The Effect of the Methods of Farming on the Environment and Growth of Cultured Red Sea Bream, *Pagrus major*

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Abstract The environment of fish farming areas and aquaculture production are considered to be closely related. Therefore, to establish the efficient use of fish farming grounds, I conducted a research on the subjects in conjunction with the rearing of red sea bream.

The presence of waste feed is assumed to provide the majority of the total particulate nitrogen discharged. The primary cause of eutrophication of fish farming grounds is excessive loading of nitrogen and phosphorus. Therefore, reducing waste is an important countermeasure to excessive nitrogen discharge. The chemical characteristics of phosphorus are different from those of nitrogen. Therefore, different measures are required to reduce phosphorus discharges.

In addition, it is suggested that rearing fish at low density is good for the growth of red sea bream, though the accumulation of more data is necessary before a clear conclusion can be reached. Furthermore, mortality caused by *Edwardsiella* decreases when fish are reared at low density. Thus, low density rearing is thought to be effective in reducing disease problems.

Key words: aquaculture, feeding frequency, rearing density, red sea bream, waste feed

Introduction

Wakayama Prefecture is located in the southwest of Honshu Island, Japan. The main fisheries products are horse mackerel, mackerel, and cultured red sea bream. Cultured red sea bream, *Pagrus major*, ranks third in terms of level of production. The species is cultured in fish farming sites scattered along the coast of the prefecture. The aquaculture industry, which produces one quarter of the fishery products in the prefecture, is important in Wakayama. The production of cultured red sea bream reaches 80% of total aquaculture production. In the 1980s, the deterioration of the sedimentary environment and the frequent occurrence of the red tides were observed in Tanabe Bay. In addition, there was an increase in aquaculture production in the bay, which today is one of the largest aquaculture sites in the prefecture (Uede 2004a, 2004b).

Tanabe Bay is located in the central part of Wakayama Prefecture. The southern part of the bay is a tranquil region with a complex coastline comprised of five inlets and some small islands. The southern part of the bay is one of the largest fish farming sites with the primary target fish being red sea bream. The aquaculture of yellow tail started in the 1970s and that of red sea bream began in 1977. Production of both species increased every year, peaking in the latter half of the 1980s. Annual production decreased from the late 1980s, and has fluctuated between 1,000 and 2,000 annually since. Fluctuation in red tide, especially associated with total duration, and fish farming production reacted with each other from 1971 to 2001 (Uede 2004a), when there was a decrease in fish farming caused by a depression in fish value that began during the latter half of the 1980s, accompanied with reductuion in the duration of the red tide events (Uede 2004a, 2004b, 2008).

When the aquaculture production increased and peaked, the acid volatile sulfide (AVS) increased and the dissolved oxygen (DO) in

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summer season decreased (Uede 2004a, 2006). An azoic zone appeared in the southern part, the most deteriorated area of the bay. However, improvements of AVS and DO were observed, when production began to decrease in the 1990s. There are significant relationships between aquaculture production and the two parameters: AVS as a sedimentary environment factor and the total duration of red tide events. Given the results presented, the environment of the bay and aquaculture production are regarded as being closely related (Uede, 2004a).

Aquaculture production should be controlled to harmonize with the surrounding ecosystem. Deterioration of the environment caused by the nutrient load discharged from aquaculture influences not only the productivity of aquaculture itself but many other values of the coastal environment as well (Brown *et al.* 1987, Weston 1990). For example, biodiversity, nutrition cycling, and the value for tourism are all affected.

To establish efficient use of fish farming grounds, I conducted a series of studies associated with the rearing of red sea bream. This paper describes the results of studies into the effects of farming methods on the environment and the growth of red sea bream.

Materials and Methods

Rearing Experiment I

The purpose of the rearing experiment was to demonstrate how much particulate carbon, nitrogen, and phosphorus originated from the discharge of fish feed and feces from the fish cages. The experiment was conducted with the apparatus illustrated in Figure 1 from October 31 to November 2, 2006. Red sea bream (55 individuals with mean body weight 105g) were distributed in the tank (Figure 1) and the particulate matter discharged was collected. The diet type given to red sea bream was extruded pellets commercially available. The pellets were give to the fishes so that no waste feed as mach as possible. Sampling was conducted 0.5, 3, 6, 24, and 48 hours after feeding, at which times water temperature was measured at the inflow. The settled particulate matter was collected by filtering the bottom water (100 liters) through a 229 μm mesh nylon net. One liter of water that passed through the net was passed through filter paper (GF/C) to collect the fine particulates. The particulates in the outflow water were collected in the nylon net during the intervals between sample collections. The collected particulates were weighed after desiccation at 90℃. Total carbon and nitrogen levels in the

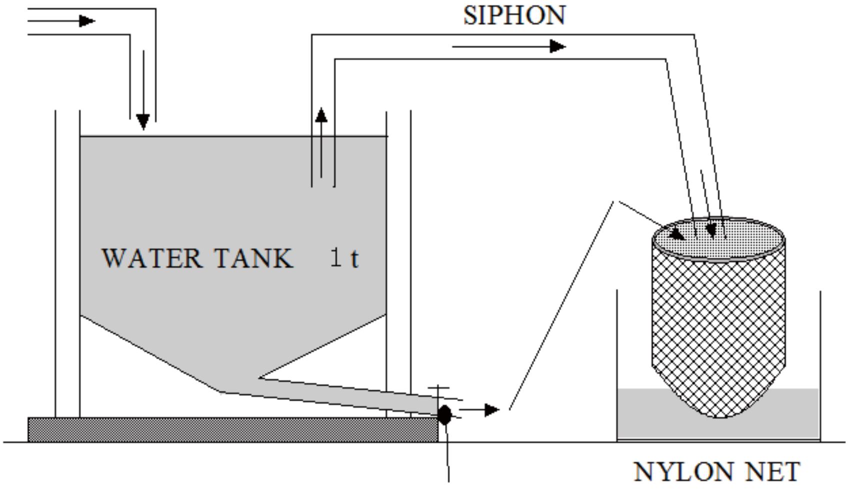

Fig. 1. Diagram of the experimental apparatus used to measure particulate compound discharged of carbon, nitrogen and phosphorus. Arrows indicate the flowing of sea water.

samples were determined with an elemental analyzer (Valio EL, Elementar). Total phosphorus was measured by the wet degradation method (The Japan Society for Analytical Chemistry 1987, Japanese Industrial Standard Committee 1998) The introduction and discharge of particulate carbon, nitrogen and phosphorus were calculated from the data collected.

Rearing experiment II

The organic load caused by rearing red sea bream is related closely to the amount of food offered. Therefore, the feeding rate is thought to be an important factor for environmental preservation. To explore this, an experiment that clarified how red sea bream's growth differed in relation to feeding frequency was conducted. Red sea bream (130 individuals with mean body weight 190g) were distributed in three cages (volume 22.5m^3). The diet type given to red sea bream was extruded pellets commercially available. Feeding experiments were conducted for 225 days, starting March 14, 2003. The feeding frequencies were four (experimental plot 1), three (experimental plot 2), and two (experimental plot 3) times a week. The results obtained from the experiment were compared with fish growth obtained from three private farms in the prefecture in 2002.

Rearing experiment III

Red sea bream (mean body weight 410 g) were distributed in four cages (volume 22.5m^3) at densities of 2.4 (fish cage 1), 3.6 (fish cage 2), 4.7 (fish cage 3), and 5.7kg/m^3 (fish cage 4). The feeding frequency was the same for all four cages. The diet type given to red sea bream was extruded pellets commercially available. The rearing experiment was conducted over for 140 days from April 9, 2004. At the beginning, the purpose was to demonstrate the relationship between growth and rearing density in red sea bream farming. But the mortality of red sea bream in fish cage 4 increased rapidly due to an outbreak of *Edwardsiella* since day 100. As a result, I changed the purpose to develop a relationship between mortality and rearing density.

Results

Rearing experiment I

Water temperature, salinity, and dissolved oxygen ranged from 22.7-23.6℃, 33.69-33.92, and 6.26-6.87 mg/l, respectively. The total amount of extruded pellets fed was 68.4 g, and the carbon, nitrogen, and phosphorus levels in the diet were 532.9, 102.2, and 16.7 mg/g, respectively.

The amounts of particulate matter and levels of carbon, nitrogen, and phosphorus discharged (per 1 kg of red sea bream) are shown in Figure 2. Particulate matter discharged as waste feed and feces were 367.7 and 1028.5 mg which correspond to 11.7% of the amount of diet fed. Carbon, nitrogen, and phosphorus discharged in waste feed were 167.4, 30.5, and 6.5 mg, respectively, while the levels in the feces were 411.1, 32.9, and 27.1 mg. The particulate matter discharged and levels of carbon and phosphorus in feces were more than 71.1% of the total amounts discharged. Nitrogen discharged as waste feed reached 48.1%, which is greater than the level of particulate carbon and phosphorus discharged as waste feed. With respect to the three elements discharged, the ratio of the phosphorus discharged to the total phosphorus in the diet offered was the largest.

C:N, C:P and N:P ratios as a function of time after feeding are shown in Figure 3. C:N was ≤6.5 in the discharged particulates until three hours after feeding. These values were similar to 6.1 of C:N in the diet. C:P and N:P at 0.5 hours were 104.2 and 16.1, whereas those ratios in the diet were 82.4 and 13.6. The values decreased sharply three hours after feeing. C:P and N:P were ≤47.6 and ≤3.6 since six hours after feeding.

Figure 4 shows the particulate carbon, nitrogen, and phosphorus discharge levels in waste feed and feces in relation to feeding extruded pellets. With respect to the particulate carbon and nitrogen discharged, the data obtained from the similar experiment by Uede (2007) were included. Particulate carbon discharged as waste feed and feces ranged from 1.9-3.2 and 4.7-6.5%. From 2.0-3.5% of the dietary nitrogen was discharged as waste feed and 2.2-2.7% was discharged as feces. In

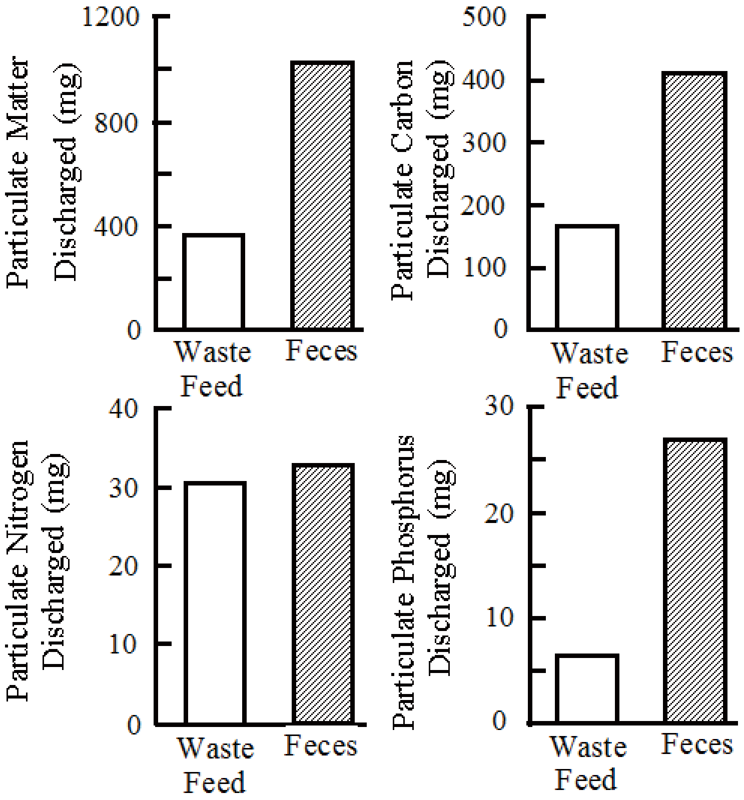

Fig. 2. Amounts of particulate matter, carbon, nitrogen and phosphorus discharged as waste feed and feces (per 1 kg of red sea bream).

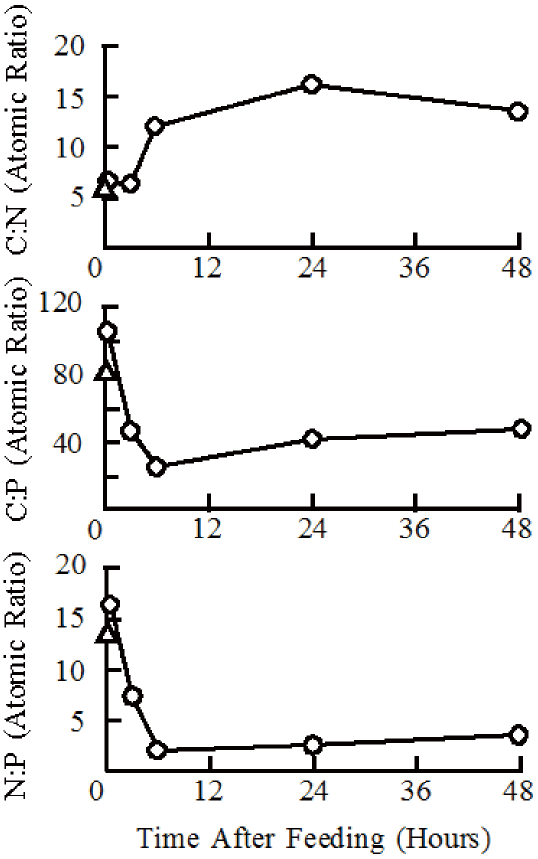

Fig. 3. C:N, C:P and N:P atomic ratio as a function of time after feeding.
△ shows each values in extruded pellets diet.

the case of phosphorus, the proportions discharged in waste feed and feces were 3.3 and 13.6%.

Rearing Experiment II

The summary of the rearing performance of the rearing experiment II is shown in Table 1. Red sea bream growth improved with increasing feeding frequency. Daily feed consumption and growth rate both increased with feeding frequency, while the feed to gain ratio decreased. Best growth was obtained from experimental plot 1 which received the highest feeding frequency.

Figure 5 indicates the growth of red sea bream from rearing experiment II in comparison to those on private farms. Table 2 provides a summary of the variables on three private farms compared to those of rearing experiment II. Both sets of data were compared after the same number of days of growth, though the times when the data were obtained were different. Fish growth in plot 1 was better than the average obtained from the three private farms.

Figure 6 shows red sea bream growth in conjunction with rearing density. In the prefecture, generally, after initial rearing is conducted in a small net pen, red sea bream of about 100 g or more are distributed into net pens for growout. The experiment was initiated at the same time that growout began on the private fish farms. Rearing density was consistently lower in the experimental cages than on the private farms.

Rearing experiment III

Fish performance in conjunction with rearing experiment III is summarized in Table 3. The change in cumulative mortality and number of survivors over time are shown in Figure 7 and 8. The mortality in cage 4 due to the outbreak of *Edwardsiella* increased rapidly from the 100th day. Best fish growth was maintained in cage 2 until day 103 (2nd period). Mortality gradually spread to fish cage 3, and occurred in cages 1 and 2 after day 130. As a result, when the rearing trial was terminated, the number of individuals in cages 2, 3, and 4 ranged from 160-172. Cumulative mortalities in cages 1, 2, 3, and 4 were 16.2, 11.8, 38.5, and 49.4%, respectively.

Change in the mean body weight of red sea bream over time is shown in Figure 9. Growth in fish cage 2 was best until day 103. However, mean body weight decreased as a result of the *Edwardsiella* outbreak except in cage 1 when the rearing trial was terminated.

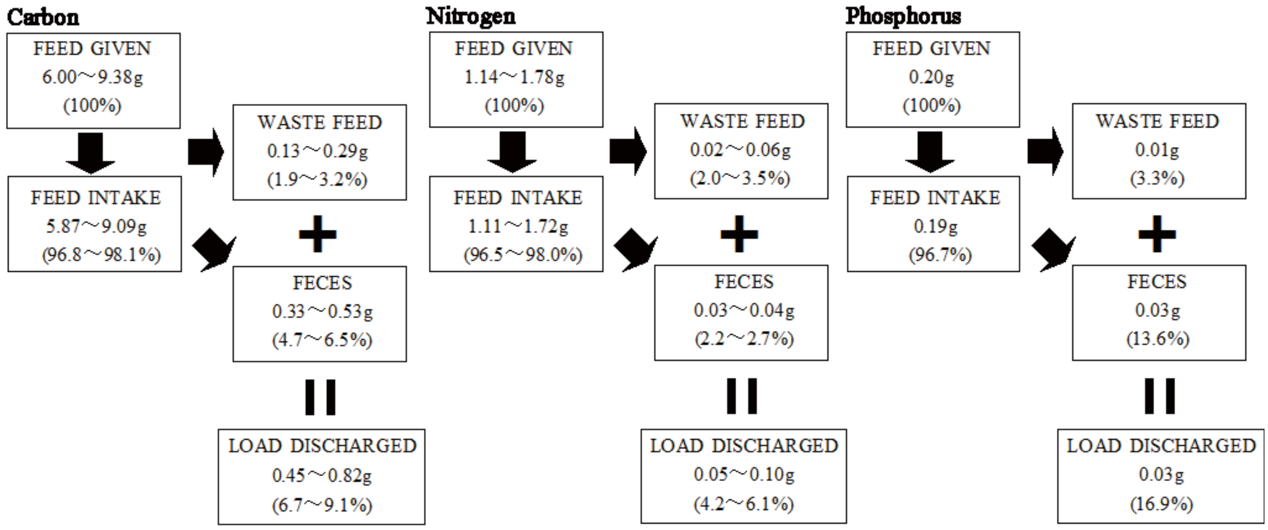

Fig. 4. Diagram showing particulate carbon, nitrogen and phosphorus discharge level in waste feed and feces in relation to feeding extruded pellets to 1 kg wet weight of red sea bream. The amount of extruded pellets to 1 kg wet weight of red sea bream was 11.9 g dry weight. With respect to the particulate carbon and nitrogen discharged, the data obtained from the similar experiment by Uede (2007) were included.

Table 1. The summary of the rearing performance of the rearing experiment Ⅱ

Experimental plot		1	2	3
Feeding frequency (times/week)		4	3	2
No. of fish	Initial	130	130	130
	1st period	124	127	126
	2nd period	124	127	126
	3rd period	120	127	126
Total fish weight (kg)	Initial	24.3	25.0	24.9
	1st period	39.3	37.8	36.6
	2nd period	58.1	55.0	50.7
	3rd period	123.5	112.8	92.6
Average body weight (g)	Initial	186.9	191.9	191.5
	1st period	316.9	297.6	290.5
	2nd period	468.1	433.1	402.0
	3rd period	1029.2	888.2	734.9
Mortality (%)		7.7	2.3	3.1
Feed supplied (kg)	1st period	17.7	15.8	13.0
	2nd period	32.5	27.8	24.6
	3rd period	89.7	81.0	66.1
	Whole period	140.0	124.6	103.7
Daily feed consumption (%)	1st period	0.97	0.88	0.74
	2nd period	1.19	1.07	1.01
	3rd period	0.86	0.85	0.81
	Whole period	0.82	0.80	0.78
Feed to gain ratio	1st period	1.07	1.16	1.02
	2nd period	1.73	1.62	1.75
	3rd period	1.31	1.40	1.58
	Whole period	1.33	1.39	1.49
Growth rate (%)	1st period	169.6	155.1	151.7
	2nd period	147.7	145.5	138.4
	3rd period	219.8	205.1	182.8
	Whole period	550.6	462.8	383.7

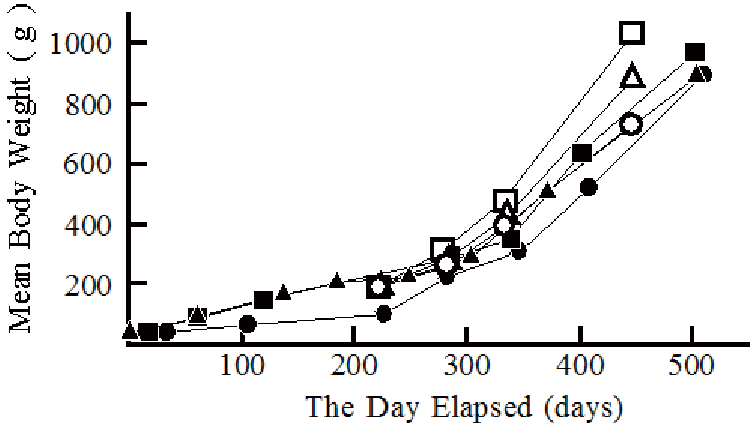

Fig. 5. Red sea bream growth from rearing experiment II in comparison to those in private farms. □ : Experimental plot 1, △ : Experimental plot 2, ○ : Experimental plot 3, ■ : Private farm No.1, ▲ : Private farm No.2, ● : Private farm No.3.

Table 2. The summary of the variable on three private farms compared to those of the rearing experiment Ⅱ

		Private farms			Number of fish cage for the rearing experiment		
		№1	№2	№3	1	2	3
Size of cage	Initial	7×7×7	6×6×4	6×6×4	3×3×2.5	3×3×2.5	3×3×2.5
	growout	15×15×9	12×12×7	13.5×13.5×9			
No. of fish		14,000	9,900	14,000	130	130	130
Date of beginning		Aug. 4, 2002	Aug. 23, 2002	Sep. 7, 2002	Mar. 14, 2003	Mar. 14, 2003	Mar. 14, 2003
Diet type		EP	EP、MP Almost EP	EP、MP	EP	EP	EP

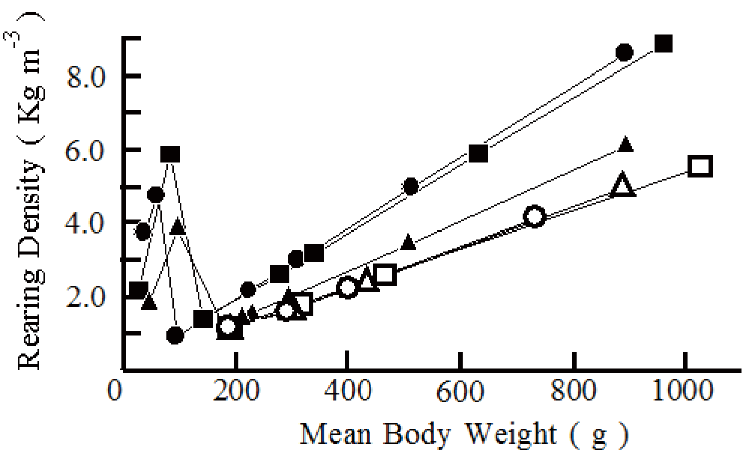

Fig. 6. Red sea bream growth in conjunction with rearing density.
□ : Experimental plot 1, △ : Experimental plot 2, ○ : Experimental plot 3,
■ : Private farm No.1, ▲ : Private farm No.2, ● : Private farm No.3.

Discussion

Particulate carbon and phosphorus in feces accounted for ≧71.1% of the total discharged. The proportion in waste feed reached 48.1% of the total amount in particulate nitrogen discharged. Waste feed is assumed to be the source of the majority of the total particulate nitrogen discharged according to Uede (2007b). That assumption is supported by the research reported here. Hence, it is concluded that the reducing the amount of feed that is not consumed by the fish is an effective way to reduce the particulate nitrogen loading in the sediments.

With respect to the C:N ratio in particulate discharges, Uede (2007b) indicated that particulate discharge for the first three hours after feeding is primarily from waste feed, after which it is from feces. The results presented here support that conclusion. The C:P ratio in the particulate matter discharged at 0.5 hours after feeding was higher than that in the diet. This indicates that phosphate, which forms the chemical union to organic compounds in the diet by an ester bond, is immediately dissociated after feeding (Laws, 1993). Six hours later, the C:P ratio decreased sharply to ≤47.6. The change in N:P was same as that of C:P. It is concluded that low values of C:P and N:P are associated with high rates of carbon and nitrogen absorption in the digestive tract of the fish. On the other hand, calcium bond phosphorus, which composes a large part of phosphorus compounds, is not highly absorbed. Uede (2007a) reported there are high phosphorus concentrations, which are predominantly composed of calcium bound phosphorus, in the sediments in fish farming areas. Compared with the ratios of C:P and N:P (≤25.5 and ≤2.82) in the sediments in fish farming areas, the values in feces found in this investigation (47.6 and 3.55) were higher. Reasons for this include the fact that a large part of the phosphate, which is predominantly calcium bound phosphorus, is discharged as feces. Moreover, calcium bound phosphorus, which is a stable compound, accumulates in the sediments for long periods of time. Hence, I need countermeasures, which are different from those that may work with respect to nitrogen discharges, to reduce the phosphate discharge.

In rearing experiment II, the best growth rates and feed to gain ratios were obtained with increasing feeding frequency. The growth in experimental plot 1 and 2 was better than on the private farms. The feeding frequencies on the three private farms were 0.41, 0.70 and 0.53 times a day, while rate associated with experimental plots 1, 2, and 3 were 0.61, 0.41, and 0.30 times a day, respectively. Feeding frequencies in conjunction with experimental plots 1 and 2, which had the best fish growth rates, were similar to the rates used on the private farms, though the fish densities in the experimental plots were lower than on the private farms. From these results, it is suggested that that rearing at low density promotes good growth in red sea bream.

Mortalities from the *Edwardsiella* outbreak decreased with decreasing fish density in rearing experiment III. Therefore, it is thought that resistance to fish diseases like *Edwardsiella* increases when the fish are present at low density.

When the above-mentioned results are considered together, it can be concluded that the amount of particulate nitrogen, which is discharged primarily from waste feed, is more than that of

Table 3. The summry of the rearing performance of the rearing experiment Ⅲ

Experimental plot		1	2	3	4
Number of fish	Initial	130	195	260	318
	1st period	128	195	259	310
	2nd period	122	194	252	296
	3rd period	109	172	160	161
Total body weight (Kg)	Initial	53.8	80.4	106.3	129.0
	1st period	70.7	113.1	146.0	173.1
	2nd period	89.3	153.6	180.3	205.6
	3rd period	85.2	128.8	110.5	107.7
Mean body weight (g)	Initial	413.8	412.3	408.8	405.7
	1st period	552.3	580.0	563.7	558.4
	2nd period	732.0	791.8	715.5	694.6
	3rd period	781.7	748.8	690.6	668.9
Mortality (%)		16.2	11.8	38.5	49.4
Feed supplied (g)	1st period	37.3	60.3	75.3	96.0
	2nd period	41.6	63.2	82.2	97.6
	3rd period	31.8	43.7	41.3	42.1
	Whole period	110.7	167.2	198.8	235.7
Daily feed consumption (%)	1st period	1.13	1.18	1.13	1.20
	2nd period	1.02	0.93	0.99	1.01
	3rd period	0.96	0.82	0.75	0.71
	Whole period	1.11	1.12	1.23	1.31
Feed to gain ratio	1st period	2.09	1.84	1.87	2.00
	2nd period	1.85	1.53	2.12	2.36
	3rd period	5.54	-5.57	-8.06	-7.18
	Whole period	2.52	2.71	3.36	3.74
Growth rate (%)	1st period	133.5	140.7	137.9	137.6
	2nd period	132.5	136.5	126.9	124.4
	3rd period	106.8	94.6	96.5	96.3
	Whole period	188.9	181.6	168.9	164.9

feces. The primary cause of eutrophication in the fish farming areas is excessive loads of nitrogen and phosphorus. Therefore, reduction in waste feed is an important means of reducing nitrogen discharges. Since the chemical characteristics of phosphorus are different from those of nitrogen, so the different countermeasures are required for phosphorus reduction in discharges. Finally, it is suggested that rearing at low density promotes the growth of red sea bream, though more data are required for verification. Low density also appears to increase resistance to *Edwardsiella*.

These results explain the opinion that reducing the nutrient loads discharged from aquaculture can help to improve environmental conditions. It is thought that rearing in a low density is good for not only the environment in fish farming areas but also may improve the health of cultured fish, though the conclusions are based on limited data. I'm now trying to establish techniques to evaluate the environment in fish farming areas. I want to develop the technologies that can provide harmony between aquaculture and coastal ecosystems. I believe that the only way aquaculture can make strides forward in the future is for it to exist in harmony with the surrounding ecosystem.

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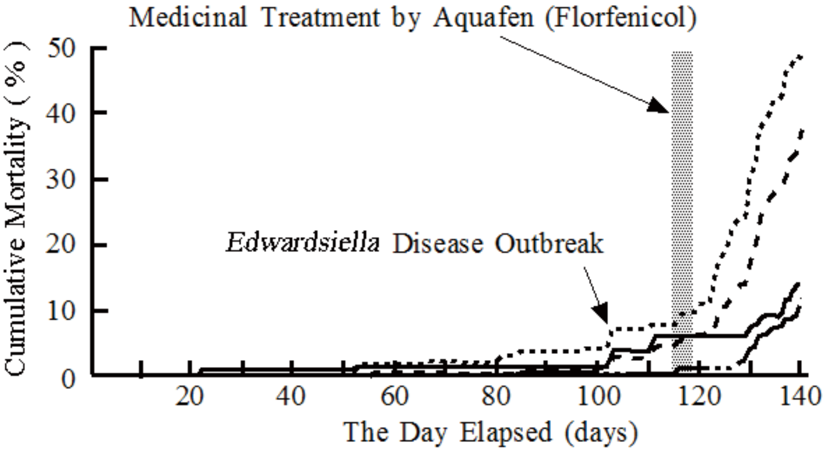

Fig. 7. Change in cumulative mortality of red sea bream as a function of the day elapsed.
——Fish cage 1, —-·—Fish cage 2, ––––Fish cage 3, ------Fish cage 4.

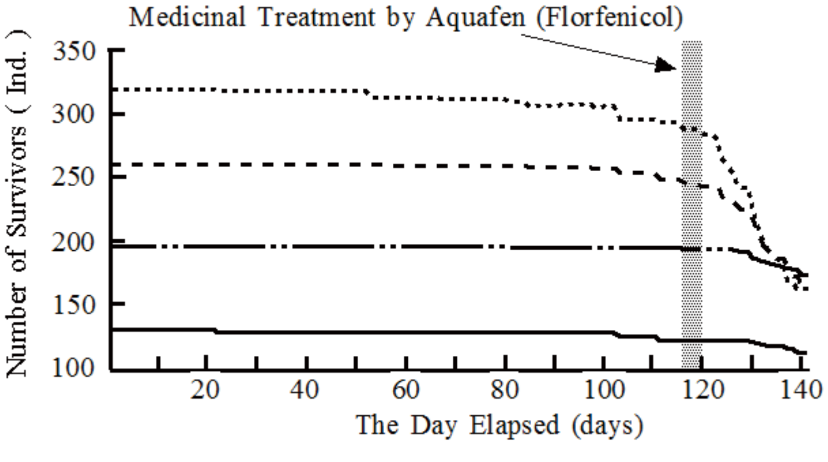

Fig. 8. Change in number of survivors of red sea bream as a function of the day elapsed.
——Fish cage 1, —-·—Fish cage 2, ––––Fish cage 3, -----Fish cage 4.

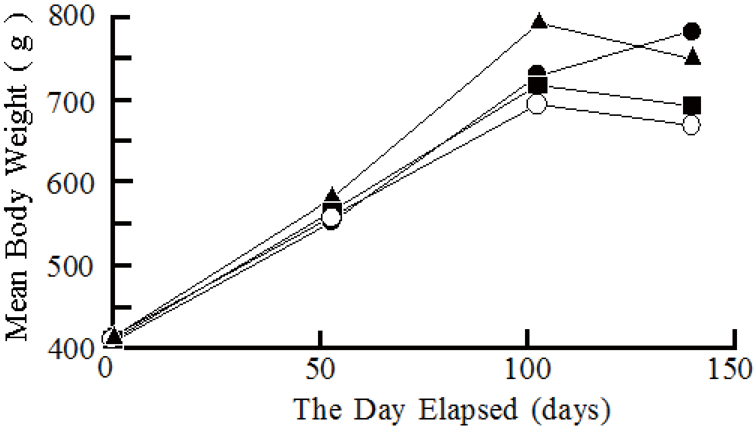

Fig. 9. Change in mean body weight of red sea bream as a function of the day elapsed. ● : Fish cage 1, ▲ : Fish cage 2, ■ : Fish cage 3, ○ : Fish cage 4

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References

Brown, J.R., R.J. Gowen and D.S. McLusky. 1987. The effect of salmon farming on the benthos of a Scottish sea loch. Journal of Experimental Marine Biology and Ecology, **109**: 39-51.

Japanese Industrial Standard Committee. 1998. pp.175-177, *In* Testing methods for industrial wastewater, JIS K 0102. Japanese Standard Association, Tokyo.

Laws, E.A. 1993. pp.21-40, *In* Aquatic Pollution: An Introductory text, second edition. John Wiley & Sons, Inc., New York, USA.

The Japan Society for Analytical Chemistry. 1987. pp.301-303 *In* Handbook for experiments of analytical chemistry, Maruzen, Tokyo.

Uede, T. 2004a. Fluctuations of environment in areas of aquaculture farms in Tanabe Bay. Bulletin of the Wakayama Research Center of Agriculture, Forestry and Fisheries, **5**: 117-124.

Uede, T. 2004b. Occurrences of red tide in the coastal waters of Wakayama Prefecture from 1981 to 2000. Bulletin of the Wakayama Research Center of Agriculture, Forestry and Fisheries, **5**: 107-116.

Uede, T. 2006. Fluctuation in dissolved oxygen in August from 1985 to 2000 in southern area of Tanabe Bay. Bulletin of the Wakayama Research Center of Agriculture, Forestry and Fisheries, **7**: 123-130.

Uede, T. 2007a. Chemical characteristics and forms of phosphorus compounds in sediment of fish farming areas. Nippon Suisan Gakkaishi, **73**: 62-68.

Uede, T. 2007b. Postprandial changes in digesta, leftovers and feces in cultured red sea breams, Pagrus major. Aquaculture Science, **55**: 409-415.

Uede, T. 2008. Occurrence and characteristics of red tides in Tanabe Bay, Wakayama Prefecture from 1971 to 2006. Nankiseibutu: The Nanki Biological Society, **50**: 38-45.

Weston, D.P. 1990. Quantitative examination of macrobenthic community changes along an organic enrichment gradient. Marine Ecology Progress Series, **61**: 233-244.