Effects of Climate Change on the World’s Ocean
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Timing is Everything? – Climate Control on the North Pacific Ecosystem Phenology

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Cherry blossom in Tokyo, March 20th 2015
Global climatology of marine phytoplankton phenological characteristics based on the SeaWiFS chlorophyll concentrations dating from Sept. 1997 to Dec. 2007. (Sapiano et al., 2012, JGR)
Seasonal Mixed Layer Process and Onset of Spring Bloom

Cool Year

Warm Year

Nutrient concentration

Critical Depth

Mixed Layer Depth

Phytoplankton bloom

Warm Year

Nutrient concentration

Critical Depth

Mixed Layer Depth

Phytoplankton bloom
Future Projection of Phytoplankton Phenology

Earlier when Warmer in mid-high latitudinal region

Fig. 4. Difference in timing of peak PP between the period 2006–2026 and 2081–2100 (where negative values indicate earlier peak timing). Only points where a 1-way ANOVA analysis showed no significant difference in the means of the 2 periods (significance at 5% level) are plotted.

(Henson et al. 2013, Biogeoscience)
Why Does Plankton Phenology Matter?
Trophic Match-Mismatch

Timing of spring bloom and the Eastern Scotian Shelf outer banks haddock fishery (Platt et al. 2003)

Mechanism: temporal match-mismatch bw/ bloom & larval development
How Does Phytoplankton Phenology Impact Zooplankton, and more?

- Climate
- Plankton
- Biogeochemical cycle
- Higher Trophic Levels
Outline

1. Phenological shift in LTL and its link to HTL in the Western North Pacific: study using long-term Zooplankton data.

2. New ocean provinces in the North Pacific based on the phytoplankton seasonality
Global Comparison of Zooplankton Time-series: SCOR WG125 (2005~2011)

Advantages in using zooplankton time-series
- Samples are preserved for decades
- Biological, chemical compositions of Zooplankton tell us environmental conditions integrated through seasons.

Zooplankton Time Series
in collaboration with SCOR Global Comparisons of Zooplankton Time Series (WG125)

World Zooplankton Map (WG125)  COPEPONTE Metabase

http://www.st.nmfs.noaa.gov/plankton/time-series

"Zooplankton-TS"
Temperature dependence of Zooplankton Phenology

“The most common phenology correlate is water temperature during and before the growing season, and the most common phenologic response to temperature is..”

“Earlier when and where warmer”....
Long-term Study in the Western North Pacific Zooplankton Phenology (1960s-1990s)

Odate Collection Data sets

Dominant Zooplankton

Peak Abundance Timing of Spring Zooplankton community

(Chiba et al, 2006, GCB)
Long-term Study in the Western North Pacific
Ontogenetic vertical migration of Neocalanus Copepods

Neocalanus species: mesopelagic spawning
=> Peak biomass is likely controlled by seasonal phytoplankton availability

Match or Mismatch?
H: Early bloom (longer bloom season) was “Good Match” For Neocalanus reproduction in the 90s.
Trophic Link Study using zooplankton Nitrogen Stable Isotope $\delta^{15}N$: Indicator of Trophic Levels and of PP availability as ZP food.

- PP Abundant (diatom dominated)
- PP Less Abundant (non-diatom dominated)

Omnivorous

$\delta^{15}N$: 2.5-3

$\delta^{15}N$: 2

$\delta^{15}N$: 1

$\delta^{15}N$: 0, 1$^+$ (2')

$\delta^{15}N$: 3.45$^+$, 2 (2')

$\delta^{15}N$: 1.8$^+$ (2'}
Long-term Study in the Western North Pacific
Nitrogen Stable Isotope Analysis

Neocalanus $\delta^{15}N$ declined ca. 3 ‰ decline = 1 trophic level

Indicating....

1. More Nitrate available in the 1990s
2. Copepods become more herbivorous and less omnivorous = more phytoplankton available

(Chiba 2012, NPAFC Tech. Rep.)
Long-term Study in the Western North Pacific Nitrogen Stable Isotope Analysis Link to HTL (Pink Salmon)

BIOMASS

δ^{15}N

Neocalanus biomass (yr)

Neocalanus & Eucalanus δ^{15}N

Pink Salmon δ^{15}N

Pink salmon catch

(Chiba 2012, NPAFC Tech. Rep.)
Summary
Plankton Phenology and Trophic Good Match in WNP during the 1990s

AL-PDO
Warming
Good Match
Good Match

Climate
Plankton
Higher Trophic Levels
Outline

2. New ocean provinces in the North Pacific based on the phytoplankton seasonality
To develop a new ocean provinces based on ecological and biogeochemical properties
NEOPS New Ocean Provinces

GOAL: Better management of Marine Ecosystem Services

① BGC Provinces

VOS Obs. Nutrients pCO2 (NIES, IOS)

Seasonal Variation

Satellite Ocean Colour Data

② Phytoplankton Provinces
NEOPS New Ocean Provinces based on the Seasonal Chl a Variation

DATA:
MODIS/Aqua (2003-2012), 8-day composites => Seasonal variation

K-means Clustering
w/ methods of Hartigan (1979) and Beale (1969)

Cluster Map (Chl a) 2003-2012 AVG

NS: No seasonal variation (CV < 0.1)
NEOPS Phytoplankton Provinces: 10 yrs
Climatology in Seasonal Timing

Note: Peak JD Range was examined for only clusters with seasonal variation (CV > 0.1)
Delineation of ecological provinces using ocean colour radiometry

Emmanuel Devred¹,²,*, Shubha Sathyendranath³, Trevor Platt²

Spring

Summer

Fall
NEOPS New Ocean Provinces: Boundary Shift

[Images of maps from 2003 to 2011 showing changes in ocean provinces over time.

Legend for the cluster map (Chl a) from 2003-2012 AVG:

- 1
- 2
- 3
- 4

Number of Clusters Counted 2003-2012

[Map showing the number of clusters from 2003 to 2012 with color coding for different numbers of clusters.]
NEOPS New Ocean Provinces: Boundary Shift

Interannual Variation in Phytoplankton Phenology in the Boundary Regions

Spring Peak Chl a (CV: area standardized)

Autumn Peak Chl a (CV: area standardized)

Seasonal Chl a Amplitude (CV: area standardized)
NEOPS New Ocean Provinces: Climate change and Boundary Shift

Which areas are more susceptible to which climatic systems?

PDO

NPGO

SOI

Spring Peak Chl a

Autumn Peak Chl a

Seasonal Chl a Amplitude

Spearman’s R

-1

0

1
NEOPS New Ocean Provinces: Climate change and Boundary Shift

Which areas are more susceptible to which climatic systems?

Spring Peak Chl a Timing

Autumn Peak Chl a Timing

PDO

NPGO

SOI
Ongoing analysis:
- Comparison to BGC Provinces
- Comparison to zooplankton distribution
Recommendation to Global Ocean Observation of Phenology

1. Zooplankton $\delta^{15}N$ as an EOV for Trophic Link (incl. phenological match-mismatch)

* Amino acid level $\delta^{15}N$ is the best, because it can detect variation in Trophic level regardless of $\delta^{15}N$ variation in phytoplankton and source water (Chikaraishi et al., 2010, Limnology and Oceanography: Method)

2. Observation in better spatial and temporal resolution in the boundary regions of the Phytoplankton Province.
TIMING IS EVERYTHING

Doctor, there's a chronometer in the arboretum that ceased working a year ago. It has been correct twice a day ever since. So you see, I do not doubt that you, too, can be...