Effects of culture density on the growth and fecal production of the oyster *Crassostrea gigas*

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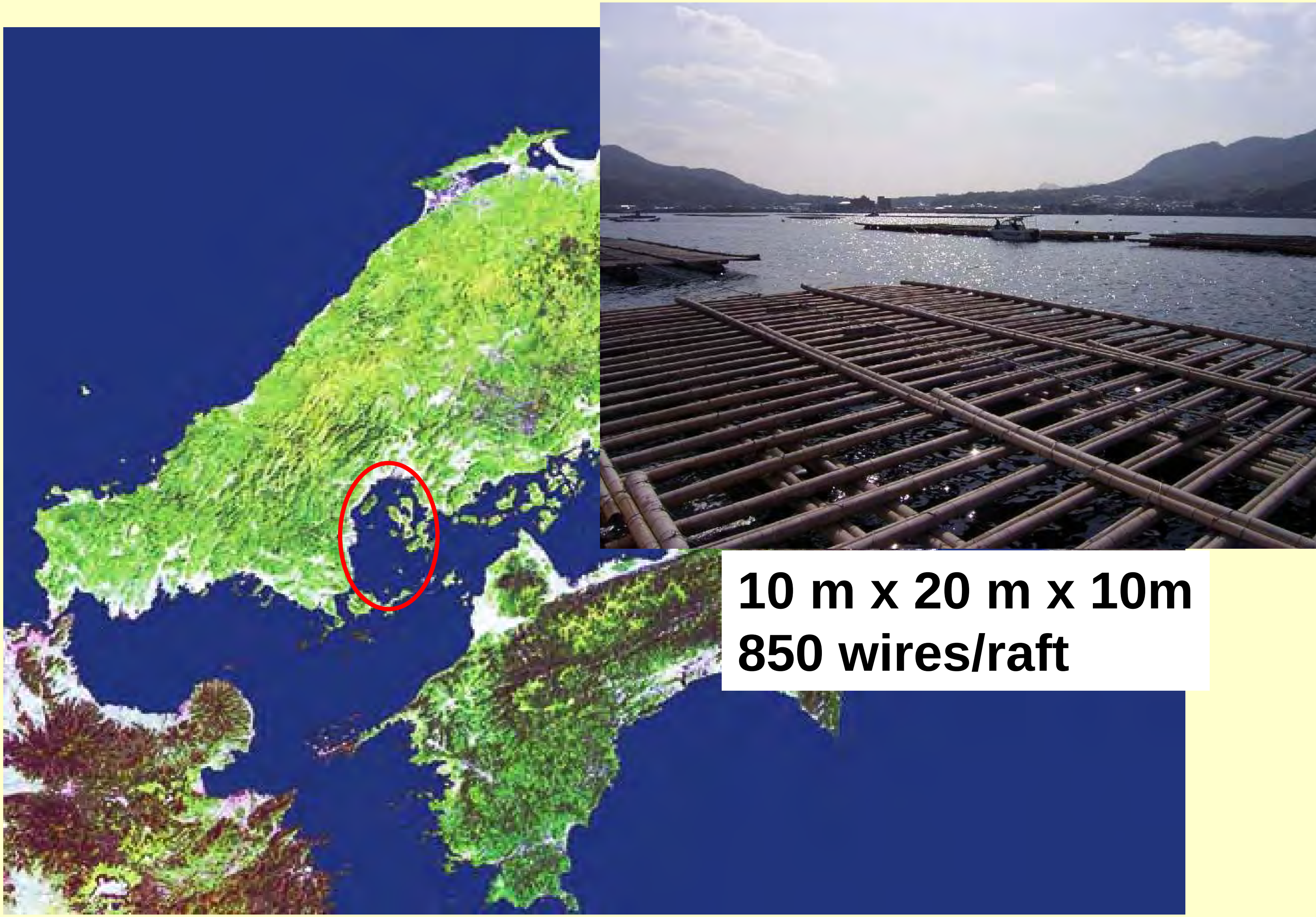
Location of Hiroshima Bay

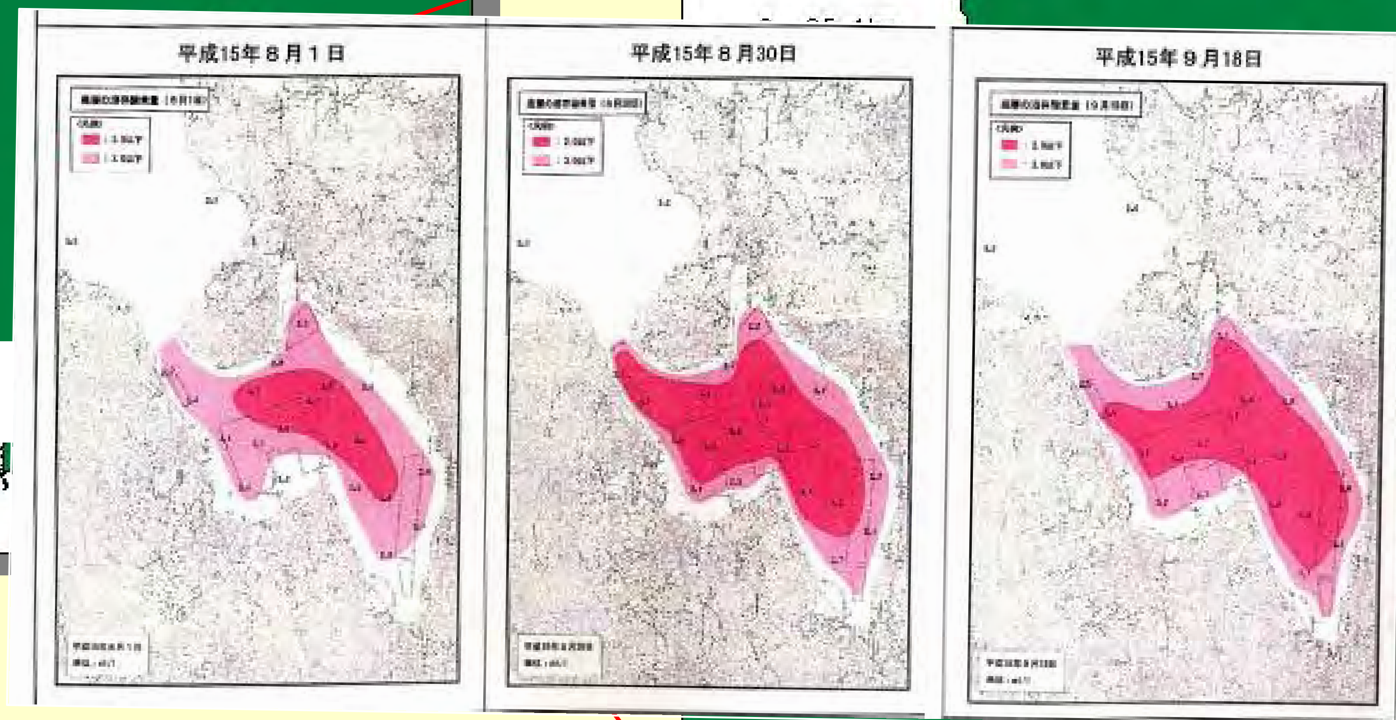


10 m x 20 m x 10m
850 wires/raft

Etajima Bay

DO <2.0 mL/L (2.9 mg/L)

DO <3.0 mL/L (4.3 mg/L)



2003/8/1 2003/8/30 2003/9/18

Hiroshima Pref. (2004)

Measures by Hiroshima Pref.

1999年(平成11年)3月18日 木曜日 朝刊

養殖いかだ数の1割削減で県
新しい標識設置へ
広島カキ緊急対策連絡会議

広島カキ緊急対策連絡会議（議長、横山巌・県水産漁港課長）が十七日、広島市中区の水産会館で開かれ、一九九九年に養殖いかだ数を一割削減することに向けて、県からいかだに新たな標識を付けるなどの具体的方法が説明された。

会議は、一月二十六日の前回会議でいかだ数の一割減や、約五年をめどに養殖規模を三割削減する改善計画が決まったのを受けて開かれた。

県によると、削減後のいかだ台数と同じ一万三千四十四枚のいかだ番号を記した標識を用意し、六月ごろまでにいかだに取り付けてもらう。この後、県の指導を受けて漁協の内部組織である漁場管理委員会が調査し、標識のないいかだの撤去を指導するとしている。

一方、県漁連のカキ問題検討委員会は、養殖業者らで小委員会をつくって四月初旬に初会合を開き、計画の実現を目指す。県、県漁連、小委員会、漁業共済組合の代表が地区ごとに説明会を開く。

会議では、漁業者から「いかだ数を減らせば赤潮は出なくなるといえるのか」「避難漁場を確保してほしい」などの意見もあったが、大筋で県の案を了承した。

今秋まで

いかだ1割削減
連絡会議 カキ生産の改善案提示

広島カキ緊急対策連絡会議（議長＝横山巌・県水産漁港課長）が二十六日、広島市中区の県水産会館で開かれた。カキの生産を安定させるため、いかだ数の削減などを盛り込んだ計画案が出された。

計画案では、九九年秋までに、現在一万四千五百台のいかだを一割削減する▽将来的には、いかだの「垂下連」を短くするなどして、潮の流れを改善し、いかだ数で三割減の効果を狙う▽カキの打ち終わり時期を四月末に設定する、などとしている。

また、漁場の管理体制を組織化することや、赤潮が発生したときの危機管理体制が協議された。

会議に出席した漁協組合長からは、いかだ数の削減について「業者のとりまとめが困難」「一律削減せず、各漁協の事情を考慮すべきだ」など不安の声が上がった。

- **10%** reduction of culture rafts by autumn of 1999
- **30%** reduction for 5 years by 2004

Present status in Apr. 2006

- ca. 11,300: 12% of 15,000 rafts reduced

“Guideline for Improving Oyster Production”

- Shortening of wire
- Reduction in number of collectors

Scientific corroboration

Analytical techniques applied in this study

- **Oyster Physiology Model**

- To estimate the water exchange rate between inside and outside of a raft to meet the observed oyster growth, giving observed water quality and prey plankton density. Then, using the estimated water exchange rate, growth of oyster and fecal production were estimated.

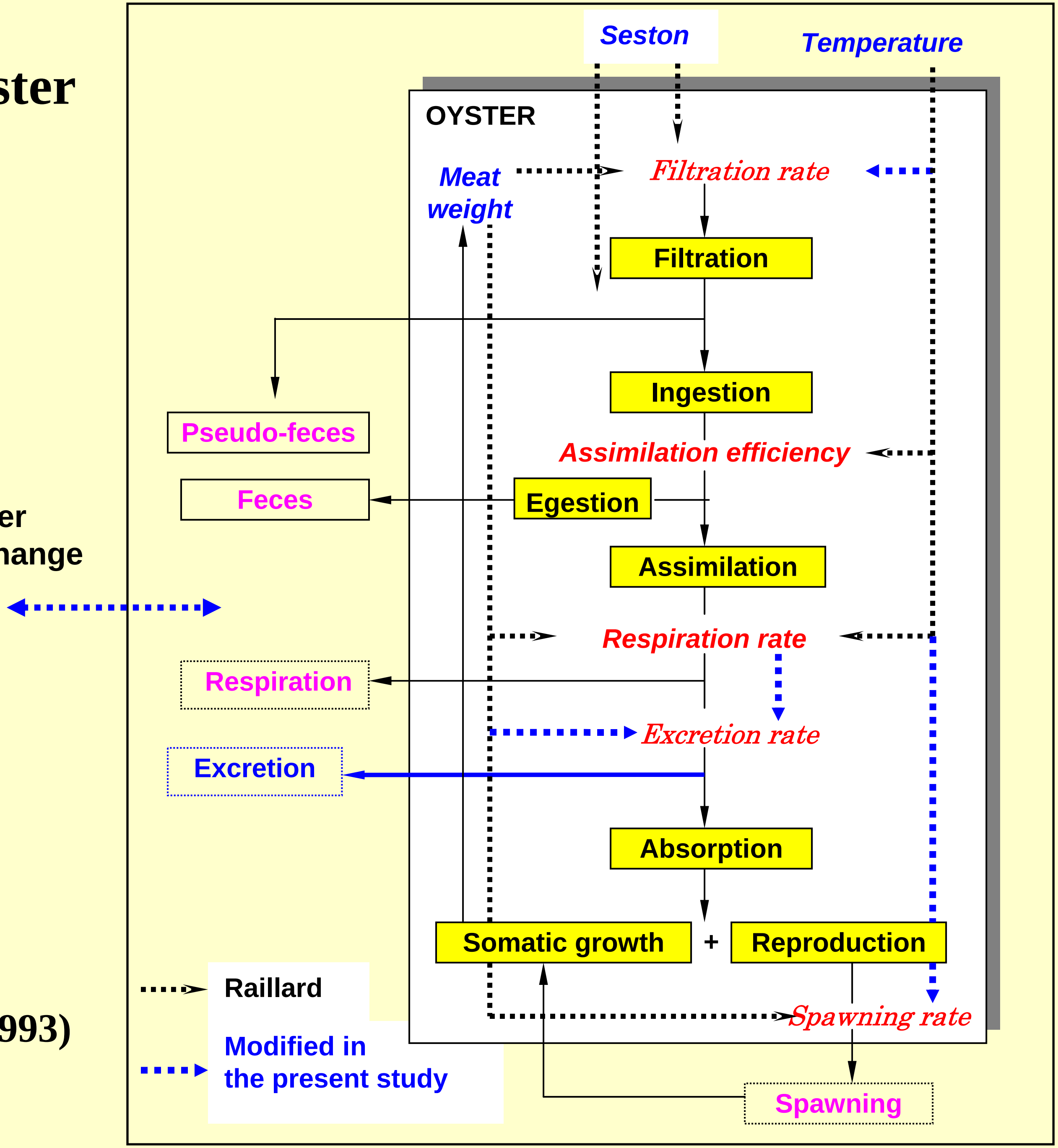
- **Ecosystem Model**

- To estimate the optimum culture density at bay-scale in terms of the balance of individual oyster weight and total crop.

-To evaluate the effects of fecal production on the DO concentration in the bottom water.

Framework of the oyster physiology model

Water exchange



modified Raillard *et al.* (1993)

Equations

$$V\frac{dC}{dt} = Q(C_{out} - C_{in}) - FC$$

V: volume of a raft (m^3)
Q: water exchange rate between inside and outside of a raft (m^3 day^{-1})
C_{out}: particulate matter concentration in the outside of raft (mg m^{-3})
C_{in}: particulate matter concentration in the inside of raft
F: filtering rate per raft (m^3 day^{-1})

$$Q = Q_0 \times 10^{-\alpha\frac{N}{200}}$$

Q_0: water exchange rate with no raft 10^8 m^3 day^{-1} （ref. Ueshima and Hayakawa，1982）
α: decreasing coef. of water exchange rate（0.47）
N: number of wires (std. 850 wires/raft=4.25 wires/m^2)

☐ Oyster

Filtration

$$F = Fmax \times e^{\{kf \times \min(0, T_{SES} - SES)\}} \times Wd^{0.4} \times P_T$$

$$P_T = 0.5943 \times \ln(T) - 0.9958$$

Fmax : Maximum filtration rate
kf : Filtration exponent for clogging
Tses : Clogging threshold
SES : Seston concentration
Wd : Dry weight
P_T : Temperature coefficient

（Songsangjinda *et al*., 1998）

Ingestion

（Kusuki, 1977）

$$I = \gamma \times F\,(PHY + DET)$$

γ : proportion of particulate matter ingested

Pseudofeces production

（Lee and Hoshika, 2000）

$$PF = (1 - \gamma)\,I$$

γ : Ingested proportion in filtered particles

Fecal production

$$Fe = (1 - \delta)\, I$$

δ : Assimilation rate

(Powell *et al.*, 1992)

Excretion

$$Ex_P = 0.08 \times \delta \times I_P$$

I_P : Ingested phosphorus
Ex_P : Excreted phosphorus

(Richard *et al.*, 1989)

Reproduction

$$Re = Sfg \times \varepsilon$$

$27℃ \leqq T$; $\varepsilon = 0.8$

$23℃ \leqq T < 27℃$; $\varepsilon = 0.16T - 3.2$

$T < 23℃$; $\varepsilon = 0$

Sfg : Assimilated energy
ε : Reprodution efficiency

(Kobayashi *et al.*, 1997)

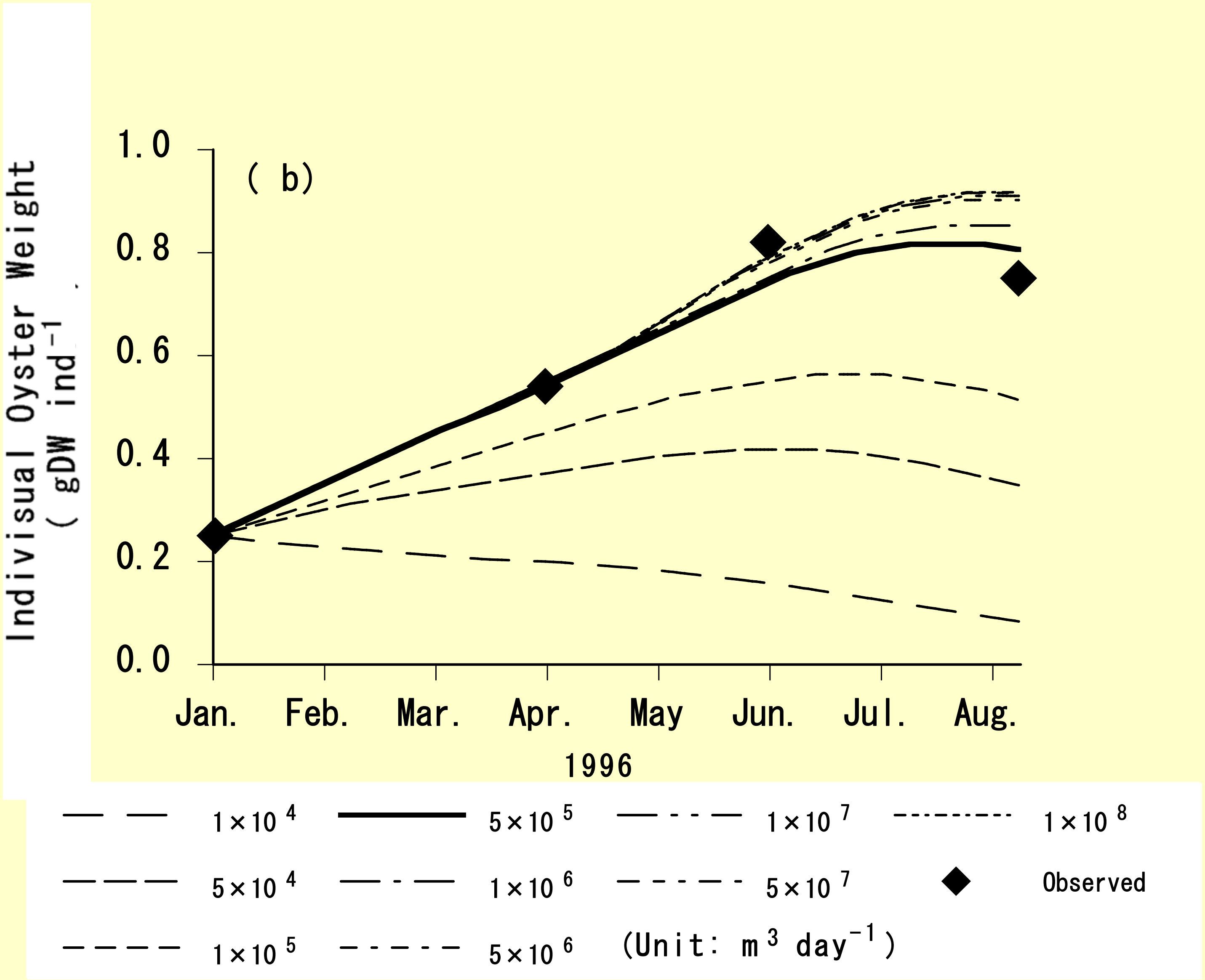
Equations and parameters

Parameter	Definition	Equation
SES	Total seston	$SES_o + SES_m$
F	Individual filtration rate	$F_{max} \cdot e^{(kf \cdot \min(0, T_{SES} - SES))} \cdot W^{bf} \cdot P_T$
P_T	Pumping proportion	$0.5943 \cdot \ln(T) - 0.9958$
Q_o, Q_m	Filtered organic and mineral seston	$SES_o \cdot F$, $SES_m \cdot F$
$PF_{[o,m]}$	Proportional rejected as pseudo-feces (either as organic or mineral seston)	$PFX_{[o,m]} \cdot (1 - e^{(kp_1[o,m] \cdot \min(0, c1 - C_t))}) + (1 - PFX_{[o,m]}) \cdot (1 - e^{(Kp_2 \cdot \min(0, c2 - C_t))})$
C_t	Standardized oyster consumption	$\frac{F \cdot SES}{W^{bf}}$
$I_{[o,m]}$	Ingestion of organic or mineral seston	$(1 - PF_{[o,m]}) \cdot Q_{[o,m]}$
$Eg_{[o,m]}$	Egested organic and mineral seston	$(1 - Ass_{[o,m]}) \cdot I_{[o,m]}$
A_o	Assimilation of organic seston	$Ass_o \cdot I_o$
EA_o	Assimilated energy from organic seston	$A_o \cdot C_c \cdot E_c$
oxy	Specific oxygen consumption	$art \cdot T + ar0$
R	Individual oyster respiration	$oxy \cdot W^{br}$
ER	Energy loss by oyster respiration	$R \cdot E_R$
$DNexc$	Specific dissolved nitrogen excretion	$234 \left(\frac{oxy}{cg}\right)^{0.63} \cdot N_{AW}$
$EXdn$	Individual dissolved nitrogen excretion	$DNexc \cdot W \cdot 24$
$EEXdn$	Energy loss by dissolved nitrogen excretion	$EXdn \cdot E_N$
Sfg	Scope for growth	$EA_o - ER - EEXdn$
S	Total energy loss by individual oyster spawning	$as \cdot W^{bs}$
ES	Daily loss of energy by spawning	$\frac{S}{ds}$
$\frac{dW_i}{dt}$	Daily energy storage	$Sfg - ES$; during spawning season Sfg; pre-and post-spawning season
W	Oyster dry weight	$DW \cdot \frac{dW}{dt}$

Equations and parameters (cont'd)

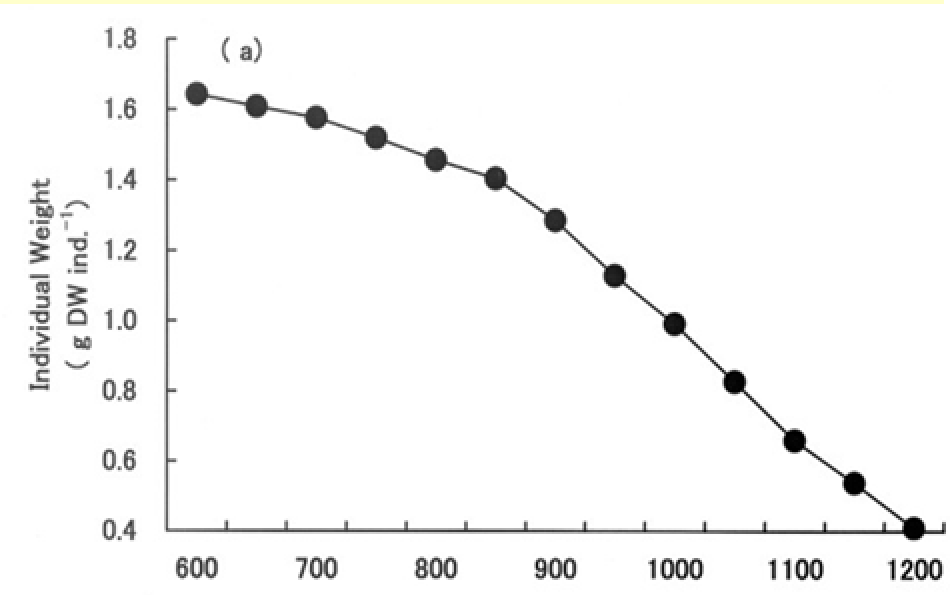
Parameter	Definition	Value
F_{max}	Maximum filtration rate	48 l d^{-1} g^{-1} DW
kf	Filtration exponent for clogging	0.07
T_{SES}	Clogging threshold	200 mg l^{-1}
bf	Allometric exponent of filtration	0.4
PFX_o, PFX_m	Pseudo-feces production step of organic and mineral seston	0.4, 0.8
kp_{1o}, kp_{1m}	First step pseudo-feces exponents of organic and mineral seston	0.15, 0.10
kp_2	First step pseudo-feces exponents	0.01
c1,c2	Pseudo-feces thresholds	120, 2400 mg DW d^{-1} g^{-1} DW
$Ass_{[o,m]}$	Assimilation efficiency for organic and mineral seston	0.746, 0
E_C	Energy conversion of organic carbon	47.7 J mg^{-1} C
art	Slope of respiration curve vs temperature	0.768 ml O_2 d^{-1} g^{-1} DW $°C^{-1}$
ar 0	Intercept of respiration curve vs temperature	-0.528 ml O_2 d^{-1} g^{-1}DW
br	Allometric exponent of respiration	0.7
cg	Avogado's number	22.4 l $mole^{-1}$
N_{AW}	Atomic weight of Nitrogen	14
E_R	Energy conversion of oxygen	20.33 J ml^{-1} O_2
E_N	Energy conversion of nitrogen	19.4 J mg^{-1} N
ds	Spawning period	141
bs	Proportional constant of spawning	0.57 x 10^{-2}
as	Allometric exponent of spawning	1.28
DW	Dry weight conversion of energy	0.05 g DW kJ^{-1}

Water exchange rate and individual oyster weight



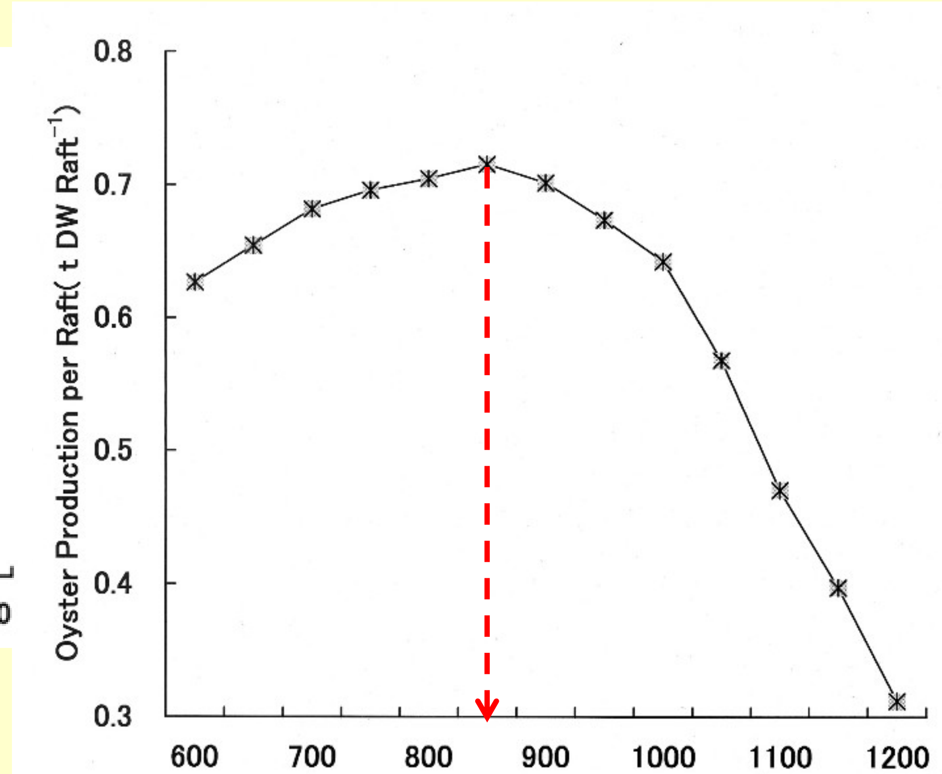
Oyster production

Individual weight



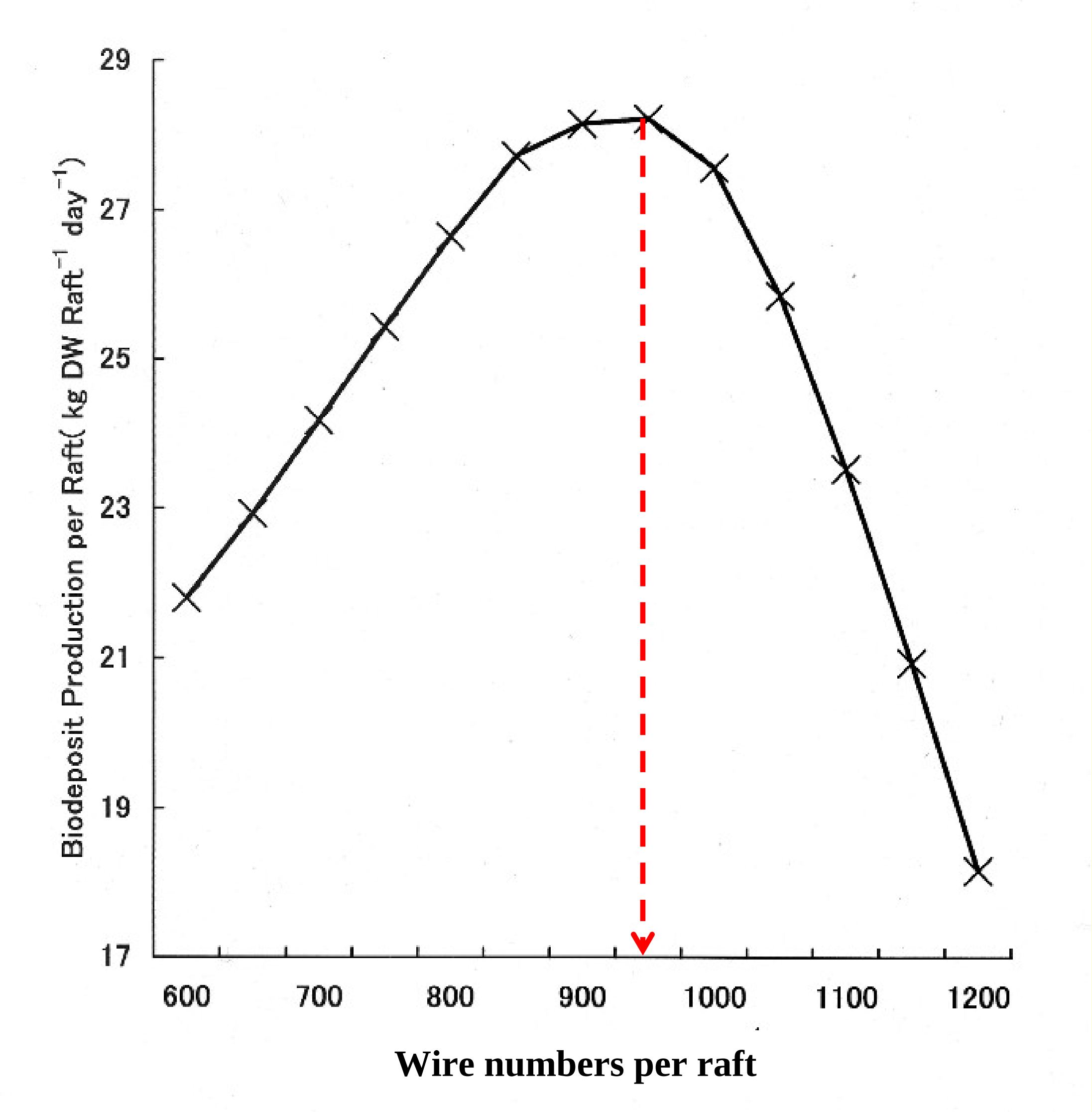
Wire numbers per raft

Weight per raft

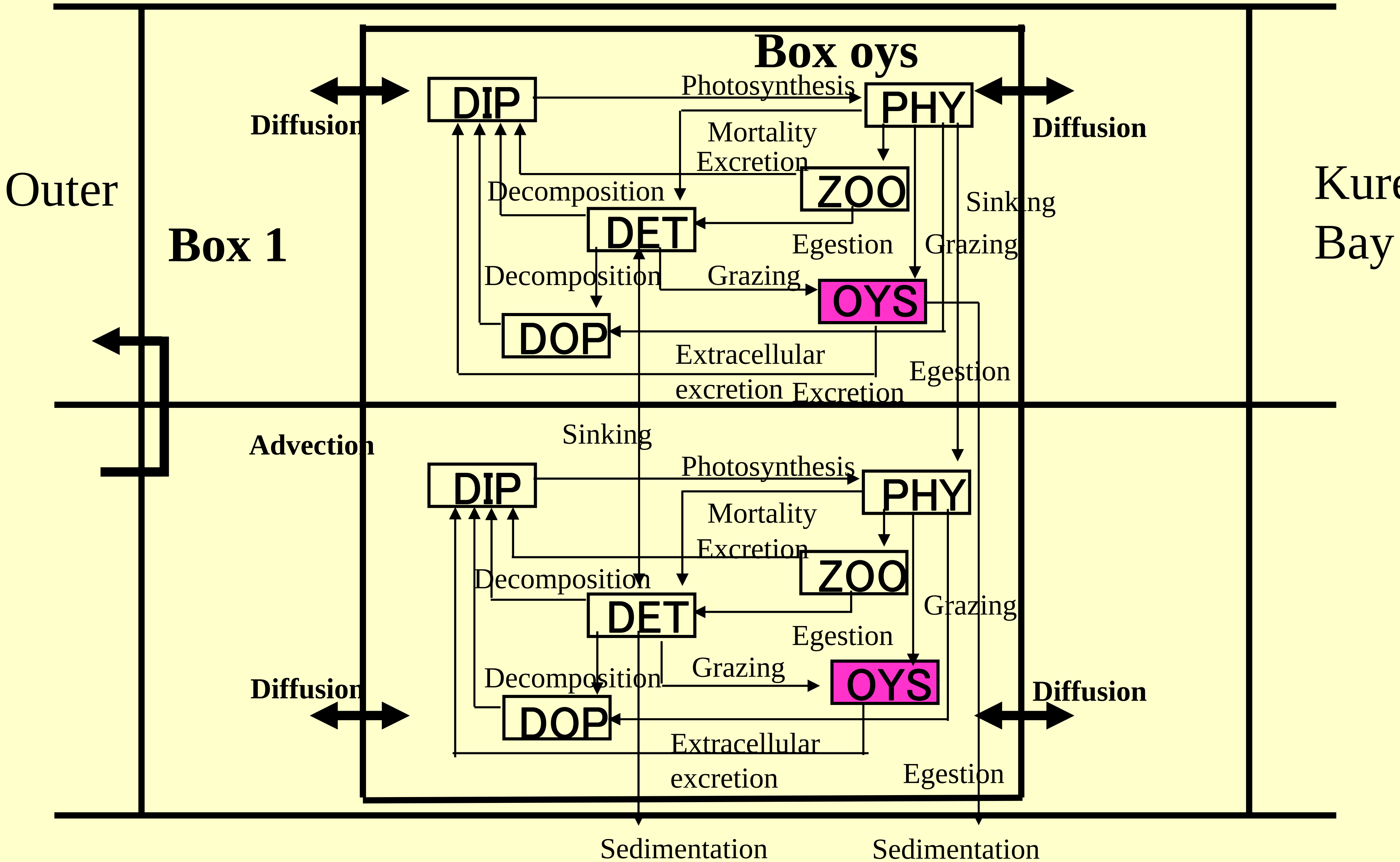


Wire numbers per raft

Egestion and biodeposit production



Framework of the ecosystem model



Mass balance equations

DIP

$$V_{1U}\frac{dDIP_{1U}}{dt}=DIP_{R1}+DIP_{P1}+OEX1_u$$
$$-V_{1U}\left(A_1PHY(P)_{1U}-B_2ZOO(P)_{1U}-C_1DET(P)_{1U}-D_1DOP_{1U}\right)$$
$$+V_{ADV}DIP_{1L}-(V_{ADV}+R_1+P_1+E_1)DIP_{1U}$$
$$-AH_{1U}\frac{KH_{1u}}{X_1}(DIP_{1u}-DIP_{2u})-AH_{KU}\frac{KH_{KU}}{X_K}(DIP_{1u}-DIP_{ku})-AV_1\frac{KV_1}{Z_1}(DIP_{1u}-DIP_{1L})$$

PHY

$$V_{1U}\frac{dPHY(P)_{1U}}{dt}=V_{1U}\left(A_1PHY(P)_{1U}-B_1ZOO(P)_{1U}-A_2A_1PHY(P)_{1U}-A_3PHY(P)_{1U}^2\right)-AV_1W_PPHY(P)_{1U}-PGR1_u$$
$$+V_{ADV}PHY(P)_{1L}-(V_{ADV}+R_1+P_1-E_1)PHY(P)_{1U}$$
$$-AH_{1U}\frac{KH_{1u}}{X_1}(PHY(P)_{1u}-PHY(P)_{2u})-AH_{KU}\frac{KH_{KU}}{X_K}(PHY(P)_{1u}-PHY(P)_{ku})-AV_1\frac{KV_1}{Z_1}(PHY(P)_{1u}-PHY(P)_{1L})$$

DET

$$V_{1U}\frac{dDET(P)}{dt}=DET(P)_{R1}+V_{1U}\left(B_4ZOO(P)_{1U}^2+B_3ZOO(P)_{1U}+A_3PHY(P)_{1U}^2-C_1DET(P)_{1U}-C_2DET(P)_{1U}\right)$$
$$-AV_1W_DDET(P)_{1U}-DGR1_u+V_{ADV}DET(P)_{1L}-(V_{ADV}+R_1+P_1-E_1)DET(P)_{1U}$$
$$-AH_{1U}\frac{KH_{1u}}{X_1}(DET(P)_{1u}-DET(P)_{2u})-AH_{KU}\frac{KH_{KU}}{X_K}(DET(P)_{1u}-DET(P)_{ku})-AV_1\frac{KV_1}{Z_1}(DET(P)_{1u}-DET(P)_{1L})$$

DOP

$$V_{1U}\frac{dDOP_{1U}}{dt}=DOP_{R1}+V_{1U}\left(A_1A_2PHY(P)_{1U}+C_2DET(P)_{1U}-D_1DOP_{1U}\right)$$
$$+V_{ADV}DOP_{1L}-(V_{ADV}+R_1+P_1-E_1)DOP_{1U}$$
$$-AH_{1U}\frac{KH_{1u}}{X_1}(DOP_{1u}-DOP_{2u})-AH_{KU}\frac{KH_{KU}}{X_K}(DOP_{1u}-DOP_{ku})-AV_1\frac{KV_1}{Z_1}(DOP_{1u}-DOP_{1L})$$

□ Phytoplankton

Growth

$$A_1 = V_{\max} \frac{DIP}{DIP + K_p} \times \exp(kT) \times \frac{I}{I_{opt}} \exp\left(1 - \frac{I}{I_{opt}}\right)$$

V_{max}	:	Maximum nutrient uptake rate (day^{-1})
K_p	:	Half-saturaration constant (mg/m^3)
k	:	Temperature dependent coefficient for photosynthesis (℃$^{-1}$)
T	:	Temperature (℃)
I_{opt}	:	Optimum light intensity (μE m^{-2} day^{-1})
I	:	Average light intensity of water column (μE m^{-2} day^{-1})

Mortality

$$A_3 = M_{po} \exp(k_{MP} T)$$

□ Zooplankton

Grazing

$$B_1 = \gamma \{ 1 - \exp \lambda \left(PHY^* - PHY \right) \}$$

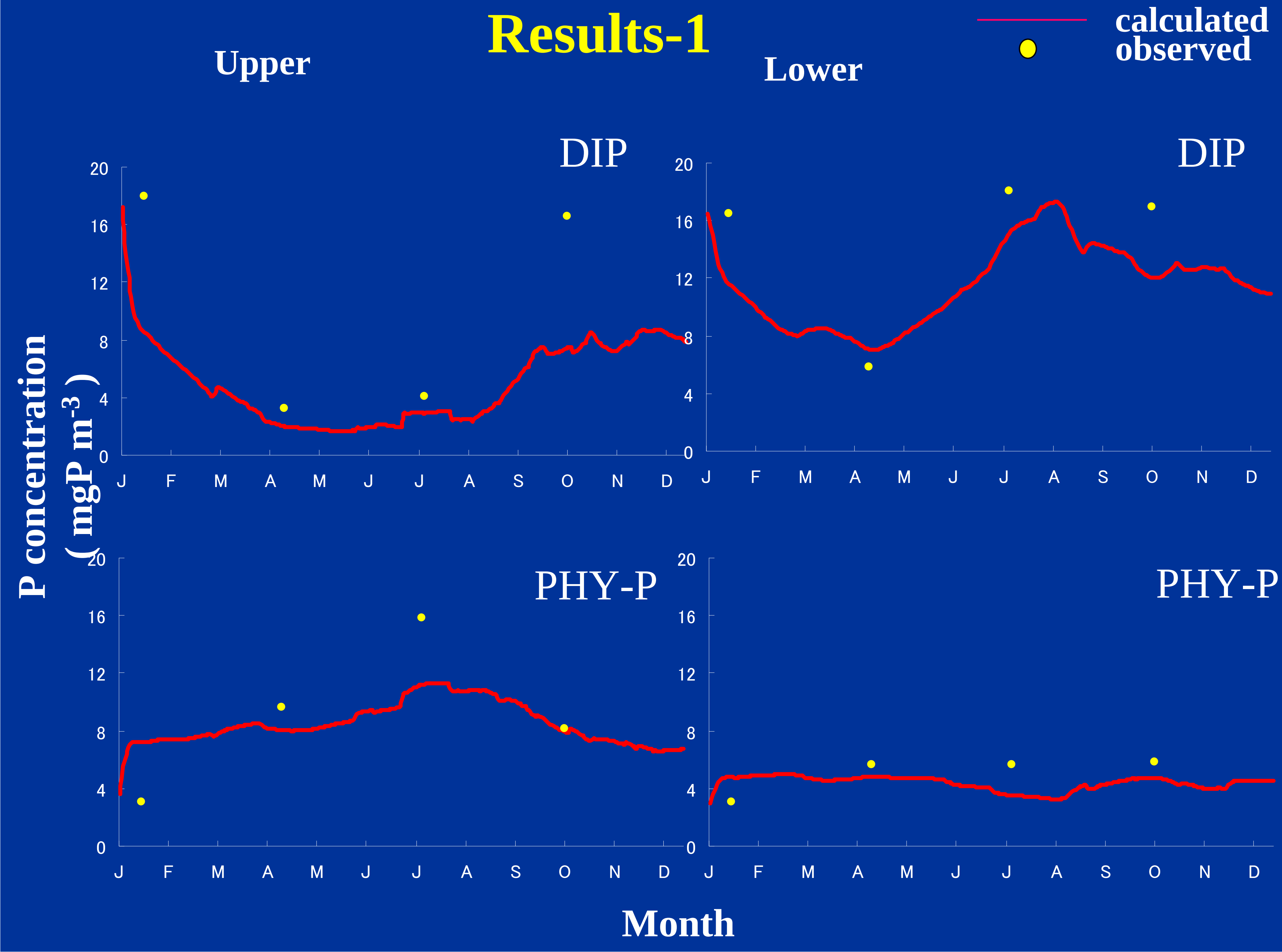
$$\gamma = G_{\max} \exp(k_g T)$$

G_{max} : Maximum grazing rate (day^{-1})
λ : Ivlev constant (m^3 mgP^{-1})
PHY* : Threshold feed concentration at grazing rate becomes zero (mg m^{-3})
k_g : Temperature dependent coefficient for feeding(℃$^{-1}$)

Parameters used in this model

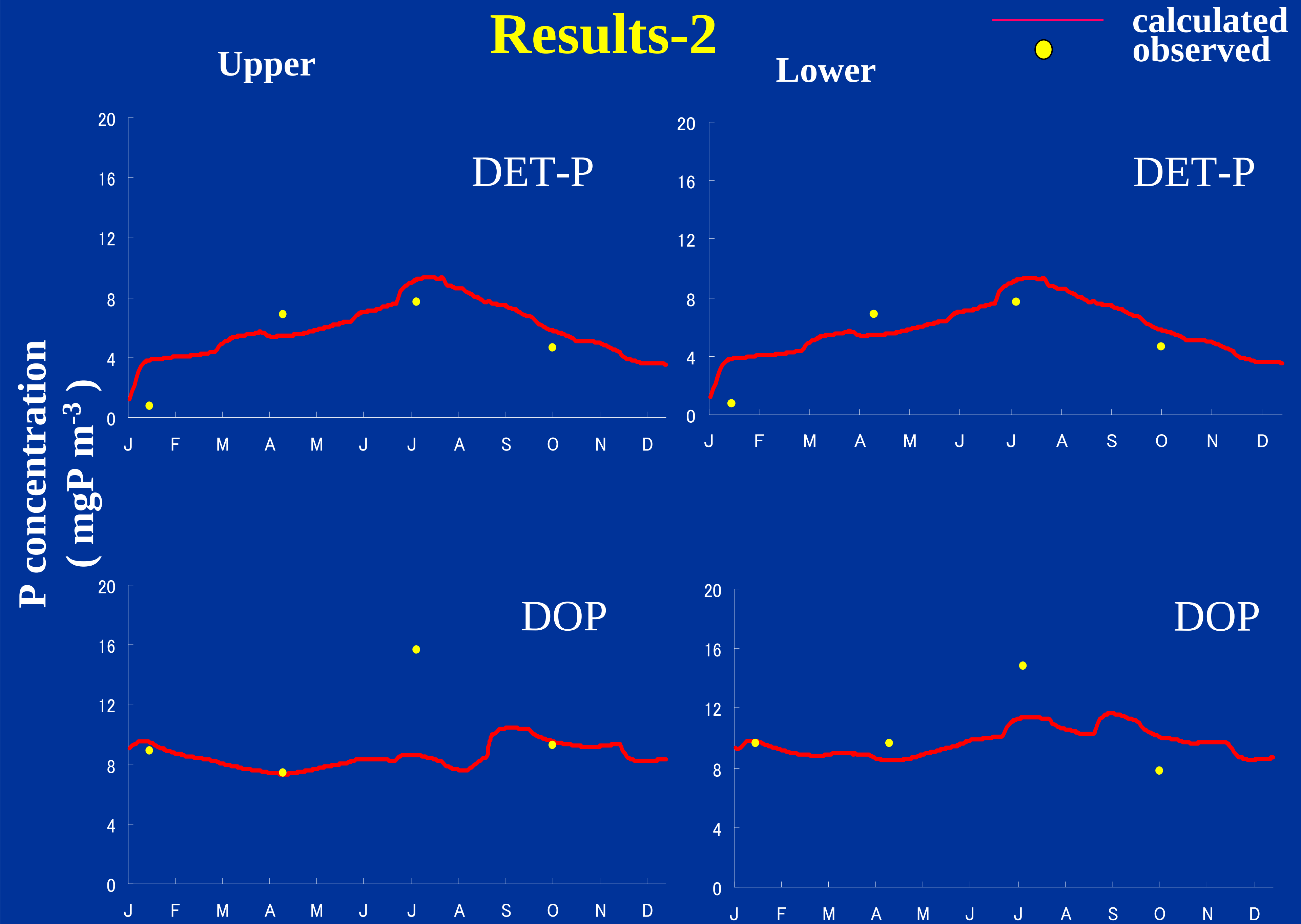
Definitions	Values	Dimension
Maximum specific nutrient uptake rate by phytoplankton	1.3	day^{-1}
Temperature coefficient for photosynthetic rate	0.063	$℃^{-1}$
Half saturation coefficient for inorganic phosphorus	4.34	$mg\ m^{-3}$
Optimum light intensity	21.6×10^5	$cal\ m^{-2}\ day^{-1}$
Ratio of extracellular excretion to photosysnthesis	0.135	
Siking speed of phytoplankton	0.05	$m\ day^{-1}$
Siking speed of detritus	0.5	$m\ day^{-1}$
Mortality of phytoplankton at 0℃	0.0145	$day^{-1} m^3\ mgP^{-1}$
Temperature dependancy of phytoplankyon mortality	0.069	$℃^{-1}$
Maximum grazing rate by zooplankton	0.2	day^{-1}
Temperature dependancy of grazing	0.069	$℃^{-1}$
Ivlev' constant	0.72	$mg\ P\ m^{-3}$
Threshold of phytoplankton destiny for grazing	0.0833	$mg\ P\ m^{-3}$
Constant for urine generation	0.4	
Constant for feacal pellet generation	0.3	
Zootoplankton mortality at 0℃	0.03	$day^{-1} m^3\ mgP^{-1}$
Temperature dependancy of zootoplankyon mortality	0.069	$℃^{-1}$
Decomposition rate of detritus to DIP at 0℃	0.03	day^{-1}
Decomposition rate of detritus to DOP at 0℃	0.02	day^{-1}
Decomposition rate of DOP to DIP at 0℃	0.02	day^{-1}
Temperate dependancy of decomposition rate of detritus to DIP	0.069	$℃^{-1}$
Temperate dependancy of decomposition rate of detritus to DOP	0.069	$℃^{-1}$
Temperate dependancy of decomposition rate of DOP to DIP	0.069	$℃^{-1}$
Sedimentation rate of detritus	4.11	$mg\ P\ m^{-2}\ day^{-1}$

Results-1



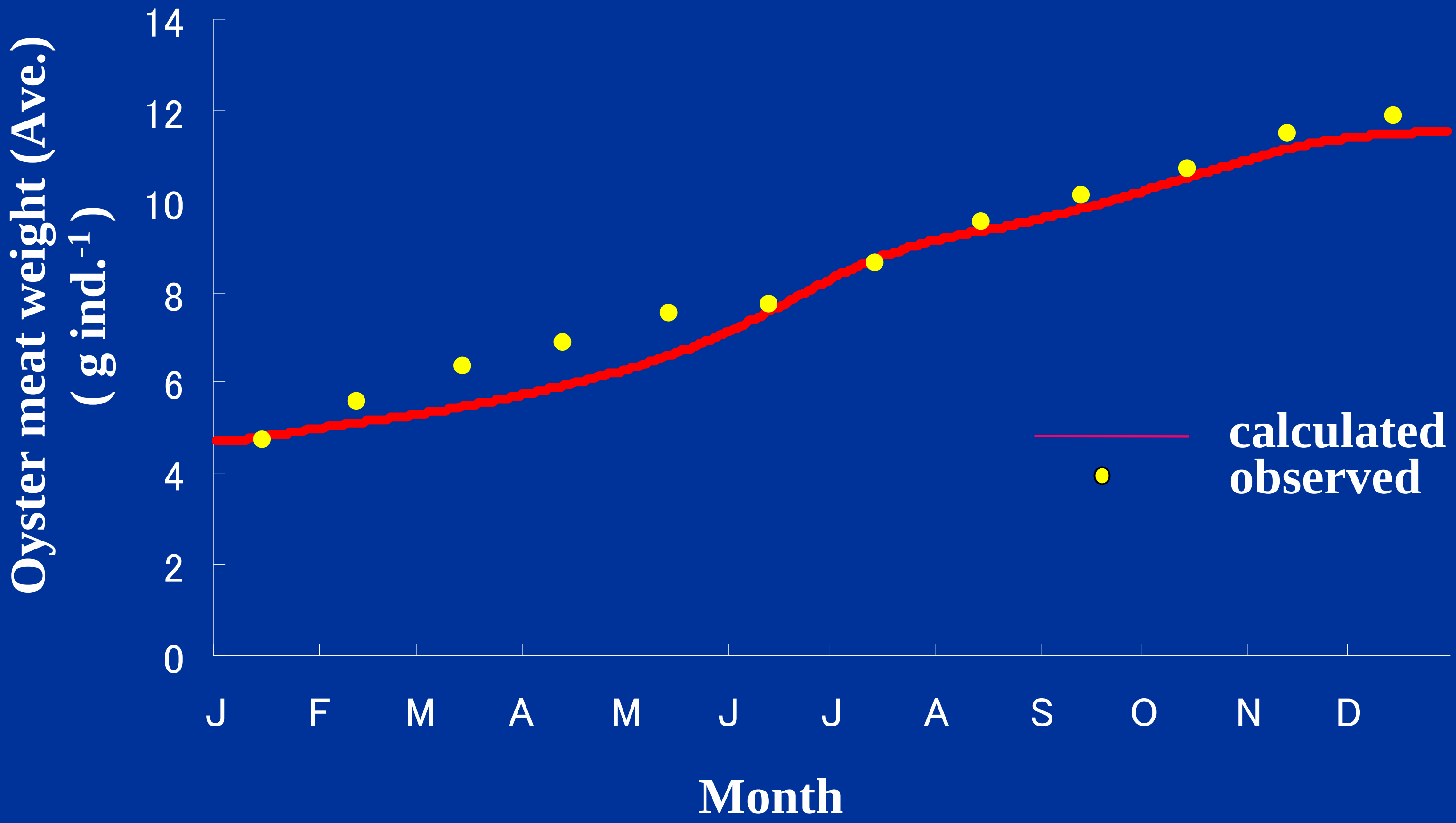
calculated
observed
Upper
Lower
DIP
PHY-P
P concentration (mgP m^{-3})
20
16
12
8
4
0
J F M A M J J A S O N D
Month

Results-2

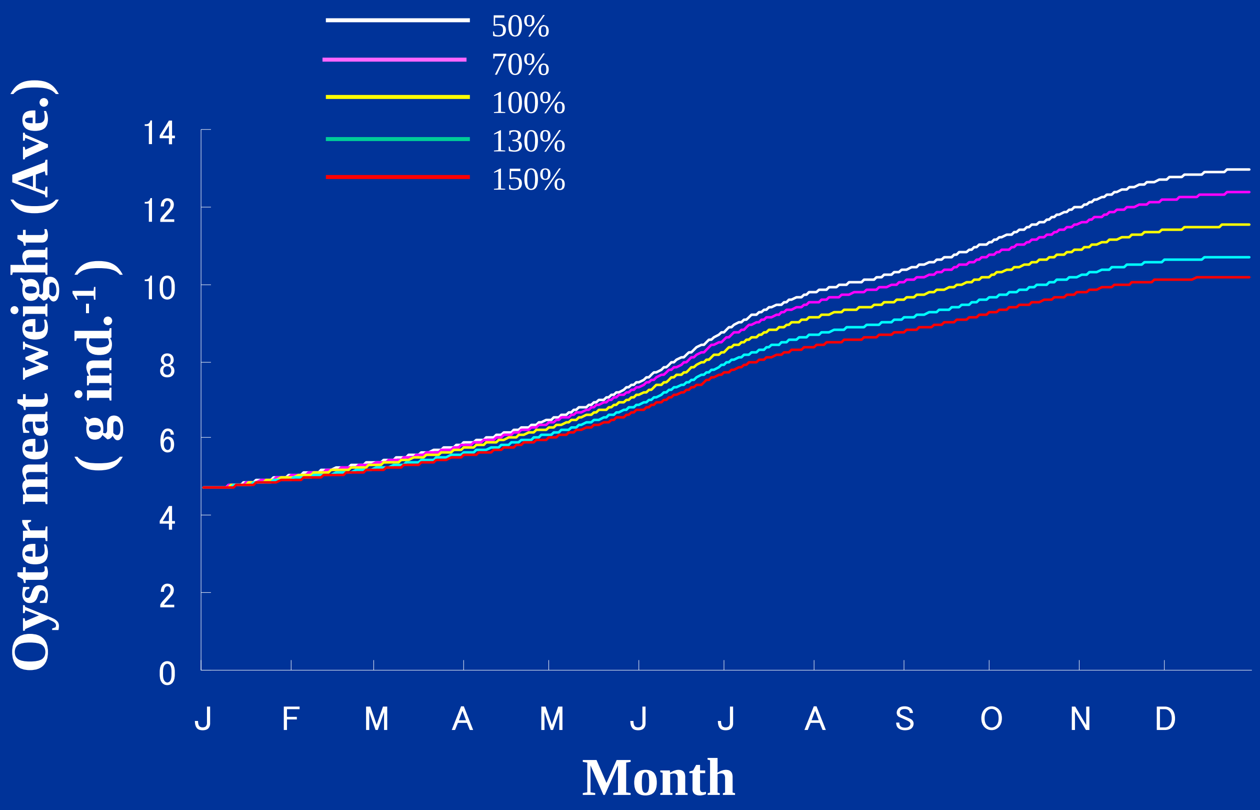


calculated
observed
Upper
Lower
P concentration (mgP m-3)
DET-P
DOP
0
4
8
12
16
20
J F M A M J J A S O N D

Increase in oyster meat waight

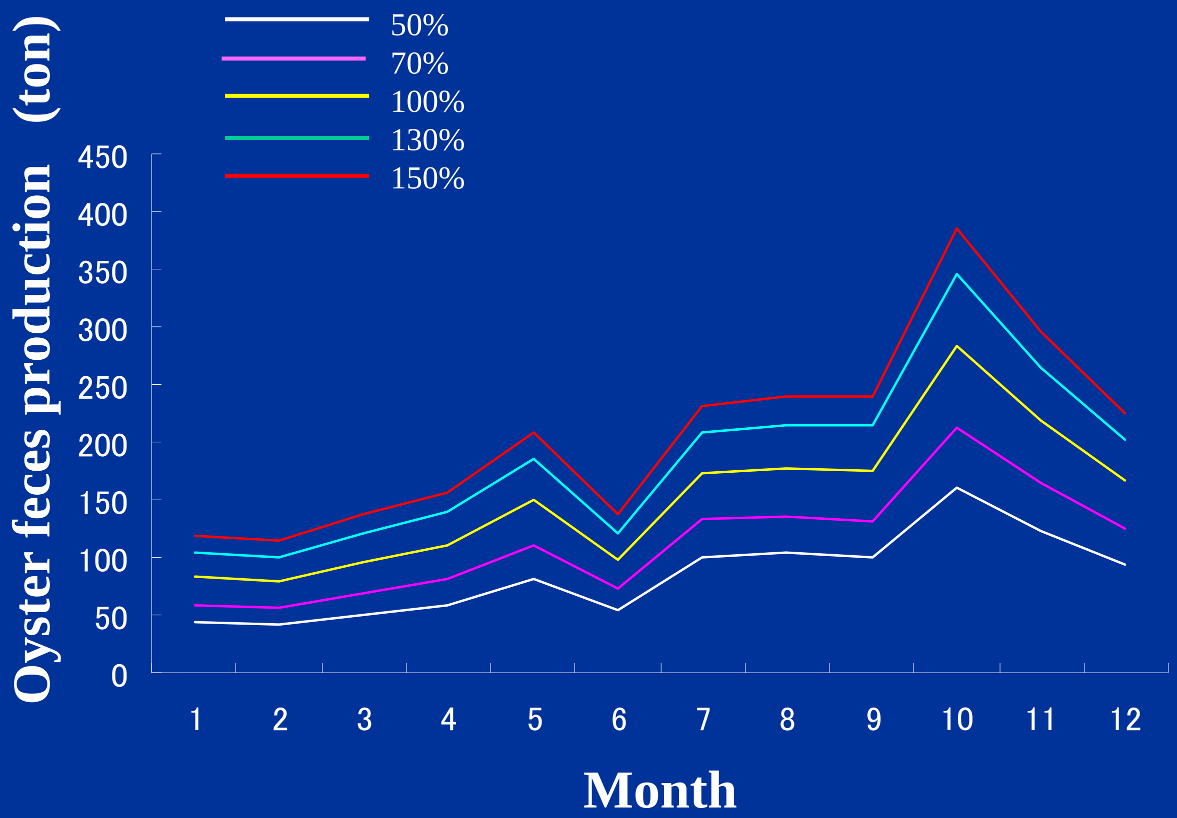


Individual oyster growth and crop



Culture density (%)	50	70	100	130	150
Ind. meat weight (%)	113	108	100	93	88
Crop (%)	52	75	100	121	132

Oyster feces production

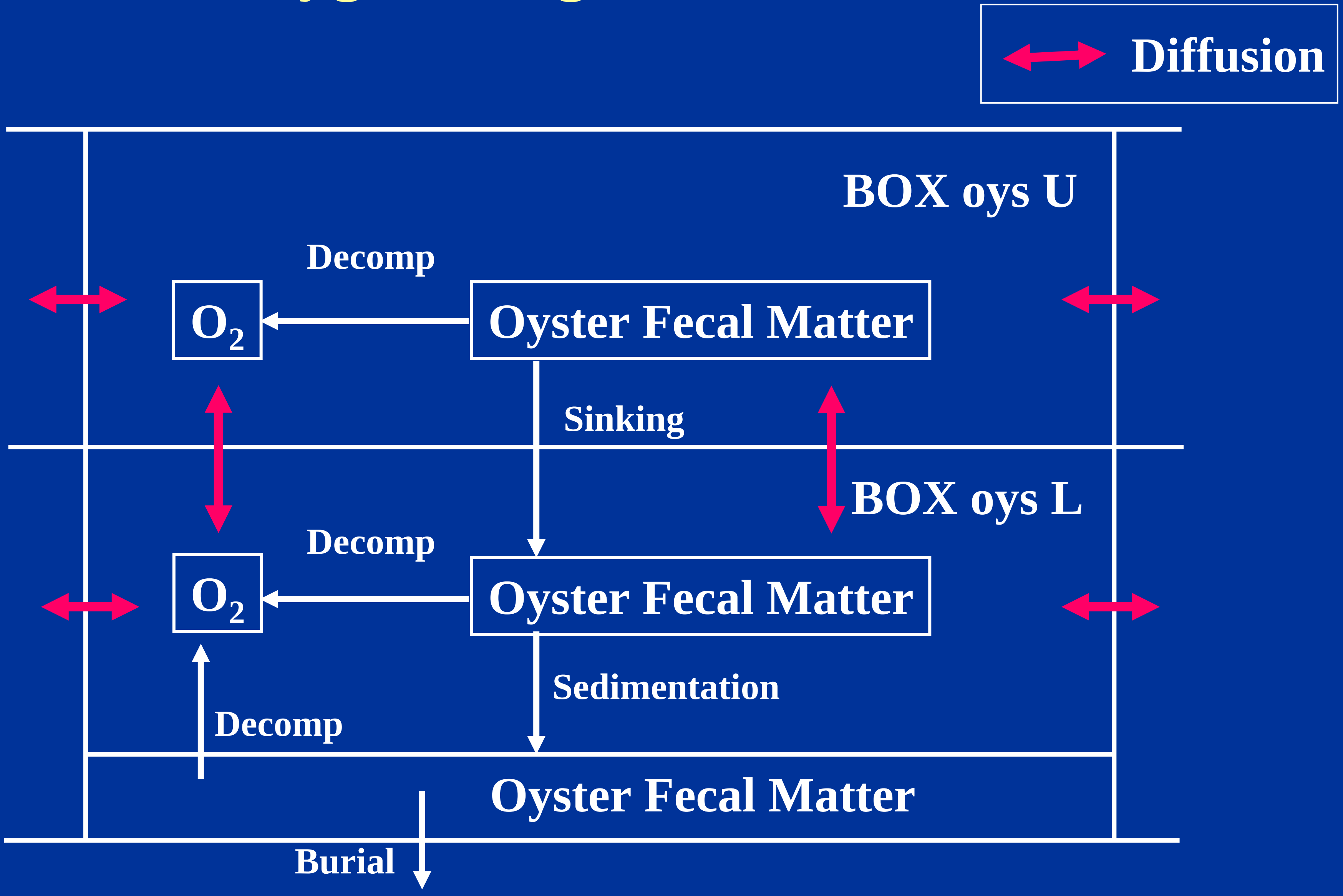


Density	Egestion
150%	137%
130%	123%
100%	100%
70%	75%
50%	56%

Annual feces production of oyster: ca. 1,800 ton

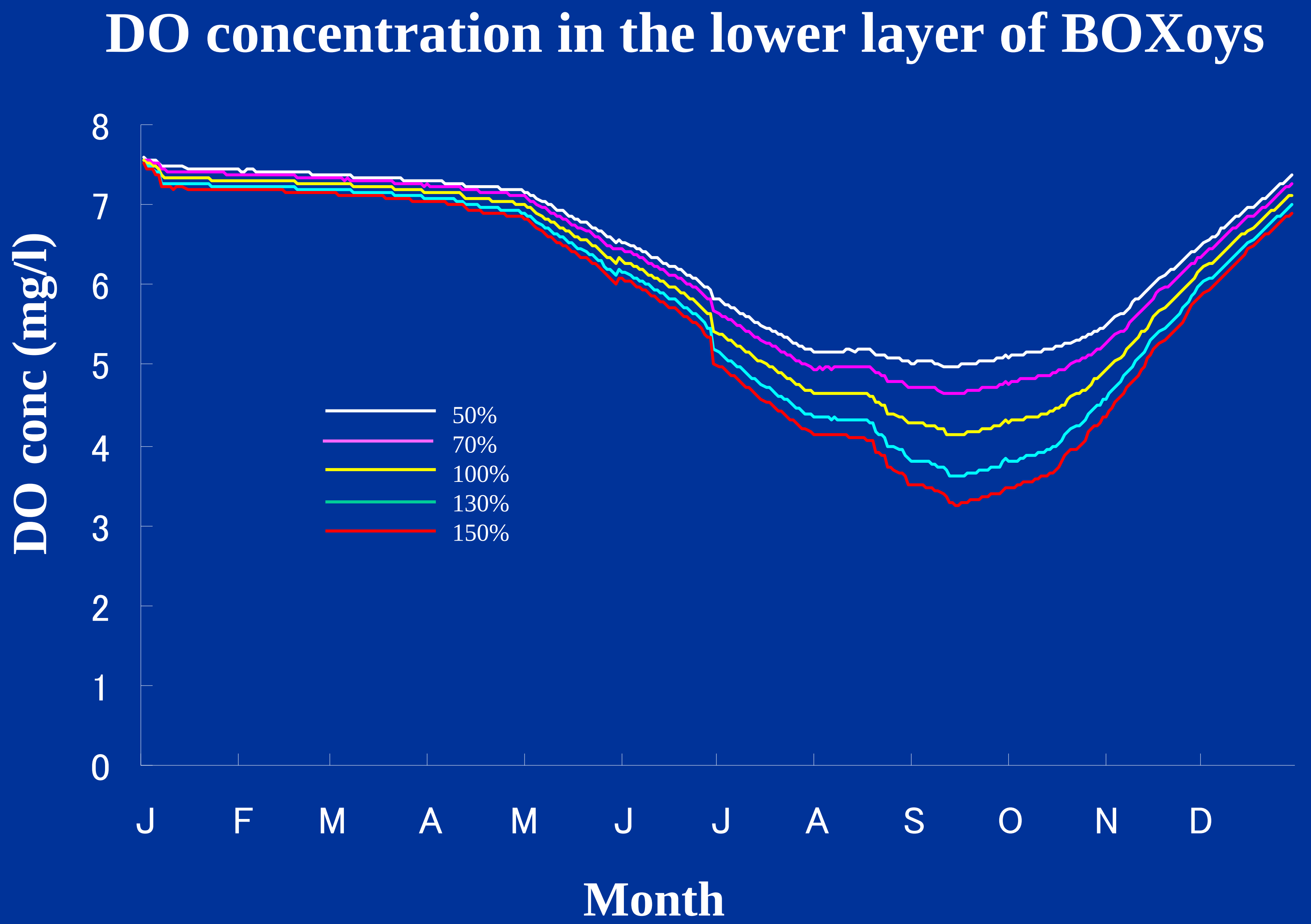
ca. 20% of the total particulate organic matter sedimentation in northern area of HB

Oxygen budget calculations

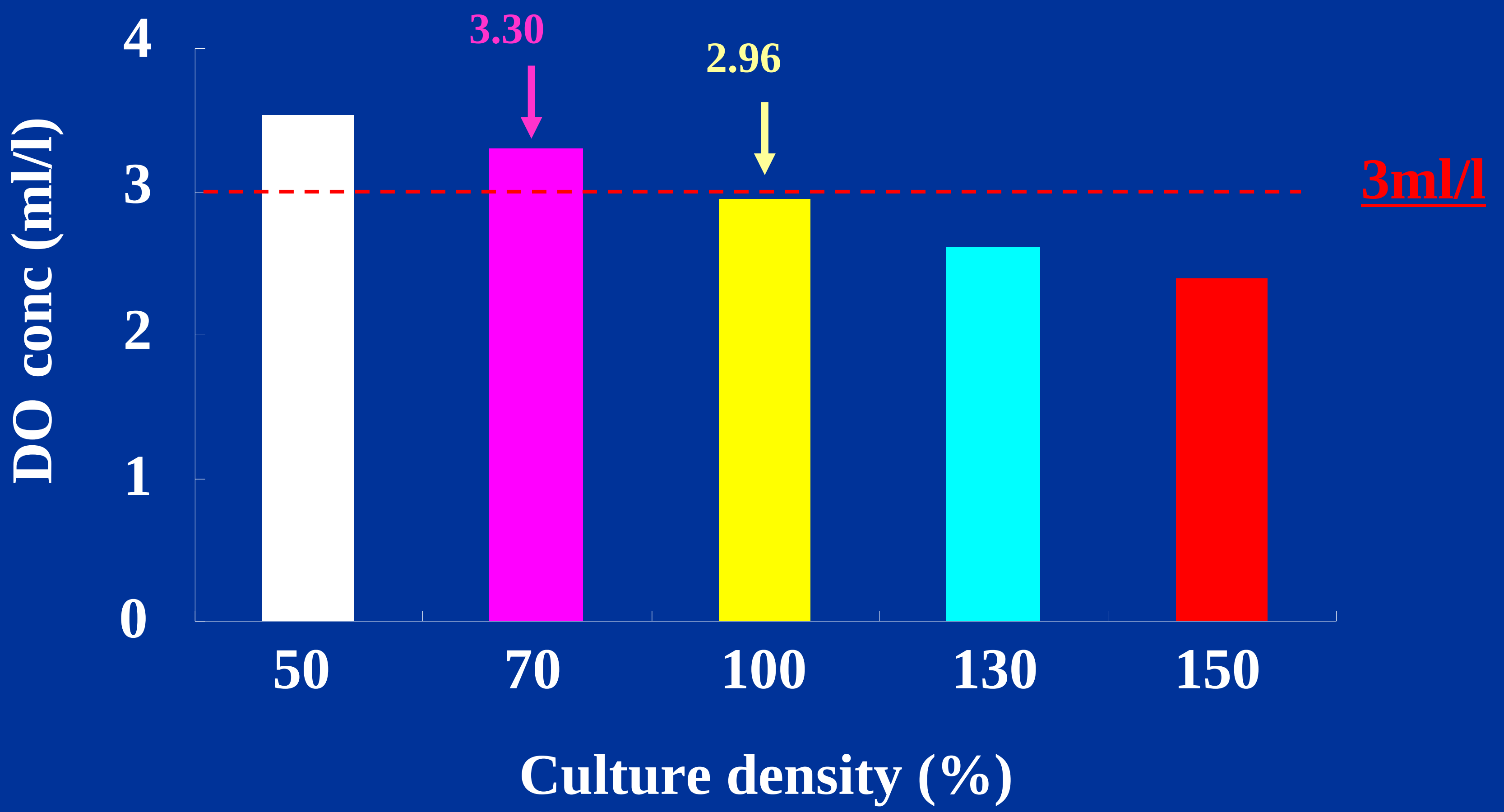


Schematic diagram illustrating oxygen budgets

Results


DO concentration in the lower layer of BOXoys
DO conc (mg/l)
8
7
6
5
4
3
2
1
0
50%
70%
100%
130%
150%
J
F
M
A
M
J
J
A
S
O
N
D
Month

DO conc in the lower layer in September



3 mL/L: lower limit of DO conc which should be maintained for aquatic organisms (JFRCA, 2006)

Summary and conclusions

For example, in the case of 30% reduction of the culture density,

1. **The individual oyster meat weight will increase 8%, but the total crop will decrease 25%.**

→Estimation of income for farmers should be performed in the next step; whether the increase of income due to increase of the size could cover the decrease of income due to decrease of the total crop.

Summary and conclusions (cont'd)

2. **Fecal production will decrease 25%, and DO concentration will be improved to 3.3 ml/l.**

→Decrease in the fecal production is quite good, but DO concentration is not so sensitive, because the contribution of oyster to the total sedimented matter is only 20%.

Farmers habitually tend to increase culture density to earn more. The results may be a great help for the local government to guide farmers to perform sustainable culture with conserving the benthic ecosystem by reducing culture density.