Assessment of the relationship between timing of sea-ice retreat and phytoplankton community size structure derived from remote sensing in the Bering and Chukchi Sea shelf region

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Introduction

Study area:
Chukchi & Bering Seas shelf region
(160–180°W, depth < 100 m)
- Seasonal ice zone
- Complex water mass
- Shallow bottom depth
- Massive algal production during spring–summer
- Supports high benthic & grazers biomass
- Grazing field for higher trophic level animals

One of the most biologically productive sea in the world

Pelagic-benthic coupled ecosystem

High primary productivity by diatoms
Efficient export
Low grazing pressure by zooplankton

Bering–Chukchi shelf region

Introduction

Recent climate change
(e.g., change of sea-ice dynamics, ocean warming)

Pelagic-benthic coupled ecosystem

Ecosystem structure change??

Changes in ecosystem have been reported
- Northward shift in the species distribution in the Bering Sea (Grebmeier, 2011 & references)
- Increase of pelagic primary production in the Arctic Ocean (Arrigo et al., 2008; 2011)
- Less productive in the Beaufort Sea (Nishino et al. 2011)
- Further evaluation of impacts on the ecosystem is required
- Ocean color remote sensing can contribute to monitoring of spatio-temporal responses of phytoplankton to the environmental changes


**Introduction**

**Timing of sea-ice retreat & phytoplankton bloom**
- Contribute to bloom timing (e.g. Hunt et al. 2002, Perette et al. 2010)
- Important for recruitment of secondary producers (e.g. Hunt et al. 2002, 2011)
- the retreat and bloom timing are changing (Kahru et al. 2010, Ji et al. 2012)
- Retreat timing can alter summer time algal composition (Fujiwara et al. 2014)

Little is known about the Bering & Chukchi Sea shelf region (e.g. timing and magnitude)

**Aims**

_The size & production are important factor for energy transport to higher trophic levels_

- How phytoplankton community size structure responses to change of sea-ice retreat timing and related environmental variables??
- How the community size structure and the retreat timing affect annual primary production??
Materials & Methods

Development & application of new ocean color algorithms

- Ocean color remote sensing can be a powerful tool to assess spatio-temporal response of phytoplankton to climate change ⇔Arctic water is optically complex (Cota et al. 2003, Matsuoka et al. 2007, 2011, Naik et al. 2013)

- **Absorption based Primary productivity model (ABPM)**
  (Hirawake et al. 2011-PB, 2012-ICESJMS)
  →Estimates primary productivity optimized for the Pacific side Arctic waters

- **Size derivation model (SDM)**
  (Fujiwara et al. 2011-BG)
  →Estimates phytoplankton community size composition (%Chla>5μm) for the western Arctic waters using optical properties (i.e. spectral absorption and backscattering)
Materials & Methods

Overview of the data processing and analysis

SeaWiFS & MODIS
$R_{rs}(\lambda)$

SeaWiFS & MODIS
PAR

AVHRR & MODIS
SST

NCEP/NCAR
Heat Flux

SSMI
Sea Ice Concentration
Daily, 9-km

Onset of sea-ice retreat
Open Water Area
Length of ice-free days

Daily %Chl>5µm
Daily $PP_{eu}$

$spring$ %Chl>5µm
$spring$ $PP_{eu}$

$spring$ SST
$spring$ Heat Flux

14-day average after sea-ice melt for each pixel

Annual Primary production
Materials & Methods

Spatial correlation analysis

1998  1999  2000  2013
Retreat timing  %Chla_{>5\mu m}  SST

Calculate rank-correlation coefficient for every one by one pixel between the 16-year time series of sea-ice retreat timing, phytoplankton variables and environmental variables.

Assess how phytoplankton size & production vary with sea-ice retreat timing.
Results & Discussion

Distribution of correlation coefficient dominates (~70% of the area) in the shelf region (~18% was significant (p<0.05))

Earlier ice-retreat leads increase of larger phytoplankton (e.g. diatoms) after sea-ice retreat

Distribution of negative correlation coefficient dominates (~70% of the area) in the shelf region (~18% was significant (p<0.05))

It is suggested that some control factors change corresponding to the sea-ice retreat timing
  - Mechanism of Nutrient supply ??
  - Under water light ??

Results & Discussion

Why earlier sea-ice retreat causes increase of larger phytoplankton??

Heat flux & SST: a proxy of stratification

- 84% of the area showed negative $p$ for heat flux, and positive $p$ for SST (81%)
  ⇒ Earlier sea-ice retreat causes colder SST and larger heat flux
  - i.e., The early retreat delays stratification due to less heat input, and vice versa
    (low air temperature & weak radiation during early melted season)
  - Continuous nutrient supply from below can be expected in the early retreat years during spring

- Under-ice bloom is likely to occur in the late retreat years
  - Sufficient light penetration into under ice can be expected in late retreat years
    (thin ice and strong radiation near summer solstice)
  - Utilization of nutrients by under-ice bloom before open water bloom in late retreat years

(Arrigo et al., 2012, Lowry et al. 2014)
Results & Discussion

What contributes to annual primary production in the shelf area?

Distributions of correlation coeff.

- Open-water period controls APP especially in the northern part of the shelf (e.g., Arrigo et al. 2008, 2011, Pabi et al. 2008)
- Phytoplankton size composition (higher productivity of large groups) during spring is also important especially in the Bering Sea shelf region

- Positive (p<0.05)
- Negative (p<0.05)

(%Chla>5µm vs APP) (length of open-water period vs APP)
Summary

Late retreat years

April  May  Jun  Jul

Sufficient light penetration

Heating

Rapid warming & stratification

Ice-algal/under-ice bloom??

Nutrient utilization

Open-water bloom (Short duration)

Decrease of larger phytoplankton

Euphotic depth

Mixed layer depth

Summary

Early retreat years

April  May  Jun  Jul

Sea ice

- Less light penetration
- Slow warming & stratification

Euphotic depth

- Mixed layer depth
- Less nutrients utilization

Open-water bloom
  (Long duration)

InCREASE OF LARGER PHYTOPLANKTON

Heating
Conclusion & Future works

• Timing of sea-ice retreat contributes to phytoplankton community size composition during spring
  – Shoaling speed of mixed layer depth
  – Under-ice and/or ice-algal bloom ⇔ open-water bloom
• Not only the length of open-water period but also spring phytoplankton size structure (productivity) contribute to annual primary production especially in the southern part of the shelf area
• Remote sensing is a powerful tool to clarify spatial relationship between environmental and phytoplankton variables

Future works
• Evaluation of the bloom mechanism (in-situ observation / modeling)
• Assessment of the contribution to annual PP of summer and fall algal community and production (cf. Occurrence of fall bloom is increasing (Ardyna et al. 2014))
• How the timing & magnitude of the bloom affect higher trophic level organisms?? (Zooplankton, Fish larvae, Benthos...,)
Thank you for your attention!