a regular square of 13-m long with 10-m depth net.

Comparing the correspondence between trend of coho salmon production and environmental conditions in bay-wide, macroscopic change of dissolved oxygen as a bottom water condition and total sulfide value as a sediment condition were reexamined by the monthly recording data-book on environmental survey of Onagawa Bay (Miyagi Prefecture, 1982～2000).

Dissolved oxygen at surface and bottom water was measured monthly from June through November 1996 in the vicinity of studying culture cage. Bottom sediments were collected by the core-tube of 6-cm diameter with a cap. Core samples were carefully collected by diver's hands at each 5-m intervals from the center point toward out-skirt with 30-m-long distance by 5-m intervals.

In order to estimate the influence of fish culture, the scale-bar marked 5-cm interval recognizing for the degree of sedimentation was set by diver at the center point of the bottom surface below culture cage in May 1996. Height of organic sediments before and after harvest derived from leftovers of moisture food pellets and fish-feces were recorded by underwater camera once in a month until following years. Monthly fluctuations of total sulfides (TS), chemical oxygen demand (COD) and ignition loss (IL) values of bottom sediments regarded as the organic indicator were monitored to define a boundary of the enriched area at each 5-m intervals from the center point below culture cage.

In addition to the measurement of environmental conditions, spatial and temporal distribution patterns of macrobenthos were compared below culture cage. Bottom sediments in a 0.2 m^2 was dragged for collecting macrobenthos with 1-mm mesh net by diver's hands from the center point toward out-skirt of 30-m-long distance by 5-m intervals in July, September, December, 1996 and February 1997.

In the course of research activities, feeding of moisture food pellets for the culture cage was discontinued at this study site after July 1996 by the cessation of culture operation with cost disadvantage. After then, distribution of macrobenthos and TS, COD and IL value of sediment were traced at the same center area below culture cage until August 1997 to compare with those of the environmental conditions in July 1996 of the harvest time.

In order to examine the dependency of *Nebalia bipes*, a dominant species of macrobenthos in the study site, shell-collector bag as a habitat for shelter substratum was set on the bottom surface at each 5-m intervals from the center point. Shell-collector bag was composed by 10 pieces of oyster shells. The control sample against shell-collector bag was collected at the direct vicinity of each area by the same square.

Besides outdoor observations for the distribution pattern of macrobenthos, feeding responses between sedentary fishes distributed around culture cage against macrobenthos were confirmed by the indoor rearing experiment, which frozen Nebalia bipes and *Schistomeringos japonica* were put into the

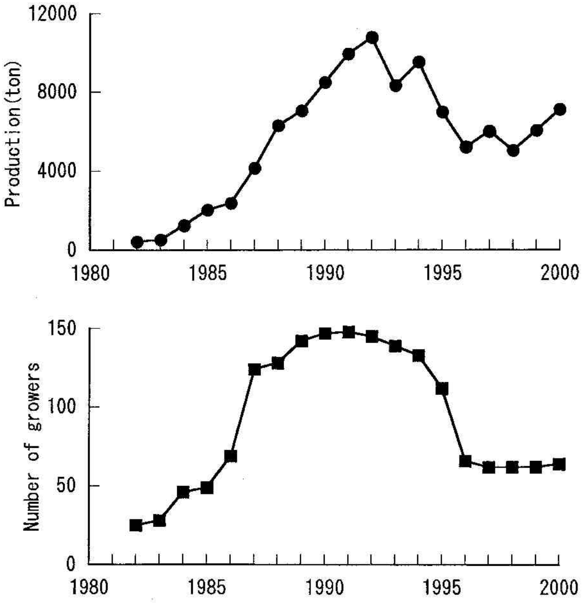

Fig. 3. Trends in production and growers of coho salmon culture in Onagawa bay, Miyagi Prefecture 1982 - 2000

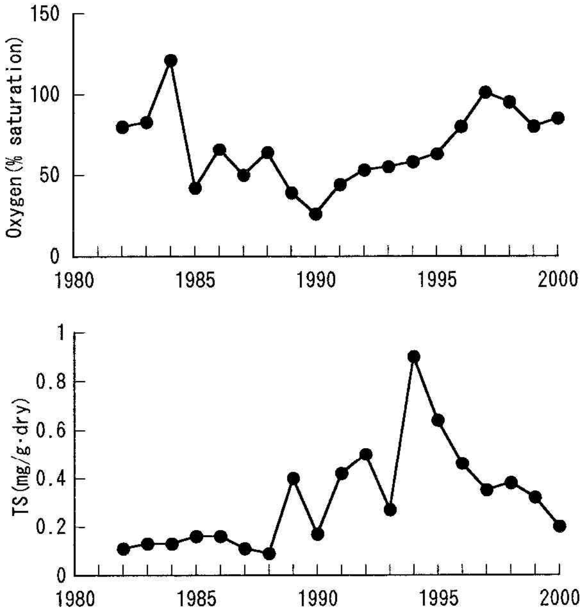

Fig. 4. Yearly changes in dissolved oxygen value of the bottom water in July and total sulfide value of the bottom sediment at August in coho salmon culture ground, 1982-2000

tank fed for several species of fishes.

Results and Discussion

1. Environmental conditions at coho salmon culture area

Production of coho salmon culture in Onagawa Bay has developed increasingly from 1980s, then matured in early 1990s and decreased in subsequent several years including cessation of operations due to cost disadvantage. The total production reached a peak in 1992 when 10,769 ton were landed with 148 growers, and bottomed in 1998 when 5,021 ton were landed with 62 growers (Fig. 3).

Changes in dissolved oxygen saturation as a bottom water condition in summer of early 1980s ranged between 120 % and 80 %, after then oxygen value decreased abruptly and attained lowest in 1990 with 26 %, and recovered yearly until 2000 with 85 % (Fig. 4). Changes in total sulfide value as a sediment condition of coho salmon culture ground also attained a highest value in 1994 with 0.9 mg/g•dry•sedi ment, which tend to follow the deterioration of water condition and recovered yearly until 2000 with 0.2 mg/g • dry • sediment. Both oxygen concentration and total sulfide value were subsequently appeared in corresponding to those peak years by over-production of coho salmon culture. In recent years, the relationship between the production of coho salmon and decreasing value of dissolved oxygen and total sulfide were regarded as a balanced load between organic deposit by culture production and decomposition by natural environment. In relation to this tendency, Yokoyama (1995) described that large biomass at the innermost part of Ohmura Bay suggest that a relatively high concentration of sulfide (0.45-0.75 mg/g• dry sediment) never prevents distributions of animals, and that organic enrichment of the sediments is sufficient to provide a rich food source but is not yet high enough to cause serious oxygen depletion .

Organic loads in bay-wide derived from coho salmon culture with feeding moisture pellets has already estimated at the same area in early 1990s by analyzing culture records of fisherman's diary (Ohmori *et al*, 1995). According to the estimation of each parameter, annual amount of organic loads as equivalent to nitrogen discharge was calculated 6,767 kg a grower from total amount of food supply. This amount of nitrogen divided into 1,640 kg as 25 % for landing of culture production and 5,127 kg as 75 % for discharging to the environmental waters (Fig. 5). Nitrogen load against the environmental waters was corresponded to 9 % of total landing of cultured coho salmon, so that annual nitrogen load was estimated approximately 2 ton/day in Onagawa Bay (Ohmori *et al.*, 1995).

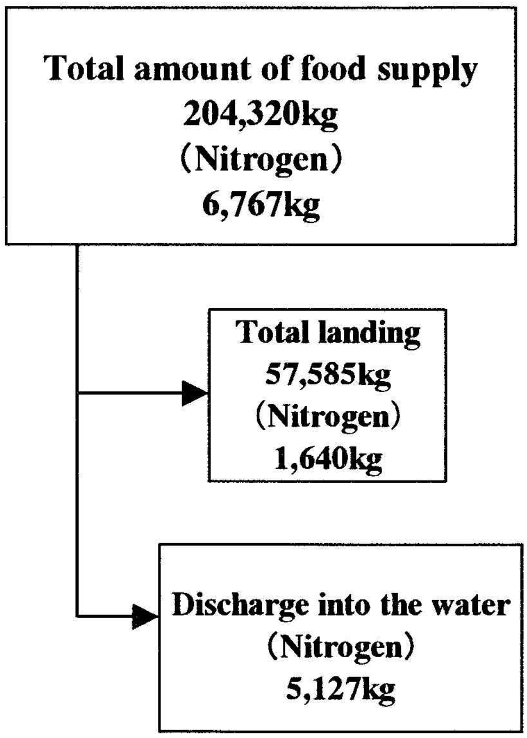

Fig. 5. Annual amount of organic loads and equivalent nitrogen discharge for a grower of coho salmon culture (after Ohmori *et al.* 1995)

2. Environmental conditions below culture cage

Saturation of dissolved oxygen at surface water in the study site was 96 % in average, ranging 137 % at highest in June and 76 % at lowest in October, and that of bottom water was 73 % in average, ranging 53 % at lowest in September and 84 % at highest in November.

Monthly changes in the height of sediment derived from leftovers of moisture food pellets and fish feces was directly measured by scale-bar set below the center of culture cage (Fig. 6). Maximum sedimentation was monitored 15 cm in height at the harvest time in July 1996, and then decreased month by month until following February 1997 when original ground was again exposed through the decomposition processes of organic sediment (Fig. 7). Feeding was ended by culture cessation in July 1996. Therefore, it was evident that the time for decomposition of organic sediment derived from food supply requires nearly 7 months under natural environmental conditions. The volume of organic sediment at harvest time was estimated approximately $37\ \mathrm{m}^3$ below culture cage, which was calculated from the distributed range of sedimentation within 25-m diameter measured by diver.

The TS, COD and IL values of bottom surface were monitored to define a boundary of the enriched sediments collected at each 5-m intervals from the center point toward outer area below culture cage, which expressed the marginal zone decomposed organic sediments by benthic communities (Fig. 8). A peak of TS values was 1.22 mg/g・dry sediment at 10-m distance in July, 1.98 mg/g・dry sediment at 5-m distance in September and 1.65mg/g・dry sediment at 5-m in December 1996. A peak of COD values was 270mg/g・dry sediment at the center in July, 255 mg/g・dry sediment at 5-m distance in September, 182 mg/g・dry sediment at the center in December 1996 and 104 mg/g・dry sediment at the center in February 1997. A peak of IL values was 59 % at the center in July, 42 % at 5-m distance in September, 35 % at the center in December 1996, and 26 % in February 1997.

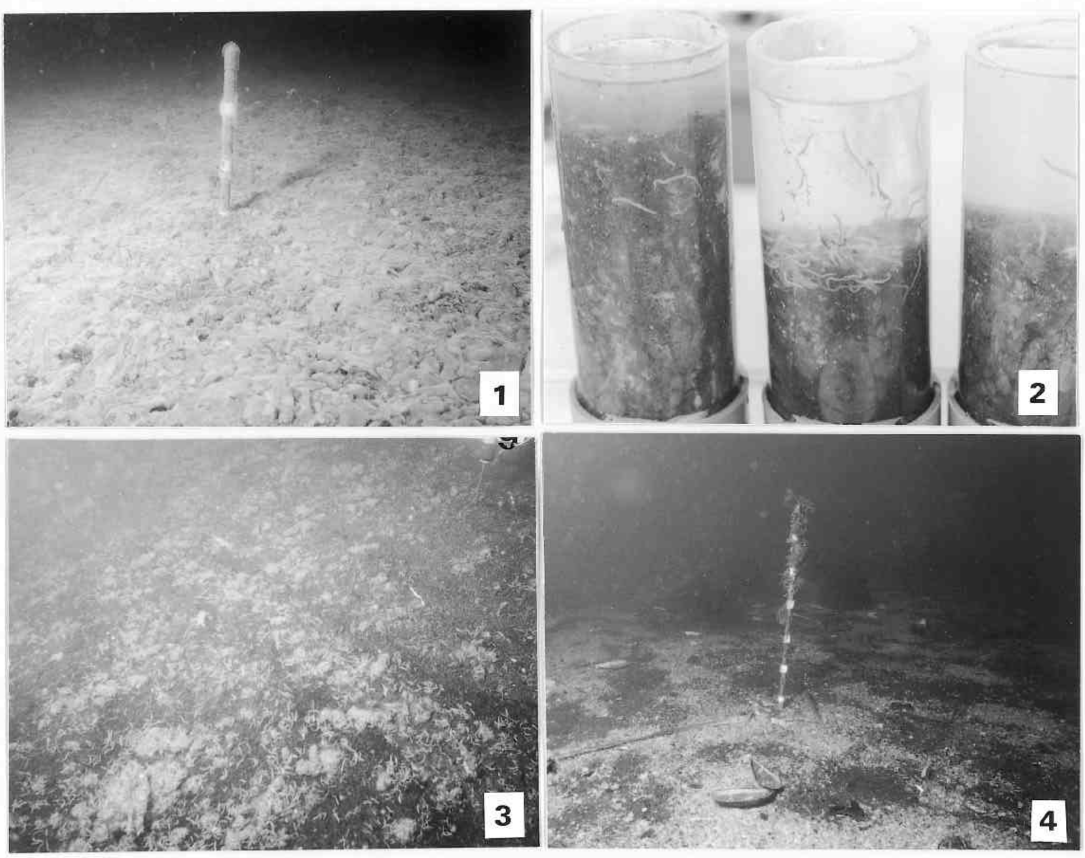

Fig. 6. 1 : Scale-bar in the bottom sediment at harvest time (photographed in July 1996). 2 : Contents of core tube samplers viewing from lateral side. 3 : Aggregative distribution of *Schistomeringos japonica* on the bottom sediment. 4 : Scale-bar in the bottom restored original condition (photographed in Feb. 1997)

According to the change in a peak position of COD and IL values below culture cage, simultaneous fluctuations corresponded to each month indicate removable contraction of organic sediment from outer marginal zone toward the center area through the decomposition processes of organic sediment. The TS, COD and IL values as a chemical indicator of the bottom conditions suggest in general that the influences of organic sediments were limited within 10 to 15-m distance area from the center point in summer and within 5-m distance in winter through the synchronous contraction. In relation to these findings, azoic conditions and high TS value (over 1.3mg/g•dry sediment) were found at the fish farm in Gokasho Bay during the summer, which suggested a key factor in eliminating the macrofauna in organic enriched habitat and significant negative correlation between the sulfide content and the density of the macrofauna (Yokoyama *et al.*, 1997).

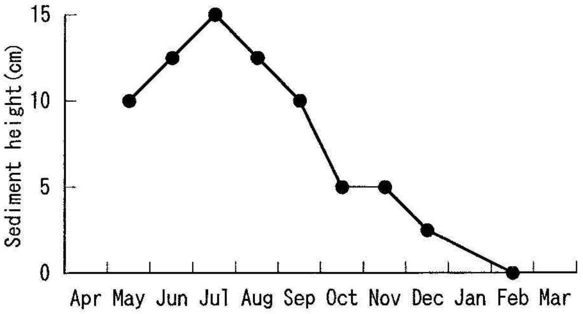

Fig. 7. Monthly changes in the height of sediment derived from leftovers and fish feces below culture cage monitored by scale-bar

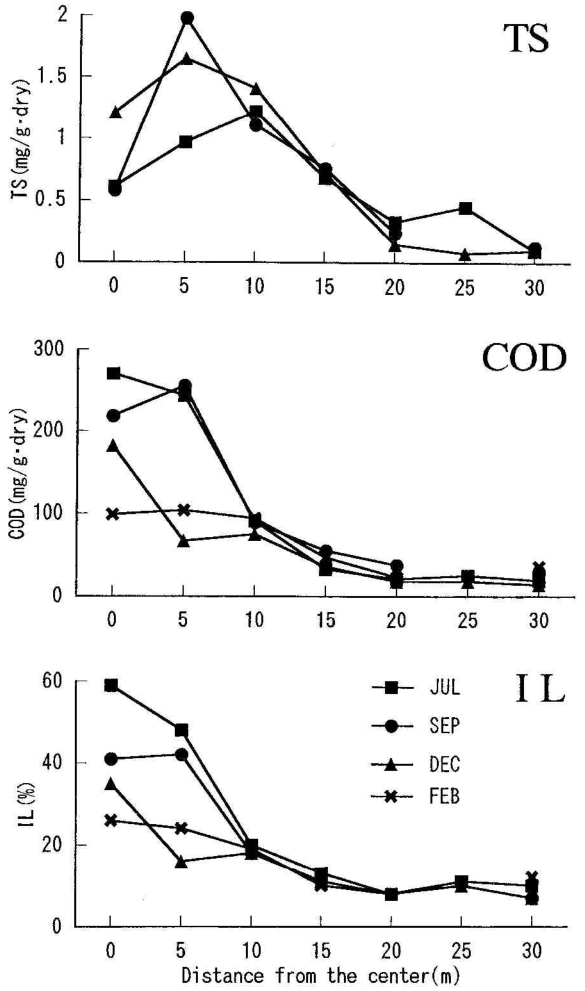

Fig. 8. Changes in total sulfide, chemical oxygen demand and ignition loss values of bottom sediment collected from each 5-m intervals within 30-m distance from the center point below culture cage

3. Distribution of macrobenthos below culture cage

Dominant species of macrobenthos collected by dragging with hands-net through bottom

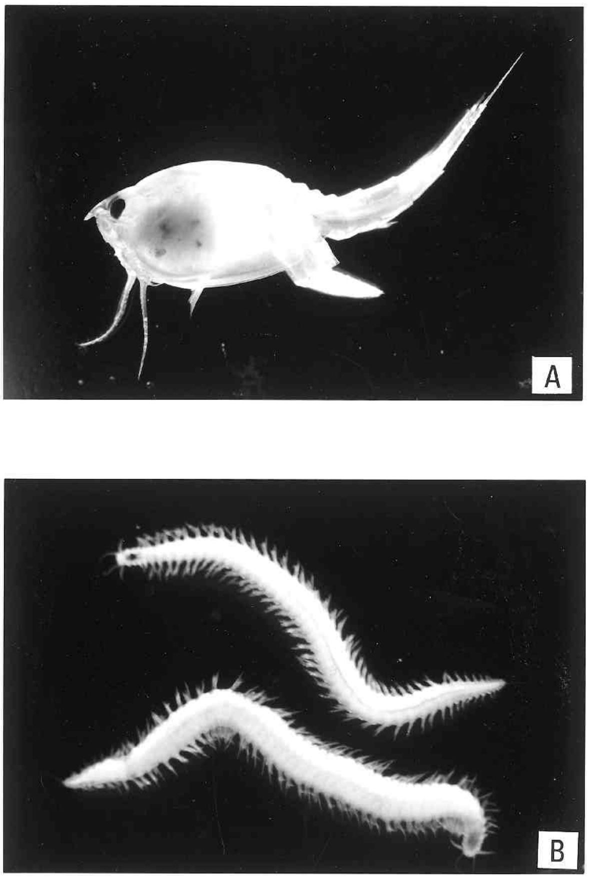

Fig. 9. Photographs of *Nebalia bipes* (A) and *Schistomeringos japonica* (B)

sediment below culture cage were identified as *Nebalia bipes* and *Schistomeringos japonica* (Fig. 9).

From the indoor observations under rearing conditions, the response of *Nebalia bipes* to the light is strongly photonegative, hiding and burrowing underneath bottom sediment in the daytime and swarming up and crawling around bottom surface in the dark. *Nebalia bipes* behaves as carnivorous feeder, which tends to cause economical damage for coastal fishing by aggregating and feeding the fishes left, caught within gill-net (Nishimura and Hamabe, 1964). The habitat of *Nebalia bipes* seems to be widely adopted to low oxygen conditions under chemically reduced environment. Maturing adults holding larvae within brood-pouch were collected in summer and subsequent juveniles were appeared in autumn. Average body length measured between carapace and telson were 6.9 mm in April, 5.7 mm in August, 4.9 mm in November 1996 and 4.2 mm in January 1997. Yokoyama *et al.* (1997) pointed out that *Nebalia bipes* had its maximum density (700 inds./m^2) at fish farm site of Gokasho Bay in May, probably due to the deoxygenation of the bottom water accompanied by increasing temperatures and increasing activities of fish farming.

From the field observations, *Schistomeringos japonicas* aggregates to the leftovers, fish feces and empty shells of fouling animals *etc.*, which distributed on the surface of sediments covered ordinarily by sulfur bacteria *Beggiatoa* spp. The habitat and behavior of *Schistomeringos japonicas* seems to be similar to that of *Nebalia bipes*, which originally adopted to chemically reduced environment. Maturing adults of *Schistomeringos japonicas* were recognized by its visible gonad through the translucent skin with body length ca. 10 mm in summer, and subsequent juveniles were appeared in autumn. *Schistomeringos japonicas* adapted for a tolerance to azoic conditions and distributed frequently in the byssus of *Mytilid* communities under polluted waters. It is supposed that this species performs important role for decomposition of organic sediments by grazing the substratum with its developed jaws under azoic conditions (Miura, personal communication).

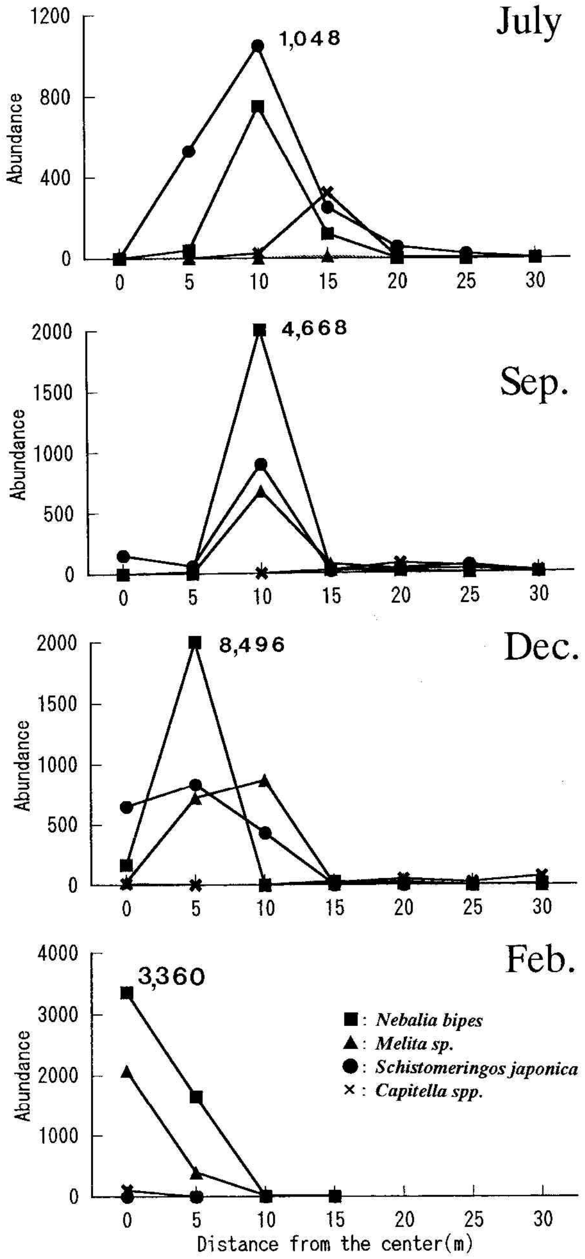

Fig. 10. Changes in the aggregative distribution of the macrobenthos (■: *Nebalia bipes*, ▲: *Melita* sp., ●: *Schistomeringos japonica* and ×: *Capitella* spp.) collected in 0.2 m^2 from each 5-m intervals within 30-m distance from the center point below culture cage

Seasonal changes in the aggregative distribution of dominant macrobenthos collected by 0.2-m^2 sediment at each 5-m intervals within 30-m distance from the center point below culture cage were shown in Fig. 10.

In the distribution of macrobenthos collected In July, highest density of *Schistomeringos japonica* was found 5,240 inds./m^2 at 10-m distance from the center, that of *Nebalia bipes* was found 3,760 inds./m^2 at 10-m distance and that of *Capitella* spp. was found 1,600 inds./m^2 at 15-m distance. *Schistomeringos japonica* and *Nebalia bipes* dominated from 5-m to 15-m with a peak at 10-m distance from the center point. Fouling organisms including oyster, mussel, barnacle etc. fell down to the bottom from culture facilities, which materials exposed on the bottom surface seem to be suitable habitats as shelters for *Schistomeringos japonica* and *Nebalia bipes*.

Distribution of macrobenthos collected in September, highest density of *Nebalia bipes* was found 23,340 inds./m^2 at 10-m distance from the center, that of *Schistomeringos japonica* was found 4,500 inds./m^2 at 10-m distance, that of Melita sp. was found 3,360 inds./m^2 at 10-m distance and that of *Capitella* spp. was found 400 inds./m^2 at 20-m distance. *Nebalia bipes*, *Schistomeringos japonica* and *Melita* sp. were dominant in order at 10-m distance from the center point. Comparing with the density of July, the number of matured individuals of *Schistomeringos japonica* was decreased by assuming mortality due to spawning. It was evident that those macrobenthos tend to aggregate around the immediate vicinity besides organic sediments and impoverish in a center area where organic sediments were abundant.

In the distribution of macrobenthos collected in December, highest density of *Nebalia bipes* was found 42,480 inds./m^2 at 5-m distance from the center, that of *Schistomeringos japonica* was found 4,160 inds./m^2 at 5-m distance, that of *Melita* sp. was found 4,350 inds./m^2 at 10-m distance and that of *Capitella* spp. was found 240 inds./m^2 at 20-m distance. In December, distribution pattern of macrobenthos were synchronously removed toward the center from out-skirt area and concentrically limited within 10-m distance around the center point. Matured individuals of *Schistomeringos japonica* were already disappeared and only juveniles dominated within 10-m distance zone. High abundance of juveniles of *Nebalia bipes* was characteristically found within 5-m distance zone from the center point. Fouling empty shells and particle fish-bones derived from raw fish in moisture pellets were exposed again on the natural ground, which corresponded to the decomposition of organic sediment below culture cage.

Distribution of macrobenthos collected in February, highest density of *Nebalia bipes* was found 16,800 inds./m^2 at the center, that of *Melita* sp. was found 10,400 inds./m^2 at the center and that of *Capitella* spp. was found 520 inds./m^2 at the center. In February, distribution pattern of *Nebalia bipes* and *Melita* sp. were concentrated within 5-m distance from the center point, which organic sediment enriched macrobenthos for the nutrient consumption as a terminal area below culture cage.

Considering the distribution pattern in respect of each species, highest density of *Nebalia bipes* was 42,480 inds./m^2 at 5-m distance from the center in December 1996, that of *Melita* sp. was 10,400 inds./m^2 at the center in February 1997, that of *Schistomeringos japonica* was 5,240 inds./m^2 at 10-m distance in July and that of *Capitella* spp. was 1,600 inds./m^2 at-15m distance in July, respectively .

According to synchronous patterns of the distribution between macrobenthos and organic sediment properties which was concerning the environmental viewpoint with the chemical indicator by TS, COD and IL values at each season, aggregating sites of each macrobenthos were closely correlated to the marginal zone of enriched sediment below culture cage.

At the time of 1-year discontinuance after culture cessation in July 1996, chemical indices of organic sediments collected at the center area in July 1997 were changed from 0.79 mg/g • dry sediment to 0.65 mg/g • dry sediment with TS value, from 257 mg/g•dry sediment to 151 mg/ mg/g • dry sediment with COD value and from 54 % to 26 % with IL value, respectively. Highest density of macrobenthos at the same area was changed from 3,760 inds./m^2 to 110 inds./m^2 with *Nebalia bipes*, from 5,240 inds./m^2 to 260 inds./m^2 with *Schistomeringos japonica*, from 50 inds./m^2 to 215 inds./m^2 with *Melita* sp. and from 1,600 inds./m^2 to 5,125 inds./m^2 with *Capitella* spp. Comparing with the data between 1996 and 1997, it was supposed that the habitat evaluation below culture cage of *Nebalia bipes* and *Schistomeringos* was decreased and that of *Melita* sp. and *Capitella* spp. was increased in accordance with those nutrient conditions indicated chemical indices mentioned above.

From the indoor rearing observation by feeding response of *Hexagrammos otakii* (greenling), *Sebastes inermis* (black rockfish), *Limanda yokohamae* (marbled sole) and *Kareius bicoloratus* (stone flounder), *Nebalia bipes* and *Schistomeringos japonica* were almost fed with a desirable reaction. Comparing the reaction time for feeding by these sedentary fishes between *Nebalia bipes* and *Schistomeringos japonica*, those fishes tended to prefer *Nebalia bipes*. It was suggested that *Nebalia bipes* and *Schistomeringos japonica* were treated for suitable bait against adjacent sedentary fishes distributed around the enriched sediment below culture cage. Furthermore, dispersion by ongrowing and retrieval by fishing of these sedentary fishes are regarded as a removal step for macrobenthos propagated by enriched sediment, which has a responsibility for promoting discharge of organic loads to outside of ecosystem through food chain in the benthic community at the fish farm site.

4. Evaluation of shell-collector

Considering the distribution of macrobenthos below culture cage, *Nebalia bipes* dominated in a year-around and recognized as effective species for decomposition of loaded organic sediment. Spatial and temporal distribution patterns of *Nebalia bipes* were reexamined by the comparative observation conducted within and without shell-collector set for a monitoring of shelter substratum (Fig. 11). Distribution of *Nebalia bipes* was delineated with aggregative pattern in a certain position, which location was seasonally shifting from outer area toward the center point corresponded to the marginal zone of enriched sediment under natural conditions (Fig. 11A). The reason for shifting distribution was supposed that the behavior of *Nebalia bipes* depended highly on the habitat with shelter materials including empty shells and so on that were exposed subsequently on the bottom surface by sediment decomposition with passing of the season.

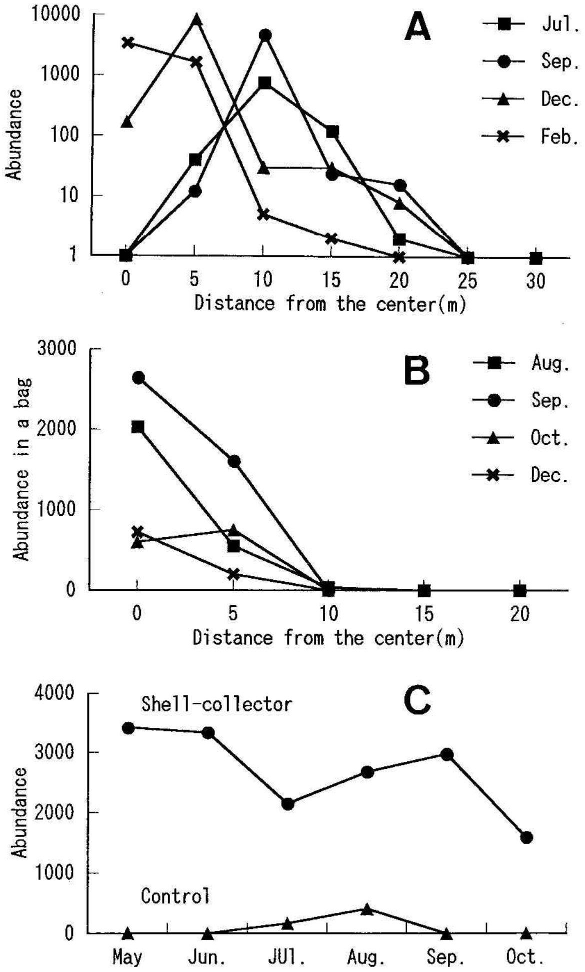

Fig. 11. Spatial and temporal distribution of *Nebalia bipes* below coho salmon culture cage. A: seasonal changes in the density in 0.2 m^2 and aggregative position on bottom surface , B: seasonal changes in the aggregative position distributed within shell-collector bag, C: comparison of monthly density between shell-collector bag and bottom surface in 0.2 m^2

The average number of *Nebalia bipes* distributed within shell-collector in summer (August and September) attained 2,335 individuals at the center and 1,075 individuals at 5-m distance zone. Furthermore, that of *Nebalia bipes* distributed within shell-collector in autumn (October and December) attained 590 individuals at the center and 817 individuals at 5-m distance zone, respectively (Fig. 11B). It was evident by the indoor rearing observation that *Nebalia bipes* expressed a photonegative response and a high dependency with substratum such as shell-collectors like a shelter for habitat in daytime. On the other hand, the number of *Nebalia bipes* without shell-collector distributed in natural bottom condition was almost nil at the center area during summer and autumn, the aggregative distribution of *Nebalia bipes* was limited outer area than 5-m distance zone without in winter as shown in Fig. 11A.

On the monthly changes in the density of *Nebalia bipes* from May through October 1996 collected at the center area below culture cage, the average number of *Nebalia bipes* distributed within shell-collector was 2,684 individuals and that without shell-collector was 97 individuals, respectively, density variance of 28 times (Fig. 11C). Comparing the efficiency of shell-collector between oyster and scallop shells, the average number of *Nebalia bipes* was 2,940 individuals with oyster and was 2,330 individuals with scallop. On the other hand, that of control sample collected direct vicinity

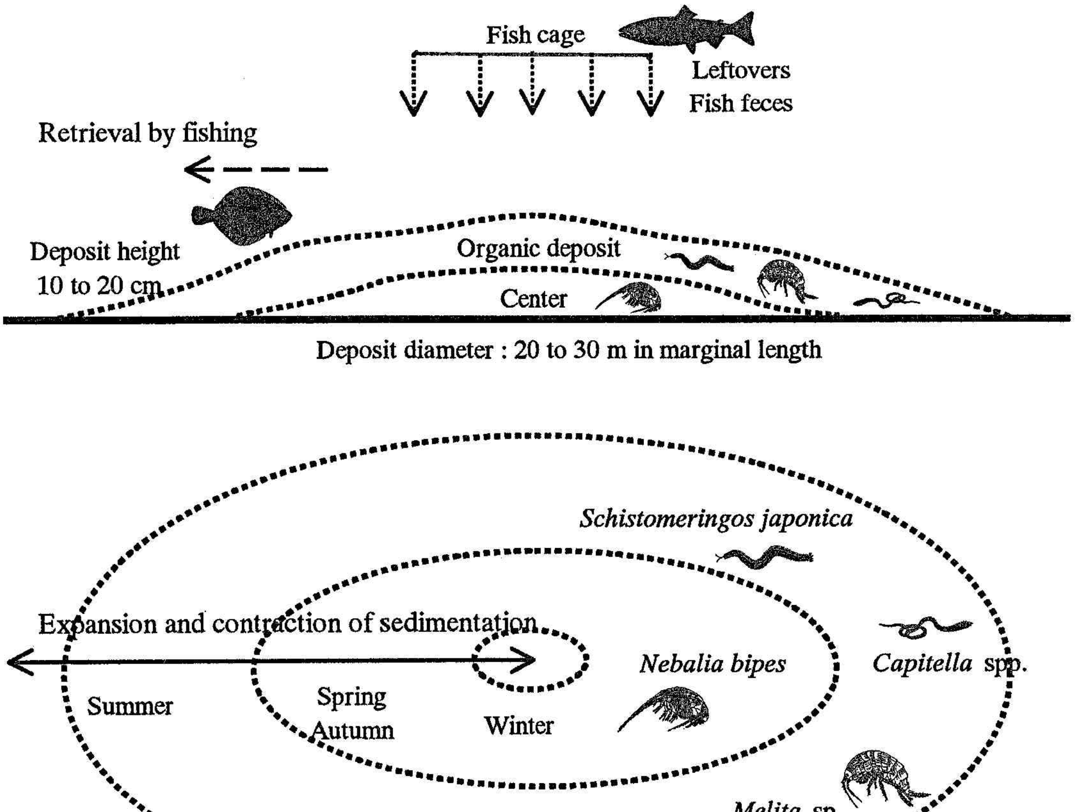

Fig. 12. Shematic diagram showing seasonal changes in sedimentation and aggregative distribution of the macrobenthos below coho salmon culture cage

of shell-collector was 13 individuals. At the same time, the number of *Nebalia bipes* collected oyster shell-collector suspended 10-cm distance above the bottom was 528 individuals. It was supposed that the suitable position of shell-collector was partially moated onto the bottom surface with enriched sediments. From the ecological viewpoint, the center area below culture cage was originally impoverished for macrobenthos by its environmental condition of bottom surface covered with enriched sediment, which was improved to the aggregative site for artificial habitat of *Nebalia bipes* set by shell-collector.

Concerning another species of macrobenthos, the average number of *Melita* sp. distributed within shell-collector at the center area was 59 individuals in summer and 453 individuals in winter. On the other hand, that without shell-collector in natural bottom sediment was almost nil at the same area below culture cage.

From monthly changes in the density of *Schistomeringos japonica* from May through July collected at the center area below culture cage, the average number of *Schistomeringos japonica* distributed within shell-collector was 1,503 individuals and that without shell-collector was 216 individuals, respectively, with mean density variance of 7 times. The adult number of *Schistomeringos japonica* was disappearing after August due to mortality attributed to reproduction.

Therefore, spreading shell-collectors regarded as a habitat for macrobenthos seems to be much more effective to promote the carrying capacity of macrobenthos below culture cage, which improve the decomposition processes of organic sediment.

Conclusion

According to direct diving observation below culture cage, it was evident that the organic sediments derived from food supply were deposited 10 to 20 cm in height and 20 to 30 m in diameter through harvest time, in which sediments were decomposing until following spring under natural environmental conditions (Fig. 12). Aggregative distribution of those macrobenthos was corresponded to the marginal zone of enriched sediments, which location was seasonally removed before and after harvest. High density of *Schistomeringos japonica* and *Nebalia bipes* were supported in accordance with organic sediments distributed around removing marginal zone below culture cage from spring to summer, and that of *Nebalia bipes*, *Melita* sp. and *Capitella* spp. were supported there from autumn to winter. On the contrary, very few macrobenthos appeared at the center of bottom surface below culture cage where enriched sediments were abundant. These faunal zones might be generally constructed by the bottom substratum for habitat based on the gradients of environmental conditions of organic loads that cause the differentiation in the concentration of oxygen in the bottom water and nature of the sediment. Ecologically these distributions of each macrobenthos, close correlation between aggregative site and organic sediments were supposed by nutrient linkage. From these findings observed in each seasons, temporal and spatial distribution pattern were recognized as a change of environmental conditions of bottom surface below culture cage. Distribution patterns of macrobenthos were concentrically removed from outer area toward the center point according to the synchronous contraction of decomposed organic sediments in marginal zone by benthic communities.

Considering to synchronous patterns of removal distribution mentioned above, biological activities of so-called bioturbation such as feeding, burrowing and gardening conducted by these macrobenthos were recognized important in preventing self-induced deterioration of fish-farming. In coastal and estuarine areas, infauna is known to affect physical, chemical and biological properties of sediment by bioturbation, namely its feeding, burrowing, tube building, defecation and ventilation activities (Kikuchi and Mukai, 1994). Tsutsumi and Montani (1993) has already pointed out that the

Capitella colonies increased rapidly and biological activities such as feeding, reworking etc. efficiently decomposed the organic matter added on the sediment. Besides these findings of *Capitella* spp., rearing experiment of *Nebalia bipes*, *Schistomeringos japonica* and *Melita* sp. would be needed to analyze the quantitative capacity of assimilation through decomposition processes of organic sediment.

A part role of decomposition and mineralization of the loaded organic matter was confirmed by bacteria and macrobenthos through cyclic processes under natural environmental conditions. Sulfate-reducing bacteria, *Beggiatoa* spp., was investigated in the bottom of coho salmon culture area and considered that occurrence and distribution of *Beggiatoa* spp. was regarded as a indicator of environmental conditions derived from the organic loads by food supply (Takekawa *et al.*, 1989). The significance in distribution of relationship between sulfur bacteria and macrobenthos would be furthermore needed to analyze the efficiency of decomposition processes of organic sediment.

In addition to natural decomposition carried out by those bacteria, it might be available that artificial habitat such as shell-collector set on the bottom surface promote the decomposition of enriched sediment through the activity of bioturbation with those species of macrobenthos. It is supposed that spreading shell-collectors as a habitat for macrobenthos on the bottom surface below culture cage seems to be effective for not only to promote the carrying capacity for decomposition of organic sediments but also to control eutrophicated conditions for improving the productivity of aquaculture biomass. From the ecological relationship between macrobenthos and sedentary fishes below culture cage, retrieval by sedentary fish propagated by macrobenthos with enriched sediment is a removal step for discharging the organic loads toward outside of natural ecosystem through food chain in the benthic community.

Future work should be focused on the goal with ecological basis for decomposition of organic sediment contributed by macrobenthos and on the relationship between sustainable carrying capacity and environmental conservation. The goal would be established by a biocontrol technology for planning mixed aquaculture that organized with algae as mineral assimilator, bivalvia as filter-feeder and fishes as organic loader in respect to the circulated eco-system through nutrient linkage.

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