水研センター研報，第19号，149－154，平成19年
Bull. Fish. Res. Agen. No. 19, 149-154, 2007

Growth, nitrogen and phosphorous uptake rates and O_2 production rate of seaweeds cultured on coastal fish farms

Yuuki KITADAI* and Shusaku KADOWAKI*

Abstract To improve the water quality in coastal fish farms throughout year, we cultured *Undaria pinnatifida* at 12-19℃ , *Laminaria japonica* at 13-26℃ , and *Ulva pertusa* at 17-28℃ in the Yatsushiro Sea. The growth, N and P uptake rates and O_2 production rate of seaweeds were estimated. The growth of the seaweeds cultured were identified and measured. Each of the seaweeds cultured was collected monthly and analyzed for N and P contents. The observed N and P uptake rates per the blade and thallus area ($P_{N,P}$, mg N,P/m_s^2/day) of each seaweed were calculated by the following formula: $P_{N,P} = (C_{N,Pt} - C_{N,P0}) \cdot \alpha \ / \ t$, where $C_{N,P0}$ is the N and P contents at the start of the experiment (mg N,P/g dry), $C_{N,Pt}$ is the N and P contents day t (mg N,P/g dry), α is the dry weight per the blade and thallus area, and t is the cultivation days. The calculated N and P uptake rates of the seaweeds cultured were estimated from the dissolved inorganic nutrients concentrations, irradiance, and water temperature characteristics found at the fish farms. The O_2 production rates of the seaweeds were measured by the Winkler' s method used light and dark oxygen bottles on fine day in the fish farm. The allowable volumes of seaweeds cultured for N uptake to N load in fish farming area, and for O_2 production to O_2 consumption by a fish cultured in cage were estimated by using the maximum N uptake rate and the maximum O_2 production values, respectively.

Key words : seaweeds, coastal fish farm, N and P uptake rates, O_2 production rate, growth

Introduction

Today, biological water purification strategies are required to solve anoxic water and prevent eutrophication, aiming to establish sustainable aquaculture that can be produced on coastal fish farms (Kadowaki, 2001). Seaweed cultivation results in dissolved nitrogen and phosphorus that can be uptaken to supply oxygen for cultivation on coastal fish farms. For an entire year we cultured seaweed on coastal fish farms, and the nitrogen (N) and the phosphorus (P) uptake rates of seaweed were fixed by the environmental factors of the dissolved inorganic nutrients, the irradiance, and the water temperature. The oxygen (O_2) production rate of the seaweed was fixed by the environmental factors of the dissolved inorganic nutrients. Furthermore, the minimum cultivation scales of seaweed to reduce the N load and improve the O_2 environment were estimated by the results of the N uptake rate and the O_2 production rate of seaweeds.

Materials and Methods

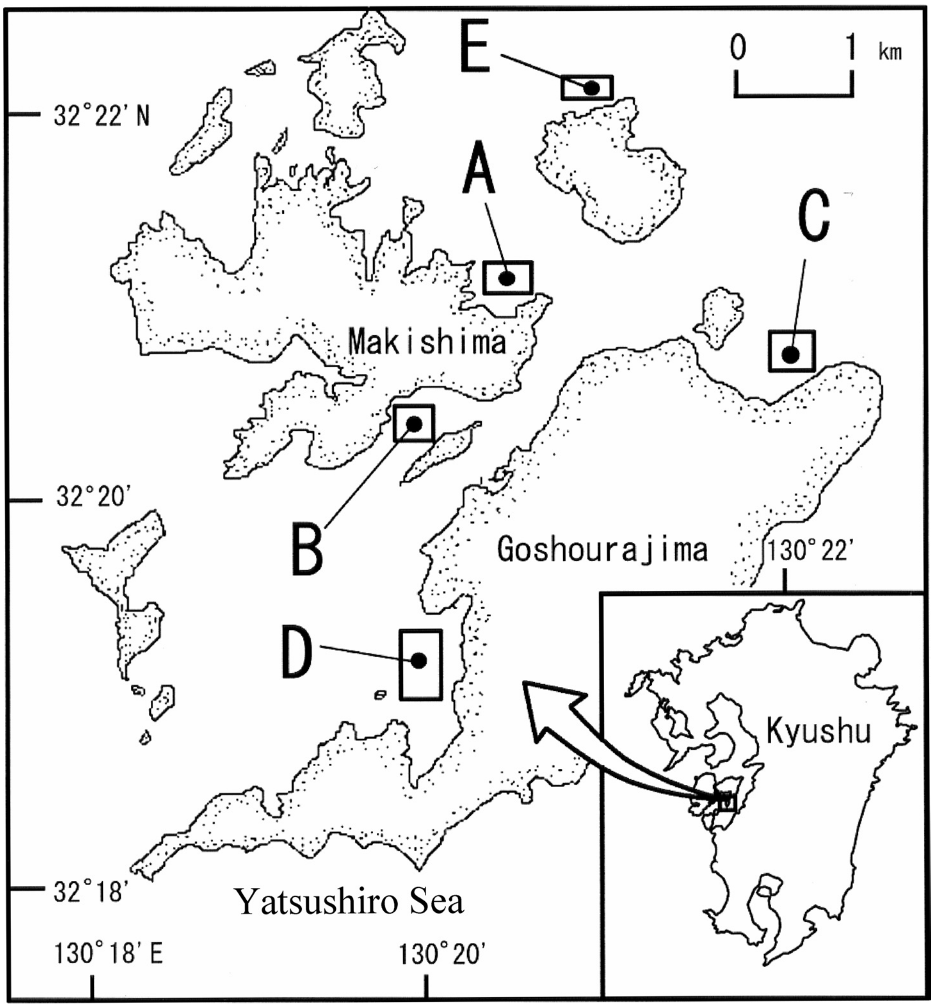
Seaweeds cultivation were carried out at stations A-E in coastal fish farms in the Yatsushiro Sea (Fig.1). During the investigation period the water temperature (WT) and the dissolved oxygen (DO) concentration of each station were recorded at 3 meter under the surface every three hours. Dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations were analyzed once a week (Strickland and Parsons, 1972). During the experiment period, downward irradiance

2006年 6 月26日受理（Received. June 26, 2006）
*Graduate School of Agricultural Science, Kagoshima University, Shimoarata 4-50-20, Kagoshima, 890-0056, Japan
E-mail: kadowaki@fish.kagoshima-u.ac.jp

was automatically recorded under the surface at the 1.3 meter and 2.0 meter depths every hour with a photon meter (LI-COR model 190SA). We cultured *Laminaria japonica* from December 2000 to July 2001, *Undaria pinnatifida* from November 2002 to May 2003, and *Ulva pertusa* from August 2002 to November 2002. *L. japonica* and *U. pinnatifida* were cultivated under the surface at the 1-4 meter layer, and *U. pertusa* was cultivated under the surface at the 0.5-8 meter layer. *L. japonica* and *U. pinnatifida* of blade length (BL), and the *U. pertusa* of the thallus area (TA) which were identified, were measured twice a month. The area, the weight, and the N and P contents in the seaweed were measured every month, and the analyzed N and P uptake rates were also measured. On fine days, the O_2 production ($P'c$) and consumption ($R'c$) rates per chlorophyll-a of the seaweed were measured between 10 a.m. and 2 p.m for 4 hours on a fish farm. The suspended depth of light and dark bottles was 2 meter at *L. japonica* and *U. pinnatifida*, and 0.5 m depth at *U. pertusa*. DO concentration was analyzed by Winkler's method.

The relationship between N and P uptake rates ($P_{N,P}$) per seaweed area and the $P'c$, DIN, and DIP concentrations were elucidated by Michaelis-Menten's formula. Maximum N and P uptake rates ($Pm_{N,P}$), maximum O_2 production rate ($P'cm$), and Michaelis-Menten's constants ($K_{N,P}$) of DIN and DIP concentration were calculated (Kitadai and Kadowaki, 2003; 2004a; 2004b). The relationship between $P_{N,P}$ and downward irradiance was analyzed

Fig. 1. Map showing the cultured sites of seaweeds at stations A-E of Goshoura coastal fish farms in the Yatsushiro Sea



by the Steel formula (Steel, 1962) to calculate the saturation irradiance (*Im*) to $Pm_{N,P}$. The relationship between $P_{N,P}$ and water temperature was analyzed by the Allometry formula (Kadowaki and Tanaka, 1994) to calculate the temperature coefficient (Q_{01}).

The densities of seaweeds cultured per fish farm area necessary to uptake the N load by the *Seriola quinqueradiata* culture were calculated. In addition, the cultivation weights of seaweeds necessary for oxygen consumption per a *S. quinqueradiata* cultured and the cultivation densities of seaweeds to oxygen consumption per cage volume of *S. quinqueradiata* cultured were provisionally calculated.

Results

Cultivation environment

The WT and DO concentration during the cultivation period were 12-28 ℃ and 5.7-10.7 mg/l at stations A-E, respectively. DIN and DIP concentrations ranged between 31-150 μg N/l and 7.0-27 μg P/l, respectively. DIN/DIP ranged from 3.1 to 8.4. The mean downward irradiance value (± SD) in the 2 meter depth for the investigation period was 650 ± 74 μ mol/m_f^2/s.

Growth of seaweeds

The maximum BL of *L. japonica* and *U. pinnatifida* reached 250 cm and 182 cm at the 2 meter depth, and their maximum growth rates were 3.0 cm/day and 4.2 cm/day, respectively. The maximum TA of *U. pertusa* reached 640 cm^2 at the 0.5 meter depth, and the maximum growth rate was 41 cm^2/day (Table.1).

N and P uptake rates of seaweeds

The Pm_N of *L. japonica, U. pinnatifida,* and *U. pertusa* were 2.9, 3.1, and 3.6 mg N/m_s^2/day, and the Pm_P were 0.43, 0.54, and 0.19 mg P/m_s^2/day, respectively. Furthermore, the K_N of *L. japonica, U. pinnatifida,* and *U. pertusa* were 29, 17, and 26 μg N/l, and their K_P were 8.7, 6.2, and 8.0 μg P/l, respectively. The *Im* of *L. japonica, U. pinnatifida,* and *U. pertusa* were 720, 670, and 730 μ mol/mf2/s, respectively. The Q_{01} at P_N of *L. japonica, U. pinnatifida*, and *U. pertusa* were 1.071, 1.090, and 1.076, and their Q_{01} at P_P were 1.062, 1.081, and 1.084, respectively (Table.2).

O_2 production and consumption rates of seaweeds

The water temperature of the *P' cm* and *R' c* of *L. japonica, U. pinnatifida,* and *U. pertusa* was 23, 20, and 28 ℃, respectively. The *P' cm* of *L. japonica, U. pinnatifida*, and *U. pertusa* were 2.6, 2.7, and 2.8 mg O_2/mg chl.a/h, and their *R' c* were 0.29, 0.24, and 0.35 mg O_2/mg chl.a/h, respectively. The *P' cm/R' c* of *L. japonica, U. pinnatifida,* and *U. pertusa* were calculated at 8.9, 11.2, and 8.0, respectively (Table.3).

Discussion

Density of seaweeds cultured to N load of fish farm area

It was reported that N load rates per fish farm area of *S. quinqueradiata* in the *L. japonica, U. pinnatifida,* and *U. pertusa* cultivation periods were 290, 115, and 520 mg N/m_f^2/day, respectively (Kouchi Fisheries Experimental Station, 1989). The minimum densities of *L. japonica, U. pinnatifida,* and *U. pertusa* per fish farm area of S. quinqueradiata were analyzed by PmN, resulting in 2.9, 3.1, and 3.6 mg N/m_s^2/day, respectively. Thus, the minimum cultivation densities of *L. japonica, U. pinnatifida,* and U. pertusa per fish farm area of *S. quinqueradiata* cultured were 105, 27, and 7.6 kg/m_f^2, respectively (Table.4).

Weight and density of seaweeds cultured to O_2 consumption of fish culture

The oxygen consumption rate per an *S. quinqueradiata* cultured in the *L. japonica, U. pinnatifida,* and *U. pertusa* cultivation periods were 879, 695, and 1392 mg O_2/a fish/h, respectively (Kadowaki, 1990; 1994). The minimum cultivation weights of *L. japonica, U. pinnatifida*, and *U. pertusa* per *S. quinqueradiata* cultured were analyzed by *P' cm*, resulting in 0.75, 0.83, and 6.39 mg O_2/g wet/h, respectively. Thus, the minimum cultivation weights of *L. japonica, U. pinnatifida*, and *U. pertusa* per a *S. quinqueradiata* cultured were 1.70, 0.83, and 0.21 kg wet/a fish, respectively. Moreover, the minimum densities of *L. japonica, U. pinnatifida*, and *U. pertusa* per cage volume of *S. quinqueradiata* cultured were 5.6, 4.0, and 1.3 kg wet/m^3,

Table 1. Maximum growth and growth rate of blade length (BL) of *L. japonica* and *U. pinnatifida*, and thallus area (TA) of *U. pertusa*

Items	Unit	*L. japonica*	*U. pinnatifida*	*U. pertusa*
Layer	(m)	2.0	2.0	0.5
Blade length	(cm)	250	182	-
Thallus area	(cm^2)	-	-	640
Growth rate of BL	(cm/day)	3.0	4.2	-
Growth rate of TA	(cm^2/day)	-	-	7.6

Table 2. Maximum N and P uptake rates ($Pm_{N,P}$), the maximum irradiance to $Pm_{N,P}$ (Im), Michaelis-Menten constants (K), and the water temperature coefficients (Q_{01}) of *L. japonica, U. pinnatifida*, and *U. pertusa*

Items	Unit	*L. japonica*		*U. pinnatifida*		*U. pertusa*	
		N	P	N	P	N	P
WT	(℃)	16 - 23		12 - 20		18 - 28	
Pm	(mg/m_s^2/day)	2.9	0.43	3.1	0.54	3.6	0.19
Im	(μ mol/m_f^2/s)	720		670		730	
K	(μ g/*l*)	29	8.7	17	6.2	26	8.0
Q_{01}		1.071	1.062	1.090	1.081	1.076	1.084

Table 3. Maximim O_2 production rates ($P'cm$) and O_2 consumption rates ($R'c$) of *L. japonica, U. pinnatifida*, and *U. pertusa*

Items	Unit	*L. japonica*	*U. pinnatifida*	*U. pertusa*
WT	(℃)	23	20	28
P'cm	(mg O_2/mg chl.a/h)	2.6	2.7	2.8
R'c	(mg O_2/mg chl.a/h)	0.29	0.24	0.35
P'cm / R'c		8.9	11.2	8.0

Table 4. Comparison of minimum density of seaweeds cultured per fish farm area for nitrogen load of *S. quinqueradiata* in *L. japonica, U. pertusa,* and *U. pinnatifida*

Items	Formula	Unit	*L. japonica*	*U. pinnatifida*	*U. pertusa*
N load rate of *S. quinqueradiata* *1	A	(mg N/m_f^2/day)	290	11	520
Pm_N	B	(mg N/m_s^2/day)	2.9	3.1	3.6
Weight of seaweed	C	(g wet/indiv.)	116	192	-
Area of seaweed	D	(m_s^2/indiv.)	0.11	0.26	-
Area per weight of seaweed	E	(m_s^2/kg wet)	-	-	19
Minimum density of seaweed per fish farm area	A･C / (B･D)	(kg/m_f^2)	105	27	-
	A / (B･E)	(kg/m_f^2)	-	-	7.6

*1Kouchi Fisheries Experimental Station (1989)

Table 5. Comparison of minimum amount of seaweeds cultured per a fish, and minimum density of seaweed cultured per fish cage volume for O_2 consumption of *S. quinqueradiata in L. japonica, U. pertusa,* and *U. pinnatifida*

Items	Formula	Unit	*L. japonica*	*U. pinnatifida*	*U. pertusa*
Water Temperature		(℃)	23	20	28
Body weight of *S. quinqueradiata* *1		(kg)	2.0	1.8	2.6
Density of *S. quinqueradiata* per cage volume *1	A	(fish/m^3)	4.8	4.8	6.3
O_2 consumption rate of *S. quinqueradiata* *2	B	(mg O_2/a fish/h)	879	695	1392
Maximum O_2 production rate of seaweed	C	(mg O_2/g wet/h)	0.75	0.83	6.39
Minimum amount of seaweed per a fish	B/C	(kg wet/a fish)	1.17	0.83	0.21
Minimum density of seaweed per fish cage volume	A･B/C	(kg wet/m^3)	5.6	4.0	1.8

*1Kadowaki (1990); *2Kadowaki (1994)

respectively (Table.5).

The *P' cm/R' c* of *L. japonica, U. pinnatifida*, and *U. pertusa* were 8.9, 11.2, and 8.0, respectively, proving that the O_2 production rate of seaweed is eight to eleven times more than the O_2 consumption rate. Therefore, seaweed cultivation is effective on the O_2 supply of fish farms.

The present study clarified the estimated water purification methodology by seaweed that N and P uptake rates, and the O_2 production rate were fixed by the environmental factors of the dissolved inorganic nutrients, irradiance, and the water temperature on coastal fish farms.

References

Kadowaki S., 1990: Production ecological studies on allowable capacity of aquaculture in yellowtail, *Seriola quinqueradiata*. Doctoral thesis of Hokkaido university, 123 pp. (In Japanese)

Kadowaki S., 1994: Energy budget for a yellowtail, *Seriola quinqueradiata* in pen culture. *Bull. Natl. Res. Inst. Aquaculture, Suppl.* **1**, 45-59.

Kadowaki S. and Tanaka Y., 1994: Oxygen consumption rates by phytoplankton and bacteria in sea water. *Suisanzoshoku*, **42**, 267-272. (In Japanese)

Kadowaki S., 2001: Creations of sea, fishes and human in 21th century for environmental conservation of mariculture. The Society of Naval Architects of Japan, **16**, 1-6. (In Japanese)

Kitadai Y. and Kadowaki S., 2003: The growth process and N, P uptake rates of *Laminaria japonica* cultured in coastal fish farms. *Suisanzoshoku*, **51**, 15–23. (In Japanese)

Kitadai Y. and Kadowaki S., 2004a: The growth and N, P uptake rates of *Ulva pertusa* cultured in coastal fish farms. *Suisanzoshoku*, **52**, 65–72. (In Japanese)

Kitadai Y. and Kadowaki S., 2004b: The growth process and N, P uptake rates of *Undaria pinnatifida* cultured in coastal fish farms. *Suisanzoshoku*, **52**, 365–374. (In Japanese)

Kouchi Fisheries Experimental Station, 1989: Load volume of nitrogen. *Bull. Kochi Pref. Fish. Exp. Stn.*, **85**, 34–41. (In Japanese)

Strickland, J. D. H. and Parsons, T. R., 1972: A practical handbook of seawater analysis. *Bull. Fish. Res. Bd. Can.*, Ottawa, pp. 45–90.

Steel, J. H., 1962: Environmental control of photosynthesis in the sea. *Limnol. Oceanogr.*, **7**, 137–150.