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


Tamiji Yamamoto, Hajime Maeda, Osamu Matsuda and Toshiya Hashimoto
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.

- **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

modified Raillard *et al.* (1993)

- Seston
- Temperature
- Filtration rate
- Meat weight
- Ingestion
- Assimilation efficiency
- Excretion rate
- Respiration rate
- Excretion
- Absorption
- Somatic growth
- Reproduction
- Spawning rate
- Spawning
- Water exchange
Equations

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

- \( V \): volume of a raft (m³)
- \( Q \): water exchange rate between inside and outside of a raft (m³ 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 (m³ day⁻¹)

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

- \( Q_0 \): water exchange rate with no raft 10⁸ m³ day⁻¹ (ref. Ueshima and Hayakawa, 1982)
- \( \alpha \): decreasing coef. of water exchange rate (0.47)
- \( N \): number of wires (std. 850 wires/raft=4.25 wires/m²)
Oyster

**Filtration**

\[ F = F_{\text{max}} \times e^{\{k_f \times \min(0,T_{\text{SES}} - \text{SES})\}} \times W_d^{0.4} \times P_T \]

\[ P_T = 0.5943 \times \ln(T) - 0.9958 \]

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

(Songssangjinda et al., 1998)

**Ingestion**

\[ I = \gamma \times F (\text{PHY} + \text{DET}) \]

- **\( \gamma \)**: proportion of particulate matter ingested

(Kusuki, 1977)

**Pseudofeces production**

\[ PF = (1 - \gamma) I \]

- **\( \gamma \)**: Ingested proportion in filtered particles

(Lee and Hoshika, 2000)
Fecal production

\[ Fe = (1 - \delta) I \]

\( \delta \): Assimilation rate  \hspace{2cm} (Powell et al., 1992)

Excretion

\[ Ex_p = 0.08 \times \delta \times I_p \]

\( I_p \): Ingested phosphorus  \hspace{1cm} (Richard et al., 1989)

\( Ex_p \): Excreted phosphorus

Reproduction

\[ Re = Sfg \times \varepsilon \]

\[ 27^\circ C \leq T \quad ; \quad \varepsilon = 0.8 \]

\[ 23^\circ C \leq T < 27^\circ C \quad ; \quad \varepsilon = 0.16T - 3.2 \]

\[ T < 23^\circ C \quad ; \quad \varepsilon = 0 \]

\( Sfg \): Assimilated energy

\( \varepsilon \): Reproduction efficiency  \hspace{1cm} (Kobayashi et al., 1997)
# Equations and Parameters

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Water exchange rate and individual oyster weight

![Graph showing water exchange rate and individual oyster weight over time.](Image)

- **Y-axis:** Individual Oyster Weight (gDW ind⁻¹)
- **Graph Title:** Observed 1996
- **Unit:** m³ day⁻¹

The graph illustrates the water exchange rate and individual oyster weight for the year 1996, with observed data points marked by a diamond symbol. The data is presented in various units from 1 x 10⁴ to 1 x 10⁸, with specific units as indicated on the graph.
Oyster production

Individual weight

Weight per raft

Wire numbers per raft

Individual Weight (g DW ind.)

Oyster Production per Raft (t DW Raft⁻¹)

Wire numbers per raft
Egestion and biodeposit production

Wire numbers per raft

Biodeposit Production per Raft (kg DW Raft⁻¹ day⁻¹)

Wire numbers per raft
Framework of the ecosystem model

Box 1

DIP → Decomposition → PHY → Diffusion

DIP → Decomposition → ZOO → Sinking

DIP → Extracellular excretion → OYS → Egestion

DIP → Decomposition → DET → Photosynthesis

DOP → Decomposition → PHY → Mortality

DOP → Decomposition → ZOO → Grazing

DOP → Extracellular excretion → OYS → Egestion

DOP → Decomposition → DET → Photosynthesis

Box oys

Photosynthesis → PHY

Photosynthesis → OYS

Mortality → PHY

Excretion → OYS

Sinking → ZOO

Grazing → ZOO

Excretion → OYS

Sinking → OYS

Box oys

Photosynthesis → PHY

Photosynthesis → OYS

Mortality → PHY

Excretion → OYS

Sinking → ZOO

Grazing → ZOO

Excretion → OYS

Sinking → OYS

DIP

DOP

DOP

DIP

Box oys

Photosynthesis → PHY

Photosynthesis → OYS

Mortality → PHY

Excretion → OYS

Sinking → ZOO

Grazing → ZOO

Excretion → OYS

Sinking → OYS

Outer Kure Bay

Box 1

Diffusion

Advection

Diffusion

Sedimentation

Sedimentation

Kure Bay
Mass balance equations

**DIP**

\[ V_{1u} \frac{dDIP_{1u}}{dt} = DIP_{R1} + DIP_{P1} + OEX_{1u} \]
\[ \quad - V_{1u} \left( A_1 PHY(P)_{1u} - B_2 ZOO(P)_{1u} - C_1 DET(P)_{1u} - D_1 DOP_{1u} \right) \]
\[ + V_{ADV} DIP_{1L} - (V_{ADV} + R_i + P_1 + E_1) DIP_{1u} \]
\[ - AH_{1u} \frac{KH_{1u}}{X_1} (DIP_{1u} - DIP_{2u}) - AH_{KU} \frac{KH_{KU}}{X_K} (DIP_{1u} - DIP_{ku}) - AV_1 \frac{KV_1}{Z_1} (DIP_{1u} - DIP_{1L}) \]

**PHY**

\[ V_{1u} \frac{dPHY(P)_{1u}}{dt} = V_{1u} \left( A_1 PHY(P)_{1u} - B_2 ZOO(P)_{1u} - A_2 PHY(P)_{1u} - A_3 PHY(P)_{1u}^2 \right) - AV_P PHY(P)_{1u} - PGR_{1u} \]
\[ + V_{ADV} PHY(P)_{1L} - (V_{ADV} + R_i + P_1 + E_1) PHY(P)_{1u} \]
\[ - AH_{1u} \frac{KH_{1u}}{X_1} (PHY(P)_{1u} - PHY(P)_{2u}) - AH_{KU} \frac{KH_{KU}}{X_K} (PHY(P)_{1u} - PHY(P)_{ka}) - AV_1 \frac{KV_1}{Z_1} (PHY(P)_{1u} - PHY(P)_{1L}) \]

**DET**

\[ V_{1u} \frac{dDET(P)_{1u}}{dt} = DET(P)_{R1} + V_{1u} \left( B_4 ZOO(P)_{1u}^2 + B_5 ZOO(P)_{1u} + A_3 PHY(P)_{1u}^2 - C_1 DET(P)_{1u} - C_2 DET(P)_{1u} \right) \]
\[ - AV_P DET(P)_{1u} - DGR_{1u} + V_{ADV} DET(P)_{1L} - (V_{ADV} + R_i + P_1 + E_1) DET(P)_{1u} \]
\[ - AH_{1u} \frac{KH_{1u}}{X_1} (DET(P)_{1u} - DET(P)_{2u}) - AH_{KU} \frac{KH_{KU}}{X_K} (DET(P)_{1u} - DET(P)_{ka}) - AV_1 \frac{KV_1}{Z_1} (DET(P)_{1u} - DET(P)_{1L}) \]

**DOP**

\[ V_{1u} \frac{dDOP_{1u}}{dt} = DOP_{R1} + V_{1u} \left( A_1 A_2 PHY(P)_{1u} + C_2 DET(P)_{1u} - D_1 DOP_{1u} \right) \]
\[ + V_{ADV} DOP_{1L} - (V_{ADV} + R_i + P_1 + E_1) DOP_{1u} \]
\[ - AH_{1u} \frac{KH_{1u}}{X_1} (DOP_{1u} - DOP_{2u}) - AH_{KU} \frac{KH_{KU}}{X_K} (DOP_{1u} - DOP_{ka}) - AV_1 \frac{KV_1}{Z_1} (DOP_{1u} - DOP_{1L}) \]
Phytoplankton

**Growth** \[ A_1 = V_{\text{max}} \left( \frac{DIP}{DIP + K_p} \right) \times \exp(kT) \times \frac{I}{I_{\text{opt}}} \exp(1 - \frac{I}{I_{\text{opt}}}) \]

- \( V_{\text{max}} \): Maximum nutrient uptake rate (day\(^{-1}\))
- \( K_p \): Half-saturation constant (mg/m\(^3\))
- \( k \): Temperature dependent coefficient for photosynthesis (\(\circ\)C\(^{-1}\))
- \( T \): Temperature (\(\circ\)C)
- \( I_{\text{opt}} \): Optimum light intensity (\(\mu\)E m\(^{-2}\) day\(^{-1}\))
- \( I \): Average light intensity of water column (\(\mu\)E m\(^{-2}\) day\(^{-1}\))

**Mortality** \[ A_3 = M_{po} \exp(k_{MP}T) \]

Zooplankton

**Grazing** \[ B_1 = \gamma \left( 1 - \exp(\lambda(\text{PHY}^* - \text{PHY})) \right) \]

\[ \gamma = \frac{G_{\text{max}}}{k_g} \exp(k_g T) \]

- \( G_{\text{max}} \): Maximum grazing rate (day\(^{-1}\))
- \( \lambda \): Ivlev constant (m\(^3\) mgP\(^{-1}\))
- \( \text{PHY}^* \): Threshold feed concentration at grazing rate becomes zero (mg m\(^{-3}\))
- \( k_g \): Temperature dependent coefficient for feeding (\(\circ\)C\(^{-1}\))
### Parameters used in this model

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<td>4.11</td>
<td>mg P m(^{-2}) day(^{-1})</td>
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Results-1

P concentration (mgP m$^{-3}$)

Upper

Lower

DIP

PHY-P

Month
Results-2

Upper

DET-P

Lower

DET-P

DOP

DOP

P concentration (mgP m⁻³)

J F M A M J J A S O N D

0 4 8 12 16 20

J F M A M J J A S O N D

0 4 8 12 16 20

observed
calculated
Increase in oyster meat weight

Oyster meat weight (Ave.) (g ind.⁻¹)

Month

Calculated
Observed
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
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

- **O2**
- **Oyster Fecal Matter**
- **Decomp**
- **Sinking**
- **Sedimentation**
- **Burial**
- **BOX oys U**
- **BOX oys L**
- **Diffusion**
Results

DO concentration in the lower layer of BOXoys

Month

DO conc (mg/l)

- 50%
- 70%
- 100%
- 130%
- 150%
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.