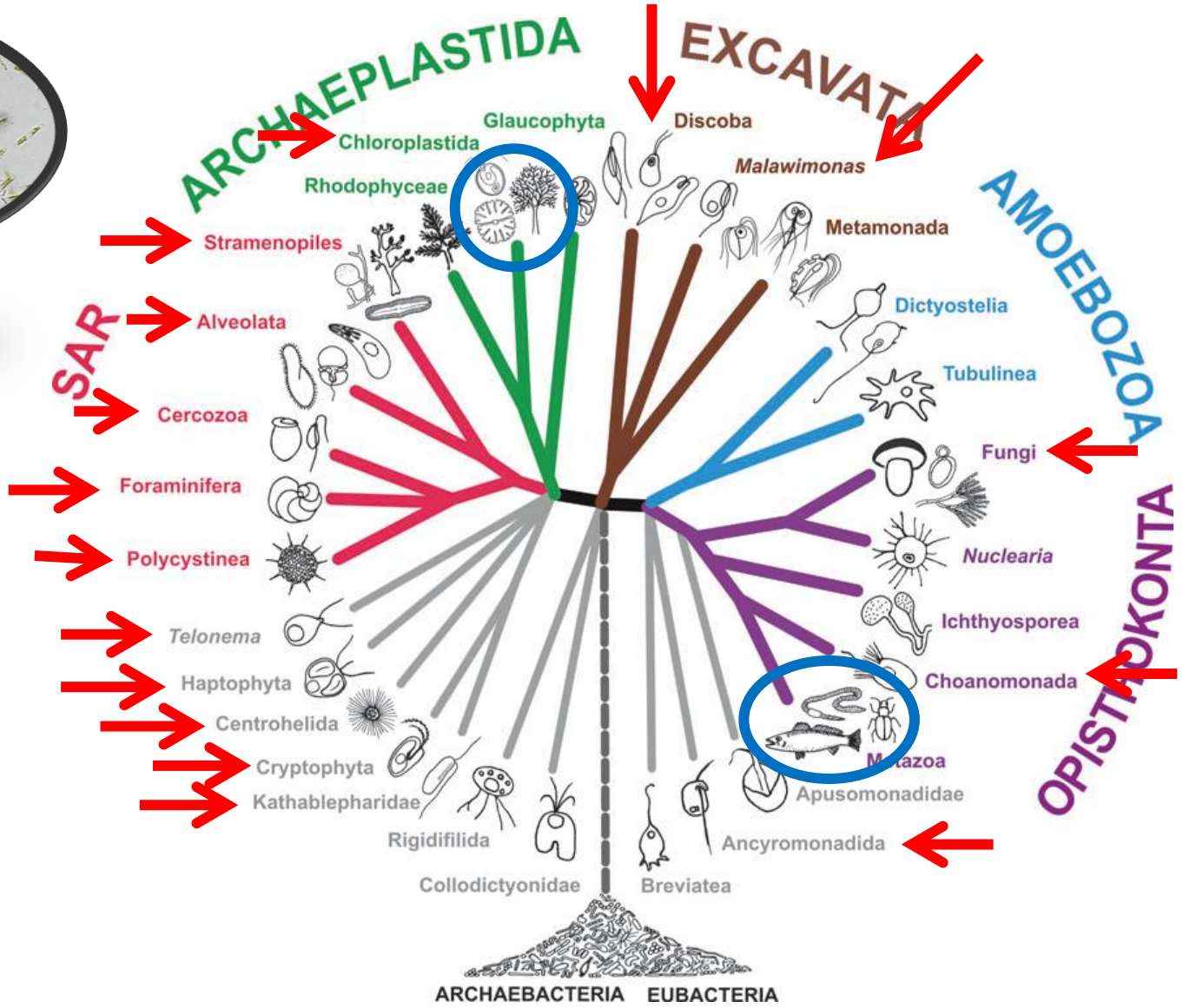
Review of current knowledge about life under sea ice and consequences for this in an ice landscape in change

Philipp Assmy

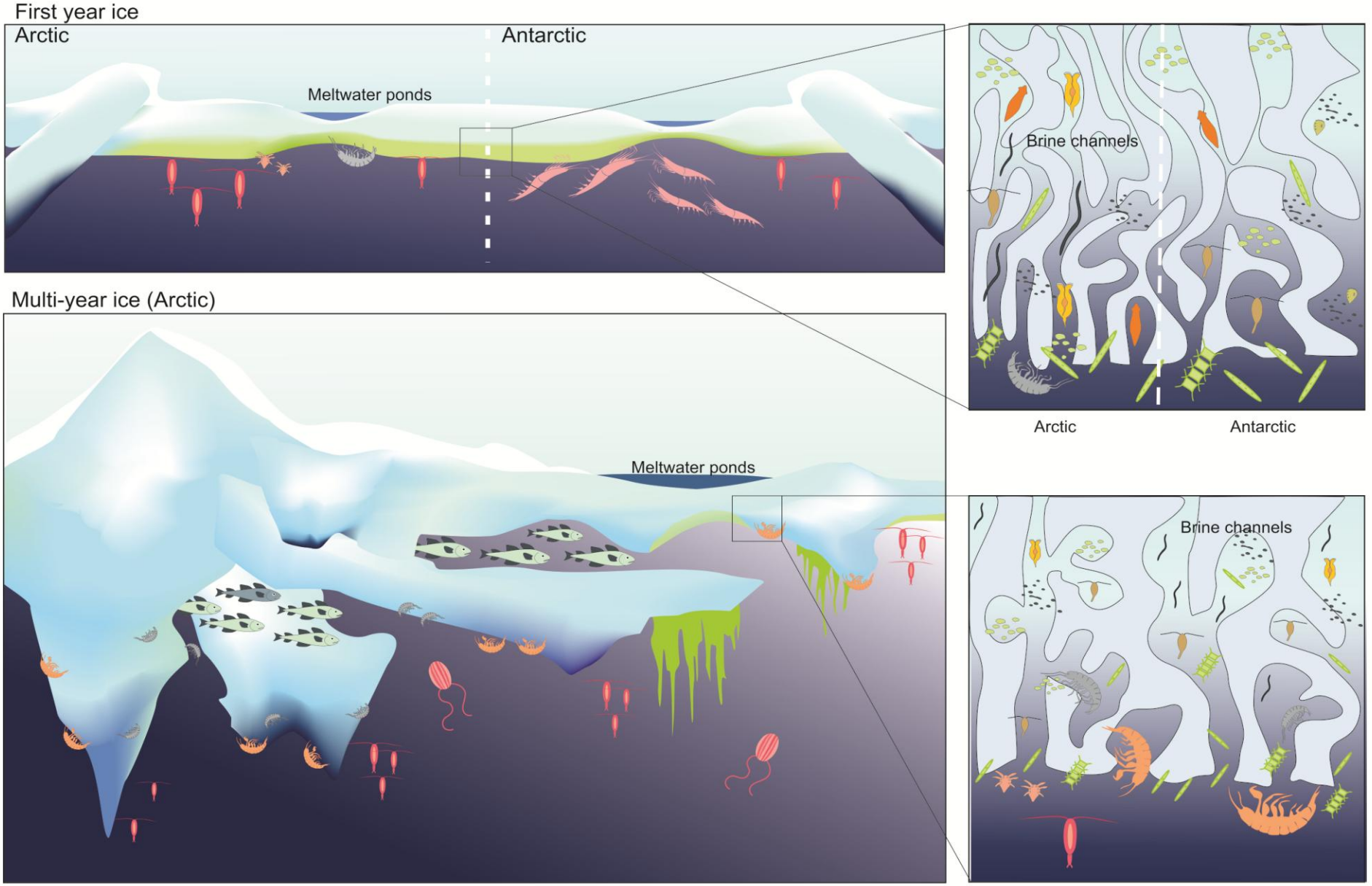
Norwegian Polar Institute

N-9296 Tromsø, Norway

The tree of life



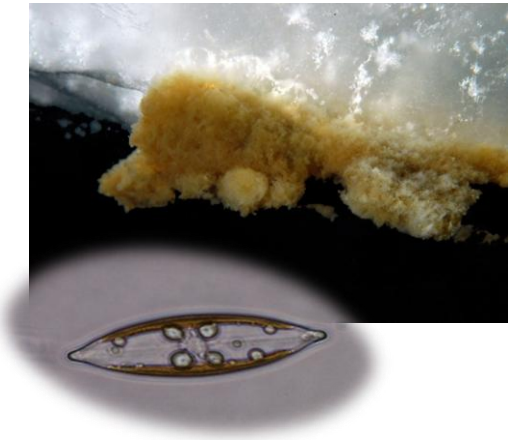
Adl et al. 2012 The Revised Classification of Eukaryotes

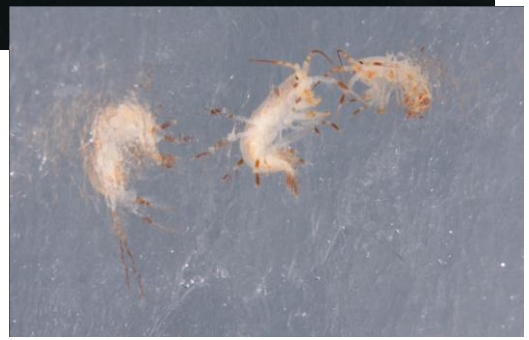


Hunt *et al.* (in prep.)

Sea ice biota

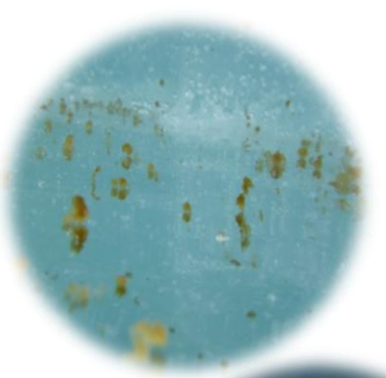
- Microbes
- Ice algae
- Meiofauna
- Macrofauna
- Polar cod
- Zooplankton (ice-associated)





Simplified Arctic marine food web

Sea-ice algae and phytoplankton are the base of the Arctic marine ecosystem



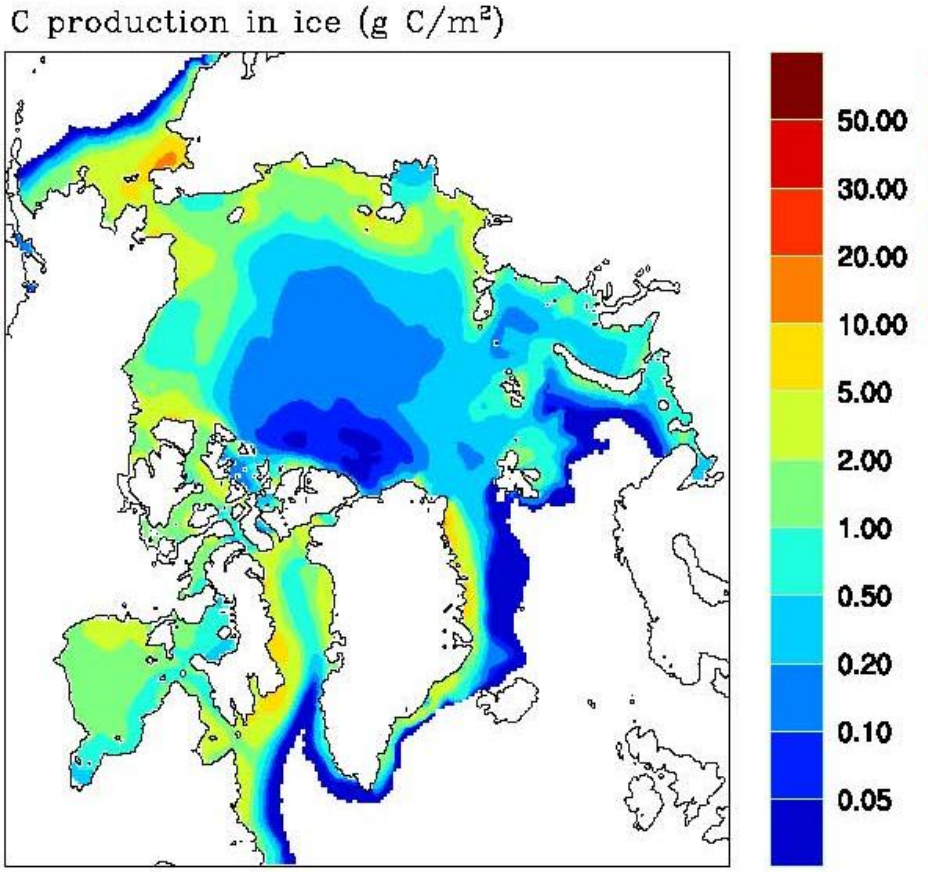





Under ice photos: Peter Leopold

Arctic primary production

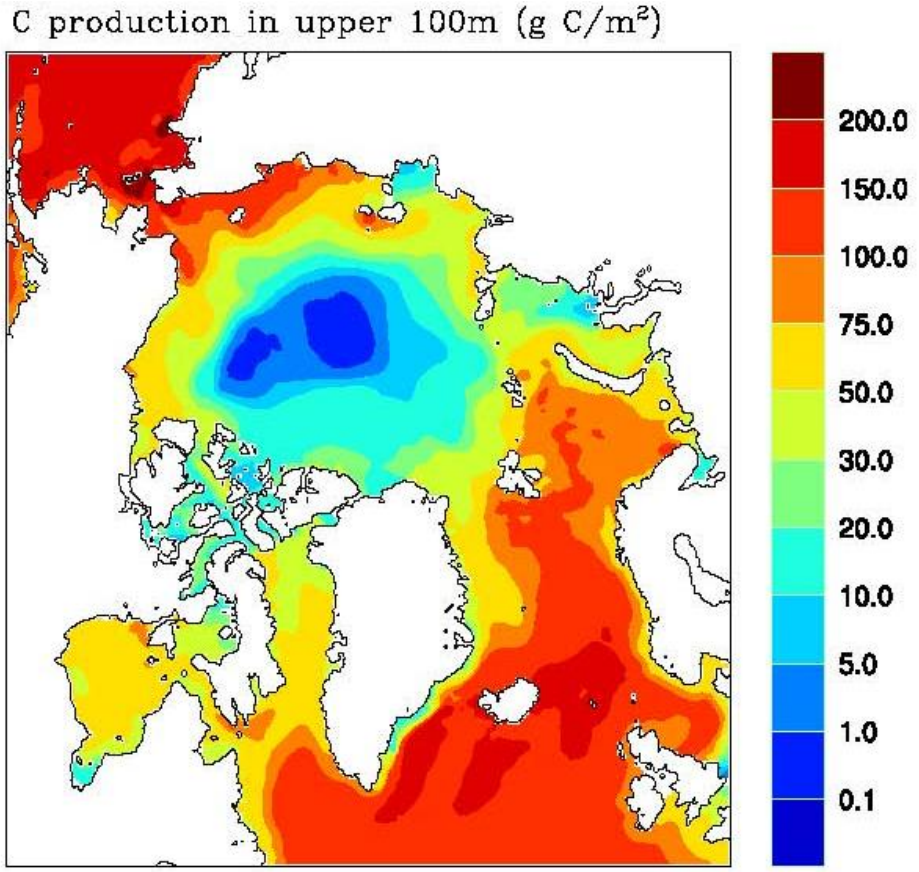
Ice algae



Model: 21.3 Tg C yr^{-1}

Multi-observational: 9-73 Tg C yr^{-1}

Phytoplankton

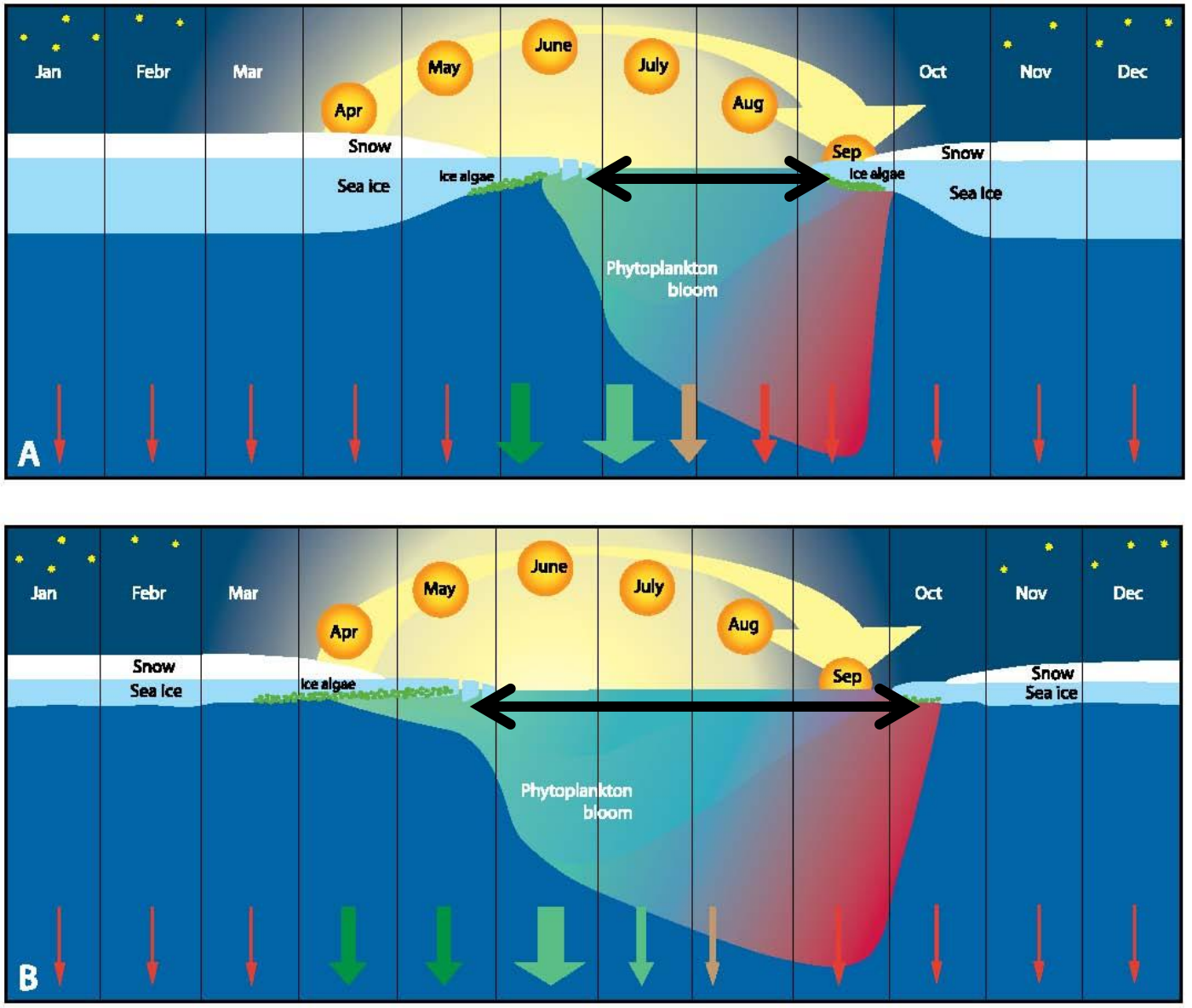


Model: 413±88 Tg C yr^{-1}

Satellite derived: 419±33 Tg C yr^{-1}

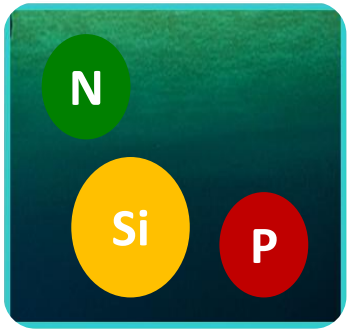
Jin et al. 2011

Temporal extension of the future seasonal ice zone



Wassmann and Reigstad 2011

Controlling factors of Arctic algal biomass and growth



Light

Snow cover

Ice cover

Melt pond cover

Clouds

Nutrients

Stratification

Winds

Upwelling

Riverine input

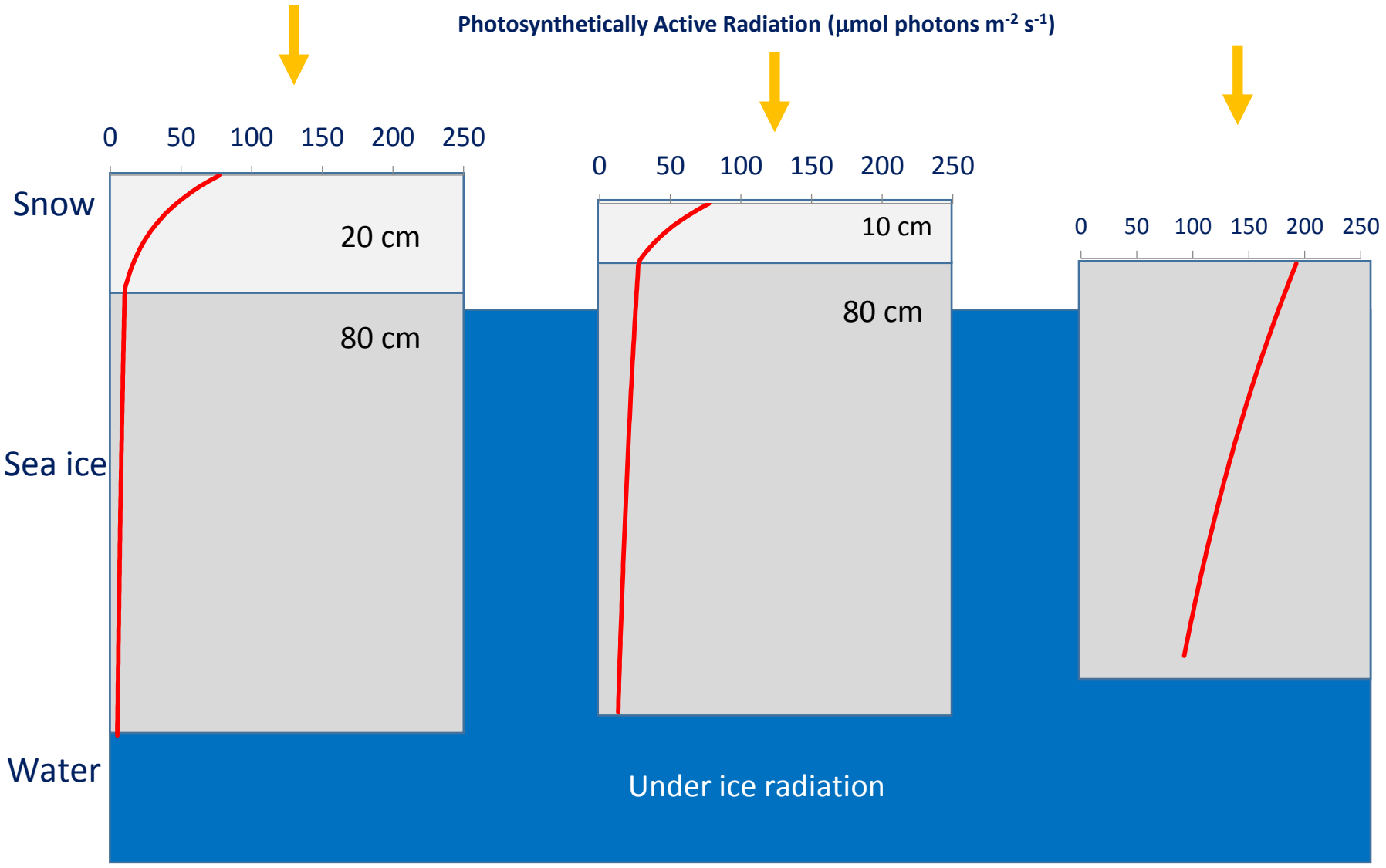
Grazing

Timing

Food quality

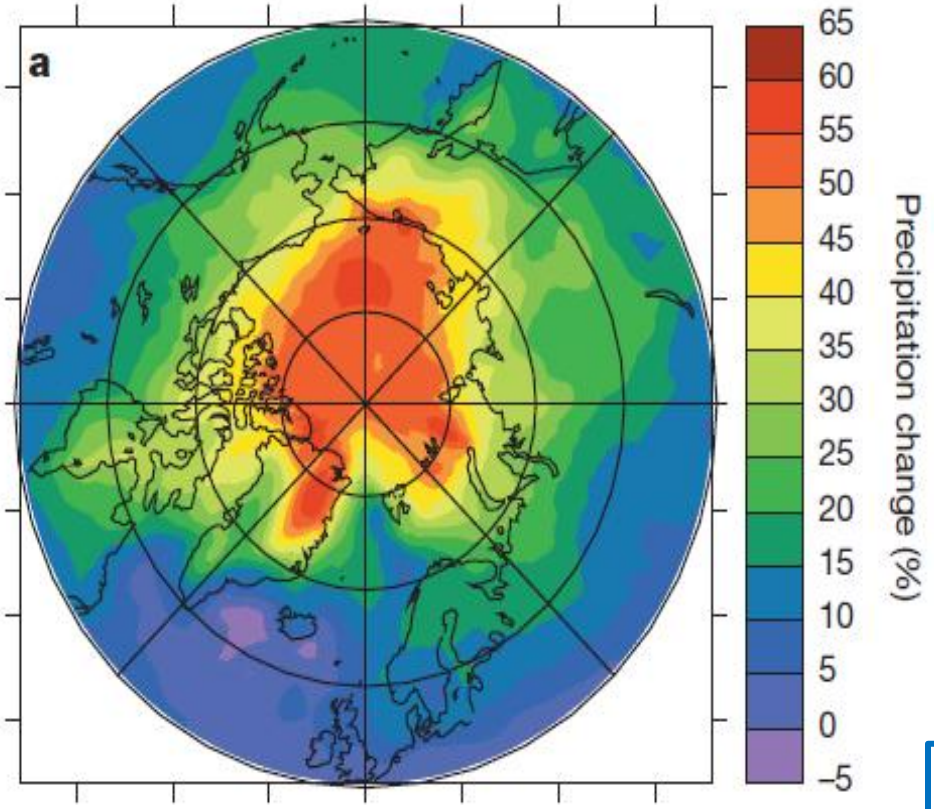
Nursery habitat

Incoming radiation



Changes in snow precipitation and accumulation on sea ice

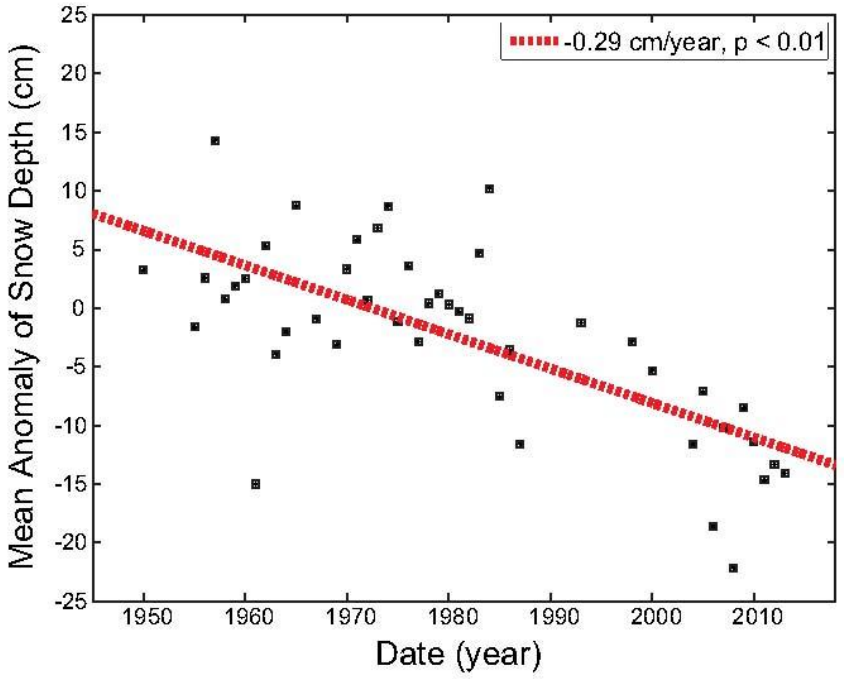
Model predictions



Precipitation is expected to **increase** by **50%** in the Arctic Ocean.

Bintanja&Selten 2014

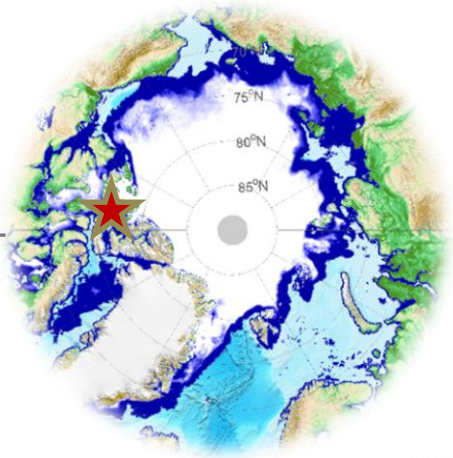
Airborne radar snow measurements

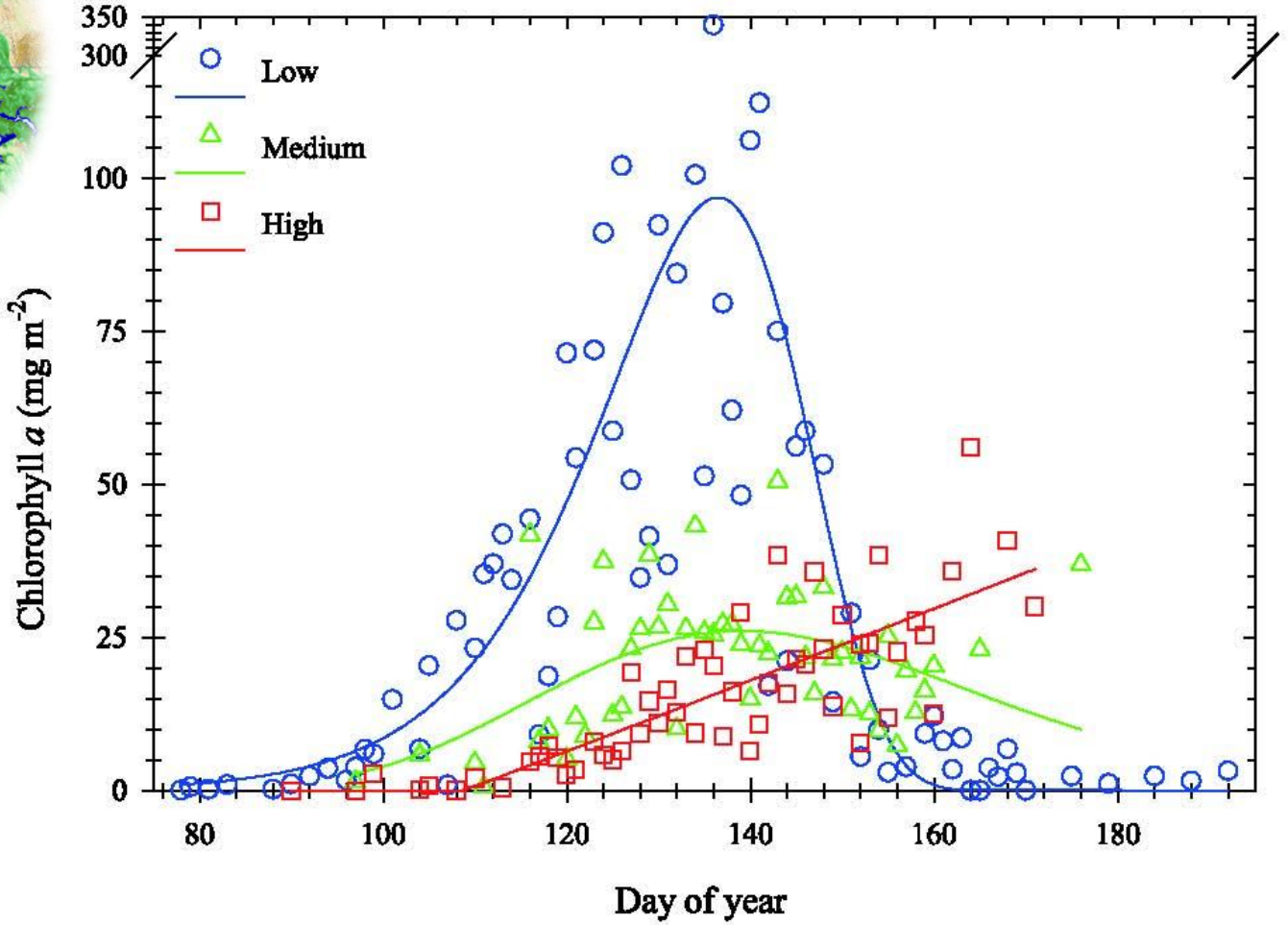


Decadal decline in spring snow depth on sea ice

Webster et al. 2014

Snow cover: the single most important predictor of ice-algal biomass

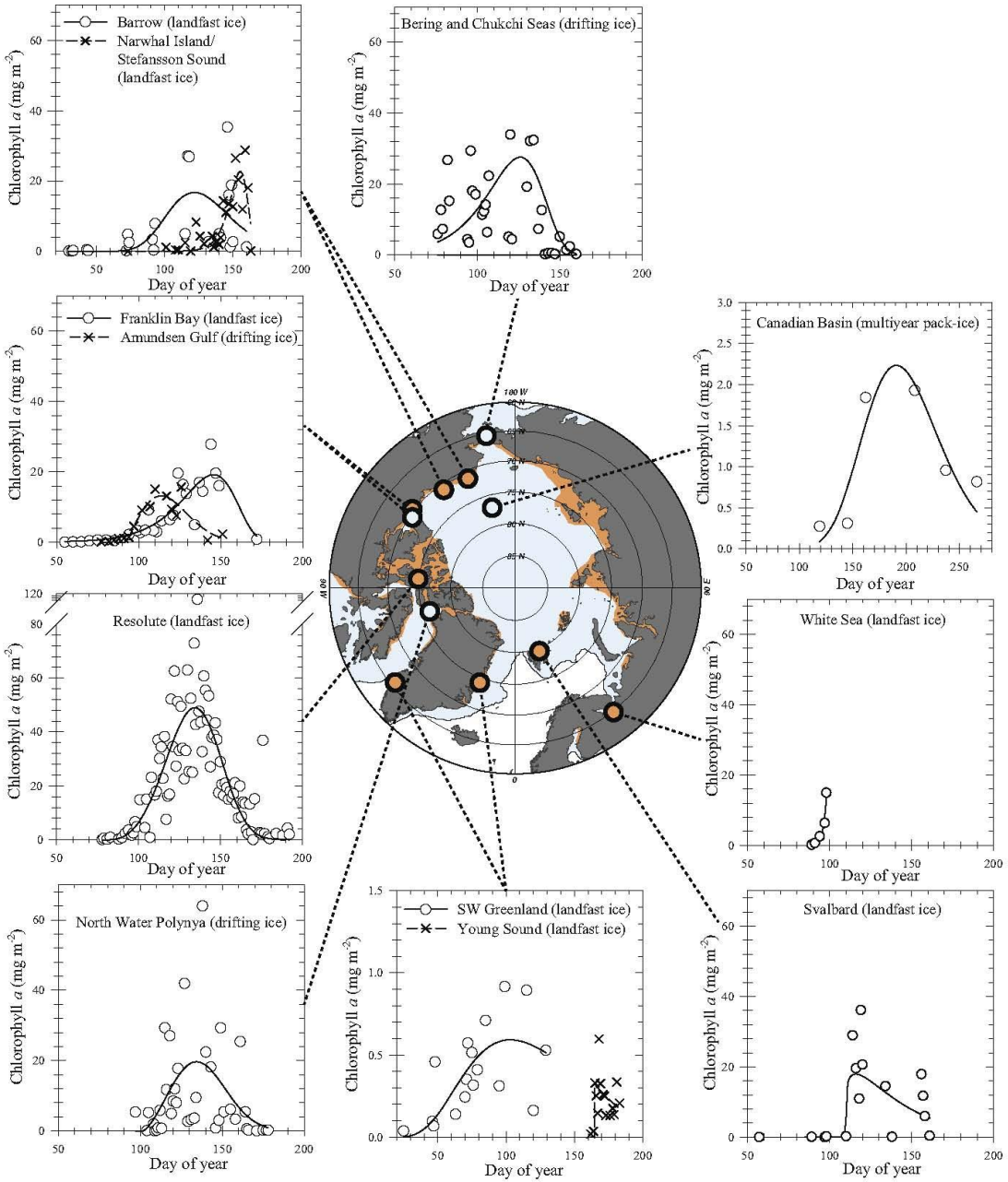




Seasonal development of ice-algal chlorophyll concentrations at Resolute Bay, Canadian Arctic under low (blue), medium (green) and high (red) snow cover.

Leu et al. 2015

Ice-algal time-series around the Arctic



No significant correlation between bloom start, peak, and end dates and latitude, ice freeze-up and ice break-up dates.

Leu et al. 2015 *Prog. Oceanogr.*

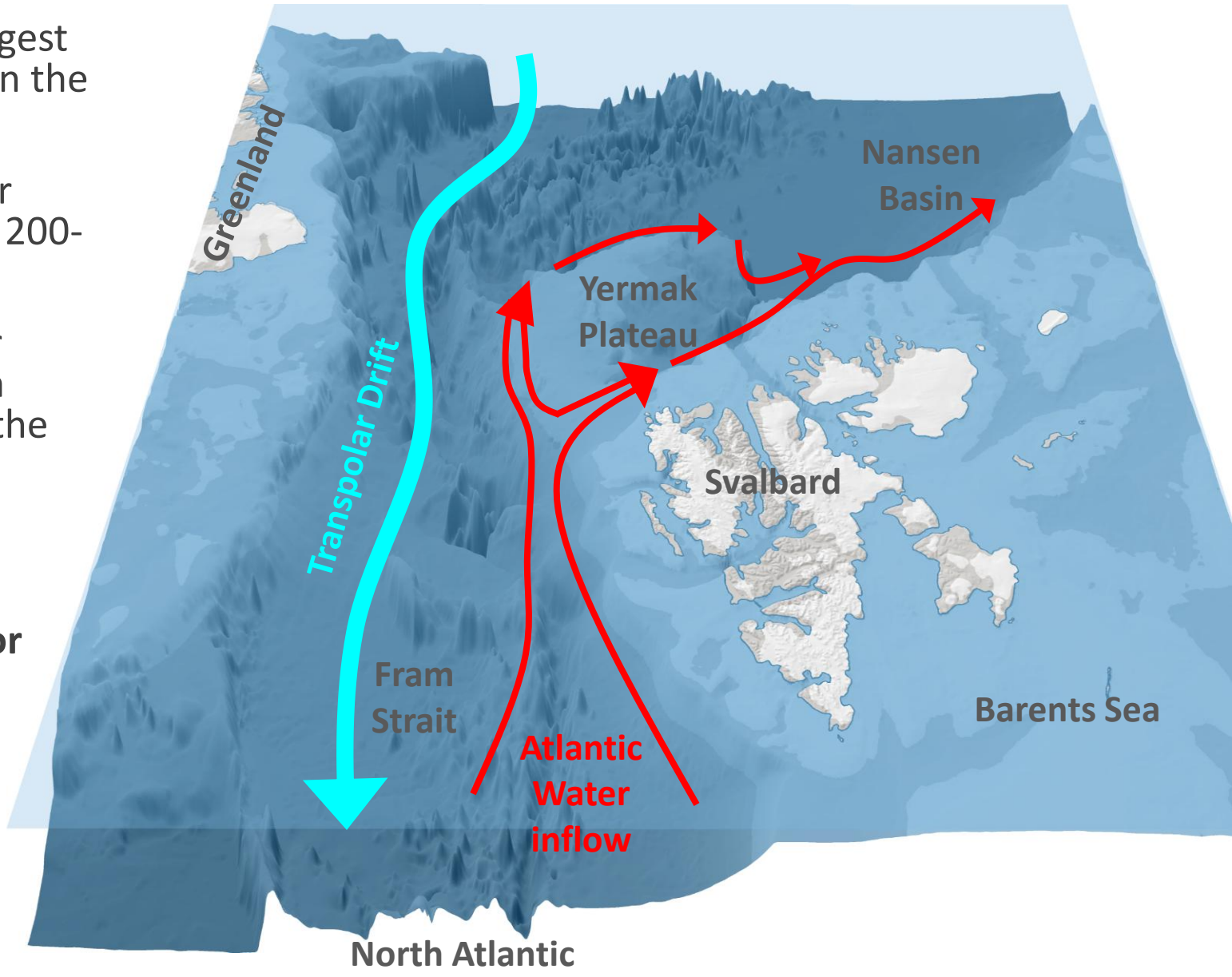
Atlantic Water inflow

- Atlantic Water inflow is the largest source of heat in the Arctic Ocean.

- Atlantic Water found between 200-800 m depth.

- Atlantic Water inflow has been warming since the late 70s.

=> What are the consequences for Arctic sea ice algae?

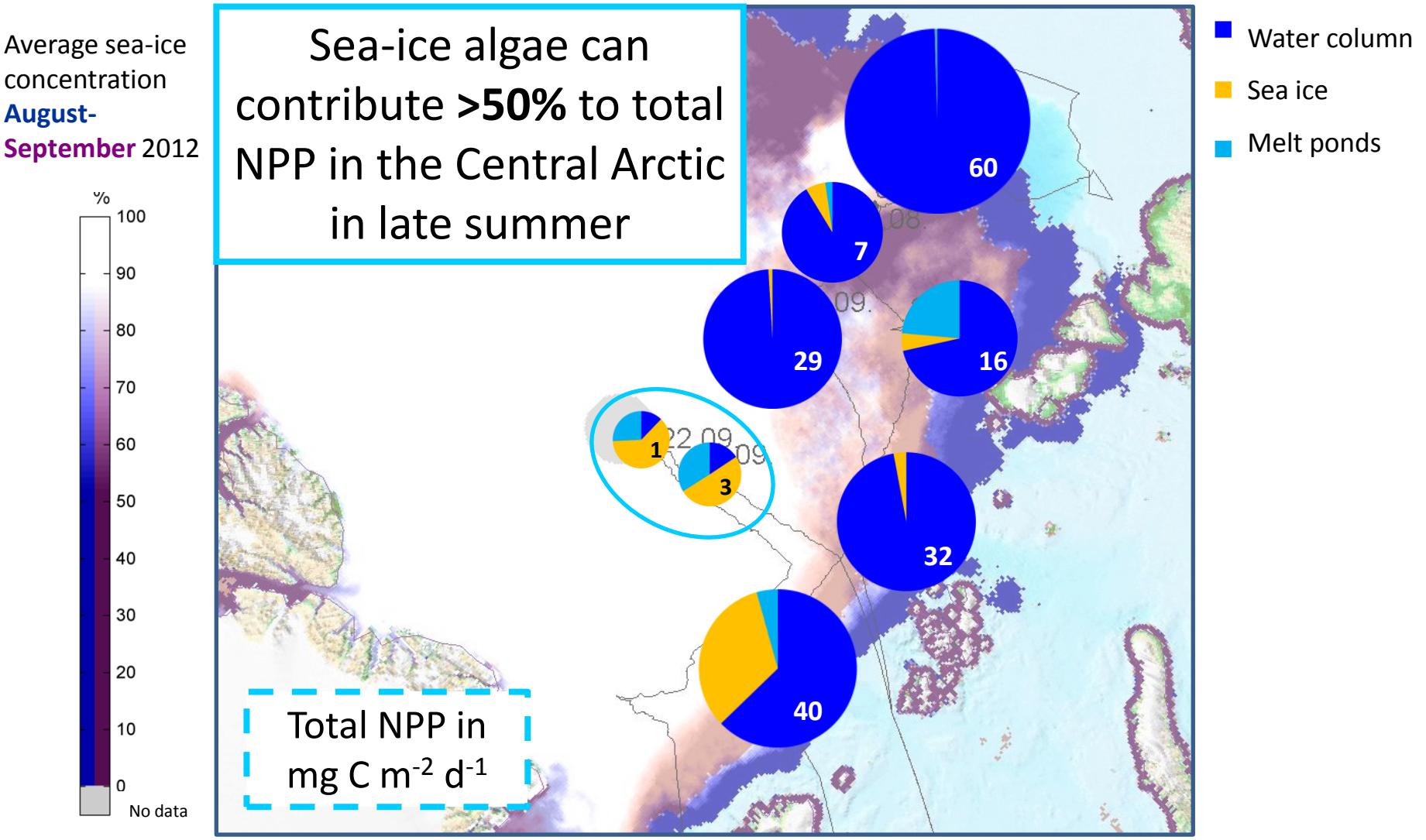


Ice-algal standing stocks for different Arctic areas

Geographic area n = number of studies	Chl *a* standing stock (mg m^{-2})
Pacific sector n = 5	**0.2 - 304**
Canadian Arctic Archipelago n = 20	**0.01 - 711**
Baffin and Hudson Bay n = 8	**0.1 - 800**
Barents and Kara Seas n = 6	**0.01 – 48**
Greenland Sea and Fram Strait n = 5	**0.1 – 3.3**
Central Arctic Ocean n = 3	**<0.01 - 14**

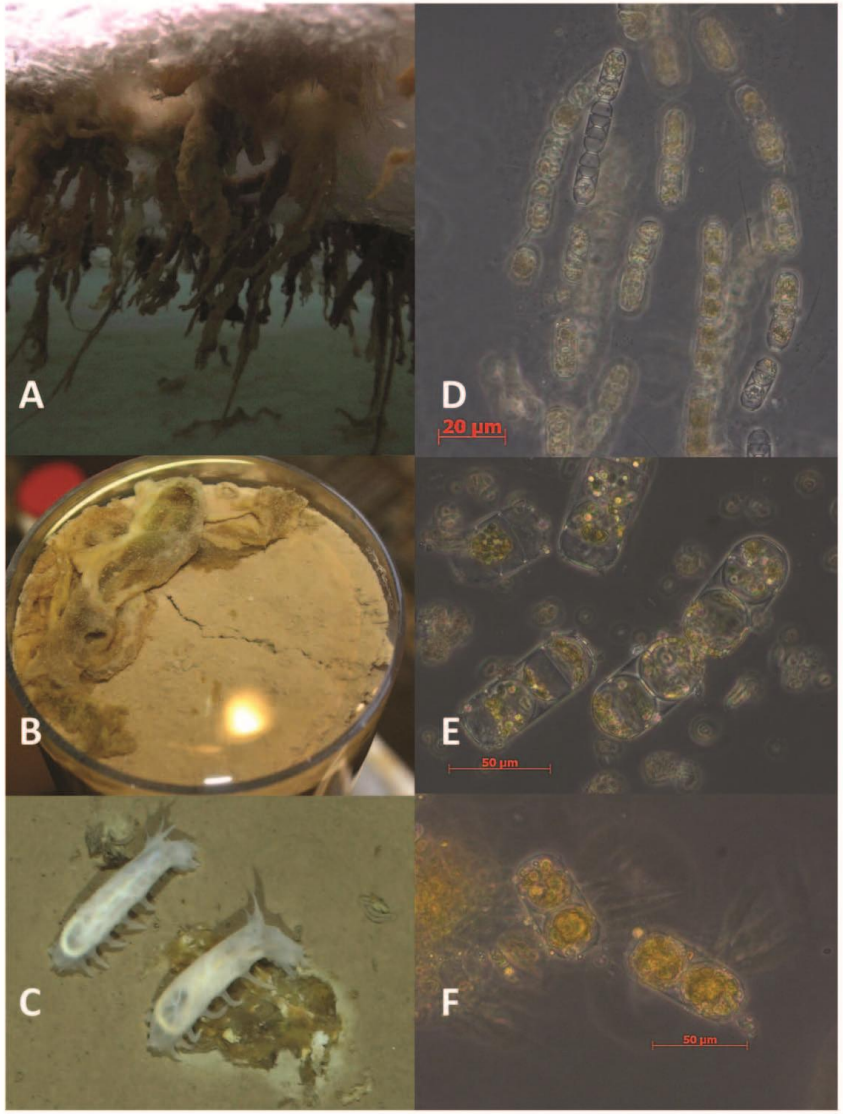
Leu et al. 2015

Depth integrated *in situ* net primary productivity (NPP)



Fernandez-Mendez et al. 2015

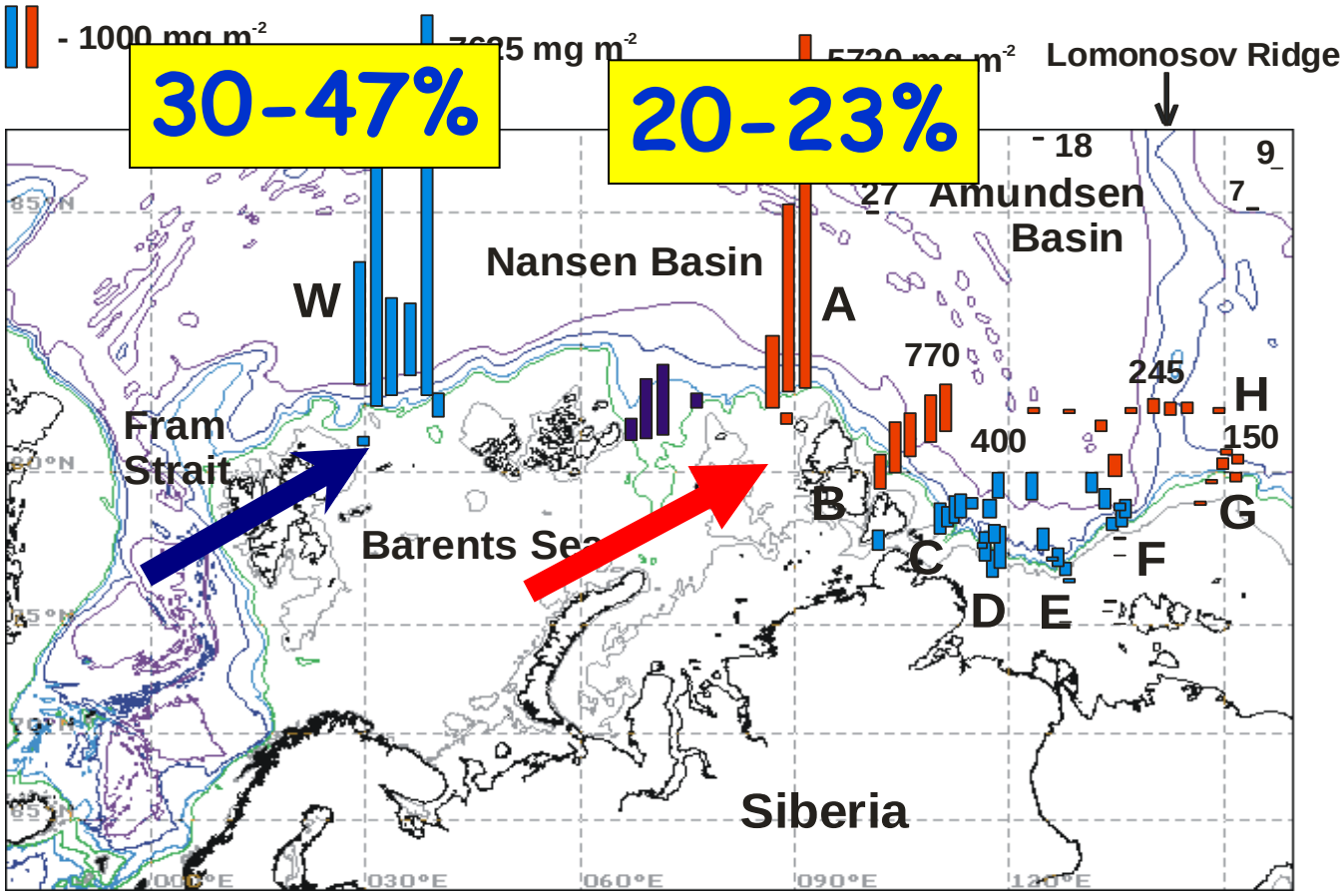
Melosira arctica drives cryo-pelagic-benthic coupling in the central Arctic Ocean



Boetius et al. *Science* 2013

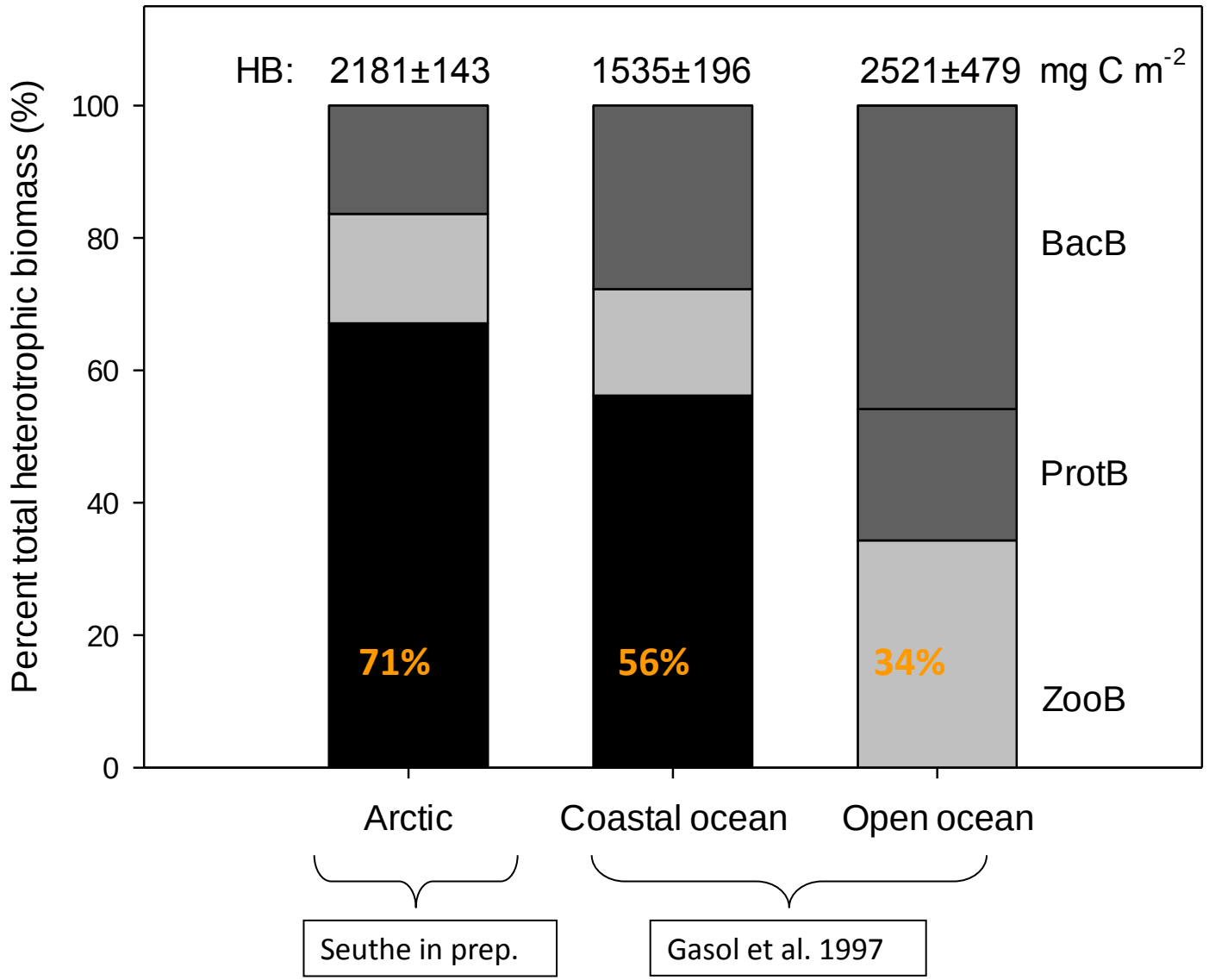
High overall biomass along the Eurasian slope is related to contribution of allochthonous (advected) zooplankton, in particular, to advection of the Atlantic copepod *Calanus finmarchicus*

Biomass,



K. Kosobokova,Shirshov Institute of Ocanology, Moscow

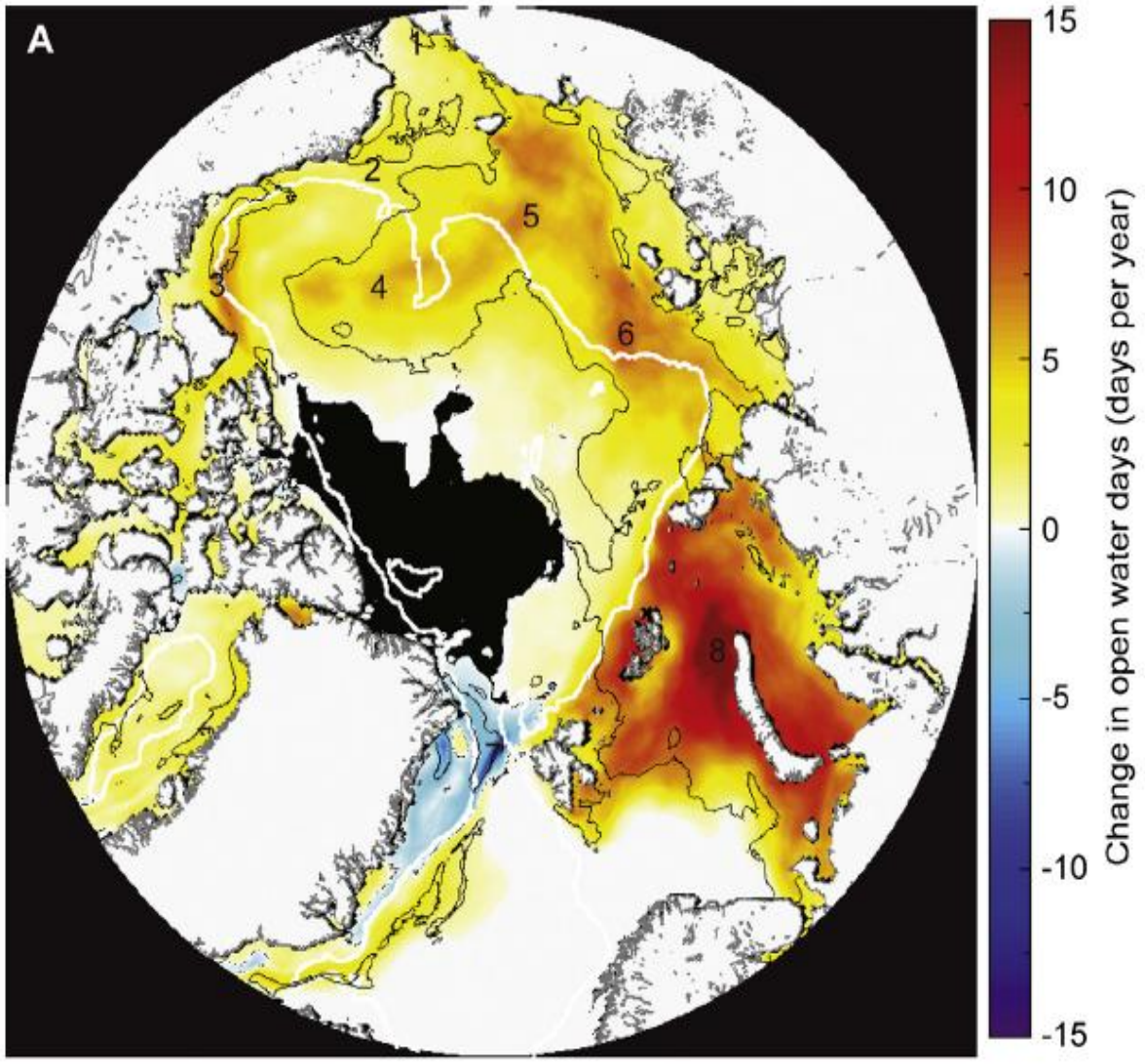
High proportion of “expatriates” in the Arctic Ocean



Seasonality in the Arctic Ocean

Due to earlier sea-ice retreat the amount of open wáter days per year has increased since 1998.

In the marginal ice zone, north of Svalbard the rate of change is very fast (10 open water days per year)



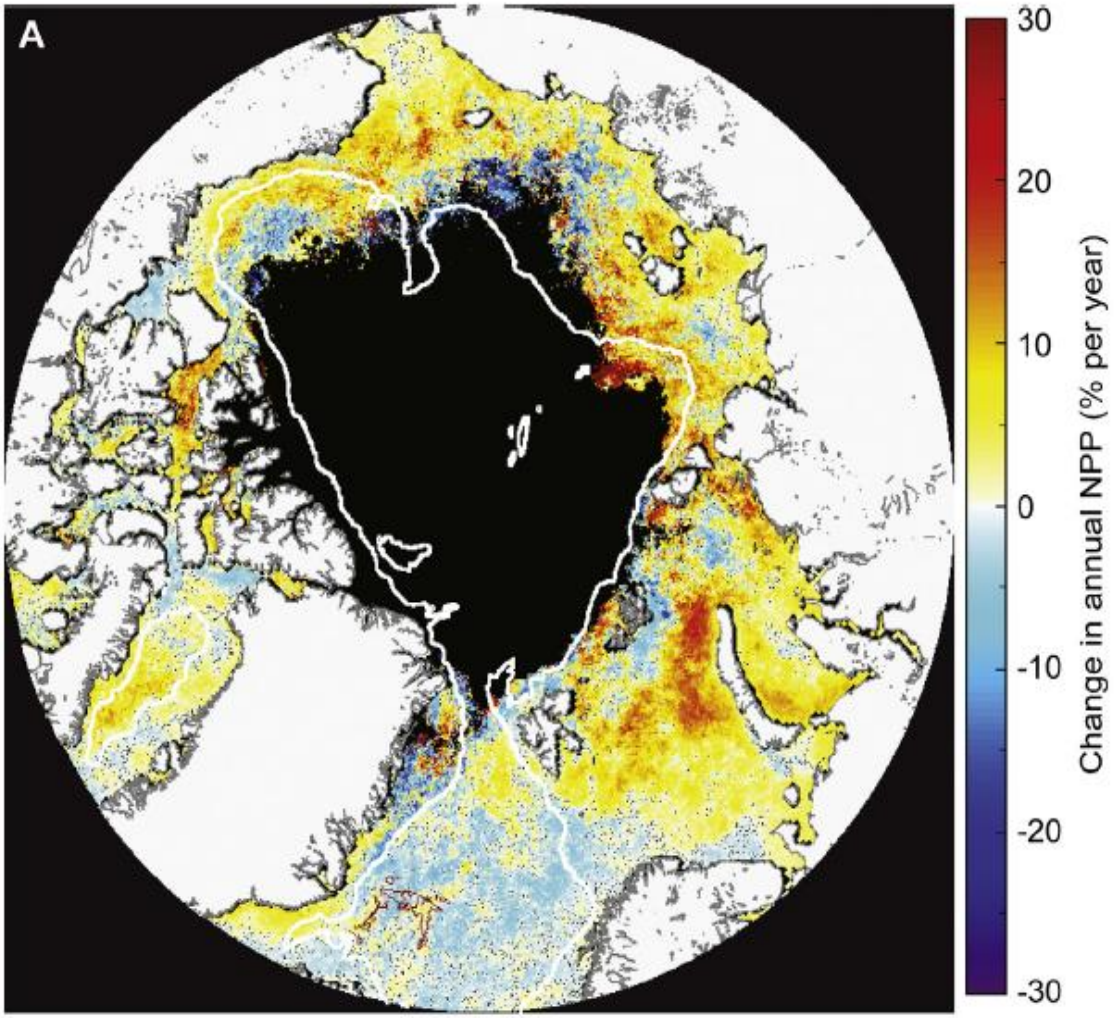
Arrigo & van Dijken 2015

Light and productivity

Continued increases in Arctic Primary Production

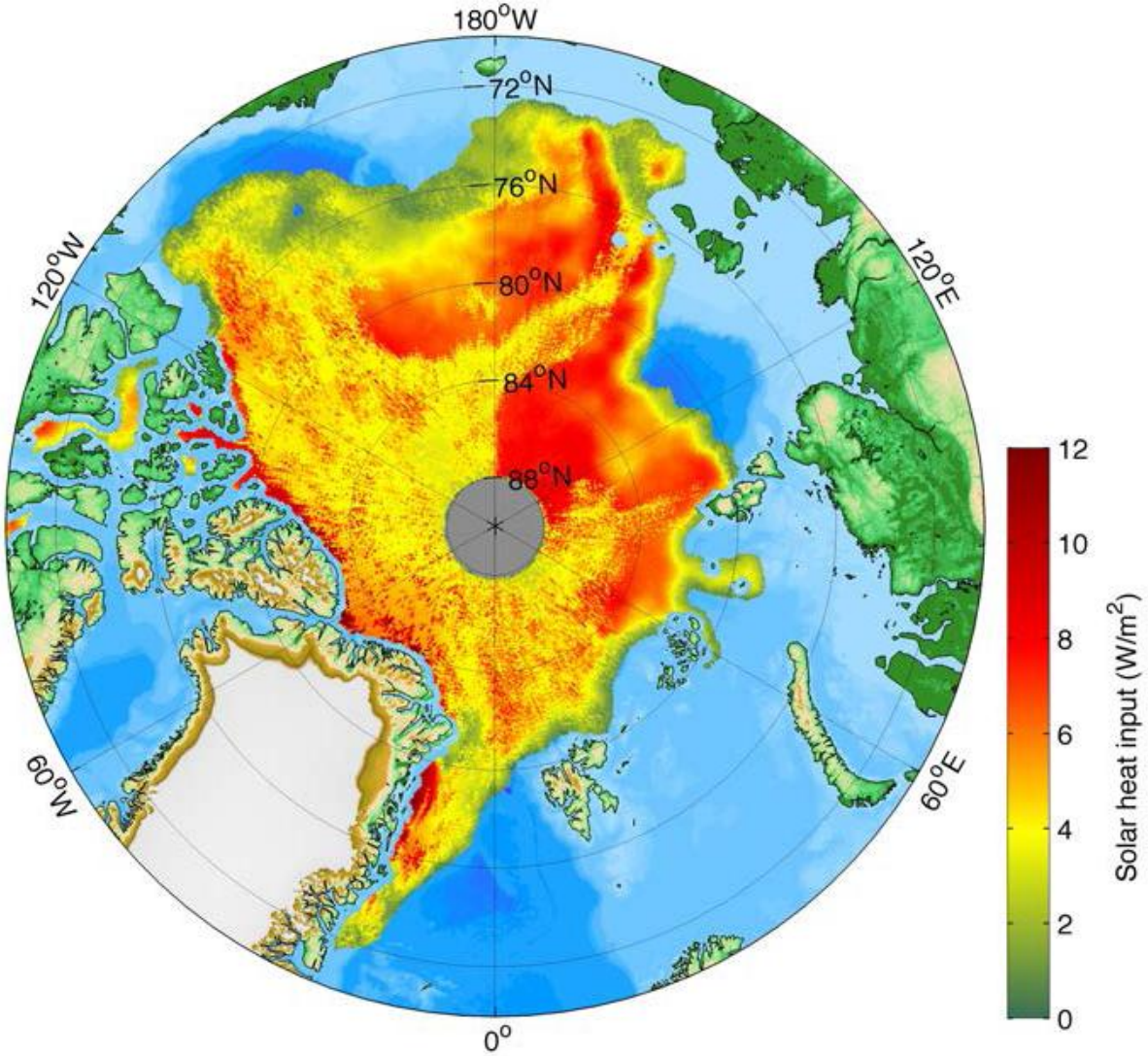
Open water receives more light and is therefore more productive if nutrients are available.

Phytoplankton production is **increasing** due to an increase in open water.



Arrigo & van Dijken 2015

BUT..what is going on below the ice??

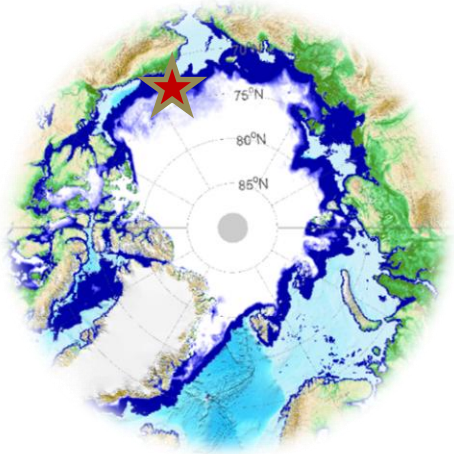


"Enlightening" the Arctic Ocean: Solar heat input into the Arctic Ocean through sea ice in August 2011. This map only considers fluxes through sea ice, excluding fluxes through open water

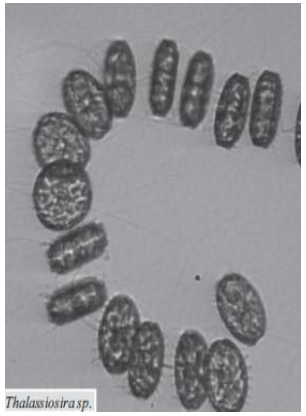
Nicolaus et al. 2012 *GRL*

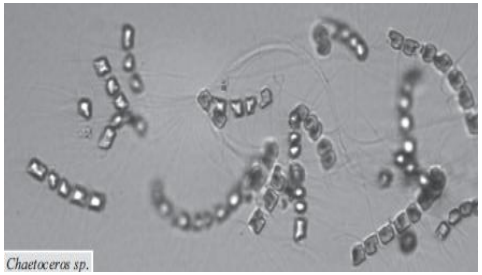
Massive under ice bloom in the Chuckchi Sea

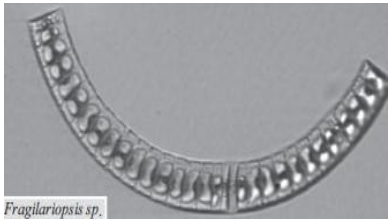
Meereisportal.de



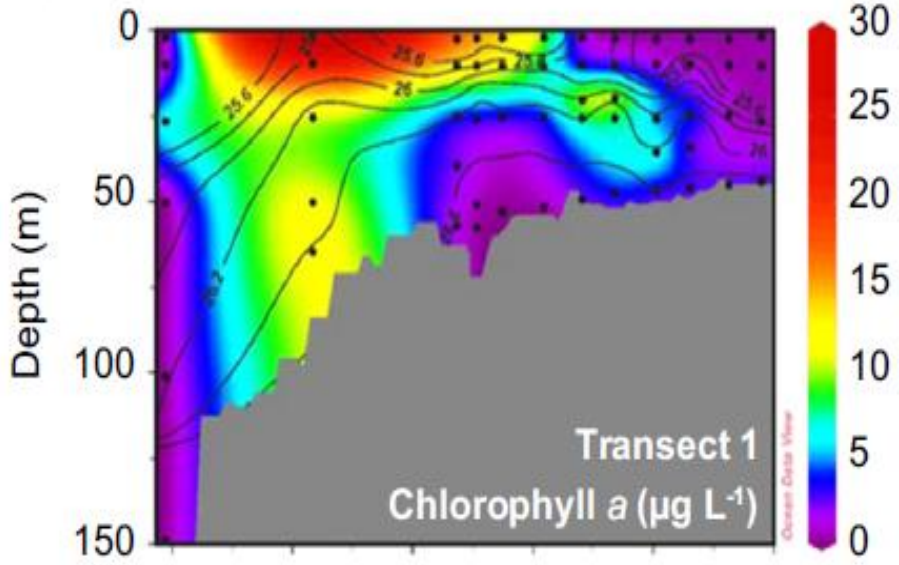
July 2011



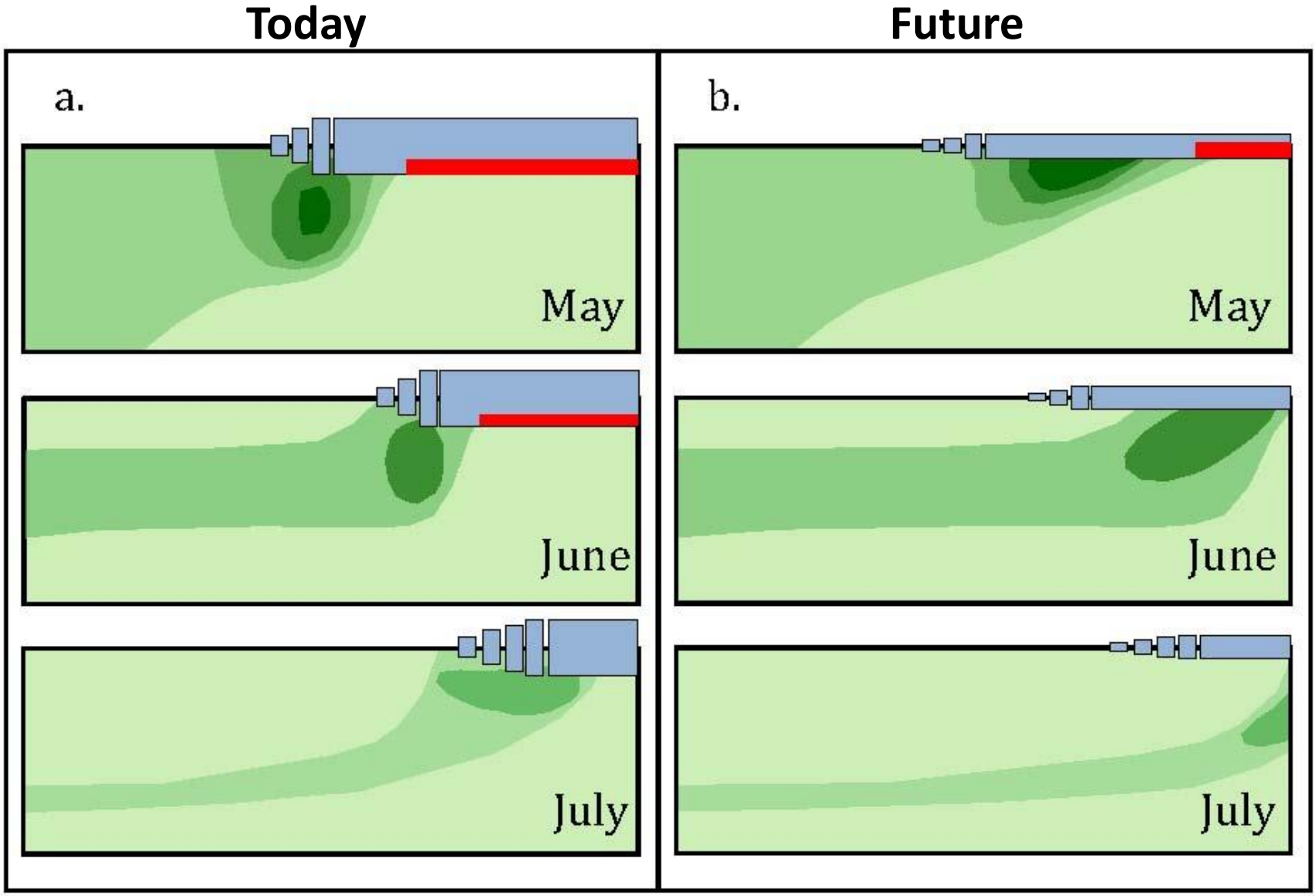




Laney&Sosik 2014



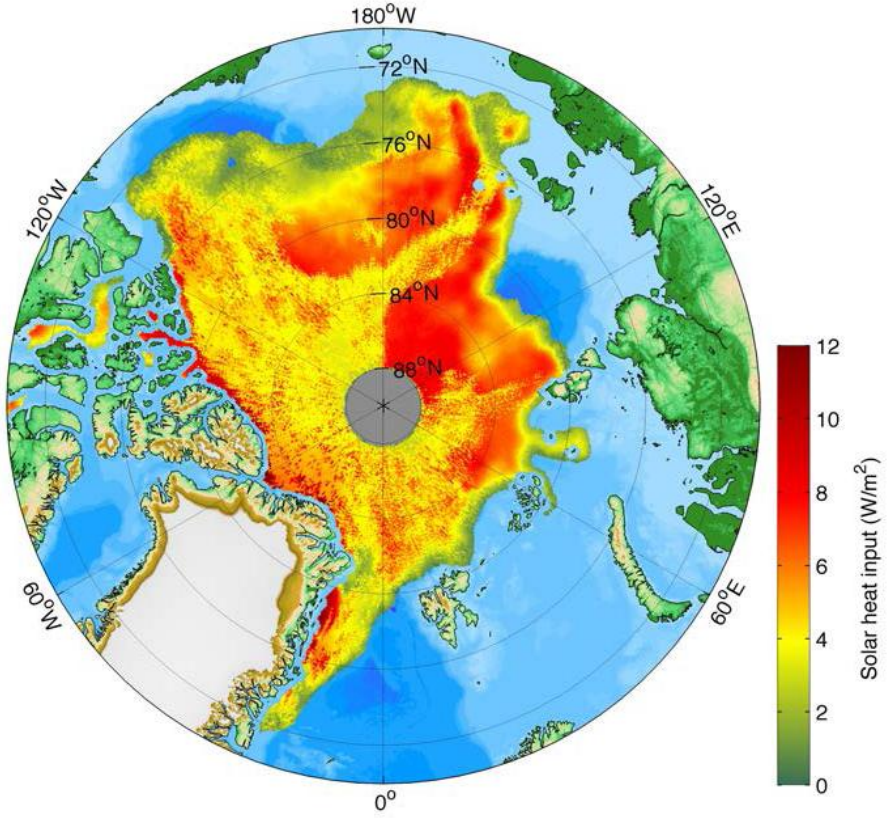
Arrigo *et al.* 2012



Spring bloom progression in the MIZ (a) and future scenario with thinner ice (b).

Barber et al. 2015

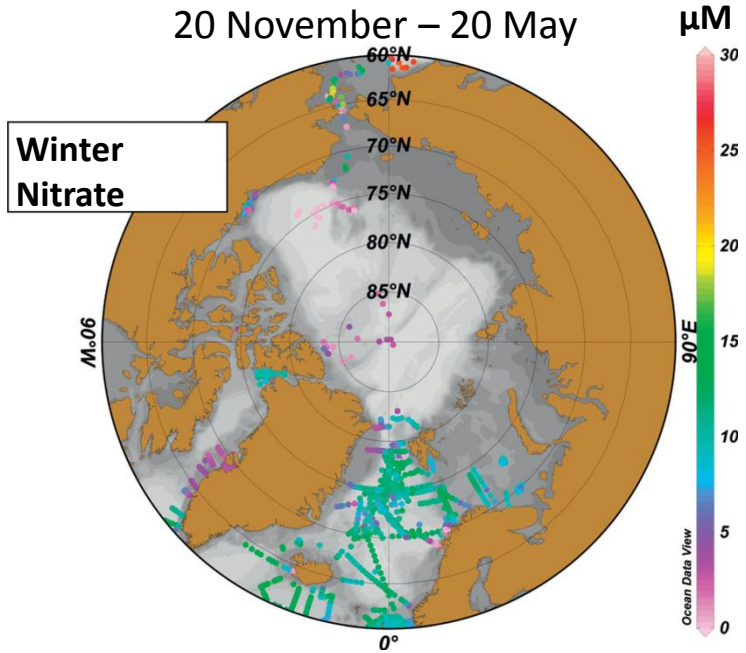
The limiting role of nutrients



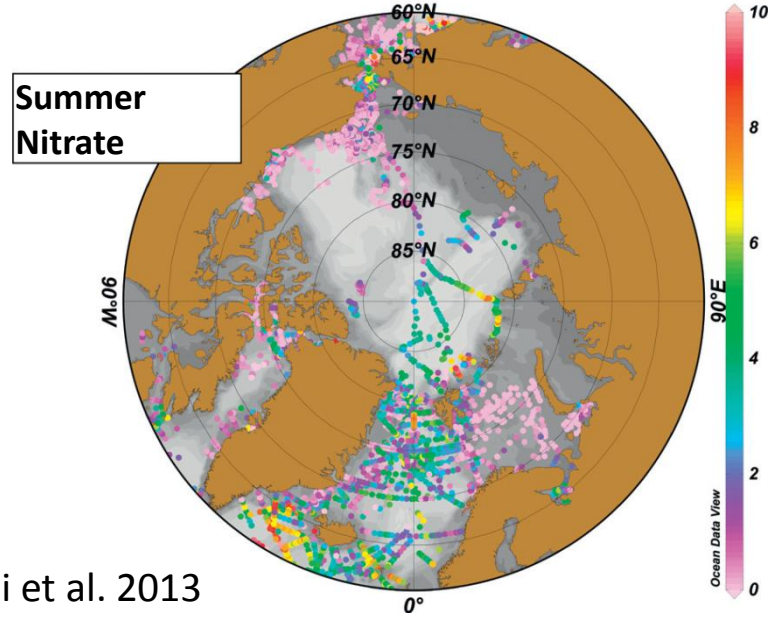
Solar heat input into the Arctic Ocean through sea ice in August 2011. This map only considers fluxes through sea ice, excluding fluxes through open water

Nicolaus et al. 2012

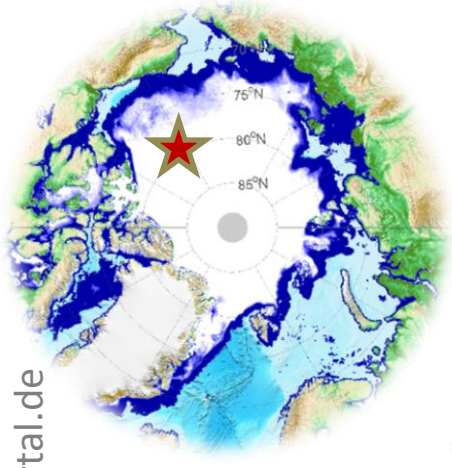
20 November – 20 May



15 June – 20 October

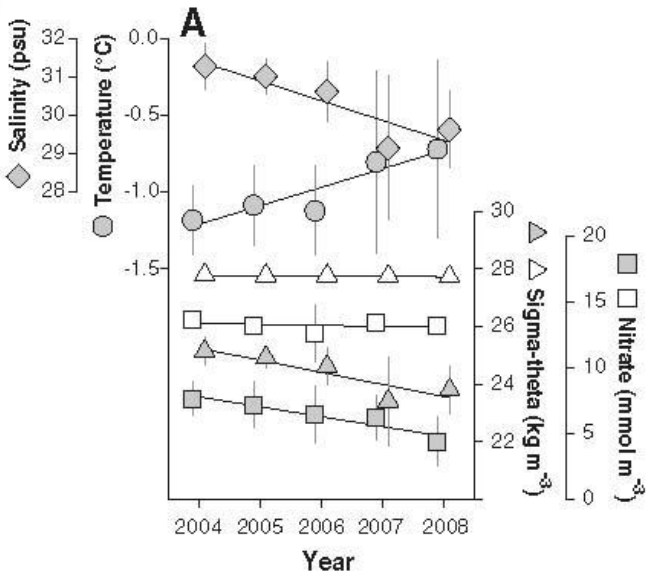


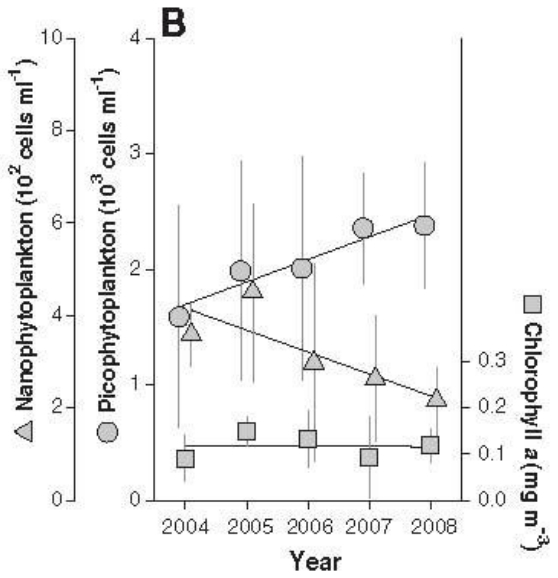
Codispoti et al. 2013

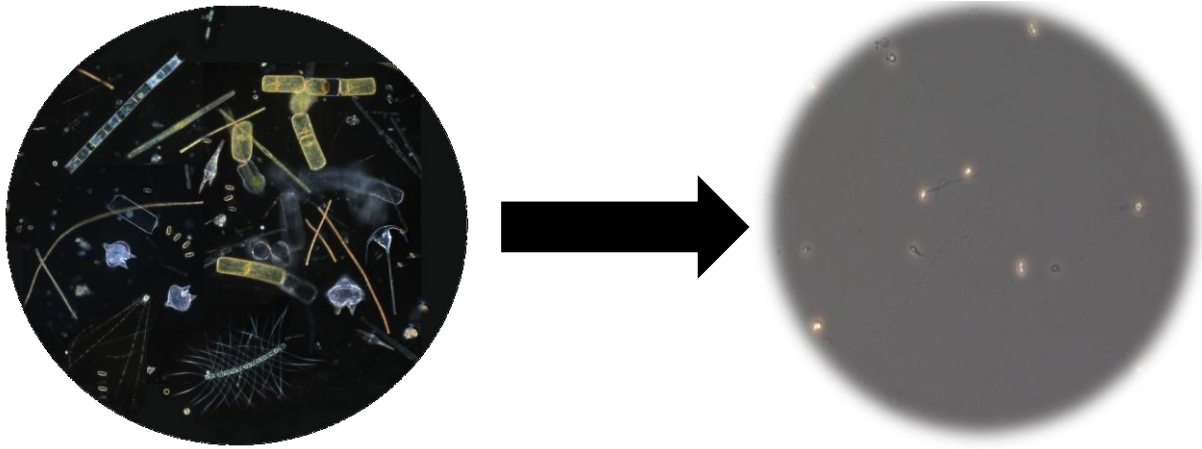


Smallest Algae Thrive As the Arctic Ocean Freshens

William K. W. Li,[1]* Fiona A. McLaughlin,[2] Connie Lovejoy,[3] Eddy C. Carmack[2]

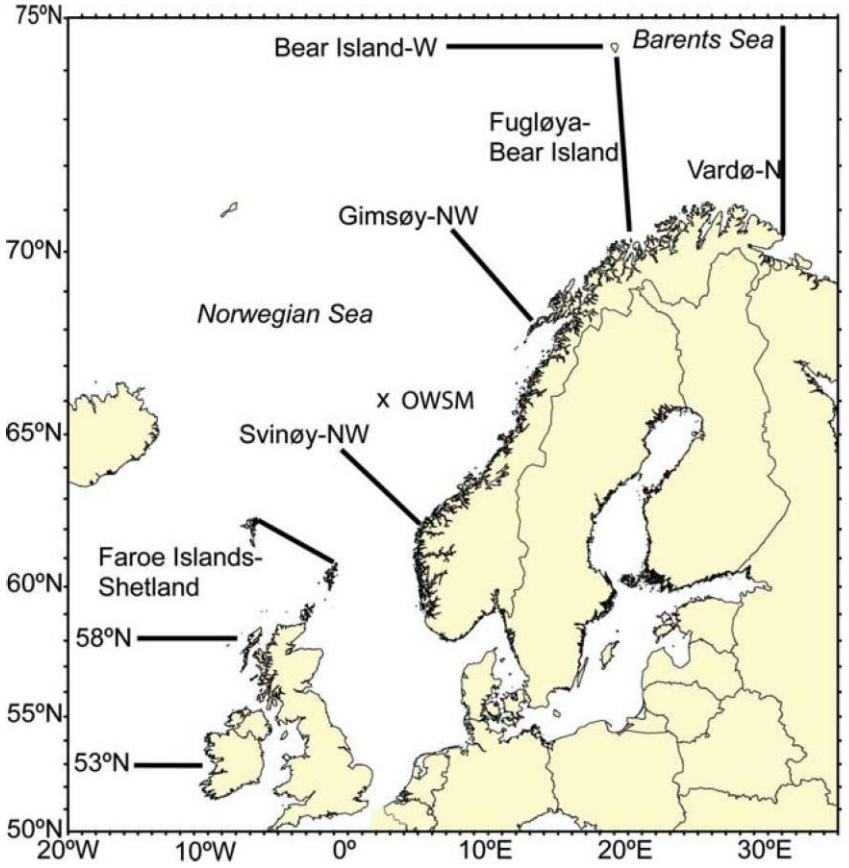


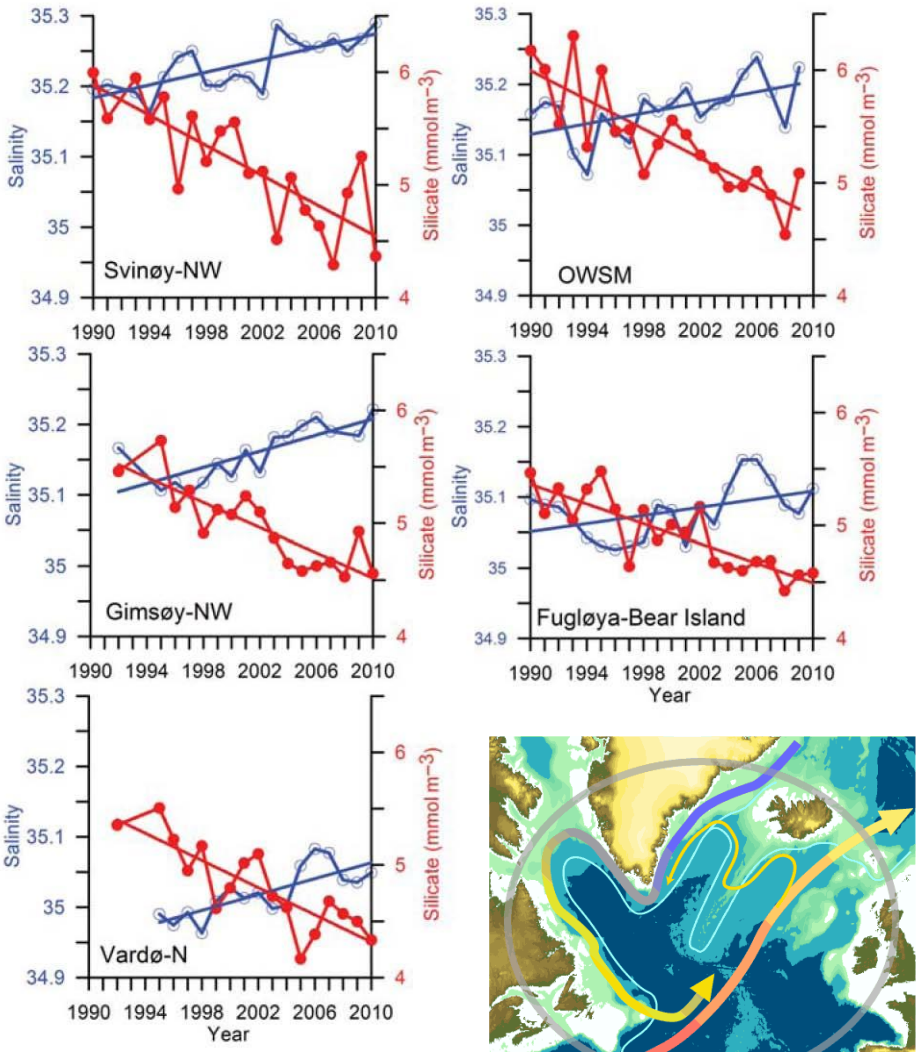




Increased freshening and warming of the surface ocean might amplify the permanent halocline and favour a regenerating community dominated by small phytoplankton.

25% decrease in winter water silicate over the last 20 years





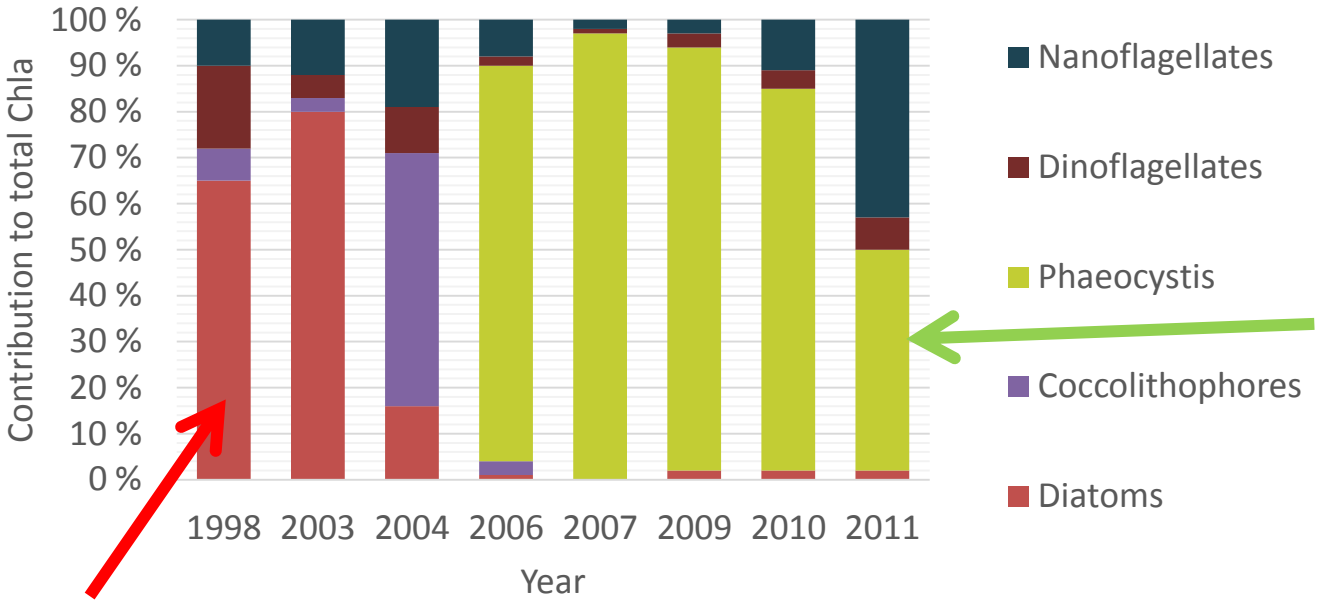
Subpolar gyre

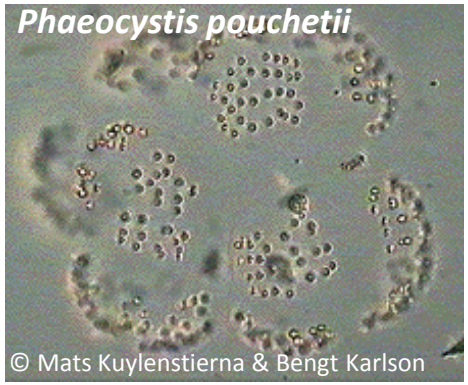
Rey 2012

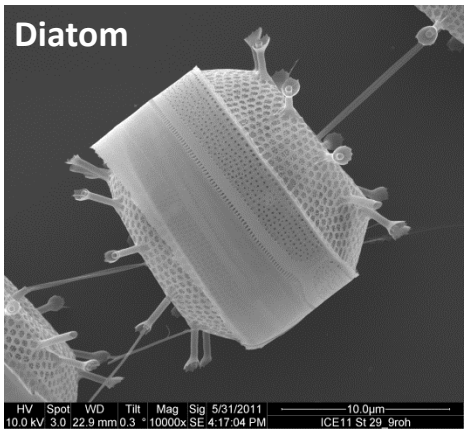
Regime shift in the Atlantic sector of the Arctic?

Increase in Phaeocystis in Fram Strait

(Nöthig et al. 2015)

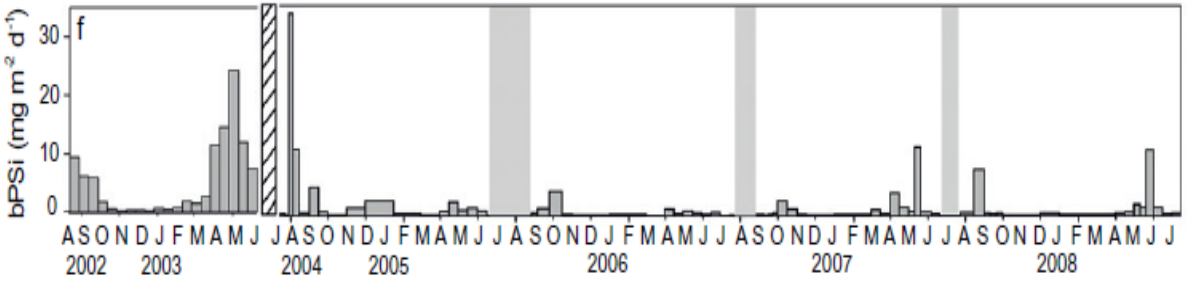


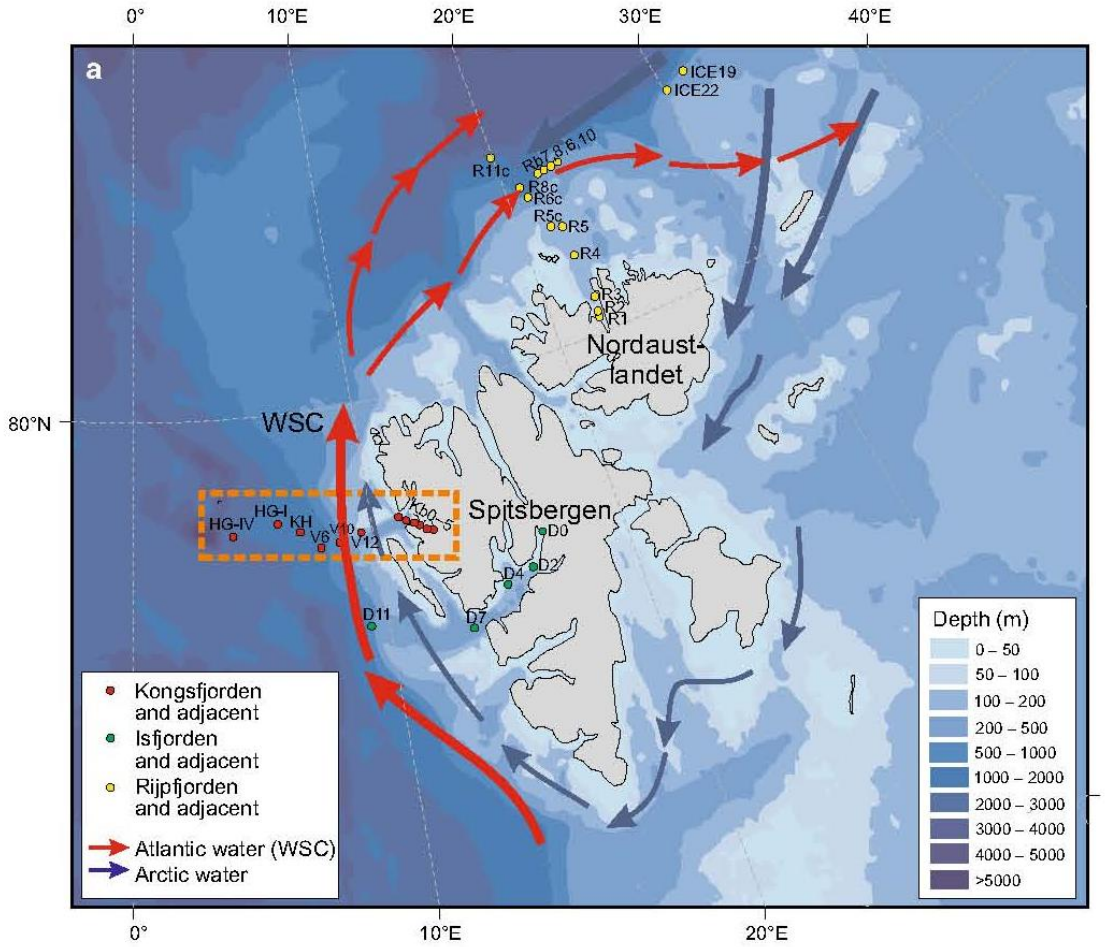


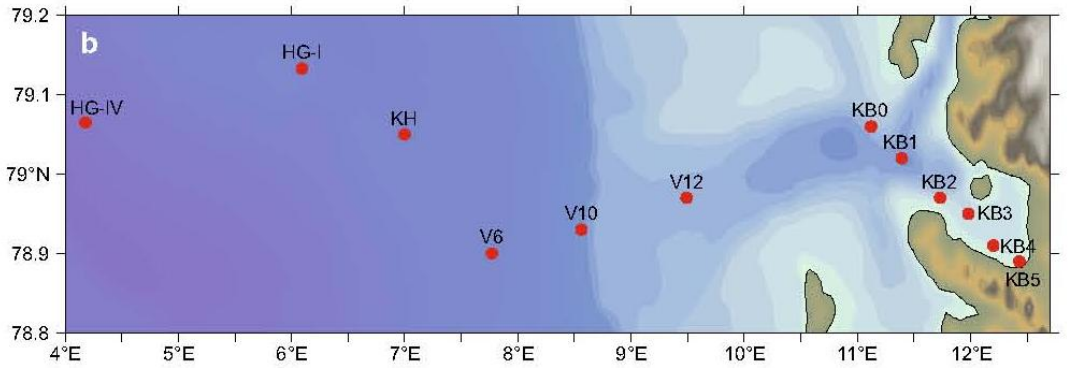


Decrease in biogenic silica (diatom) export in Fram Strait

(Lalande et al. 2013)







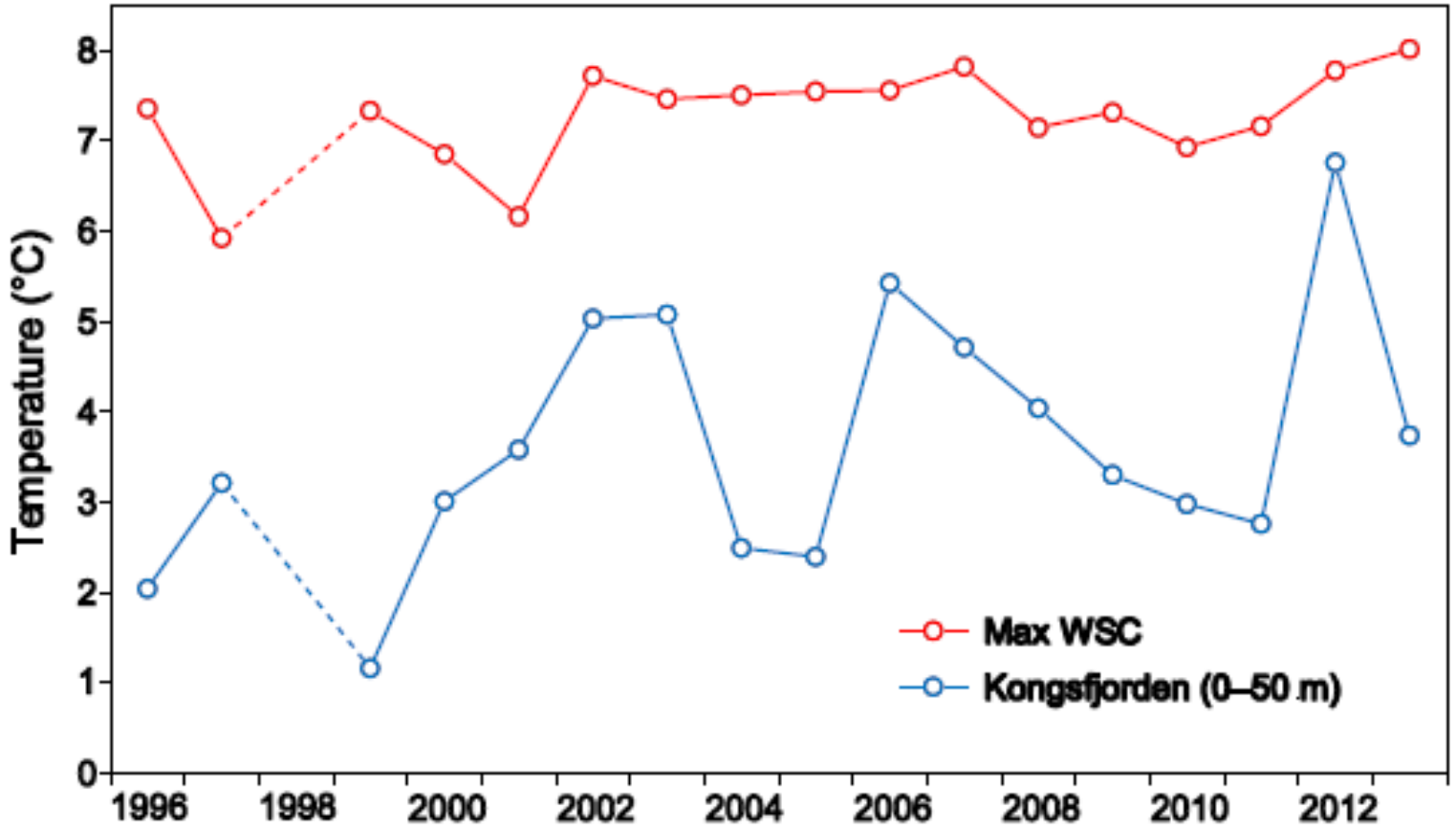
Kongsfjorden 1996-2015

MOSJ

Dalpadado et al. 2016

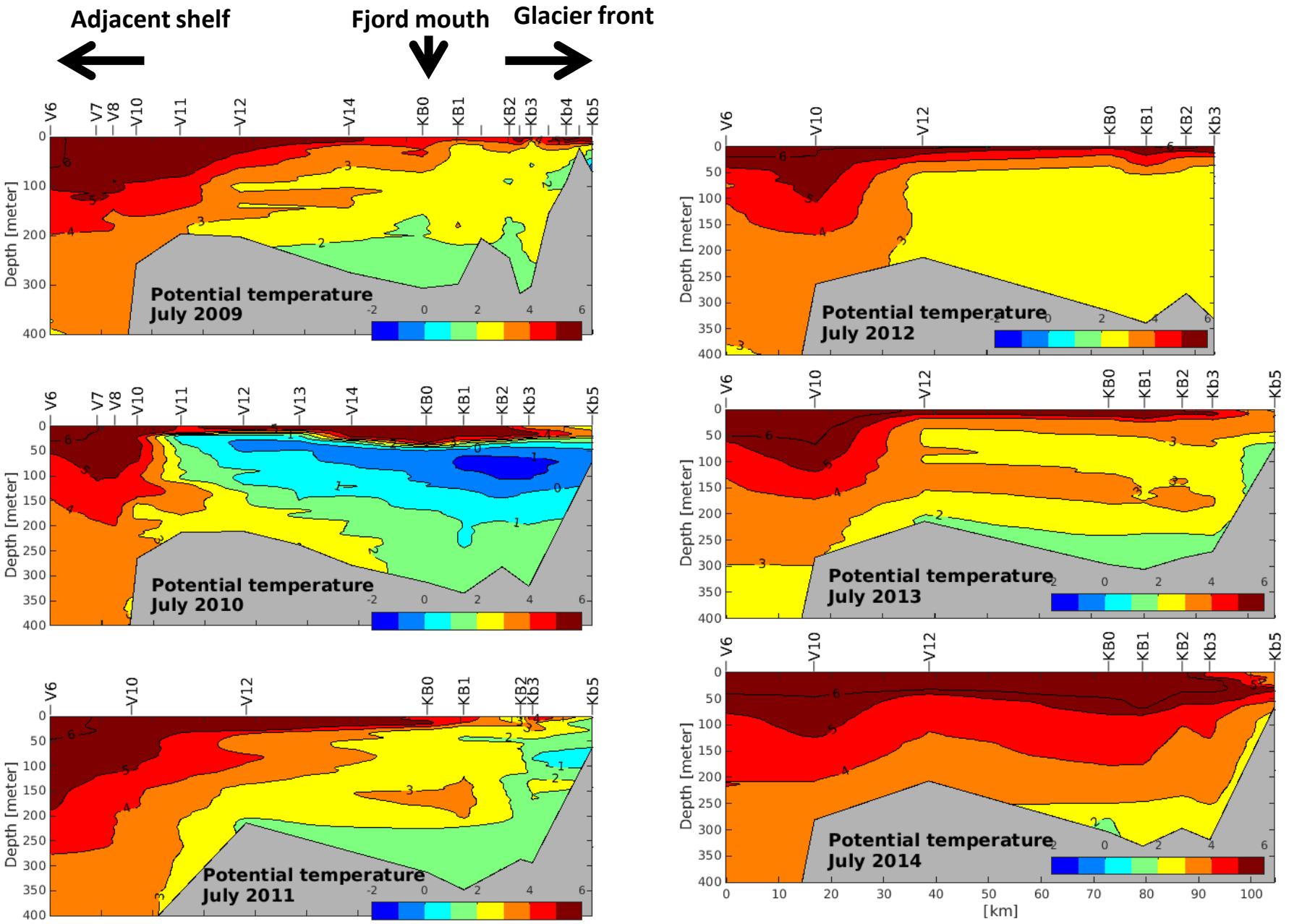
Temperature Kongsfjorden vs. WSC

July-August



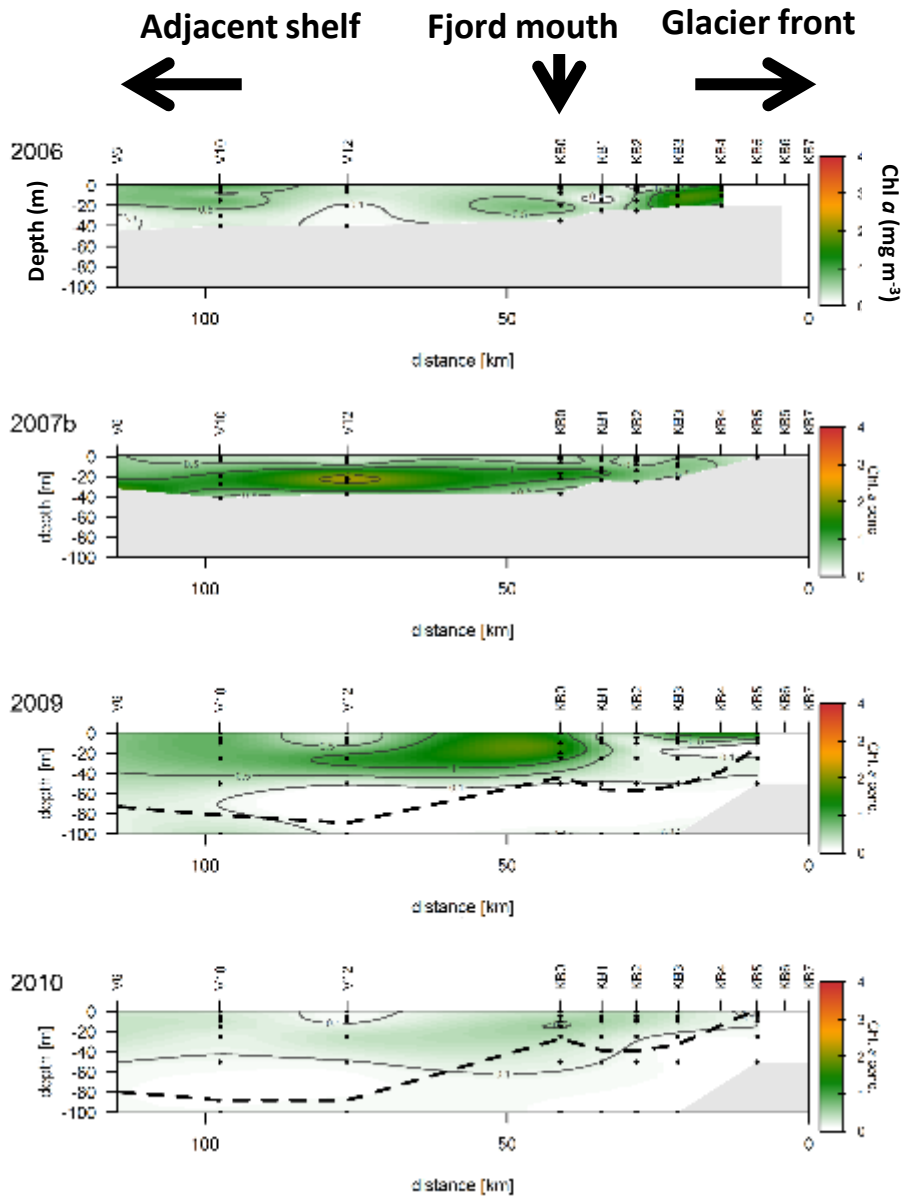
Dalpadado et al. 2016

“Atlantification” of Kongsfjorden



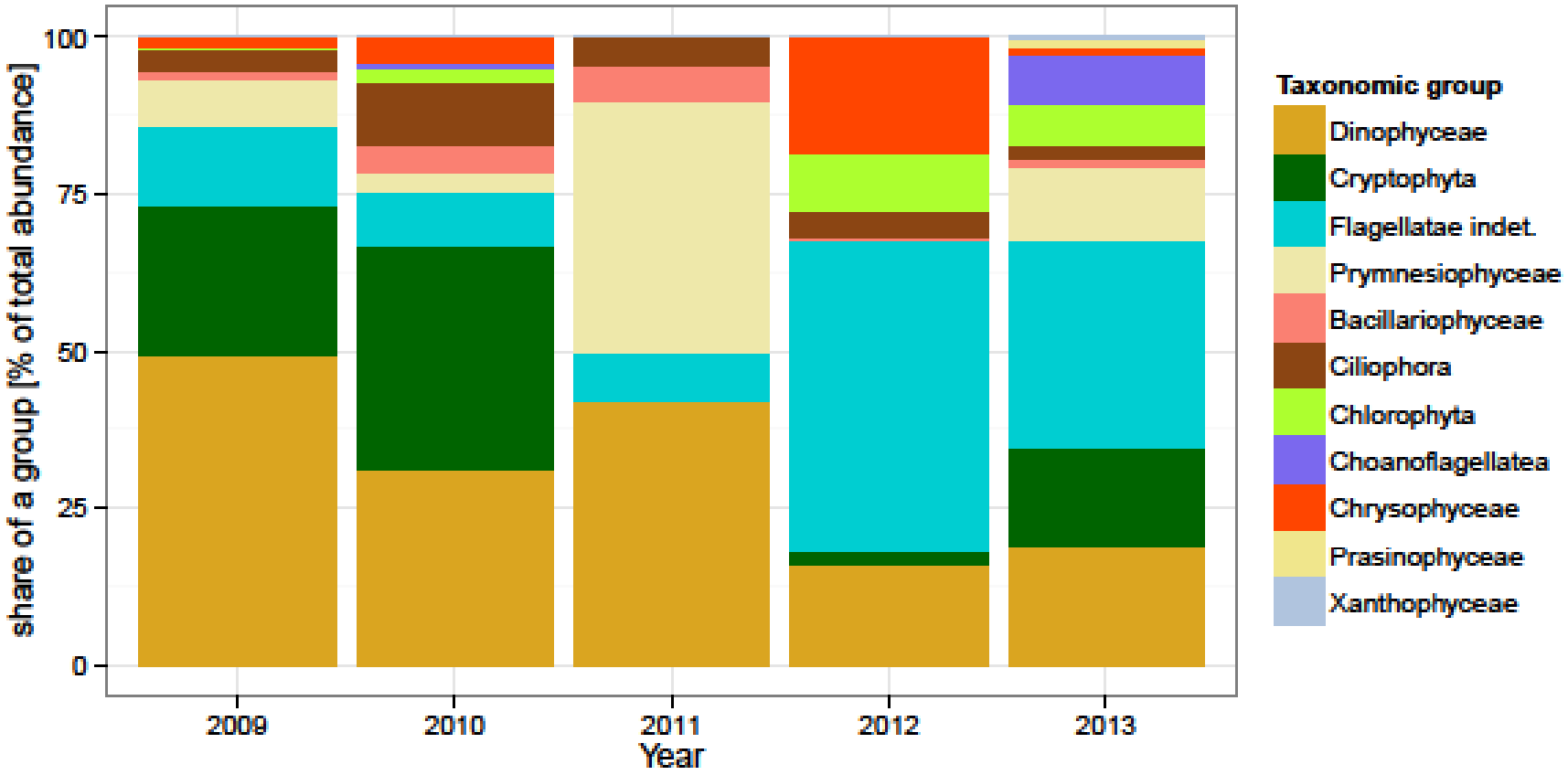
Hydrographic data NPI

Summer chlorophyll time-series 2006-2014



Chlorophyll data NPI

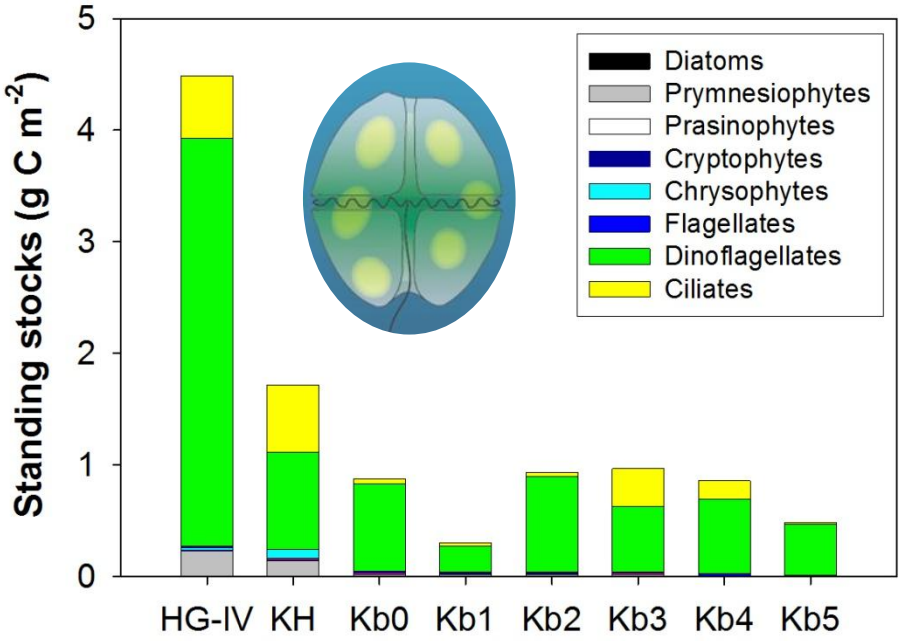
Taxonomic composition of protist plankton in summer in Kongsfjorden (Kb3)

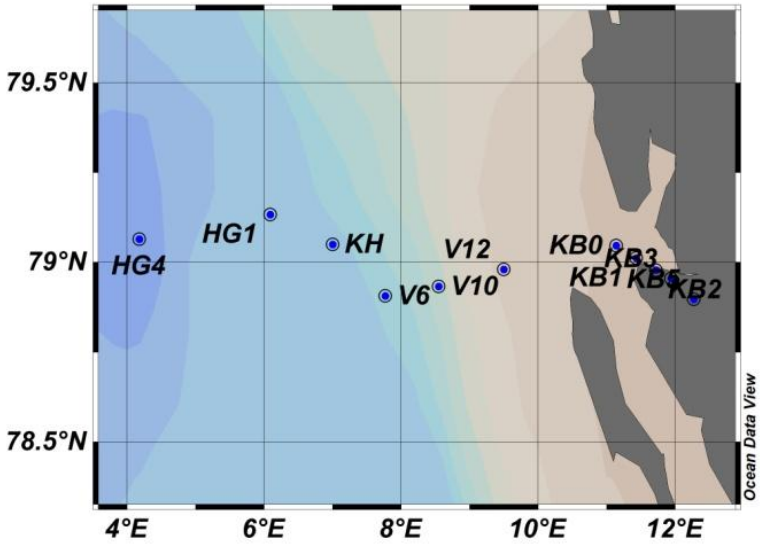


Phytoplankton data NPI

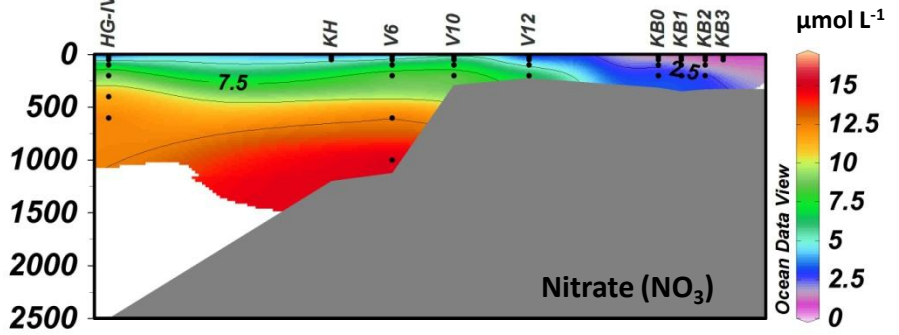
Summer post-bloom scenario in Kongsfjorden and Fram Strait

Protist community composition 2009

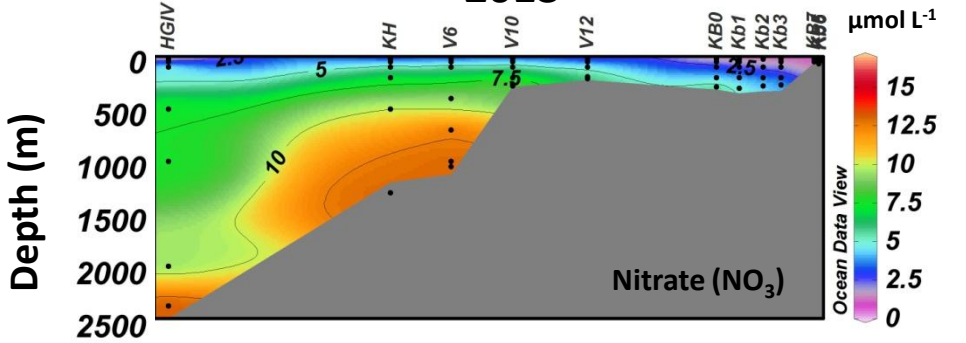




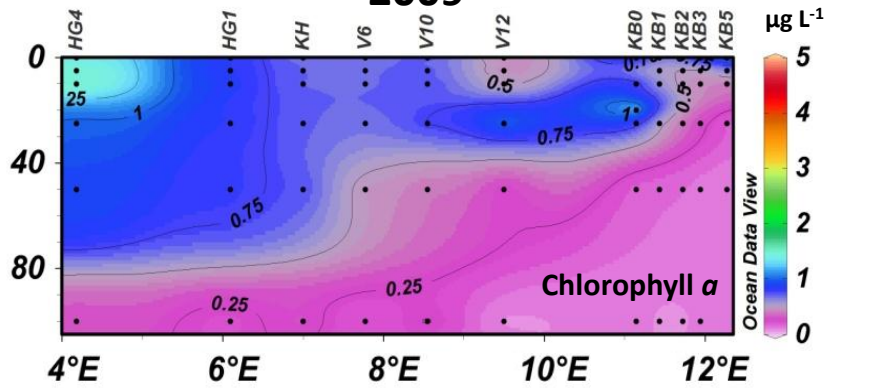
2012



2013

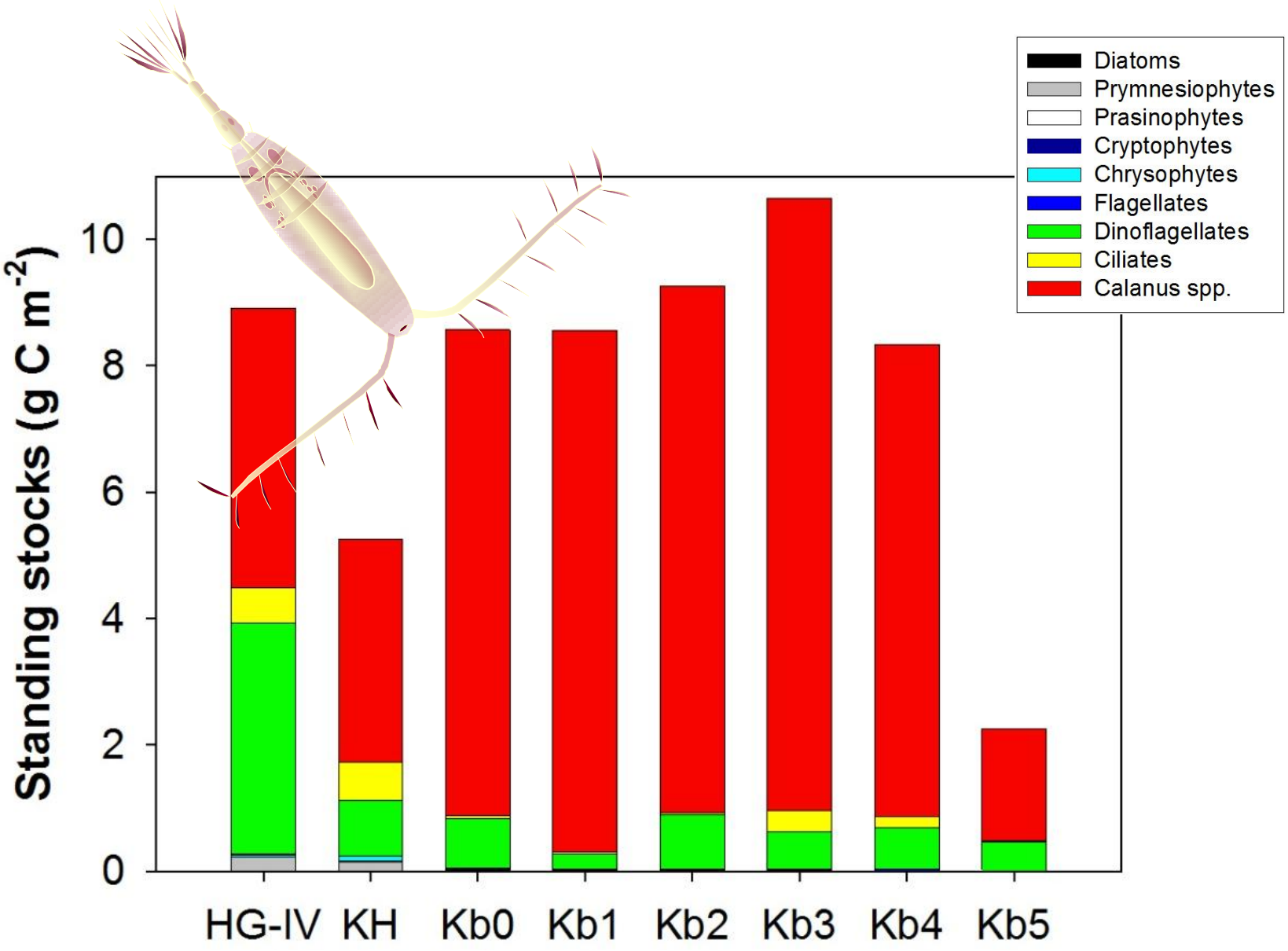


2009



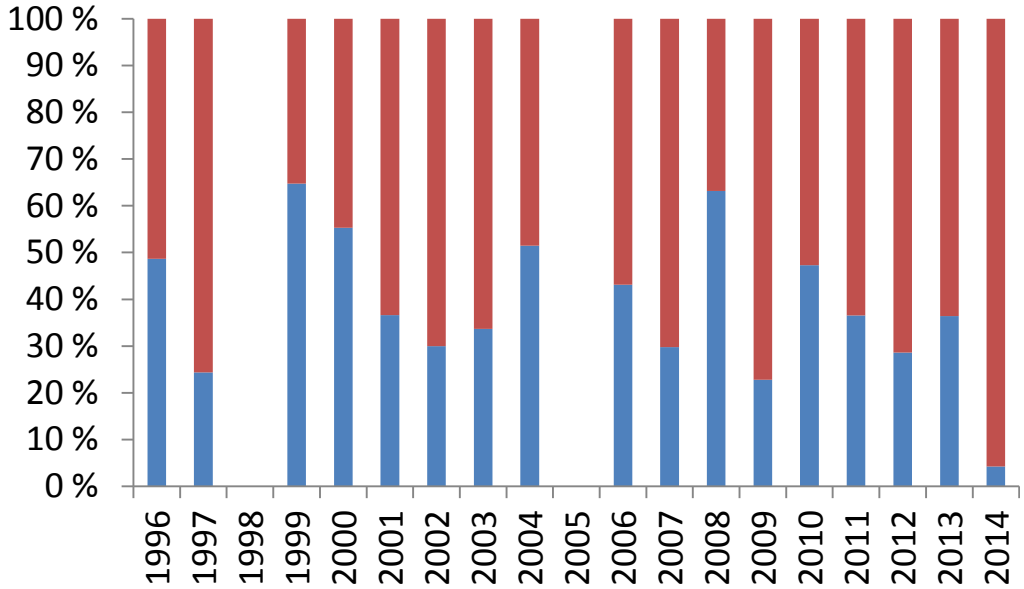
Plankton and nutrient data NPI

Top-down regulation by *Calanus* copepods



Plankton data NPI

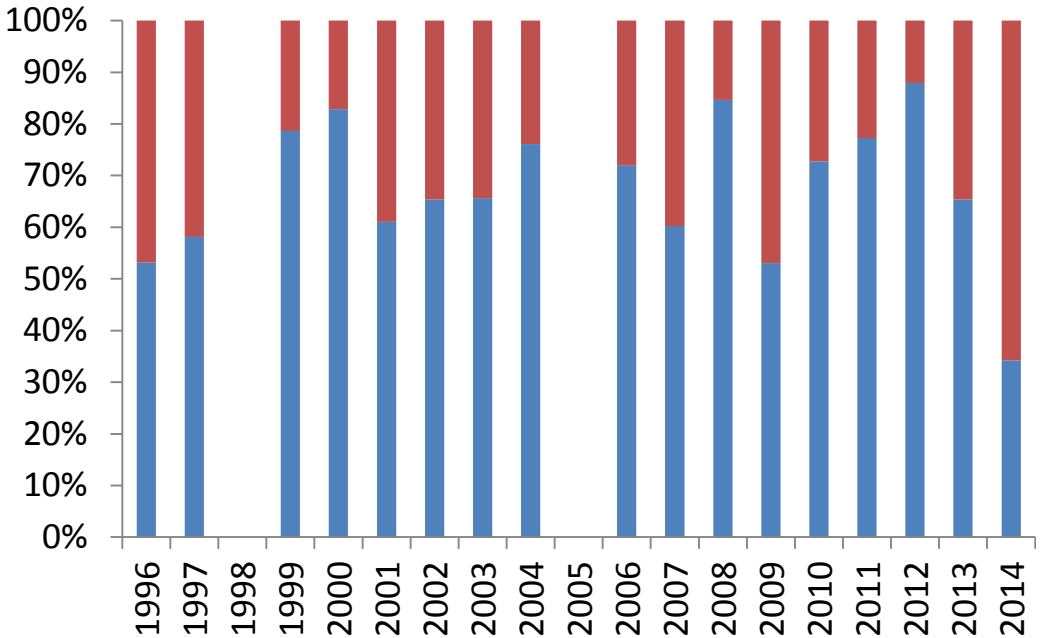
Arctic vs Atlantic *Calanus* species in Kongsfjorden



Based on abundance

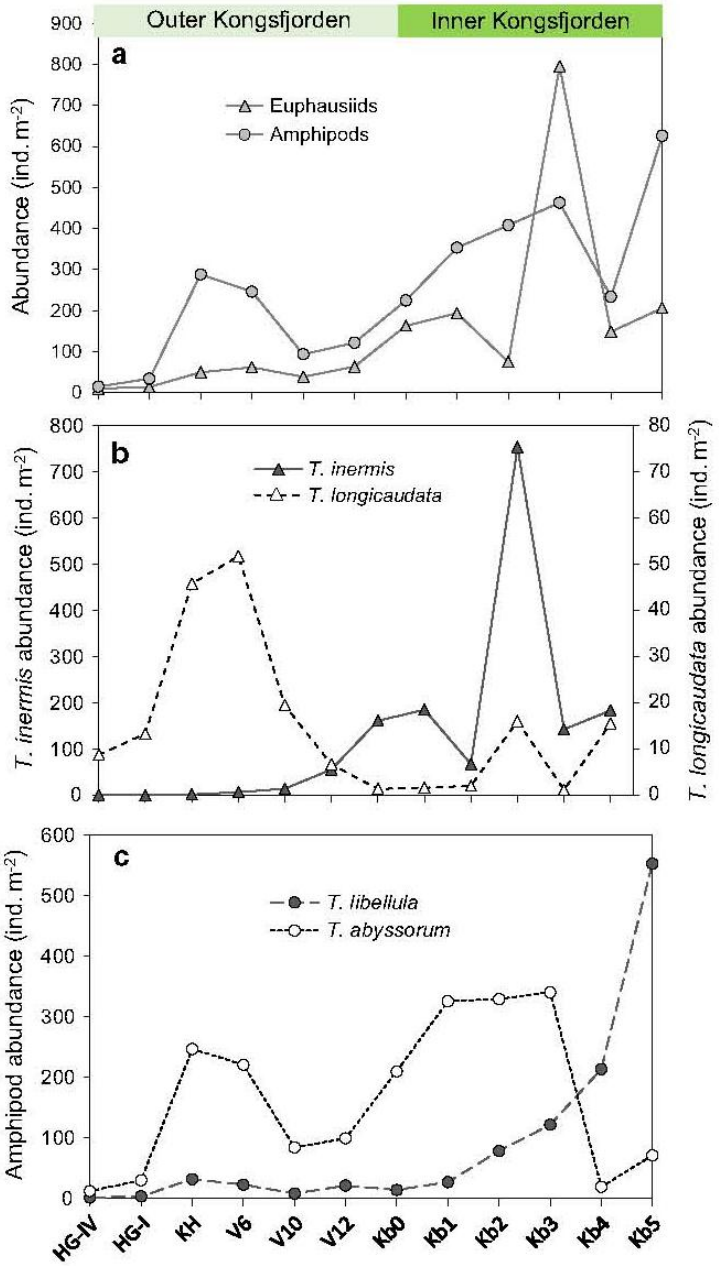
Arctic: *C. glacialis* (& *C. hyperboreus*)
Atlantic: *C. finmarchicus*

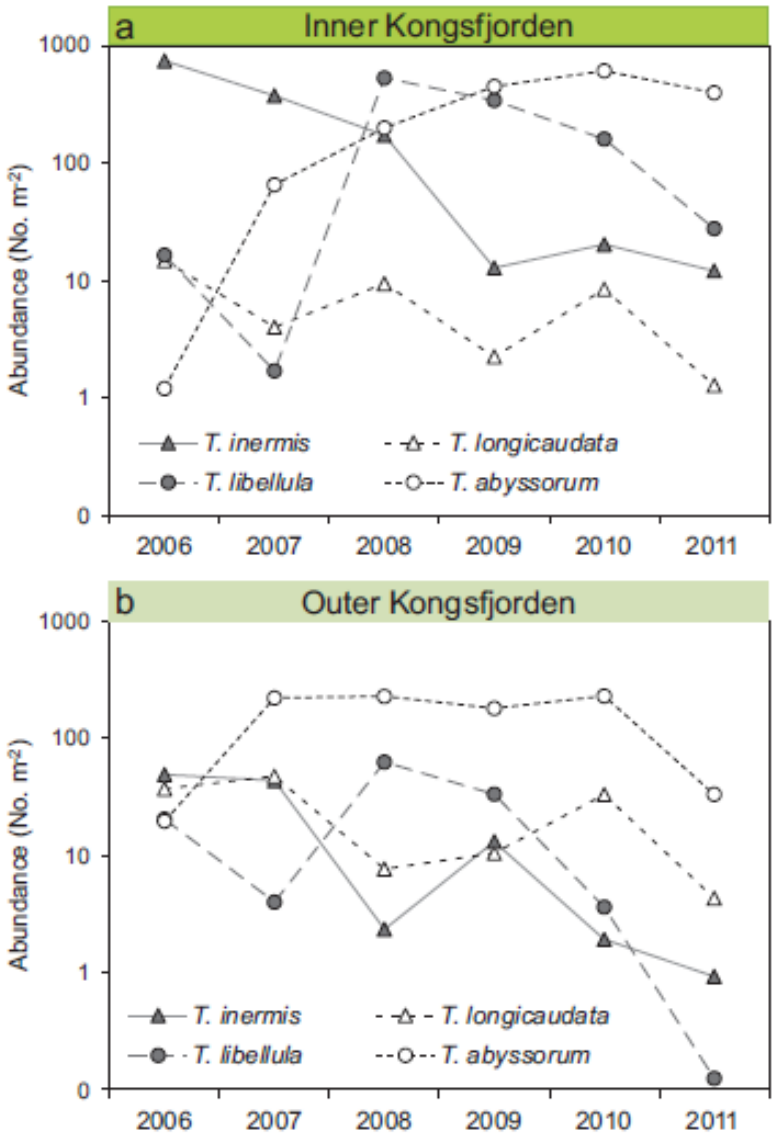
Based on biomass



Zooplankton data NPI

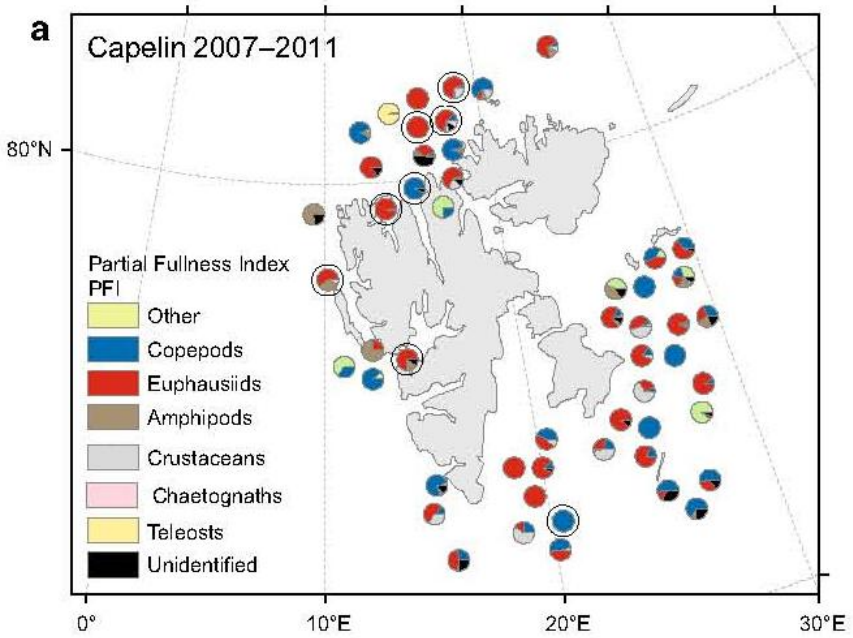
Spatial and temporal trends in krill and amphipods in Kongsfjorden

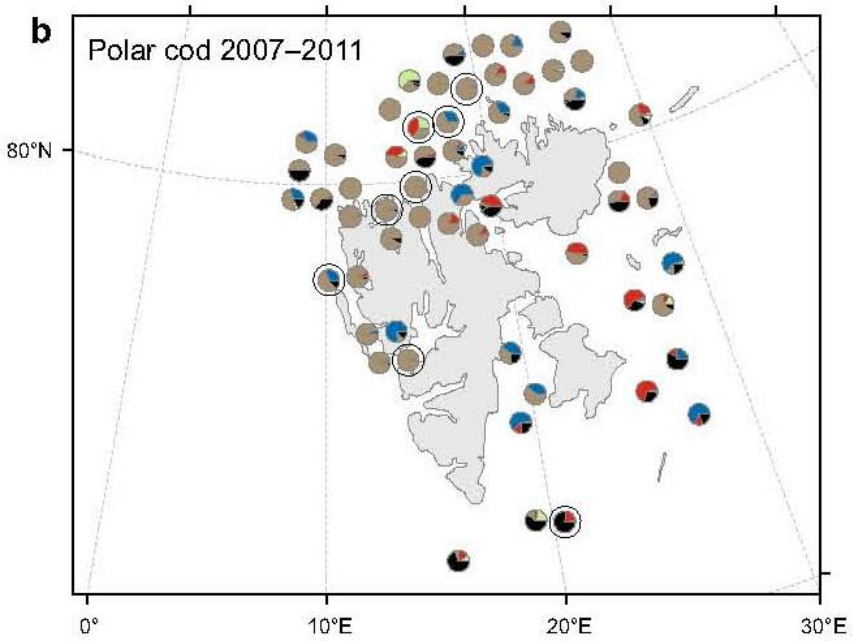




Dalpadado et al. 2016

Amphipod and krill feeders

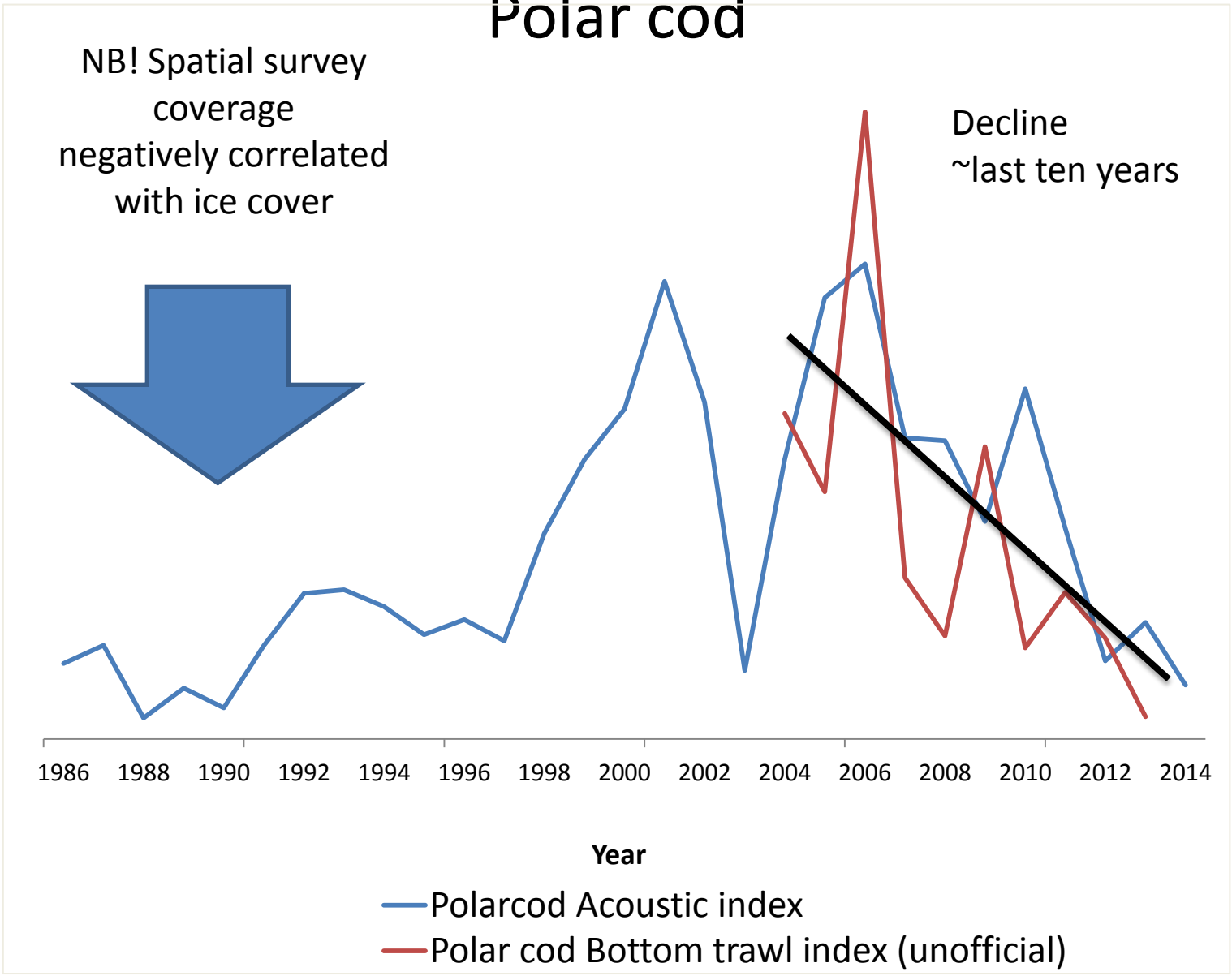




Dalpadado et al. 2016

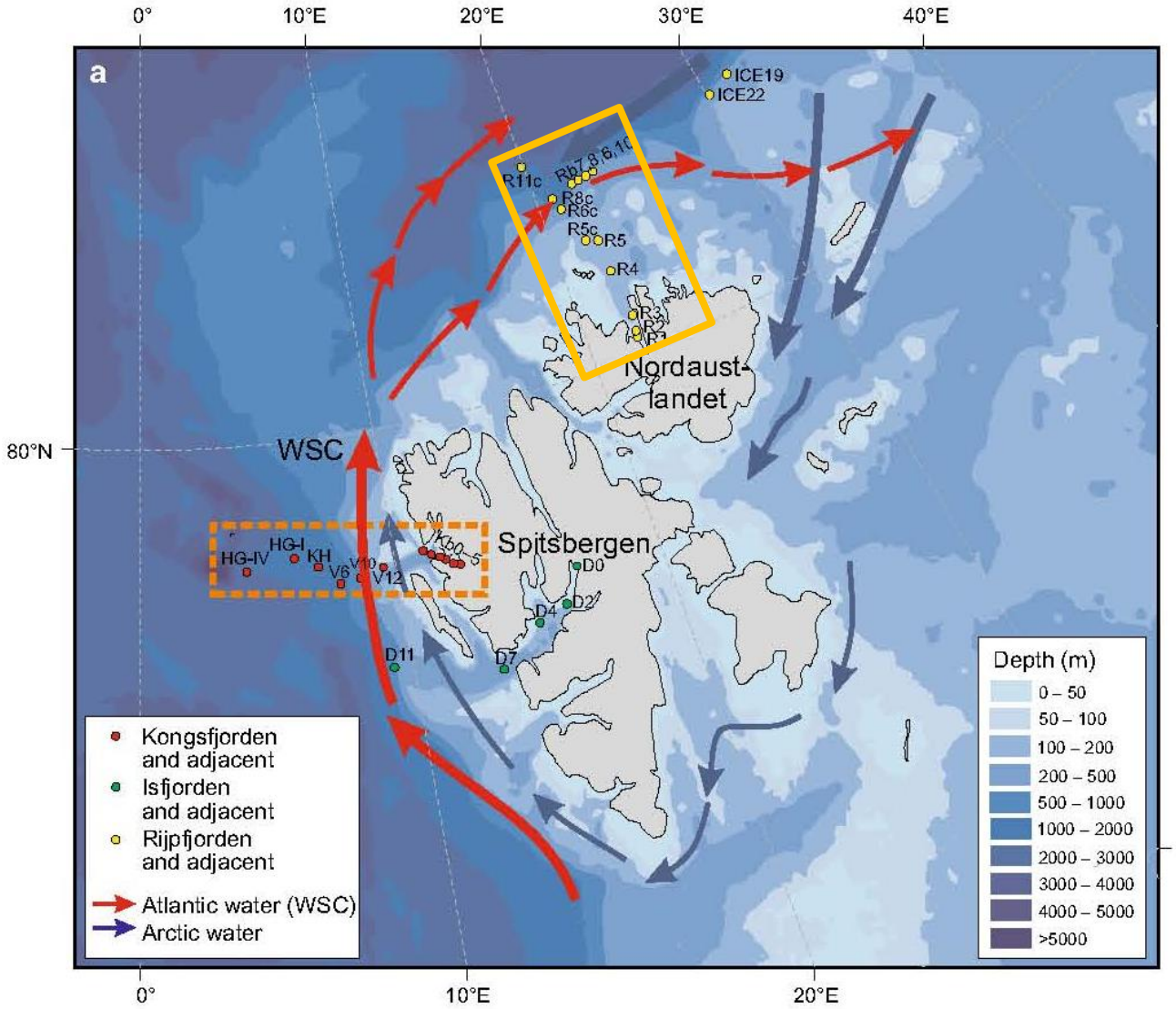
Temporal development in the Barents Sea

Polar cod

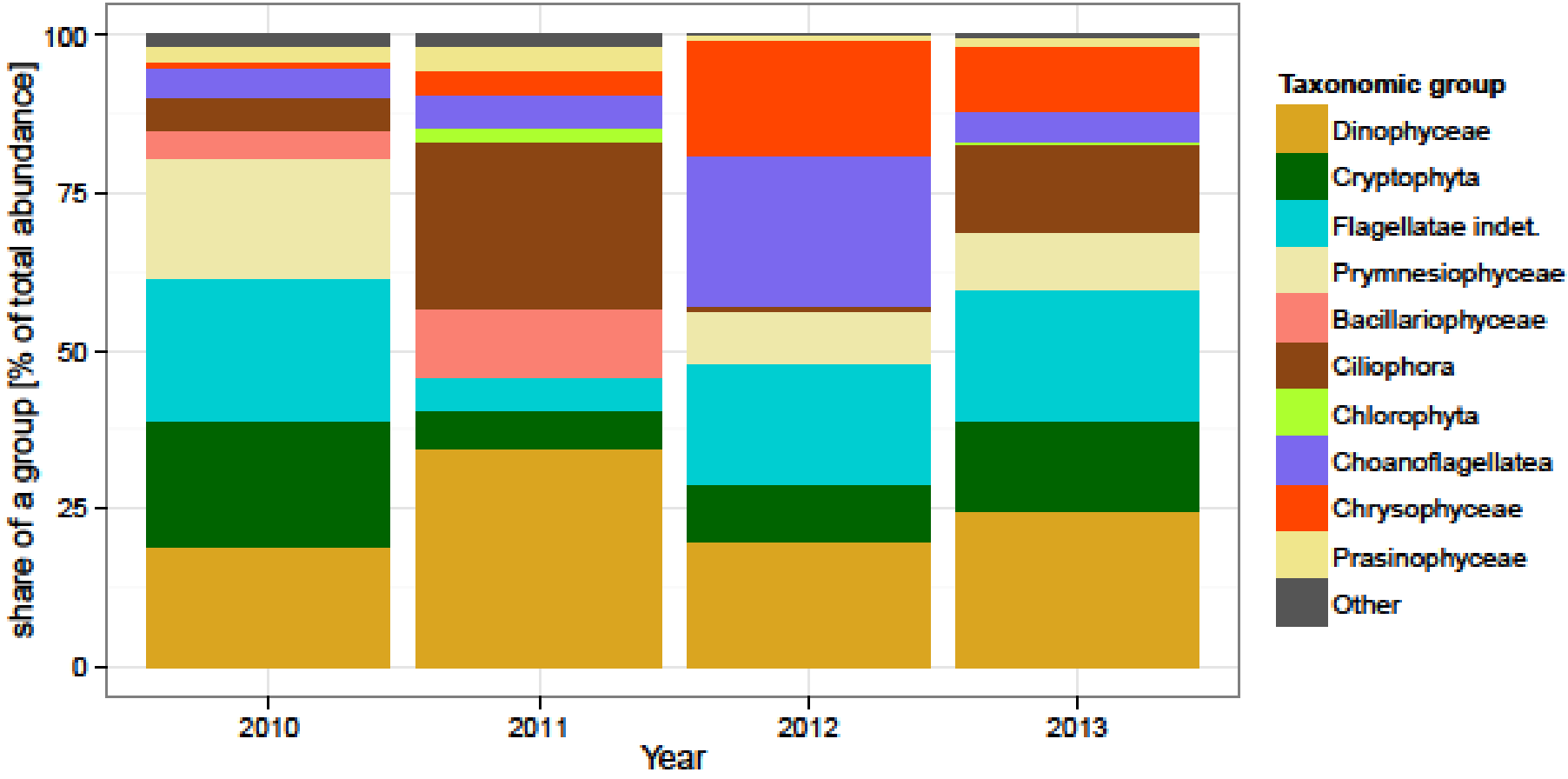


IMR-data

Rjipfjorden 2006-2014



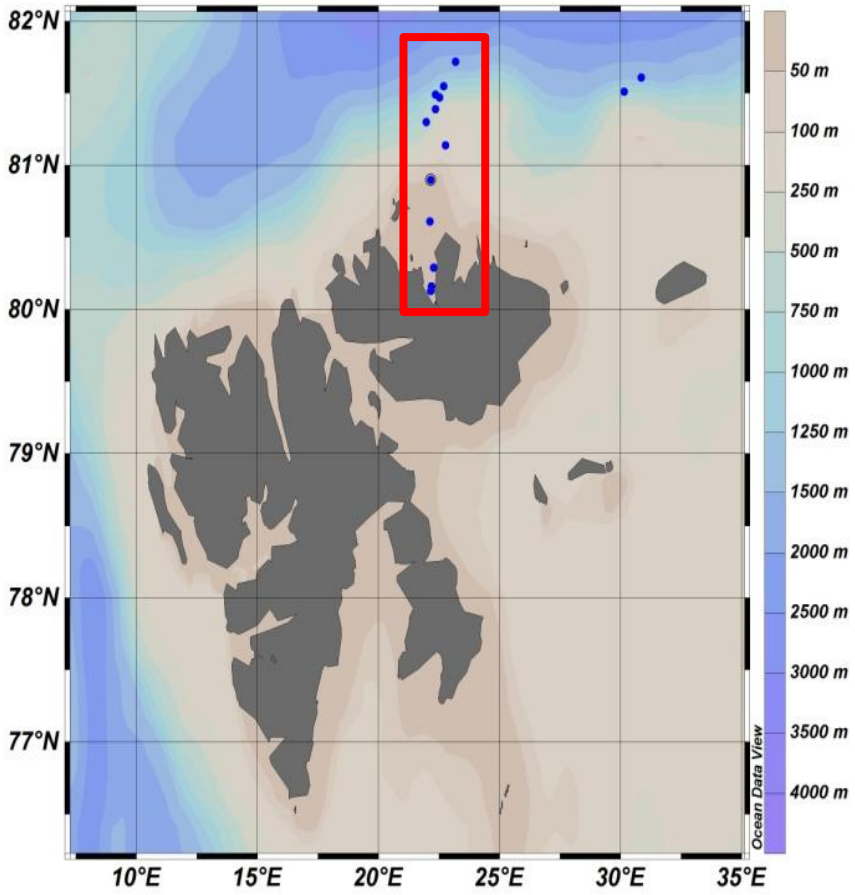
Taxonomic composition of protist plankton in summer in Rijpfjorden (R3)



Phytoplankton data NPI

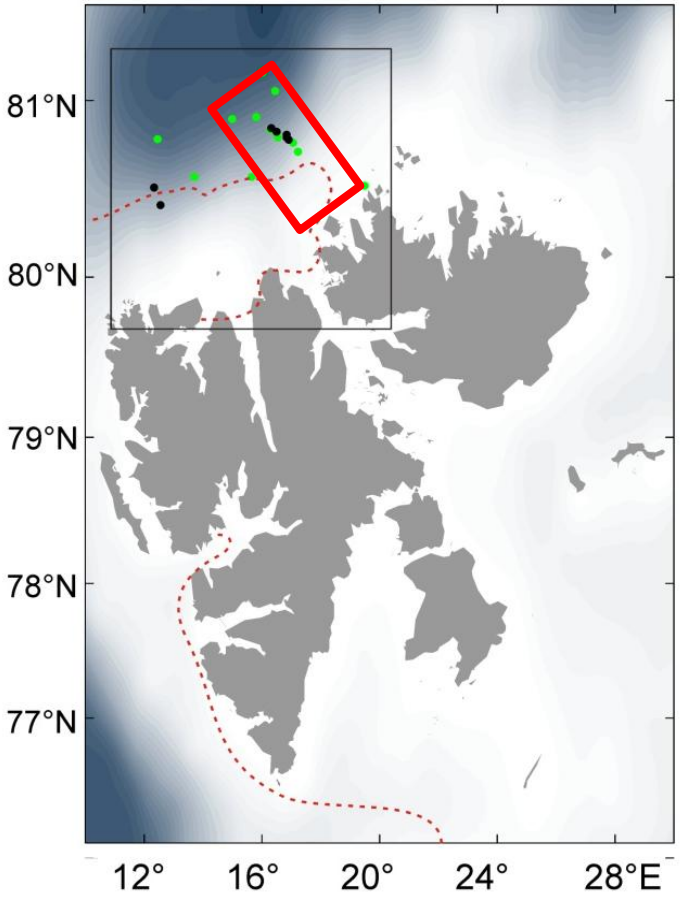
Cross shelf transects north of Svalbard

ICE 2010



August/September

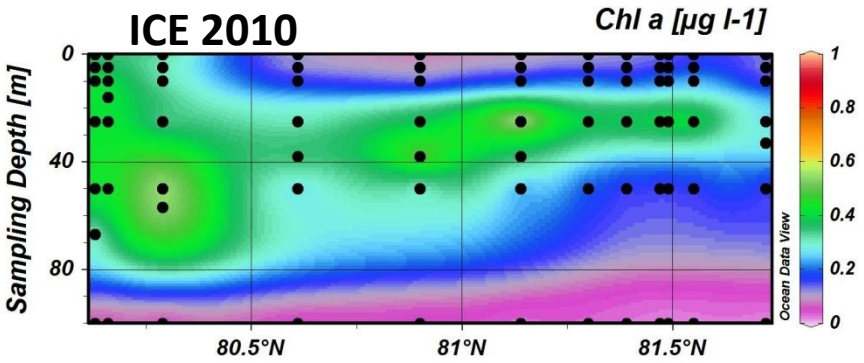
ICE 2011

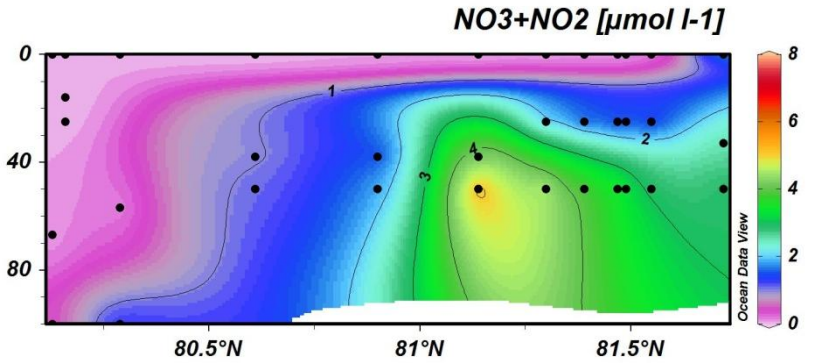


April/May

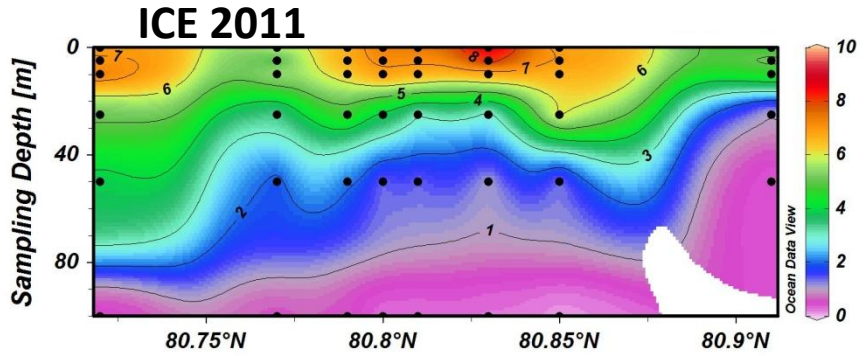
Seasonal patterns in chlorophyll concentrations

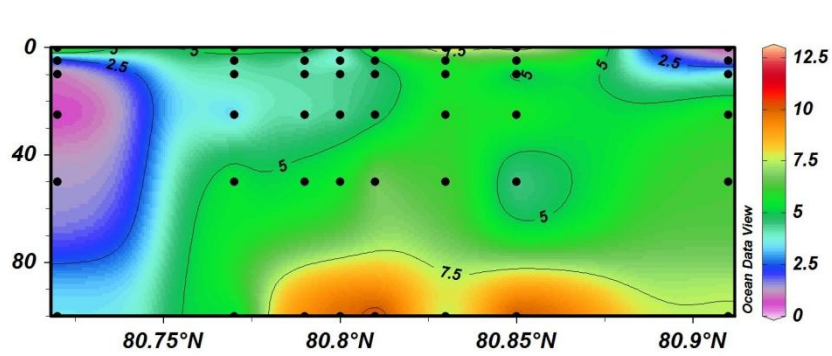
Post-bloom subsurface Chl *a* max





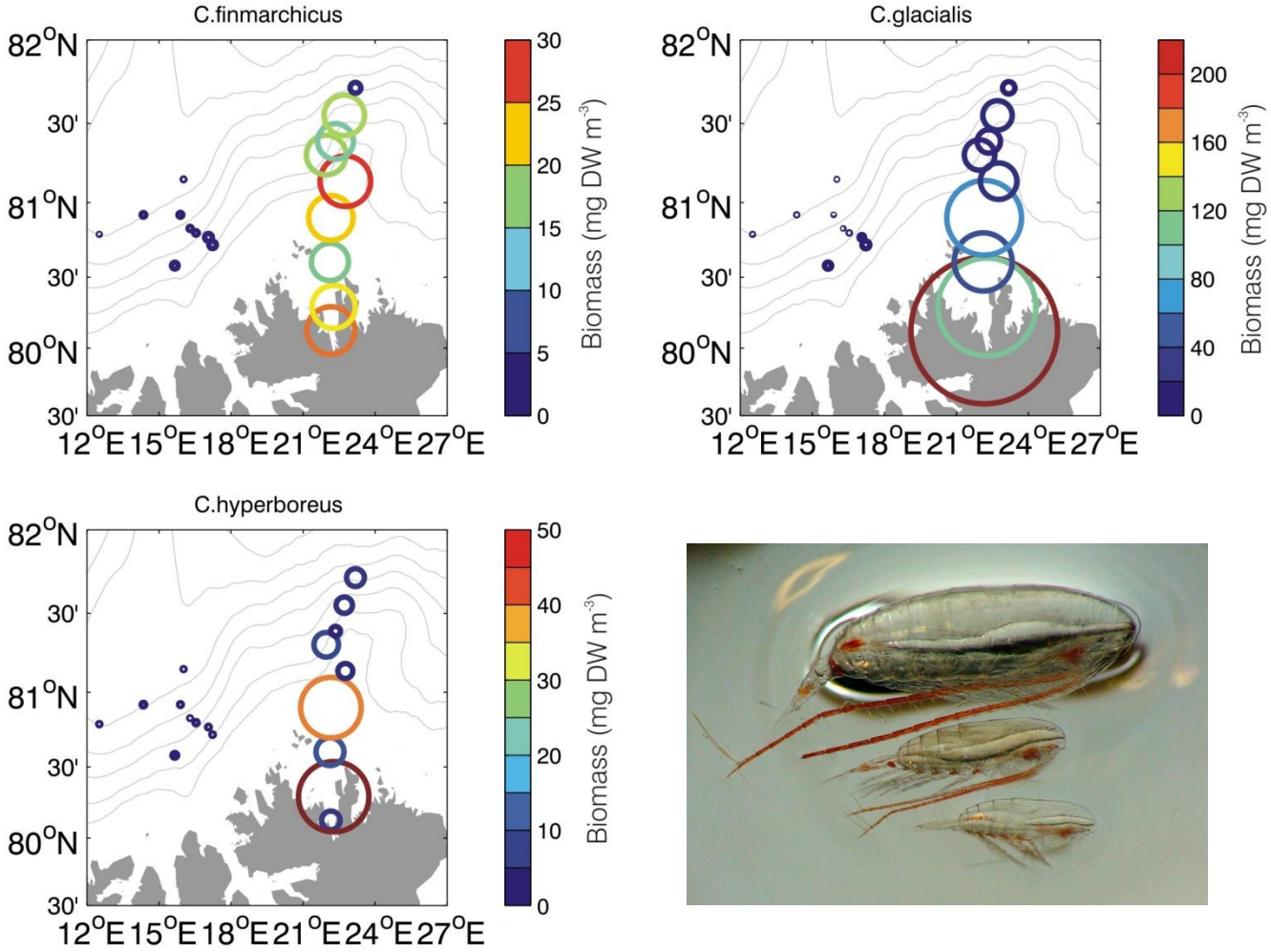
Spring bloom





Chlorophyll data NPI

Biomass of *Calanus* species
ICE 2010 + ICE 2011

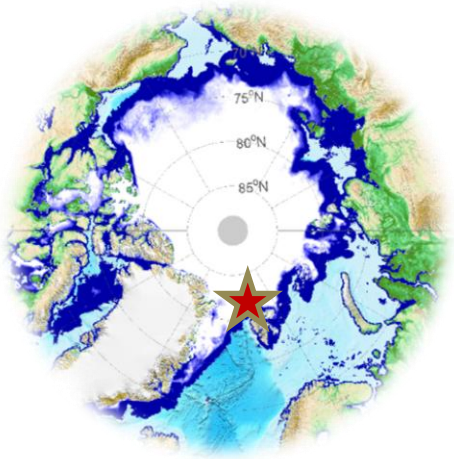


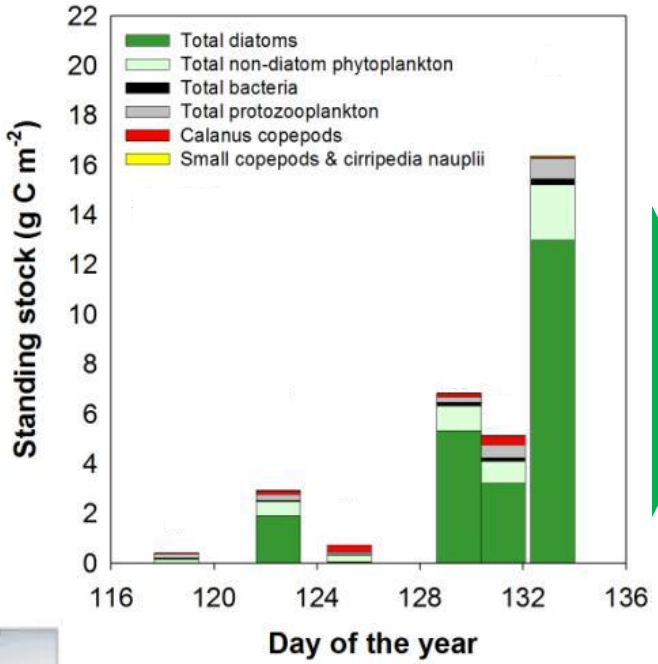
Very low Calanus biomass in May 2011
compared to August 2010

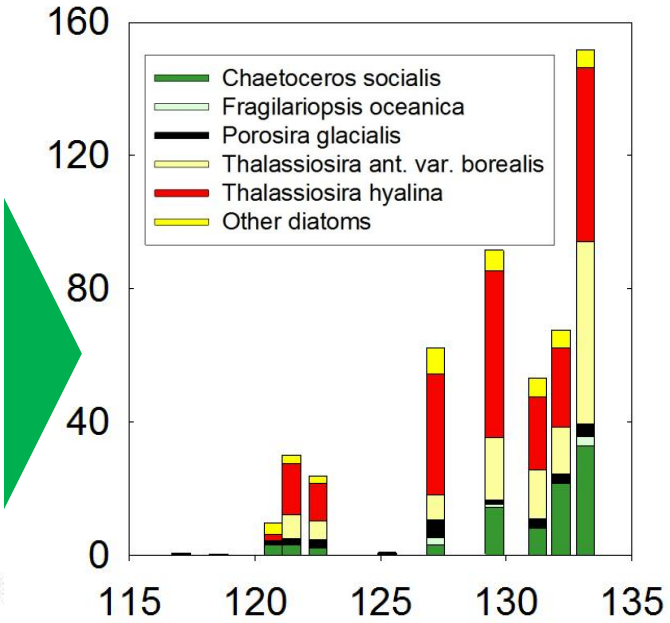
Zooplankton data NPI

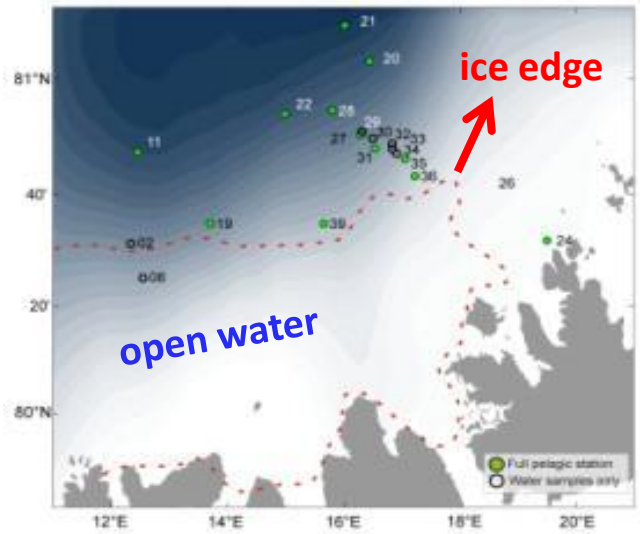
Early phytoplankton spring bloom north of Svalbard

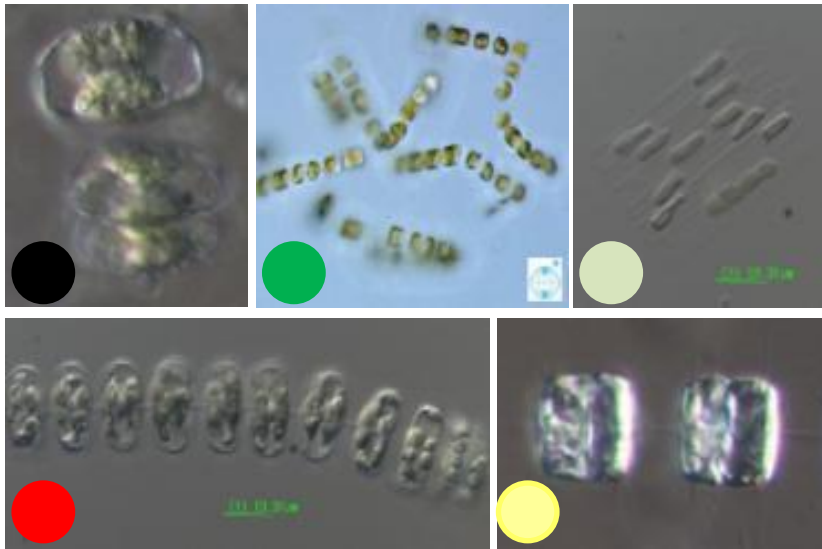
Meereisportal.de





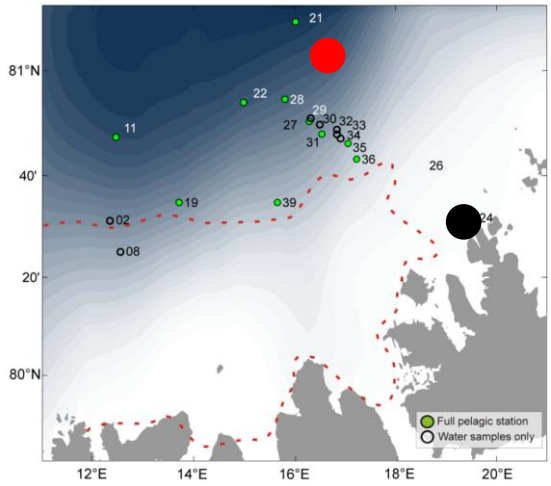




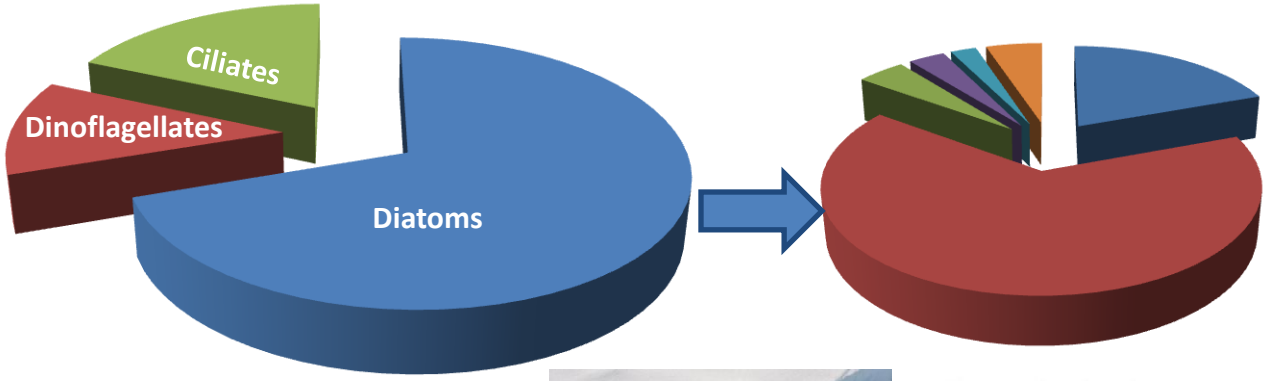


Phytoplankton data NPI

Regional differences in ice algal biomass and community composition

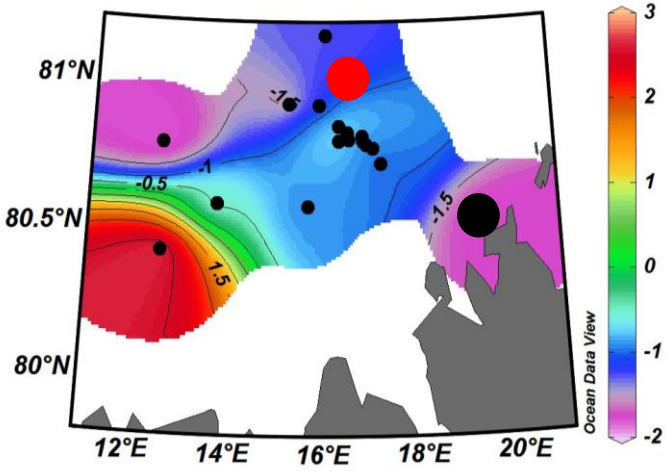


Shelf-slope, low biomass (ICE11-20)

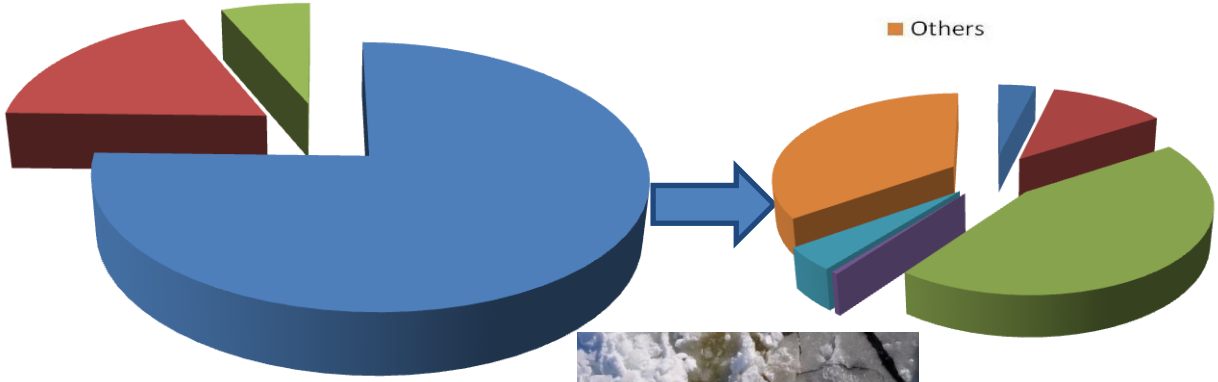


- Nitzschia frigida
- Navicula spp.
- Entomoneis kjelmanii
- Synedropsis hyperborea (epiphyte on N. frigida)
- Cylindrotheca closterium
- Others

Temperature @ 10m **°C**

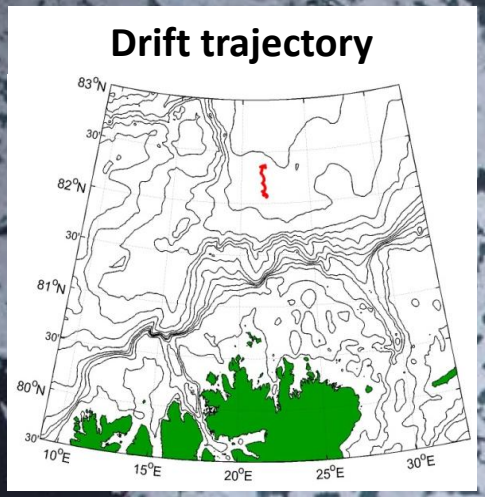


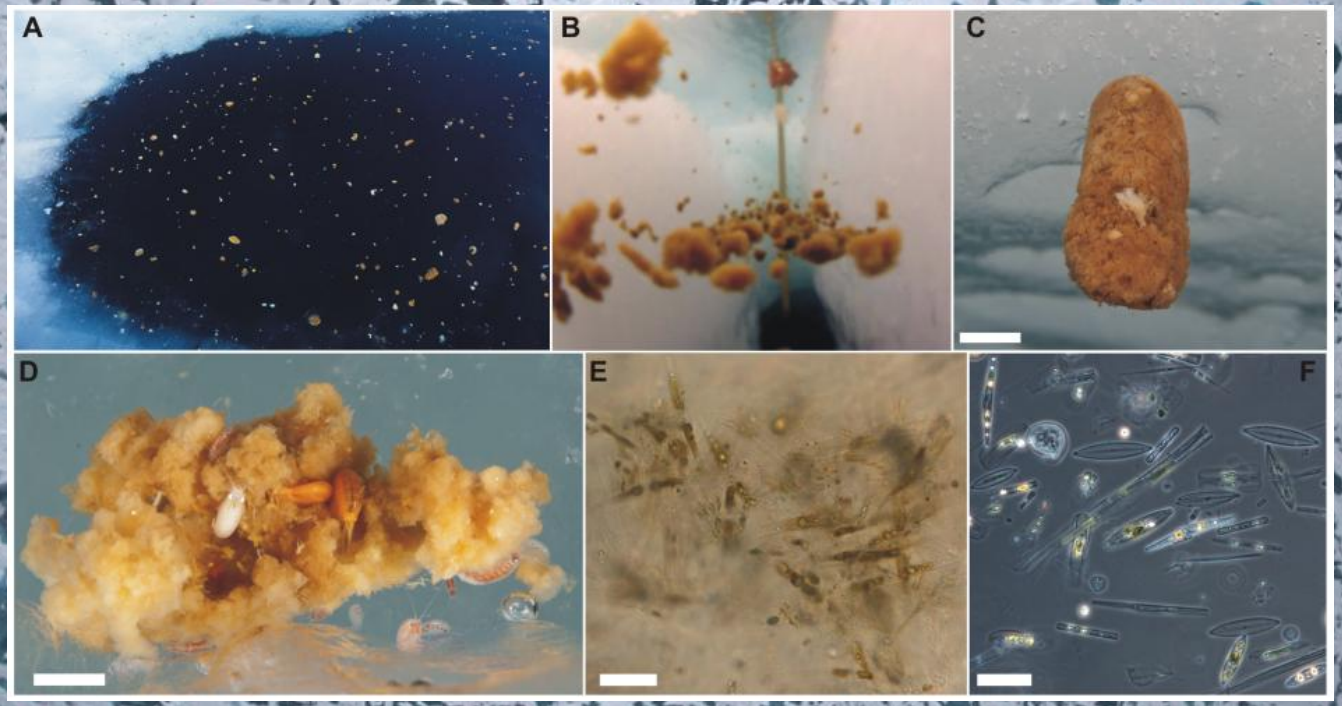
Coastal, high biomass (ICE11-24)



Ice algae data NPI

Floating ice-algal aggregates below melting Arctic sea ice





Assmy et al. 2013 *PLoS ONE*

Thank you for your attention!