Interannual to interdecadal variations of Primary Production and the Carbon Cycle in the North Pacific using the 3-D NEMURO MODEL

Maki Noguchi AITA$^{1,2}$, Akio ISHIDA$^{1,2}$, Michio J. KISHI$^{1,3}$, Yasuhiro YAMANAKA$^{1,2,3}$

1: Frontier Research Center for Global Change (FRCGC), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama, Kanagawa, JAPAN
2: Core Research for Evolutional Science and Technology (CREST), Japan Science and Technology Agency (JST), Kawaguchi, Saitama, JAPAN
3: Hokkaido University, Sapporo, JAPAN
Object of This Study

Many marine ecosystem studies have focused on Regime shifts.

-Venrick et al., 1987; Roemmich and McGowan, 1995; Chai et al., 2003; Sugimoto and Tadokoro, 1997; Hare and Mantua, 2000 etc.

The climate regime shift of the 1970s played an important role in lower trophic ecosystem change, especially in the North-western Pacific and Bering Sea.

We investigated the interdecadal changes in dynamics of the lower trophic ecosystem related to this Climate Regime shift.
Model Background

Physical model: CCSR Ocean Component Model (COCO) 3.4
(developed at Center for Climate System Research, University of Tokyo)

Biological model: NEMURO

Configuration

- Horizontal resolution: 1 degree * 1degree (360x180)
- Vertical resolution: 54 levels from the surface to the bottom (5000m). 5m for all layers within upper 100m.

Boundary conditions (daily surface forcing)

- NCEP 6-hourly dataset from 1948 to 2002
  - Sea surface temperature
  - Fresh water flux
  - Surface wind stress
  - Solar radiation

- Sea Ice: HadISST (Hadley Centre Global Sea Ice and Sea Surface Temperature Analyses)

- Nitrate and Silicate concentrations: WOA 1998
NEMURO developed by PICES Model Task Team

Seasonal Vertical Migration

Spring
Ascend to the upper layer

Fall
Return to the deep layer

Nitrogen flow
Silica flow
Modeled spatial distribution
difference of 1977-2000 mean minus 1956-1975 mean

North central Pacific, increased primary production corresponds to the eastward stretching of the Kuroshio extension, which deepened MLD. Also the intensified Ekman pumping is important to exchange nutrients from the subsurface layer to the mixed layer.
In the coastal region of Gulf of Alaska, primary production decreased. After the mid 1970’s regime shift, MLD deepened which caused light limitation, and because the Ekman upwelling weakened.
The Kuroshio extension and Oyashio fronts shifted southward as a result of intensified ALP, which brought low temperature - low salinity water from boreal region. This low density water inhibited mixing which reduced nutrients supply. The region of maximum MLD shifted southward, while the surface nutrients decreased (increased) north (south) of the Kuroshio extension.
Selected locations in the North Pacific
Trends in anomalies of annually averaged Primary Production

KOT

Average = 645.5 mg C m\(^{-2}\) d\(^{-1}\)

BE

Average = 207.6 mg C m\(^{-2}\) d\(^{-1}\)

ALS

Average = 117.5 mg C m\(^{-2}\) d\(^{-1}\)

NWP

Average = 71.08 mg C m\(^{-2}\) d\(^{-1}\)

NCP

Average = 387.1 mg C m\(^{-2}\) d\(^{-1}\)

NEP

Average = 391.7 mg C m\(^{-2}\) d\(^{-1}\)

Regime Shift

Regime Shift

Regime Shift
**NEP (Off California)**

**Observed Data**

(redrawn from Fig. 1 & Fig. 2 of Roemmich et al., 1995)

- Biomass of zooplankton

**Modeled Data**

- Primary Production [NEP]
  - Average = 391.7 mgC m⁻² d⁻¹

- ZL (Large Zooplankton) [NEP]
  - Average = 0.044 mmol N m⁻³

- Nitrate [NEP]
  - Average = 5.494 mmol N m⁻³
NEP (Off California)

Observed Data
(redrawn from Fig. 1 & Fig. 2 of Roemmich et al., 1995)

Modeled Data

- Primary Production [NEP]
  - Average = 391.7 mg C m$^{-2}$ d$^{-1}$

- Zooplankton (Large Zooplankton) [NEP]
  - Average = 0.044 mmol N m$^{-3}$

- Nitrate [NEP]
  - Average = 5.494 mmol N m$^{-3}$
**Observed Data**
(redrawn from Sugimoto & Tadokoro, 1998)

Chlorophyll-a concentration

From 1980s through the early 1990s Chlor-a concentration was lower than that in the 1970s

**Modeled Data**

Chlorophyll-a concentration

PS (Small Phytoplankton) [NWP] Average= 0.026 mmol N m⁻³

PL (Large Phytoplankton) [NWP] Average= 0.009 mmol N m⁻³

ZL (Large Zooplankton) [NWP] Average= 0.007 mmol N m⁻³
**KOT** (Koroshio-Oyashio Transition area)

![Map of KOT and PH-line](image)

**Primary Production**

- **Observation**
- **Model**

**Biomass of large zooplankton**

- **Observation**
- **Model**

Correlation of PDO and Primary Production (7 years running mean)

Pacific Decadal Oscillation index

negative correlation positive correlation
In the sub-arctic zone and North central Pacific, primary production correlates positively with PDO, while in the East and Western North Pacific the correlation is negative.
We also investigated the interannual to decadal variability of the carbon cycle related with climate regime shift and ENSO.
Carbon Cycle: OCMIP3 (NOCES) protocol

We conducted simulations with two boundary conditions for atmospheric pCO2: one using the historical increase in atmospheric pCO2 from year 1837 to 2002 (historical run), another with a constant pre-anthropogenic concentration of 278 ppmv (control run).
Acidification at Station HOT (23N, 158W)

Data

Degree of Saturation for Aragonite

$$\Omega = \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]}{K_p}$$

- $$\Omega > 1 \rightarrow$$ supersaturation → precipitation
- $$\Omega < 1 \rightarrow$$ undersaturation → dissolution

Kleypas et al. (2006)
Acidification at Station HOT (23N, 158W)

Kleypas et al. (2006)
Primary production is inversely related to both $pCO_2$ and $CO_2$ flux (control RUN).

Increased Primary production resulted from decreased SST and deepened MLD because of intensified Aleutian Low Pressure after the mid 1970’s regime shift.

This increased oceanic carbon uptake.

Control: constant pre-anthropogenic concentration of 278 ppmv simulation results.
Simulated primary production decreased after the regime shift, because the increased SST reduced nutrient supply. This also affected ocean carbon uptake.

El Niño clearly affected the lower trophic ecosystem and carbon cycle:
- Primary production: decrease (increase)
- $\text{CO}_2$ flux: ocean uptake decrease (increase)
Summary

We simulated the effect of physical regime shift in the late 1970s and ENSO on the lower trophic ecosystem in the North Pacific, using a three-dimensional physical biological (3D-NEMURO) model. The simulation results showed that interdecadal changes of biomass of phytoplankton, zooplankton, and primary production correlate with PDO.

As for carbon cycle, we focused on the control run to examine the relations among the ecosystem, natural carbon cycle, and climate variations, without anthropogenic perturbations. In the central North Pacific, the model’s interannual variability of air-sea CO2 flux and primary production were positively correlated. That is, interdecadal change of SST controls primary production and oceanic uptake of CO2.
Probably we are already out of time, so…… if you have any questions & comments…….. Let’s discuss at the Ice Breaker tonight while we cool our heads, but also keep warm with wine and beer!