The growth, N, P uptake rates and photosynthetic rate of seaweeds cultured in coastal fish farms

Yuuki KITADAI and Shusaku KADOWAKI
(Kagoshima university)

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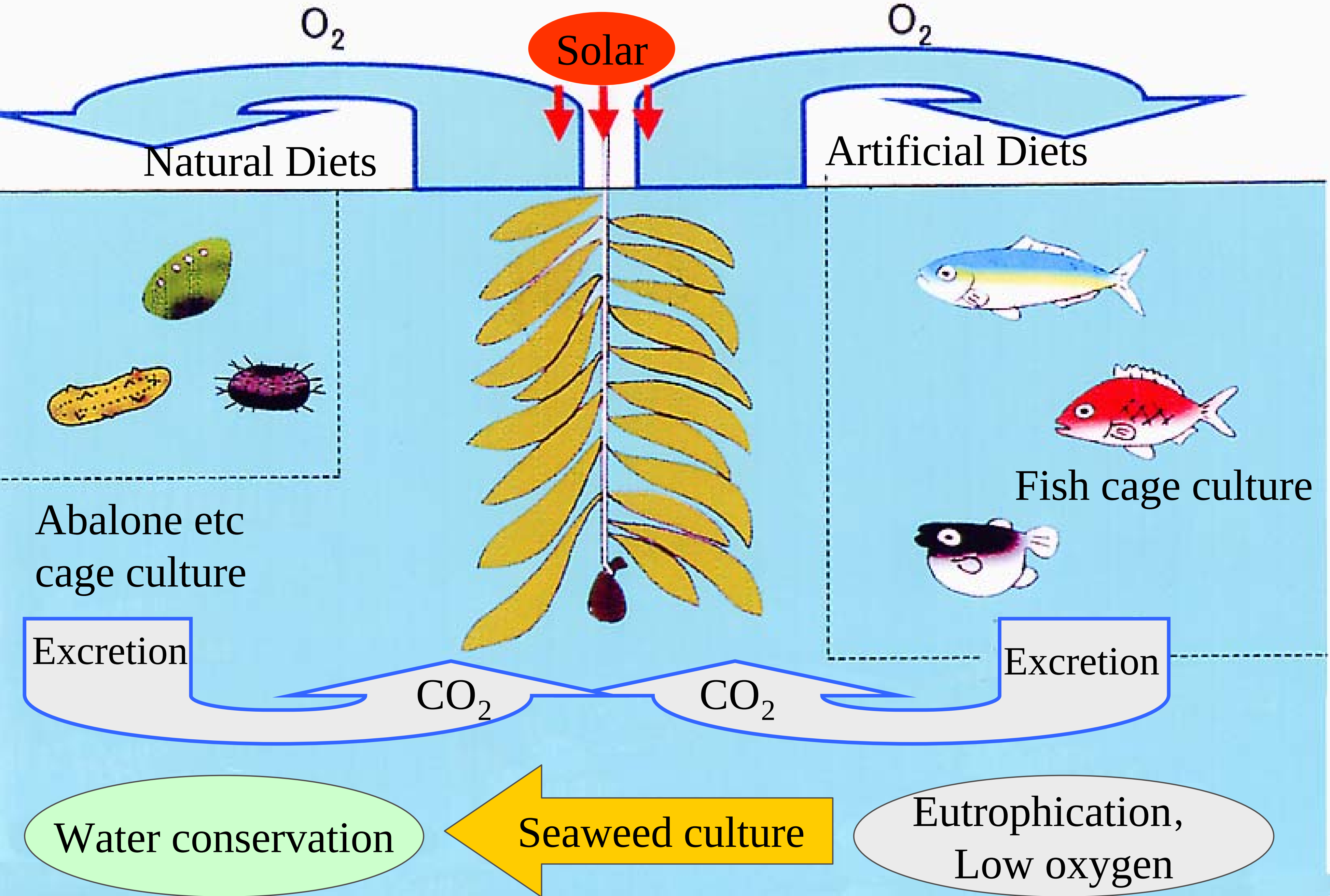
Enviromental conservation by polyculture with fish, seaweed and shellfish in coastal fish farm



Whole year seaweed culture in coastal fish farms for water purification in theYatushiro sea

Maximum growth and daily growth rate of *U.pinnatifida*, *L. japonica* and *U. pertusa*.

	U.pinnatifida	*L.japonica*	*U. pertusa*
Cultured layer (m)	2	2	0.5
Blade length (cm)	182	250	—
Thallus area (cm^2)	—	—	640
Growth of BL (cm/day)	4.2	3.0	—
Growth of TA (cm^2 /day)	—	—	41

Maximum O_2 production and O_2 consumption rates of *U.pinnatifida*, *L. japonica* and *U. pertusa*.

	U.pinnatifida	*L.japonica*	*U. pertusa*
	12～20 ℃	16～23 ℃	18～28 ℃
Maximum O_2 production (mg O_2/mg chl.a/h)	2.7	2.6	2.8
O_2 consumption (mg O_2/mg chl.a/h)	0.24	0.29	0.35
Maximum O_2 production / O_2 consumption	11.2	8.9	8.0

Observed N, P uptake rates of seaweed

$$P_{ob} = (C_t - C_0) \cdot \alpha / t$$

P_{ob} : N, P uptake rates of seaweed area (mg / m_S^2 / day)

C_0 : N, P contents on the beginning day (mg / g dry)

C_t : N, P contents after t days (mg / g dry)

α : dry weight per area of seaweed (g dry / m_S^2)

t : cultured periods (days)

Calculated N, P uptake rates of seaweed

① Nutrient (S, μ g / *l*) : Michaelis-Menten

$$P_{cal} = Pm \cdot S / (K + S)$$

② Irradiance (I , μ mol / m² / sec) : Steel Model

$$P_{cal} = Pm \cdot (I / Im) \cdot \exp(1 - I / Im)$$

③ Water Temperature (θ ,℃) : Allometry

$$P_{cal} = P_T \cdot Q_{01}^{(\theta - T)}$$

P_{cal} : caluculated N, P uptake rates of seaweed (mg / m_s^2 / day)

K : Michaelis-Menten constant (μ g / *l*)

Q_{01} : Water temperature coefficient

T : *U.pinnatifida* 16 ℃, *L.japonica* 20 ℃, *U.pinnatifida* 25 ℃

Calculated coefficient at N, P uptake rates of *U.pinnatifida*, *L. japonica* and *U. pertusa*.

	U.pinnatifida		*L.japonica*		*U. pertusa*	
	12～19 ℃		12～ 23 ℃		17～28 ℃	
	P_N	P_P	P_N	P_P	P_N	P_P
P_m mg/m_s^2/day	3.1	0.53	2.9	0.43	3.6	0.19
I_m μ mol/m^2/s	670		720		730	
$\overline{K}$ μ g / l	17	6.1	29	8.7	26	8.6
Q_{01}	1.090	1.081	1.071	1.062	1.076	1.084

Length of *L.japonica* and *U.pinnatifida* seeding yarn for nitrogen load by *S.quinqueradiata* per cultured area

$$Z = N \,/\, (P_N \cdot s \cdot n)$$

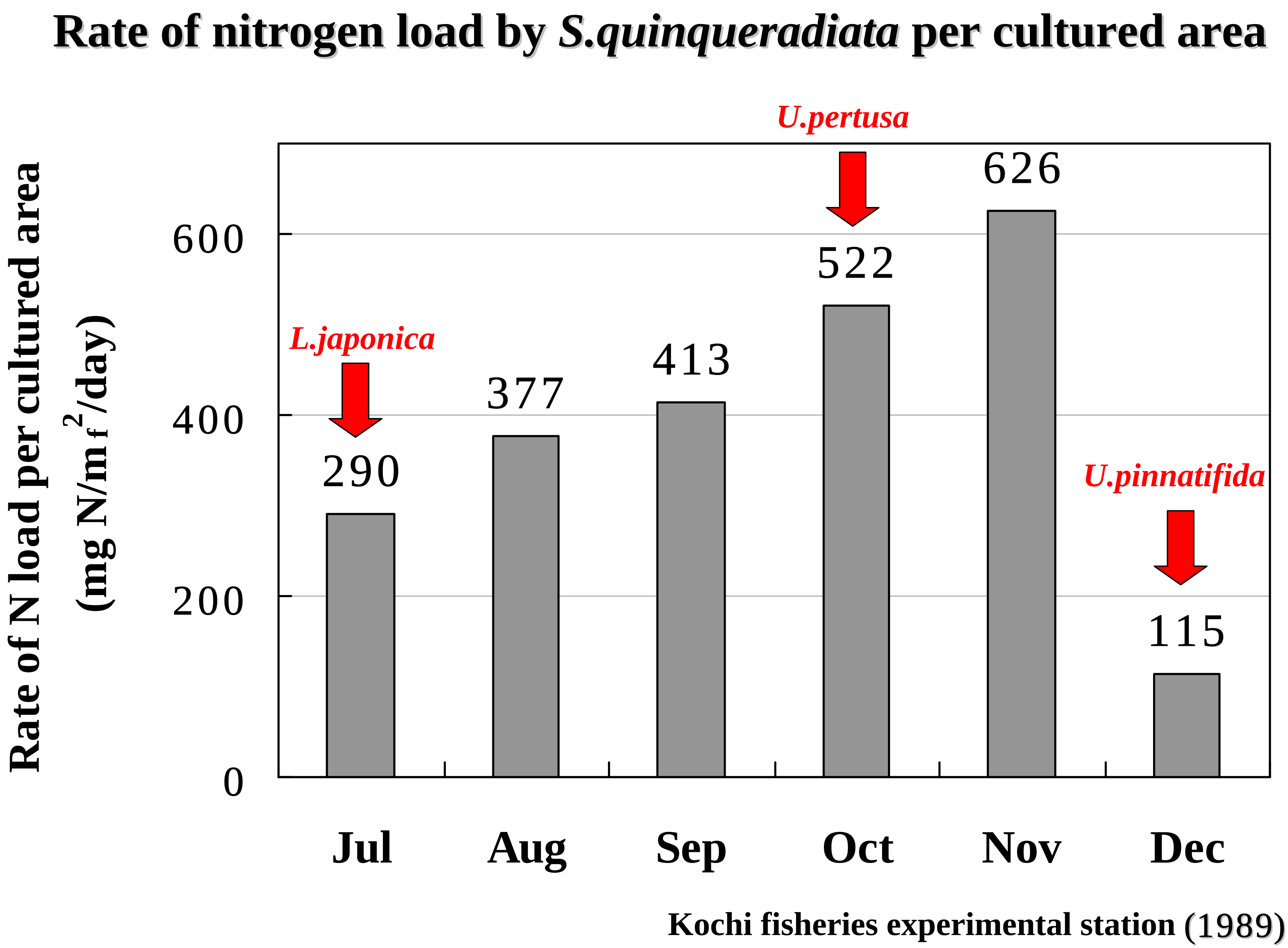
Z : Length of seeding yarn for N load (m)

N : Rate of N load by yellowtail per cultured area(mg N / m_f^2 / day)

P_N : Rate of N uptake by seaweed per blade area (mg N / m_S^2 / day)

s : Blade area of seaweed per an individual (m_s^2 / indiv.)

n : Adnated number per one meter seeding yarn (indiv. / m)



Rate of nitrogen load by S.quinqueradiata per cultured area
Rate of N load per cultured area
(mg N/m$_f^2$/day)
0
200
400
600
L.japonica
U.pertusa
U.pinnatifida
290
377
413
522
626
115
Jul
Aug
Sep
Oct
Nov
Dec
Kochi fisheries experimental station (1989)

Cultured density and length of *U.pinnatifida* seeding yarn for N load by *S.quinqueradiata* per cultured area

Rate of N load by yellowtail : 115 **mg N / m_f^2 / day** *1

Rate of N uptake by *U.pinnatifida* : 2.0 **mg N / m_s^2 / day** *2

Blade area : 0.260 **m_s^2 / indiv.**

Number of adnation : 87 **indiv. / m**

Weight of Blade : 192 **g wet / indiv.**

Length of seeding yarn for N load : 2.5 **m/m_f^2**

Cultured density for N load : $2.5 \times 87 \times 0.192 = 41$ **kg wet/m_f^2**

*1) : **Kochi fisheries experimental station :1989,** *2) : **Kitadai・Kadowaki :2004**

Cultured density and length of *L.japonica* seeding yarn for N load by *S.quinqueradiata* per cultured area

Rate of N load by yellowtail : 290 **mg N / m_f^2 / day**[*1]

Rate of N uptake by *L.japonica* : 2.9 **mg N / m_s^2 / day**[*2]

Blade area : 0.110 **m_s^2 / indiv.**

Number of adnation : 160 **indiv. / m**

Weight of Blade : 116 **g wet / indiv.**

Length of seeding yarn for N load : 5.6 **m/m_f^2**

Cultured density for N load : 5.6×160×0.116 = 103 **kg wet/m_f^2**

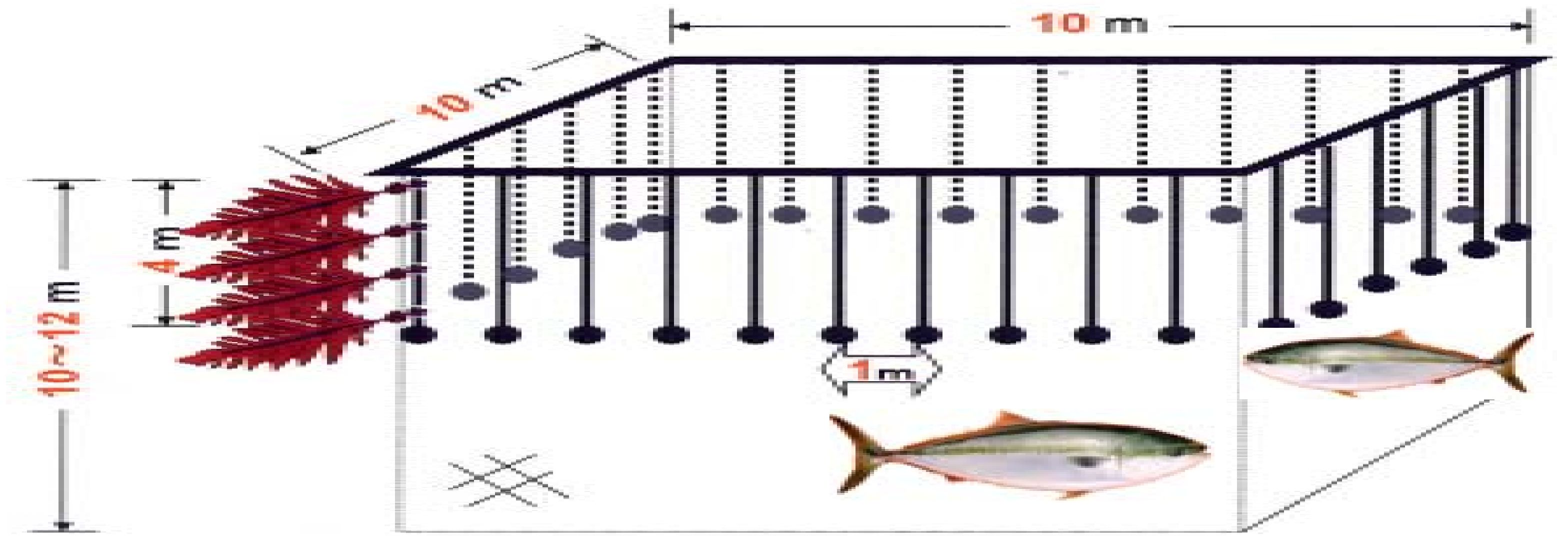
＊1) : **Kochi fisheries experimental station :1989,** ＊2) : **Kitadai・Kadowaki :2003**

Production of *U.pinnatifida* and *L.japonica* around the fish cage

●**Length of seeding yarn** ： 160 **m =** 4 **m** × 10 **yarns** × 4 **sides**

●**Production of *U.pinnatifida*** ： 2600 **kg =** 160 **m** × (41 **kg** ／ 2.5 **m**)

●**Production of *L.japonica*** ： 2900 **kg =** 160 **m** × (103 **kg** ／ 5.6 **m**)



N uptake ratio to load

U.pinnatifida ： 63 % = 100 × 2600 kg ／ (41 kg/m_f^2 ×100 m_f^2

L.japonica ： 28 % = 100 × 2900 kg ／ (103 kg/m_f^2 ×100 m_f

Density of cultured *U.pertusa* for nitrogen load by *S.quinqueradiata* per cultured area

$$Z = N \,/\, (P_N \cdot s)$$

Z : Density of cultured seaweed for N load (kg wet / m_f^2)

N : Rate of N load by yellowtail per cultured area (mg N / m_f^2 / day)

P_N : Rate of N uptake by seaweed per thallus area (mg N / m_s^2 / day)

s : Thallus area of seaweed per one kg (m_s^2 / kg wet)

Cultured density of *U.pertusa* for N load by *S.quinqueradiata* per cultured area

Rate of N load by yellowtail : 520 mg N / m_f^2 / day＊1

Rate of N uptake by *U.pertusa* : 3.6 mg N / m_s^2 / day ＊2

Thallus area per weight : 116 m_s^2 / kg wet

Cultured density for N load : 7.6 kg wet/m_f^2

＊1) : Kochi fisheries experimental station :1989, ＊2) : Kitadai・

Area ratio of cultured *U.pertusa* to fish and N uptake ratio to load

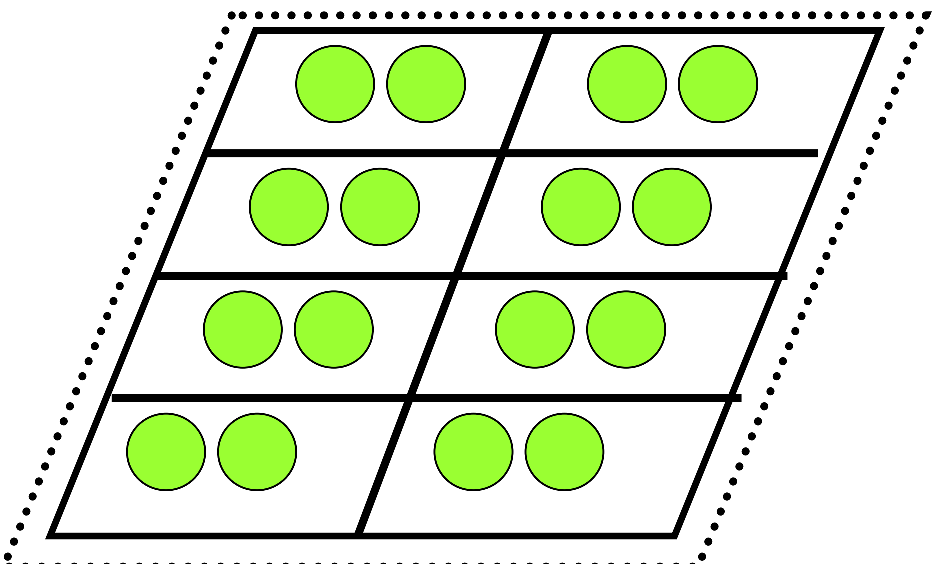
- **Calculated density of *Ulva***

  7.6 kg wet/m_f^2

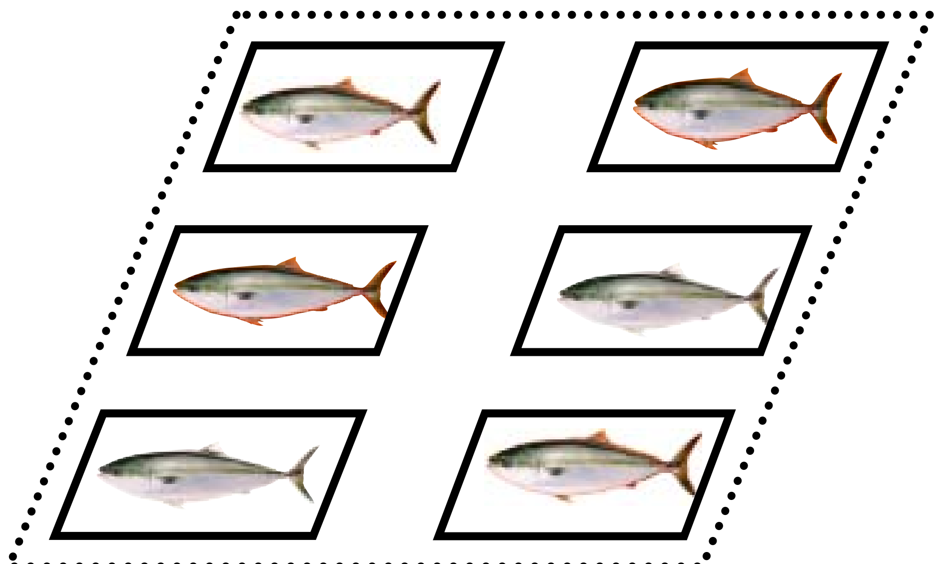
- **Efficient density of *Ulva***

  3.0 kg wet/m_f^2

S／F		**N uptake ratio to load** (%)
1.0	1.0×3.0 / 7.6	40
2.5	2.5×3.0 / 7.6	100



Area of ***U.pertusa***：**S**



Area of ***S.quinqueradiata***：**F**

Area ratio of cultured *U.pinnatifida* to fish and N uptake ratio to load

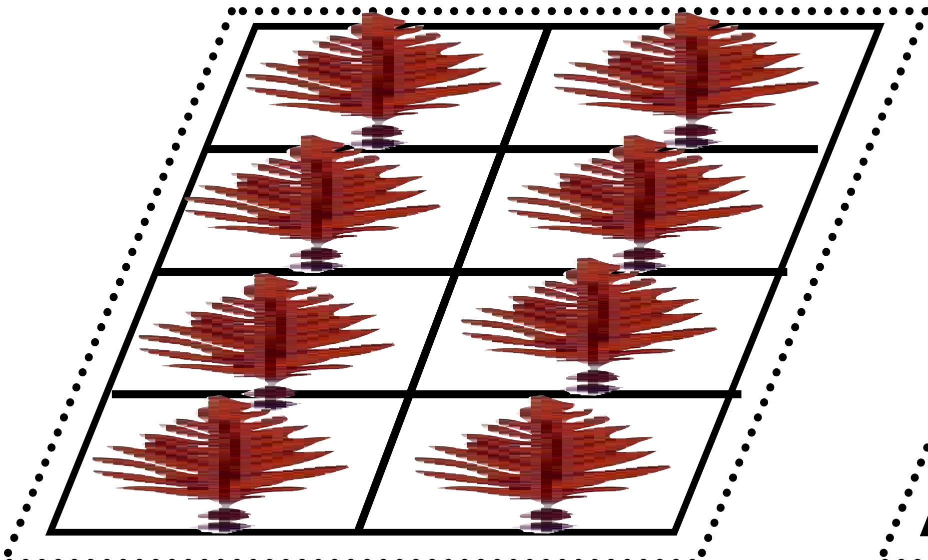
●**Calculated density of *Undaria***

41 kg wet/m_f^2

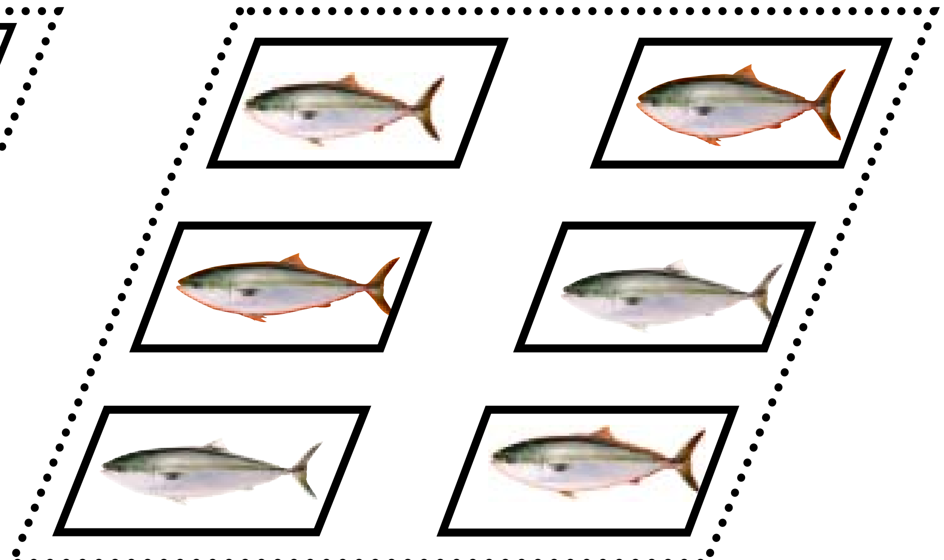
●**Efficient density of *Undaria***

65 kg wet/m_f^2

S／F		**N uptake ratio to load** (%)
0.6	0.6×65 / 41	100
1.0	1.0×65 / 41	160



Area of ***U.pinnatifida***: S



Area of ***S.quinqueradiata*** : F

Area ratio of cultured *L.japonica* to fish and N uptake ratio to load

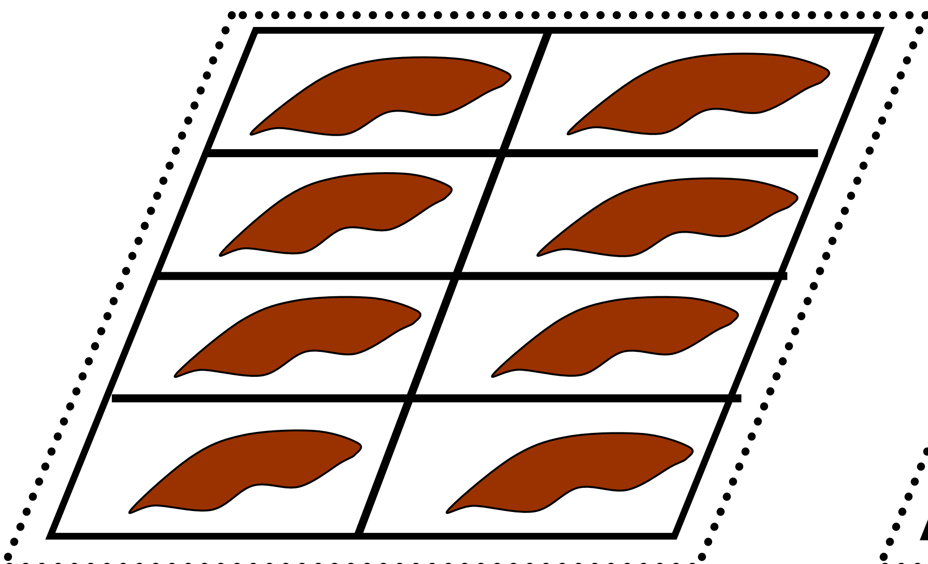
● **Calculated density of *Laminaria***

103 kg wet/m_f^2

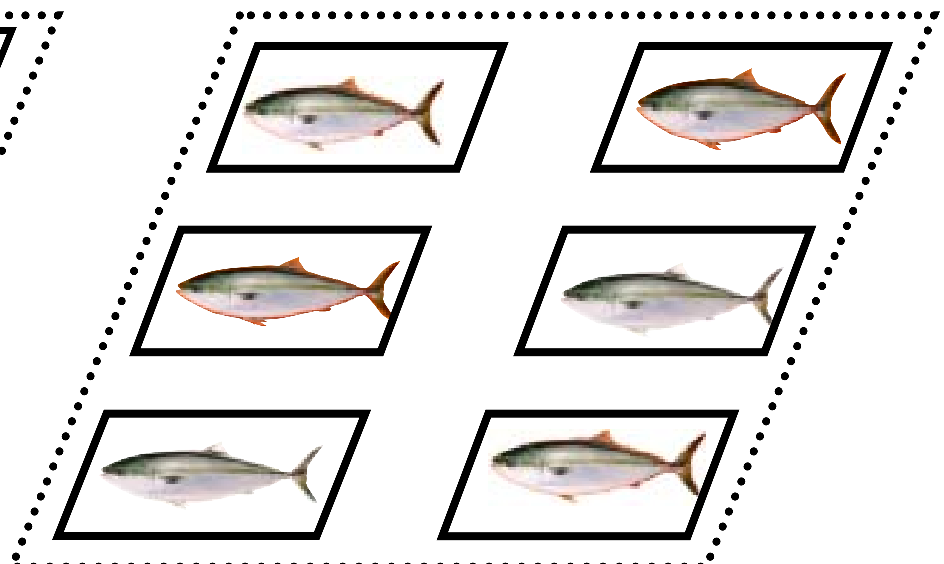
● **Efficient density of *Laminaria***

73 kg wet/m_f^2

S／F		N uptake ratio to load (%)
1.0	1.0×73 / 103	70
1.4	1.4×73 / 103	100



Area of ***L.japonnica*** **: S**



Area of ***S.quinqueradiata*** **: F**

Table 8. Comparison between *L.japonica, U.pertusa* and *U.pinnatifida* to DO consumption rate of *S.quinqueradiata*, DO production rate of seaweed, body weight and density of *S.quinqueradiata*, amount of seaweed to a fish and density of seaweed in fish farm

Items	Unit	*L.japonica*	*U.pertusa*	*U.pinnatifida*
Water Temperature	℃	16 ～ 23	18 ～ 28	12 ～ 20
Body weight of *S.quinqueradiata*	kg	1.6 ～ 2.0	2.6 ～ 4.0	1.5 ～ 1.8
Density of *S.quinqueradiata*	kg / m^3	4.8 ± 0.05	4.1 ± 0.15	7.2 ± 2.3
DO consumption rate of *S.quinqueradiata*	$mg\ O_2$ / a fish / h	700 ± 130	1380 ± 130	540 ± 100
DO production rate of seaweed	$mg\ O_2$ / g wet / h	0.61 ± 0.11	4.4 ± 1.3	0.66 ± 0.14
Amount of seaweed to a fish	g wet / a fish	1140 ± 26	340 ± 99	830 ± 57
Density of seaweed in fish farm	$kg\ wet / m^3$	5.4 ± 0.18	1.3 ± 0.34	5.9 ± 2.2

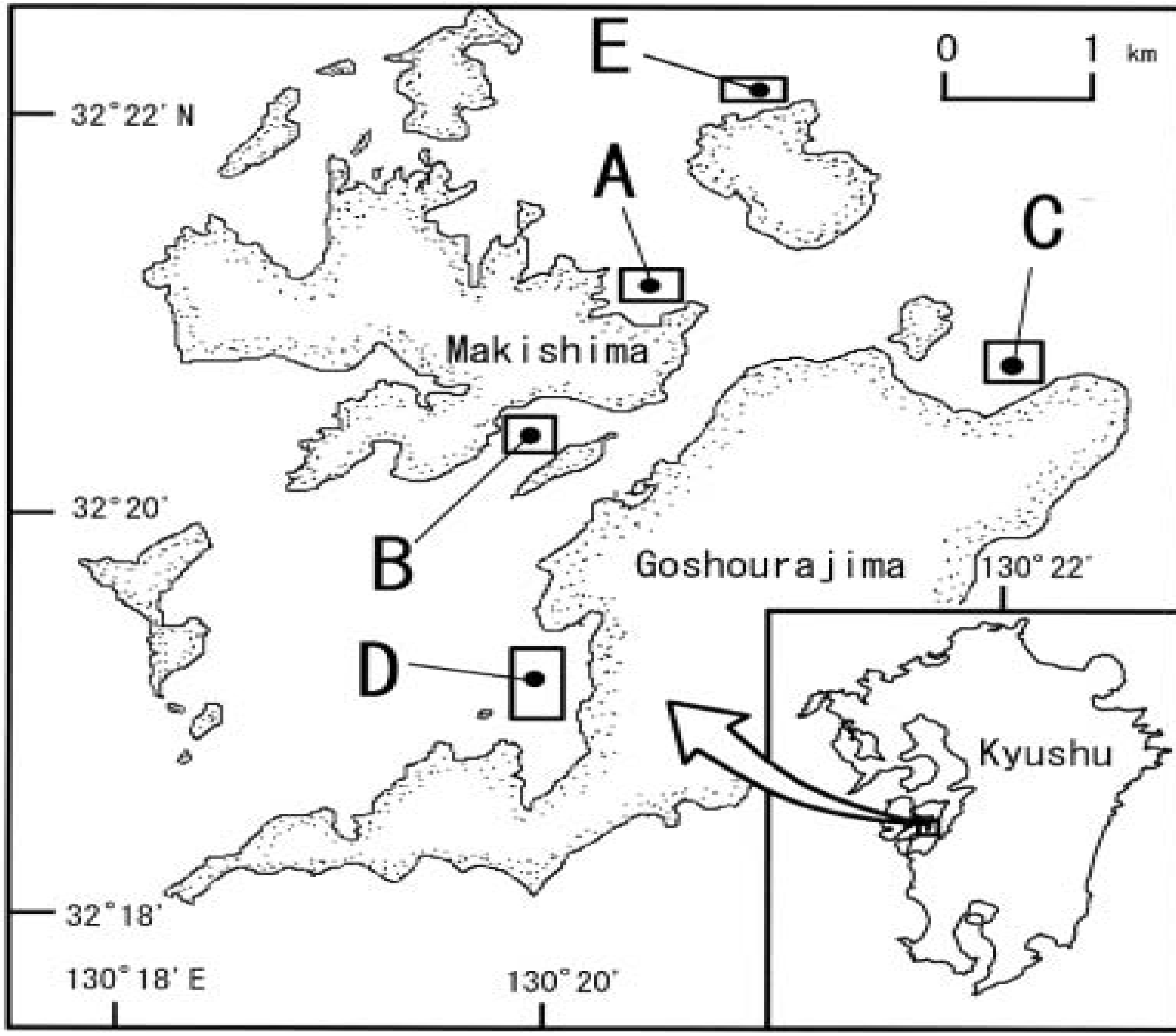
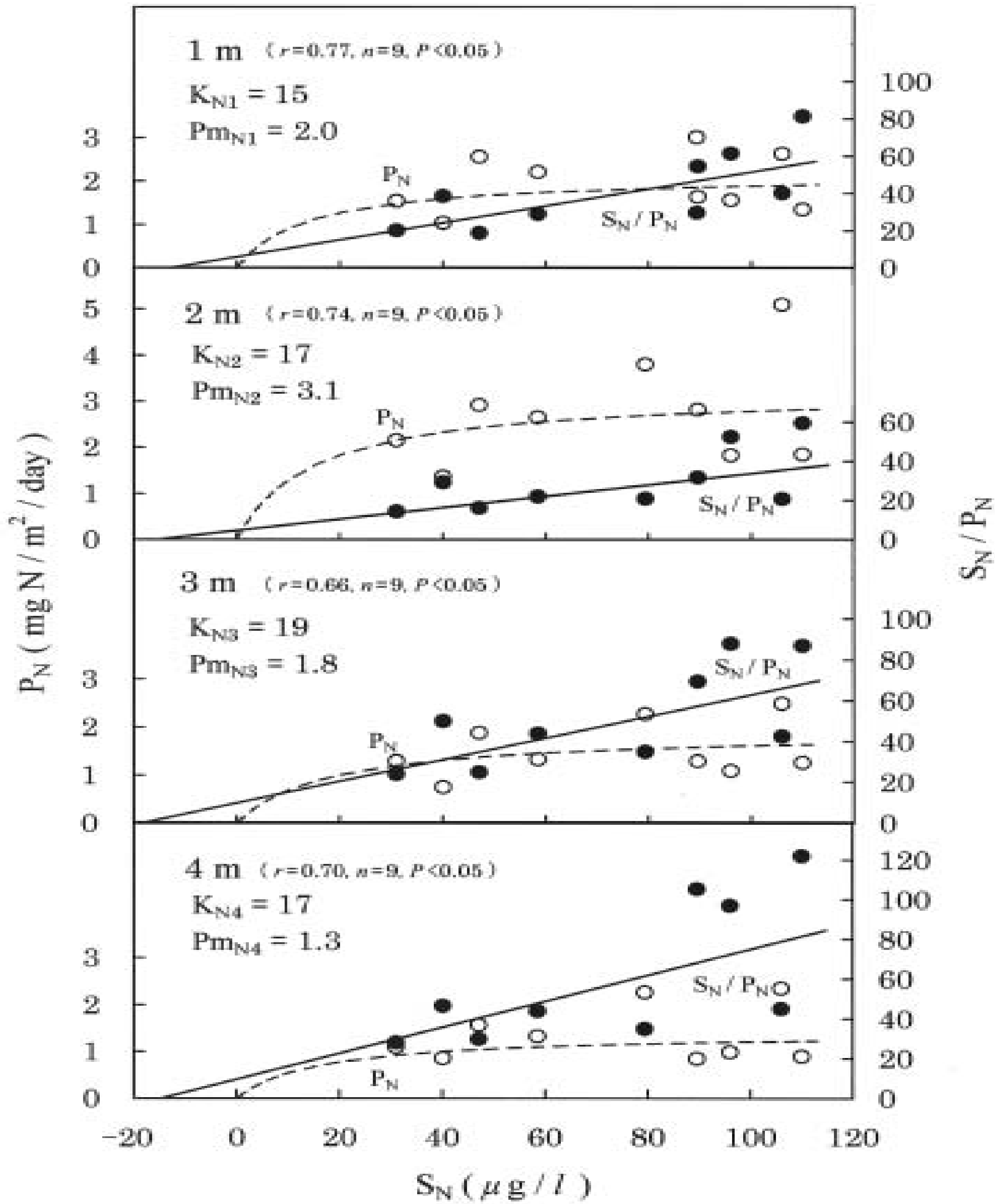
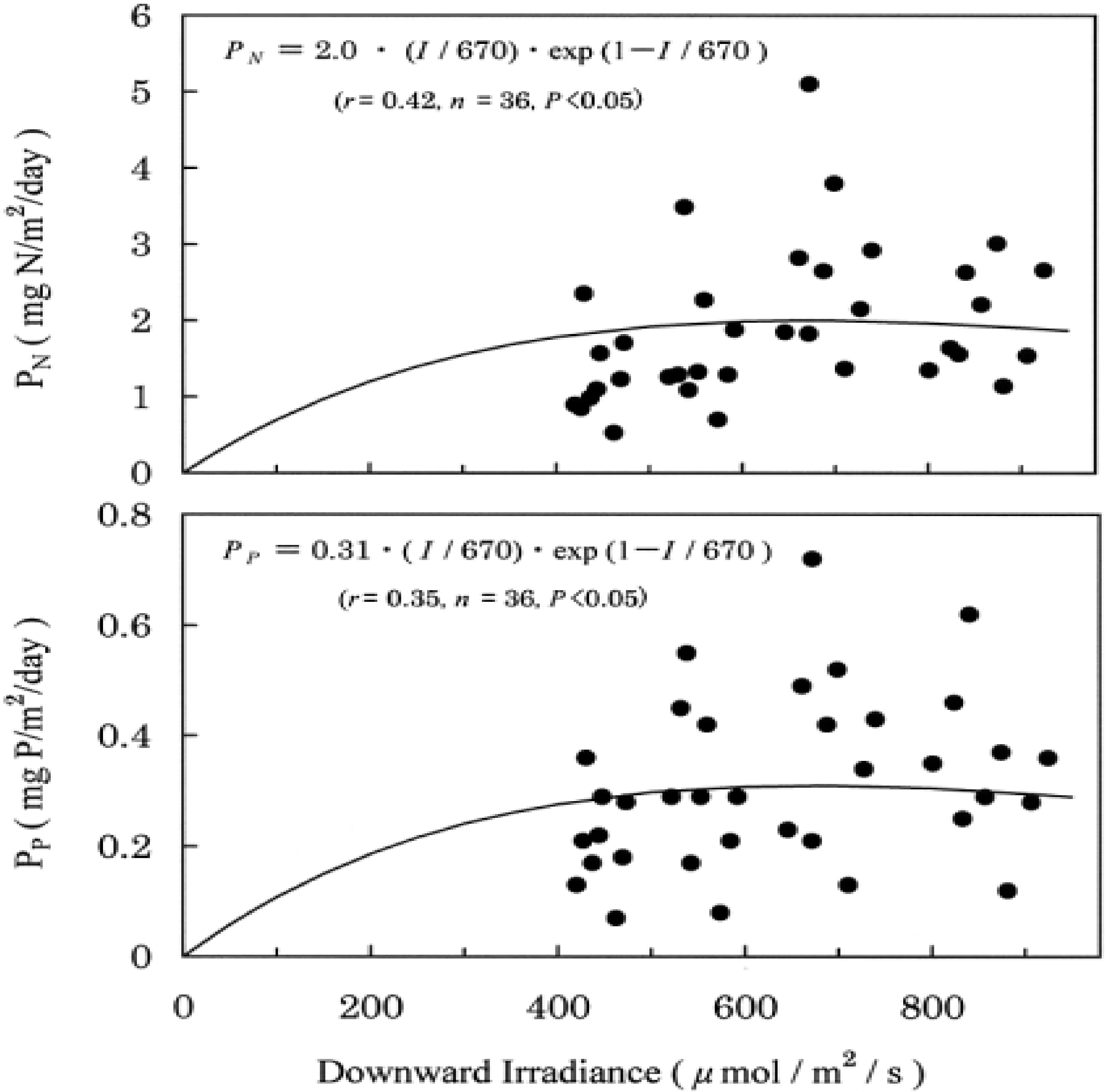


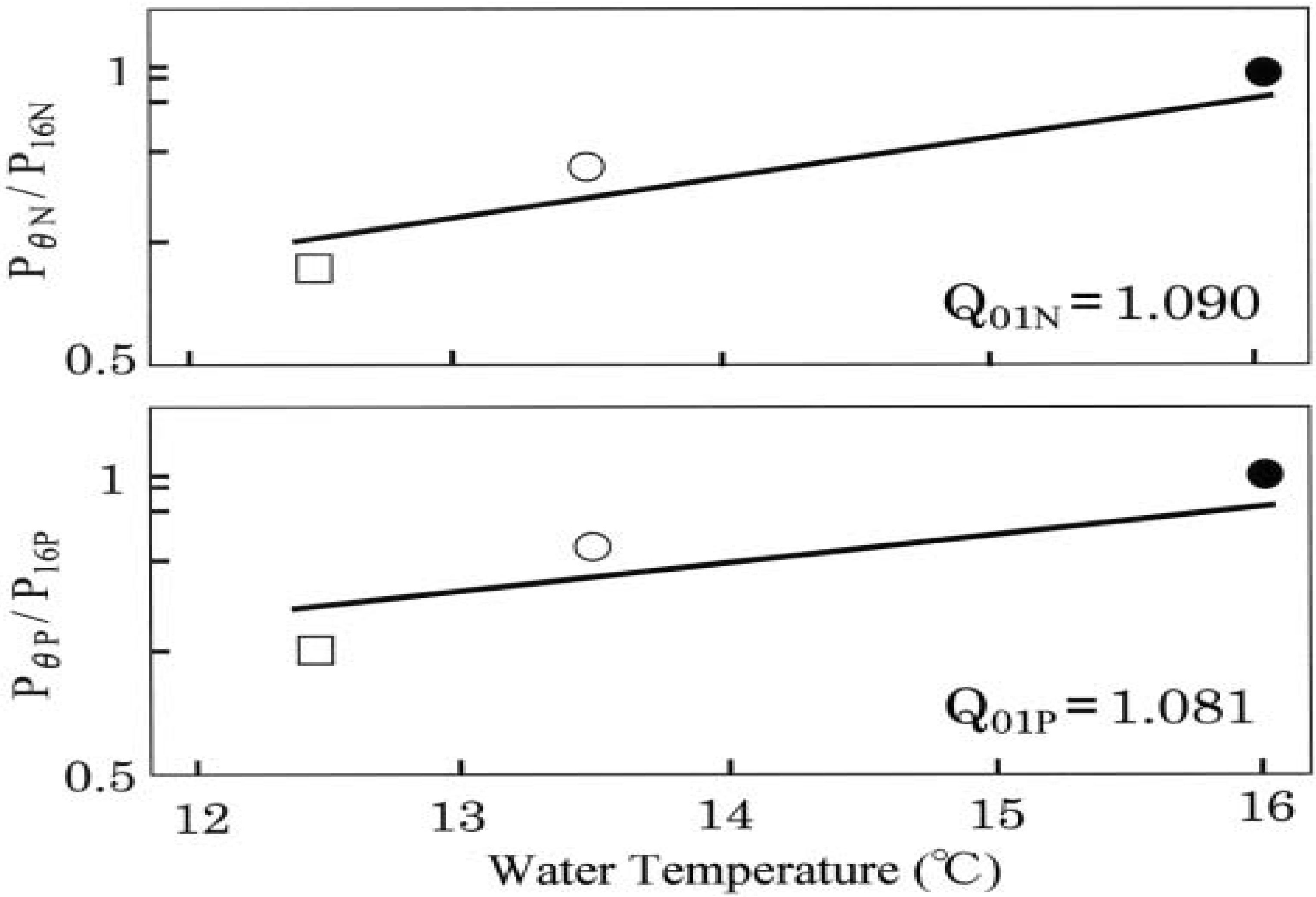
Fig.1. Map showing the test stations (A~E) at Goshoura coastal fish farms in the Yatushiro Sea.



1 m (r=0.77, n=9, P<0.05)
K N1 = 15
Pm N1 = 2.0
2 m (r=0.74, n=9, P<0.05)
K N2 = 17
Pm N2 = 3.1
3 m (r=0.66, n=9, P<0.05)
K N3 = 19
Pm N3 = 1.8
4 m (r=0.70, n=9, P<0.05)
K N4 = 17
Pm N4 = 1.3
P N
S N / P N
P N (mg N / m2 / day)
S N (μg / l)

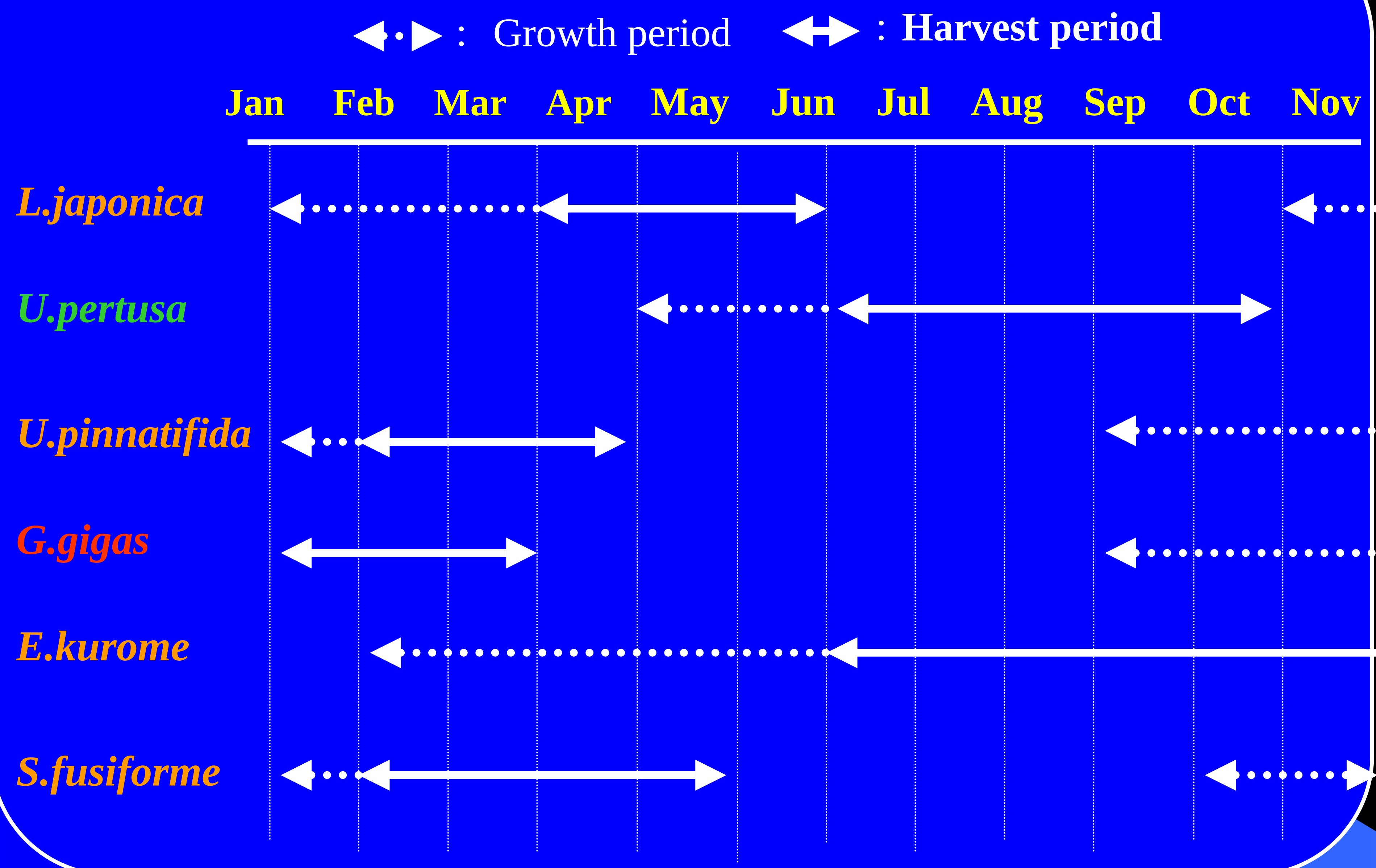


$P_N = 2.0 \cdot (I / 670) \cdot \exp(1 - I / 670)$
($r = 0.42$, $n = 36$, $P < 0.05$)
P_N (mg N/m^2/day)
0
1
2
3
4
5
6
$P_P = 0.31 \cdot (I / 670) \cdot \exp(1 - I / 670)$
($r = 0.35$, $n = 36$, $P < 0.05$)
P_P (mg P/m^2/day)
0
0.2
0.4
0.6
0.8
0
200
400
600
800
Downward Irradiance (μ mol / m^2 / s)



1
0.5
$P_{\theta N} / P_{16N}$
$Q_{01N} = 1.090$
1
0.5
$P_{\theta P} / P_{16P}$
$Q_{01P} = 1.081$
12
13
14
15
16
Water Temperature (℃)

Calendar of seaweed cultivation



Cultivation method of *U.pertusa* by square cage

DO production and consumption rate per chl.a of seaweed

① DO production rate ($P'c$, mg O_2 / mg chl.a / h)

$$P'c = P' / \text{chl.a}$$

② DO consumption rate ($R'c$, mg O_2 / mg chl.a / h)

$$R'c = R' / \text{chl.a}$$

③ Nutrient : Michaelis-Menten (***S*** , **μg / *l***)

$$P'c = P'cm \cdot S / (K + S)$$

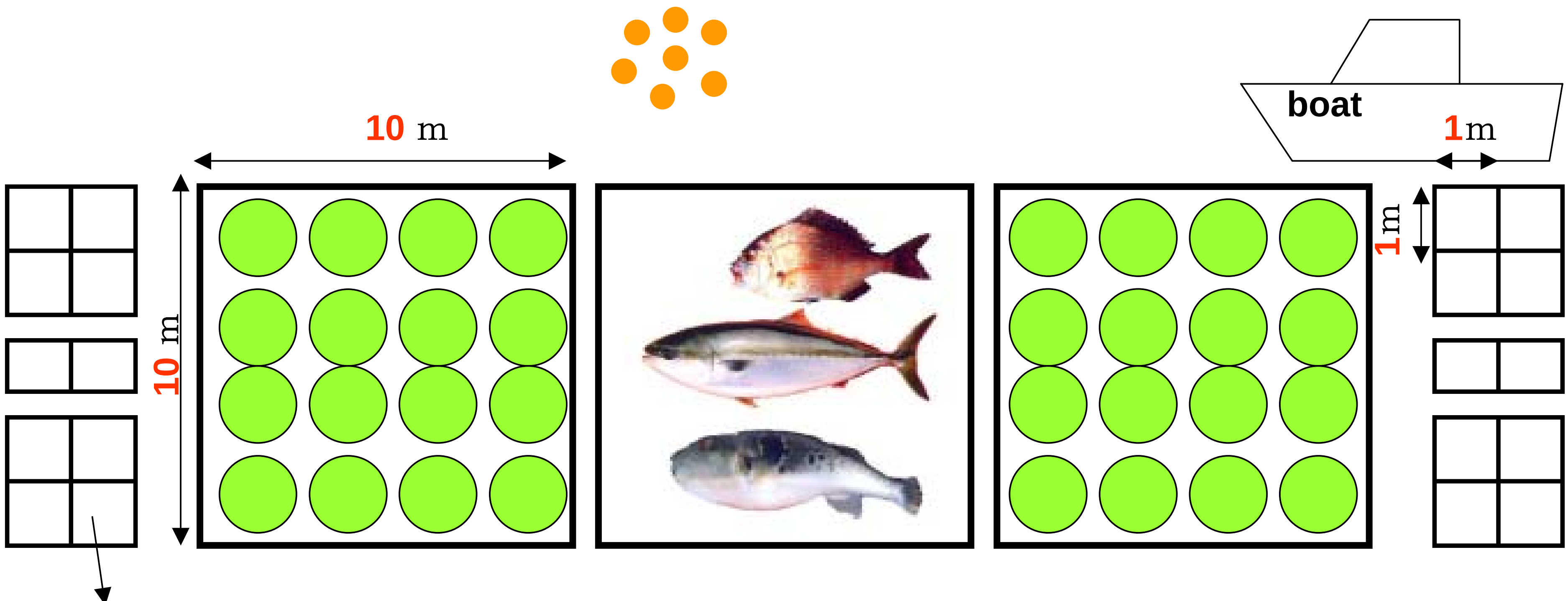
P' : **DO production rate** (mg O_2 / l / h)

R' : **DO consumption rate** (mg O_2 / l / h)

chl.a : Amount of chl.a of seaweed (mg chl.a / l)

K : **Michaelis-Menten constant** (μg / l)

Eco³-polyculture of fish, seaweed and abalone



$$\frac{\textit{U.pertusa}\ \ 7.6\ \ \mathbf{kg/\ m_f^2} \times 10\ \mathbf{m_f} \times 10\ \mathbf{m_f} \times 2}{\mathbf{cage}} = 95\ \ \mathbf{k}$$

conversion factor of abalone 16

95 **kg abalone** ／ 0.07 kg/indiv. = 1350 indiv.