Comparison of seasonal characteristics in biogeochemistry among the subarctic North Pacific stations described with a “NEMURO” marine ecosystem model

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**Introduction**

**Time-series stations in the subarctic North Pacific**

- **Alaska Gyre (AG)**
  - Ocean Station PAPA (50°N, 145°W)

- **Western Subarctic Gyre (WSAG)**
  - A-line including A7 (41.5°N, 145.5°E)
  - KNOT (44°N, 155°E)
What have been recognized about the subarctic North Pacific?

• A high nitrate low chlorophyll (HNLC) region

• Seasonality of physical conditions (e.g. SST, MLD) and biogeochemistry (e.g. nutrients): WSAG > AG

• Annual chlorophyll and primary productivity: WSAG > AG

→ These features are characterized by both physical conditions and internal biogeochemistry at each site
What have not been fully understood about the subarctic North Pacific?

- How much of the west-east biogeochemical differences are driven by physical conditions versus internal ecosystem dynamics at each site
- The magnitude of limiting factors on phytoplankton growth
Objective

To know:
1. What factors generate west-east biogeochemical differences in the subarctic North Pacific
2. What factors may constrain primary productivity at each site

→ Ecosystem model may help quantitative comprehension!
An ecosystem model “NEMURO”

A lower trophic level ecosystem model NEMURO (North pacific Ecosystem Model Used for Regional Oceanography) was developed by PICES MODEL Task Team, focusing on a linkage between lower and higher trophic levels. More than 30 papers have been published or submitted.
**Model Experimental Design**

- NEMURO + mixed layer model
- Applied to Stations A7 (WSAG), KNOT (WSAG) and PAPA (AG)
- Driven by daily wind (NCEP), weekly temperature (Reynolds) and monthly salinity (WOA01) at each site
- Eighteen-year (1982-1999) mean results were compared and discussed
Results: Physical conditions

ΔSST
(A7) 16°C
(KNOT) 12°C
7 °C (PAPA)

Mixed layer depth max.
> 170m (A7)
> 120m (KNOT)
< 100m (PAPA)
Results: Biogeochemistry

Surface nitrate

$\Delta$NO$_3$ [mmol m$^{-3}$]
19 (A7)
15 (KNOT)
5 (PAPA)

Primary productivity
A7 > KNOT >> PAPA

- Imai, 2002
- Wong, 1995
What factors control diatom growth?

Diatom growth

\[ V_{\text{max}L} \times \min \left\{ \frac{[\text{NO}_3]}{[\text{NO}_3] + K_{\text{NO}_3}^{\text{NO}_3}} + \frac{[\text{NH}_4]}{[\text{NH}_4] + K_{\text{NH}_4}^{\text{NH}_4}}, \frac{[\text{Si(OH)}_4]}{[\text{Si(OH)}_4] + K_{\text{Si(OH)}_4}^{\text{Si(OH)}_4}} \right\} \times 1 - \exp\left( -\alpha \times \text{Light} \right) \times \exp\left( k_L \times \text{Temp} \right) \]
Strong limitation on diatom growth

**Limitation:**
Light >> Si(OH)$_4$ > NO$_3$+NH$_4$ > Temp.
In western subarctic North Pacific

- Strong silicate limitation in summer
- Light limitation in spring and summer due to shelf-shading by phytoplankton
Diatom growth

\[
V_{max}\sub{L} = \min\left\{ \frac{[NO_3]}{[NO_3] + K_{NO_3}}, \frac{[NH_4]}{[NH_4] + K_{NH_4}}, \frac{[Si(OH)_4]}{[Si(OH)_4] + K_{Si(OH)_4}} \right\} \\
\times \left\{ 1 - \exp\left( -\frac{\alpha \times Light}{V_{max}\sub{L}} \right) \right\} \times \exp(k_L \times Temp)
\]

Maximum growth rate: A7 > KNOT >> PAPA

<table>
<thead>
<tr>
<th></th>
<th>A7</th>
<th>KNOT</th>
<th>PAPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{max}\sub{S}) (Picoplankton) [day(^{-1})]</td>
<td>0.74</td>
<td>0.59</td>
<td>0.37</td>
</tr>
<tr>
<td>(V_{max}\sub{L}) (Diatoms) [day(^{-1})]</td>
<td>1.33</td>
<td>1.18</td>
<td>0.71</td>
</tr>
</tbody>
</table>
Previous observational and modeling studies have revealed higher diatom growth rate with higher bioavailable iron concentrations.

Phytoplankton growth rate: A7 > KNOT >> PAPA

← Iron concentration: A7 > KNOT >> PAPA

Airborne iron to the ocean [mg m\(^{-2}\) yr\(^{-1}\)]
(Duce and Tindale, 1991)

<table>
<thead>
<tr>
<th>AG</th>
<th>Iron</th>
<th>NO$_3$+NH$_4$</th>
<th>Si(OH)$_4$</th>
<th>Light</th>
<th>Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>O</td>
<td>X</td>
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<tr>
<td>Spring</td>
<td>O</td>
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<td>O</td>
<td>X</td>
</tr>
<tr>
<td>Summer</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>O</td>
<td>X</td>
</tr>
<tr>
<td>Autumn</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>O</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WSAG</th>
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<th>Temp.</th>
</tr>
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<tr>
<td>Winter</td>
<td>Δ</td>
<td>X</td>
<td>X</td>
<td>O</td>
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<td>Spring</td>
<td>Δ or O</td>
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<tr>
<td>Summer</td>
<td>O</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>X</td>
</tr>
<tr>
<td>Autumn</td>
<td>Δ or O</td>
<td>X</td>
<td>Δ</td>
<td>O</td>
<td>X</td>
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</table>
Conclusion

Significant west-east biogeochemical differences are:
- primarily characterized by physical conditions at each site
- Secondary caused by internal ecosystem dynamics due to iron bioavailability at each site

Diatom growth is restricted by:
- light and iron in the Alaska Gyre
- light, iron and silicate in the Western Subarctic Gyre

NEMURO works.
What NEMURO needs next?

• Realistically incorporating the oceanic iron cycling and iron limitation on phytoplankton growth
• Further validation for grazing on phytoplankton (top-down control)