水研センター研報，第19号，143－147，平成19年
Bull. Fish. Res. Agen. No. 19, 143-147, 2007

Nutrient uptake by *Undaria undarioides* (Yendo) Okamura and application as an algal partner of fish-alga integrated culture

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Abstract : Nitrogen (N) and phosphorus (P) budgets in a fish-alga integrated culture were studied using an edible kelp, *Undaria undarioides* and the red sea bream *Pagrus major* in Tanabe Bay, Japan. The kelp was cultured on one rope (16 m in length) surrounding a fish culture cage (3 x 3 x 3 m) to reduce the loads of fish discharge. From 2002 December to 2003 March, 260 young red sea breams (172.7 g in average), were cultured in the cage by feeding 18.4 kg of artificial compounds containing 1435 g nitrogen and 282 g of phosphorus. At the end, 8.3 kg of fish growth was obtained; 243 g (16.9 % of the given feed) of N and 71 g (25.2 %) of P were stored in the fish bodies. During the culture, kelp absorbed N and P at estimated rates of 3.11 μg atm/wet g/hr and 0.16 μg atm/wet g/hr, yielding 161 kg of commercial size on the rope. The total amounts of N and P absorbed by kelp corresponded to 40.5 % and 25.9 % of those in given food, respectively. This is the first report of the total N and P budgets in a fish-alga integrated culture in Japan.

Introduction

An edible kelp, *Undaria undarioides* (Laminariales, Alariaceae), which is close to a widely distributed and utilized species, *U. pinnatifida*, is localized in southern parts of warm temperate in Japan (Okamura 1915). As the unique kelp is commercially important as a local high-priced food, culture has been attempted in southern coasts of Wakayama Prefecture (Kimura & Notoya 1996). On the other hand, cultures of red sea bream, *Pagrus major* have been popular in these areas (Uede & Takeuchi 2004). As the fish cultures are localized in inner bays, where seawater exchanges are limited, lords of nitrogen and phosphorus discharged from fish cultures, including excretion and defecation from fish, dissolution from residual feeds or re-suspension from the bottom sediments, are becoming problematic (Uede & Takeuchi 2004). These nitrogen and phosphorus, however, are essential nutrients for the growth of seaweed. Therefore, enriched seawater stagnating around fish culture is highly expectant for cultures of commercial seaweeds including *U. undarioides,* particularly in the form of fish-alga integrated culture. Although integrated cultures are worldwide concerns (ex. Troell *et al.* 2003, Neori *et al.* 2004), the combination of red sea bream and *Undaria* species is limited to Kitadai & Kadowaki (2004 b), in which nutrient uptake by *U. pinnatifida* was determined. In the present study, the authors reported the nitrogen and phosphorus budget in a red sea bream-*U. undarioides* integrated culture.

Materials and Methods

Culture of red sea bream:

Red sea bream was cultured in the Mera Cove of Tanabe City in Wakayama Prefecture (Fig.1) from 2002 Dec. 14 to 2003 Mar. 12. A total of 260 fish of a mean body weight of 172.7 g were kept in a cage (3x3x3m) fixed at the sea surface and satiated by feeding soft-dry pellet (SP)(See Table 1) 4 days (in evenings) a week. This type of feed was used to minimize the load to the ambient water. The total weights of fish were determined at the beginning

2006年6月26日受理（Received. June 26, 2006）
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and the end after 89 days culture. The seawater temperature ranged between 12.2 and 19.2 ℃ during the culture.

Estimations of nitrogen and phosphorus from red sea bream:

In analysis of fish body composition, 5 fish samples were taken at the beginning of the experiment, and whole fish bodies were used after slicing. Water, protein, lipid, ash and phosphorus contents were determined using methods of the normative thermal desiccation, quantitative nitrogen desiccation, Soxhlet extraction, direct ashing and vanado-molybdic acid absorbance, respectively. Nitrogen or phosphorus loads discharged from cultured fish were estimated by subtracting the value of each component obtained from the harvested fish bodies from that obtained from the total weight of given feed. Nitrogen was assumed to be 16 % of proteins contained in the feed and the fish bodies.

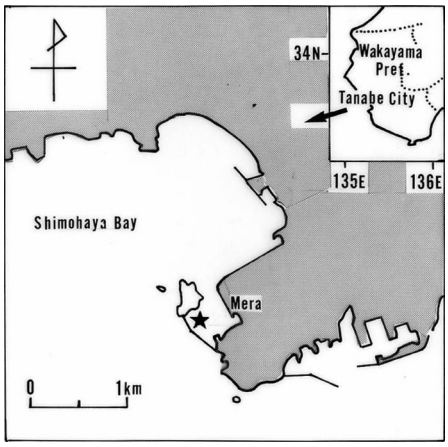

Fig. 1. Map showing the location for cultivation of red sea bream and *Undaria undarioides* (Yendo) at Shimohaya Bay in Wakayama Prefecture. (★) The place which examined.

Table 1. Composition of the experimental a diet

Ingredients		
Jack mackerel meal	50	%
Defatted soybean meal	5	
Corn gluten meal	5	
Wheat flour	17	
Pregelatinized starch	5	
Pollock liver oil	15	
P-free mineral mix	1	
Vitamin premixture	2	

Diet of nutrient content		
Moisture	2.1	%
Crude protein	49.0	
Crude fat	20.4	
Crude ash	9.2	
Phosphorus	1.54	

Culture of kelp:

Juveniles of *U. undarioides*, produced in Fish Farming Laboratory Fisheries Experimental Station, Wakayama Research Center of Agriculture, Forestry and Fisheries on 2002 Nov. 28, were kept in the form of square (4 × 4 m) at a depth of 1 m around the cage of *P. major* cultures using a rope of 16 m long. The strings of 30 mm long, on which juveniles attached, were stuck into the rope (18 mm in diameter) at 20 cm intervals, resulting in sticking out of each string end by 6 mm long on both sides of the rope. Namely, a total of 80 strings with two ends were set around the cage. As the growth of *U. undarioides* varied, all of the thalli growing on one end of a string (called unit string hereafter) were collected from 5 sites of the rope. The mean weight and number of kelp per half-side string was estimated after removing excess water. The samplings were conducted on 2002 Dec 28, 2003 Jan. 6, 20, 30, Feb. 10, 21 and Mar. 14. On the last day, although some of thalli were matured, matured ones were eliminated.

Estimations of nitrogen and phosphorus absorbance by cultured kelp:

Nitrogen and phosphorus levels incorporated into the kelp from sea water were estimated from weight gain of the thalli and their ratios of water, total nitrogen and total phosphorus contents. Total nitrogen and total phosphorus were determined by Kjeldhal method and vanado-molybdenum absorbance method, respectively.

RESULTS

Estimated nitrogen and phosphorus contents in red sea bream culture: The growth and analytical data (including data of feed) of red sea bream are shown in Table 2 and Table 3, respectively. The total weight of given feed was as low as 18.3 kg for 89-day period, yielding weight gain of 8.3 kg in fish bodies. The nitrogen and phosphorus contained in

Table 2. Results of red sea bream feeding with the EP-pellet in the 3×3×3m net cage from Dec.14 to Mar.12

No. of fish	Average body fish(g)		Daily feed intake(%)	Weight gain(g)A	Growth rate(%)	Amount of diets(g) B	Feed efficiency	Mortality (%)
	Initial	Final						
260	172.7	205.3	0.42	8,297	1.19	18,300	45.3	1.15

Table 3. Composition of the Whole body of red sea bream

		Diet	Body
Moisture	%	2.1	67.3
Crude protein	%	49.0	18.3
Crude fat	%	20.4	9.6
Crude ash	%	9.2	4.7
Phosphorus	%	1.54	0.85

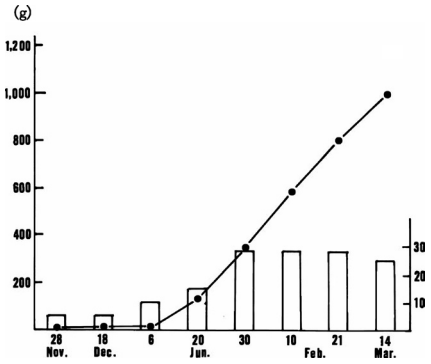

Fig. 2. Changes in the weight (—●—) per culture unit string and number (□) of blade *Undaria underioides*.

the given feed were 1,435 g and 282 g, respectively. Nitrogen and phosphorus pooled in the harvested fish bodies were 243 g (cumulative rate: 16.9 %) and 71 g (cumulative rate: 25.2 %), respectively. Using these data, the nitrogen and phosphorus loads to the ambient water were calculated as 1,192 g (83.1 %) and 212 g (74.8 %), respectively.

Estimated nitrogen and phosphorus absorbance by the cultured kelp:

Changes in weight, height and number of the kelp per unit string were shown in Fig. 2. The kelp grew rapidly between Jan. 6 and Mar. 14 after a lag phase lasting 40 days, recording final biomass of 1,007 g per unit string or 37.3 g per thallus. As 5 strings were stuck into 1 m of rope and each sample was collected from one end of each string, the yield was estimated as 10 kg/m (≒ 1,007 kg × 2 x 5) or a total of 161 kg on the rope (16 m) around the cage of fish culture.

Composition of the kelp blade was shown in Table 4. The nitrogen and phosphorus incorporated through cultivation were 483 g and 54.7 g, respectively. Therefore, 40.5 % and 25.9 % of the nitrogen and phosphorus loads the ambient water (1,192 g and 211 g, see above) were assimilated by the cultured kelp, respectively. The budgets of nitrogen and phosphorus in the present integrated culture were summarized in Fig. 3. Using the growth data, the *in situ* uptake rates of nitrogen and phosphorus by the kelps were calculated as 2.34 μg atm/wet g/hr and 0.26 μg atm/wet g/hr, respectively.

Discussion

In the present study, we could obtain commercial-sized edible kelp *Undairia undarioides* by utilizing the nitrogen and phosphorus discharged from a red sea bream culture, although the experiment is limited in winter, when growth of the kelp is high (Kimura & Notoya 1996) but that of red sea bream *P. major* is low because of low feeding activity in low temperatures (Fukusho 1986). For the warmer seasons, *Sargassum fusiformes* and *Ulva pertusa* (Kimura & Tanaka 2004) are now on trial as the candidates for the algal partners.

In the previous studies on red sea bream and seaweed integrated culture, *U. pertusa* (Hirata *et al.* 1993, Kitadai & Kadowaki 2004a), *Laminaria japonica* (Kitadai & Kadowaki 2003) or *U. pinnatifida* (Kitadai & Kadowaki 2004b) was used as algal partners. In these studies, however, only absorption of nutrients by algae was paid attention without demonstrating any data on nutritional input and

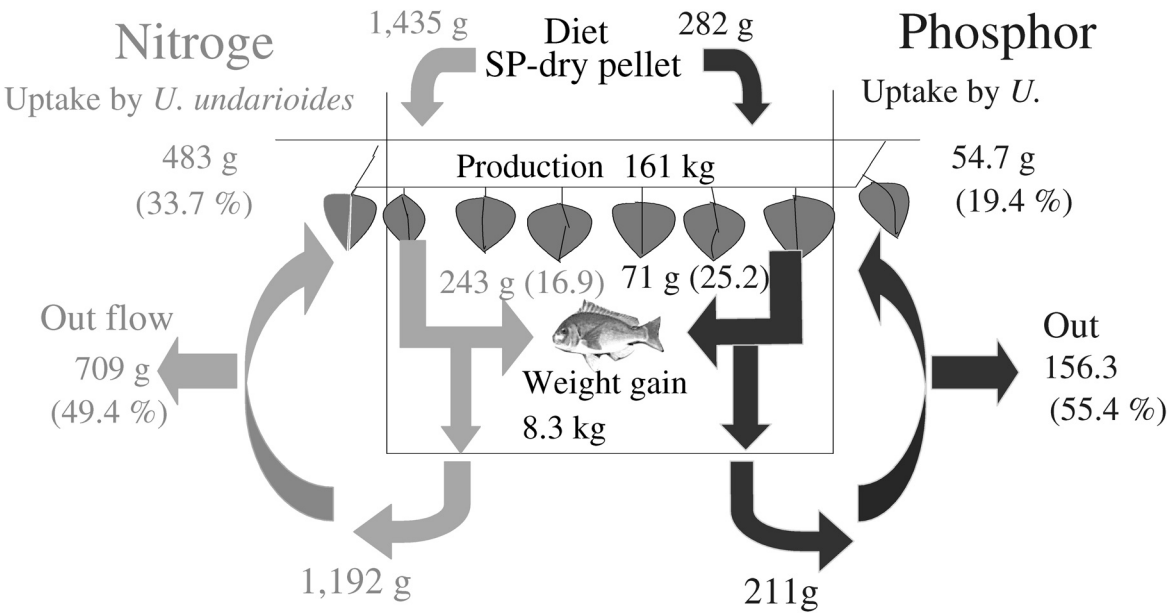

Fig. 3. Circulation of nitrogen and phosphorus at the red sea bream with *Undaria undariodes* culture.

Table 4. Composition of the blade of *Undaria undarioides*

Moisture	g/100g	90.3
Total amount of nitrogen	g/100g	0.3
Total amount of phosphorus	mg/100g	34

output from red sea bream culture. Therefore, this is the first report that showed the total nutrient budgets in the red sea bream-alga integrated culture. Furthermore, we could provide several benefits of the integrated system other than the above moral benefit as followings.

First of all is the depth merit. The depth of *U. undarioides* culture in the present integrated system (1 m) was shallower than depths (2 to 8 m) of its natural habitats (Okamura 1915; Kimura 1995). However, Kimura and Notoya (1996) revealed that the growth of the cultured kelp was faster at depths of 0.5 and 1.5m than at a depth of 2.5m. In addition, the subsurface culture of the kelp also gives spatial refuge to juvenile kelps because browsing by the herbivorous fish, *Siganus fuscens* is the most significant factor causing the reduction of the kelp at depths from 2.5 to 7 m from November to February, in which the water temperatures are enough high (>16 ℃) for its browsing (Kimura 1995). Thus the culture depth of *U. undarioides* is well coincidence with that of the red sea bream culture usually practiced near sea surface (Fukusho 1986).

The present integrated system could reduce equipments for *U. undarioides* culture such as anchors and floats by using a framework of the red sea bream culture, resulting in the decrease of cost of equipment by ca 90 % (ca 200,000 yen) comparing with the case of non-integrated culture of the kelp. Additional income (ca 40,000 yen in the present case) was also available for the culturists by selling the kelp at the price of 350 yen/wet kg. These economical benefits substantially support the introduction of integrated cultures by raising the motivation of fishermen.

Acknowledgement

This study was supported by a grant from the Wakayama Prefecture Collaboration of Regional Entities for the Advancement of Technological Excellence of the JST.

References

Fukusho, K. (1986) Red sea bream. p.219-245. In: (ed)

Shigen Kyokai, Aquaculture in shallow waters, Tokyo.

Hirata H., E. Kohirata, F. Guo, Bo-Toa Xu and E. Danakusumah (1993) Culture of the sterile *Ulva sp.* (Chlorophyceae) in a mariculture farm. *Suisanzosyoku*, **41**, 541-545.

Kimura H. (1995) *Undaria undarioides* and *Ecklonia radicosa* Okamura along the coasts of Wakayama Prefecture. Nippon Suisan Gakkaishi, 61, 109-110.

Kimura H. (1995) *Undaria undarioides* and *Ecklonia radicosa* Okamura along the coasts of Wakayama Prefecture. Nippon Suisan Gakkaishi, 61, 109-110.

Kimura H. and Notoya M. (1996) Suitable time and depth of outplant seedling for cultivation *Undaria undarioides* (Yendo) Okamura at Tanabe Bay in Wakayama Prefecture, *Japan.Nippon Suisan Gakkaishi*, **62**(5), 723-726.

Kimura H. and Tanaka T. (2004) Development of polyculture system. Reports of Fish Farming Laboratory Fisheries Experimental Station, Wakayama Research Center of Agriculture, Forestry and Fisheries. 35, 37-50.

Kitadai Y. and Kadowaki S. (2003) The growth process and N, P uptake rates of *Laminaria japonica* culture in coastal fish farm. *Suisannzosyoku*, **51**, 15-23.

Kitadai Y. and Kadowaki S. (2004a) The growth process and N, P uptake rates of *Ulva pertusa* culture in coastal fish farm. *Suisannzosyoku*, **52**, 65-72.

Kitadai Y. and Kadowaki S. (2004b) The growth process and N, P uptake rates of *Undaria pinnatifida* culture in coastal fish farm. *Suisannzosyoku*, **52**, 365-374.

Neori, A., Chopin,T., Troell, M., Buschmann A.H., Kraemer, G.P., Halling, C., Shipgel,M and Yarish, C. 2004. Integrated aquaculture: rationale, evolution and state of the art mphasizing seaweed biofiltration in modern mariculture. Aquaculture, 231, 361-391.

Okamura, K. (1915) *Undaria* and its species. Bot.Mag., 29: 266- 278.

Troell, M., Halling, C., Neori, A., Chopin, T., Buschmann, A.H., Kautsky, N. & Yarish, C. (2003) Integrated mariculture: asking the right questions. Aquaculture, 226, 69-90.

Uede T. and Takeuchi T. (2004) Report of project in conservation of environment in aquaculture ground. Fish Farming Laboratory Fisheries Experimental Station, Wakayama Research Center of Agriculture, Forestry and Fisheries. 24pp.