Nitrogen and Phosphorus Cycles in Constructed Tidal Flat in Tokyo Bay

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The Role of Tidal Flat for Coastal Environment

- Habitat
- Fishery
- Water Quality
- Water Birds
- Education
- Recreation
The Purpose of the Study

- The Role of Tidal Flat on Water Environment
- To Know the Nutrient Flux in the Tidal Flat
- To Grasp the Mechanism of Nutrient Cycle in the Tidal Flat
Tokyo Bay
Area 960km²
Mean Depth 15m
Population 26 million

Reclamation Lands (>95% disappeared)
Trend of Fishery Production in Tokyo Bay

Amount of fish catch (ton)

- Total
- Shell fish
- Seaweed
- Pelagic fish

No. 5
Tidal Flat in the Tokyo Port Wild Bird Park
Study Site

Tokyo Port Wild Birds Park
artificial tidal flat (57000m²)
1960's : reclamation
1989 : open for birds park
Nutrient Cycle in the Tidal Flat

Atmospheric Deposition → Load → Reed or Algae → Sediment

Denitrification → Reed or Algae → Benthos

Water Birds

Water Exchange

Uptake → Benthos → Release
Nutrient Flux between Tidal Flat and Adjacent Sea

Channel 1 & 2

Macro-benthos
Sediment
Sea Water
Channel 1 & 2
Dissolution rate
Observation Results (elevation, concentration of N)

\[ \text{Flux } N = \sum_{I=1}^{2} \sum_{t=1}^{N} Q_{I,t} \cdot C_{I,t} \]

\[ Q_t = (\zeta_{t+1} - \zeta_t) A_t \]
Observation Results (elevation, concentration of P)

\[
\text{Flux } P = \sum_{I=1}^{2} \sum_{t=1}^{N} Q_{I,t} \cdot C_{I,t}
\]

\[
Q_t = (\zeta_{t+1} - \zeta_t) A_t
\]
<table>
<thead>
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<th></th>
<th>2007</th>
<th>2008</th>
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<th>2010</th>
</tr>
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<tbody>
<tr>
<td>TP</td>
<td>-107</td>
<td>-74.4</td>
<td>-41.8</td>
<td>21.6</td>
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<td>PO₄-P</td>
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<td>740</td>
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<td>522</td>
<td>461</td>
<td>287</td>
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<td>NH₄-N</td>
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<td>Chl-a</td>
<td>46.3</td>
<td>0.97</td>
<td>11.4</td>
<td>18.8</td>
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</tbody>
</table>

Red Digit: inflow flux from adjacent sea to tidal flat
Black Digit: outflow flux from tidal flat to adjacent sea
Nutrient Flux between Sediment and Overlying Water

- Intertidal Zone
- Reed Grass
- Adjacent Sea
- Tidal Flat
- Channel 1 & 2
- Macro-benthos
- Sediment
- Sea Water
- Dissolution rate
- Sampling Points
- Agitated Equipment
- No.14
Nutrient Flux between Sediment and Overlying Water

**intertidal zone**

**subtidal zone**

<table>
<thead>
<tr>
<th>NO$_2$-N</th>
<th>NO$_3$-N</th>
<th>NH$_4$-N</th>
<th>DIN</th>
</tr>
</thead>
</table>

For intertidal zone:
- NO$_2$-N
- NO$_3$-N
- NH$_4$-N
- DIN

For subtidal zone:
- NO$_2$-N
- NO$_3$-N
- NH$_4$-N
- DIN

**PO$_4$-P**

FLUX (mg/m$^2$/h)
Nutrient Flux from Water Birds (food or excretion)

Sampling Points
- Macro-benthos
- Sediment
- Sea Water
- Dissolution rate

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No. 16
Observation Results (number of water birds)

Hourly variations of number of water birds in the flat

Monthly variations of number of water birds in the flat
Nutrient flux by water birds

\[ BC = \frac{1}{A} \sum_i N_i \left( K \times F W_i \times N_{FC} - C_i \times D W_i \times N_{EC} \right) \]

**BC**: Nutrient flux by water birds  
**\( N_i \)**: Number of water birds (\( i \) species)  
**\( K \)**: the rate of feeding action  
**\( F W_i \)**: the amount of food by water birds  
**\( N_{FC} \)**: Nutrient content of the food  
**\( C_i \)**: the rate of excretion loaded to flat  
**\( D W_i \)**: the amount of excrement by birds  
**\( N_{EC} \)**: Nutrient content of the excrements

Nutrient Flux from birds to Tidal Flat

N: 9.36mg/m²/d  
P: 5.68mg/m²/d
Nutrient Flux by Benthos and Reed

$\text{S\ampling\ Points}$

- Macro-benthos
- Sediment
- Sea Water

- Dissolution rate

**Map Notes:**
- Intertidal Zone
- Reed Grass
- Tidal Flat
- Channel 1 & 2
- Pond
- Channel 1
- Channel 2
- Adjacent Sea

**Map Symbols:**
- Sampling Points
- Macro-benthos
- Sediment
- Sea Water
- Dissolution rate

**Legend:**
- N

**Data Reference:**
- No. 19
Nutrient flux by Benthos

\[
N_{fd} = O_{fd} \times (1 - E_C) \times C
\]
\[
O_{fd} = M \times \left(\frac{P}{B}\right) / T
\]

- \(N_{fd}\) : Nutrient removal by Benthos
- \(O_{fd}\) : the amount of food by Benthos
- \(E_C\) : Excretion efficiency
- \(C\) : Nutrient content of the food
- \(M\) : Biomass of the Benthos
- \(P/B\) : PB ratio of product
- \(T\) : Efficiency of conversion

Annelid
Mollusca
Crustaceans

July 22
August 10
December 14

No.20
$$NE_R = N \times A_R \times N_{AR} / A$$

$NE_R$ : the amount of nutrient removal

$N$ : number of reed per unit area (1m²)

$A_R$ : area of reed habitat

$N_{AR}$ : assimilation rate by reed

$A$ : area
August

December

Nitrogen

Phosphorus

50
40
30
20
10
0

mg/m²/day

August

December

No.23
Nutrient Flux by Dentrification and Anammox

Diagram showing locations of Pond, Channel 1, Channel 2, Adjacent Sea, Intertidal Zone, Reed Grass, Tidal Flat, and Sampling Points with symbols indicating Macro-benthos, Sediment, Sea Water, and Dissolution rate.
**r-IPT Method** (after Risgaard et al. 2003)  
(Revised Isotope Pairing Technique)

\[ r - IPTp^{14} = 2r_{14} \cdot (p^{29}N_2 + p^{30}N_2 \cdot (1 - r_{14})) \]

Original **IPT Method** (after Nielsen 1992)

\[ p^{14} = \frac{p^{29}N_2}{2 \cdot p^{30}N_2} \left(2 \cdot p^{30}N_2 + p^{29}N_2\right) \]

- incubation (1) 100µmol $^{15}$NO$_3$
- incubation (2) 200µmol $^{15}$NO$_3$
Dining PAM

Nutrient Flux by microphytobenthos

Measuring point (20cm x 20cm: quadrat)

: Sampling Points (Intertidal Zone)
- : Sampling Points (Subtidal zone)
Relationship between Chlorophyll-a (laboratory) and fluorescence yield (Diving PAM)

\[ y = 0.0027x + 0.3477 \]
\[ R^2 = 0.4256 \]
<table>
<thead>
<tr>
<th>Measuring Station</th>
<th>Chlorophyll-a (mg/m²)</th>
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<tr>
<td></td>
<td>2010</td>
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<tr>
<td>Sandy Mud</td>
<td></td>
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<tr>
<td>A-1</td>
<td>0.38</td>
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<tr>
<td>B-1</td>
<td>1.28</td>
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<tr>
<td>C-1</td>
<td>0.45</td>
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<tr>
<td>D-1</td>
<td>0.68</td>
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<tr>
<td>Gravel</td>
<td></td>
</tr>
<tr>
<td>E-1</td>
<td>0.35</td>
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<tr>
<td>F-1</td>
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<td>Sandy Mud</td>
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<td>A-2</td>
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<td>B-2</td>
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<tr>
<td>Total N</td>
<td>mol N</td>
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<tr>
<td>Total P</td>
<td>mol P</td>
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</table>
Nitrogen Cycle in the Tidal Flat in Summer

- **Denitrification** (370mg/m²/d)
- **Load**
- **Reed** (38.9mg/m²/d)
- **Phytobenthos** (1.20mg/m²/d)
- **Sediment**
- **Benthos** (18.6mg/m²/d)
- **Adsorption** (651mg/m²/d)
- **Water Birds** (9.36mg/m²/d)
- **Water Exchange** (727mg/m²/d)
Nitrogen Cycle in the Tidal Flat in Winter

**Load**

- Reed (15.1mg/m²/d)
- Phytobenthos (1.02mg/m²/d)
- Benthos (10.52mg/m²/d)
- Sediment

**Denitrification** (370mg/m²/d)

**Water Exchange** (331.9mg/m²/d)

**Adsorption** (245.3mg/m²/d)

**Water Birds**

(11.73mg/m²/d)

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**Phytobenthos**

**Water Exchange**

**Load**

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**Denitrification**

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**Adsorption**

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**Water Birds**

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**Phytobenthos**
Phosphorus Cycle in the Tidal Flat in summer

**Load**
- Reed (3.2mg/m²/d)
- Phytobenthos (0.17mg/m²/d)
- Sediment
- Benthos (2.73mg/m²/d)

**Water Exchange** (90.5mg/m²/d)

**Water Birds** (5.68mg/m²/d)

**Release** (35.7mg/m²/d)
Phosphorus Cycle in the Tidal Flat in winter

Load

Water Birds
(7.09mg/m²/d)

Water Exchange
(22.5mg/m²/d)

Release
(6.8mg/m²/d)

Reed
(1.2mg/m²/d)

Phytobenthos
(0.14mg/m²/d)

Sediment

Benthos
(1.33mg/m²/d)
Concluding Remarks

The Role of the Tidal Flat on Water Environment

- The Flat is net sink for Nitrogen, and is net source for Phosphorus

- The excretion of water birds is a source of Phosphorus, but the nutrient flux by birds is not so large

- The nutrient flux between sediment and overlying water in the flat is quite large

- The main factor of a net sink of Nitrogen is denitrification and anammox
Thank you so much!

Finish!