Arctic Ecosystems in a Changing Climate

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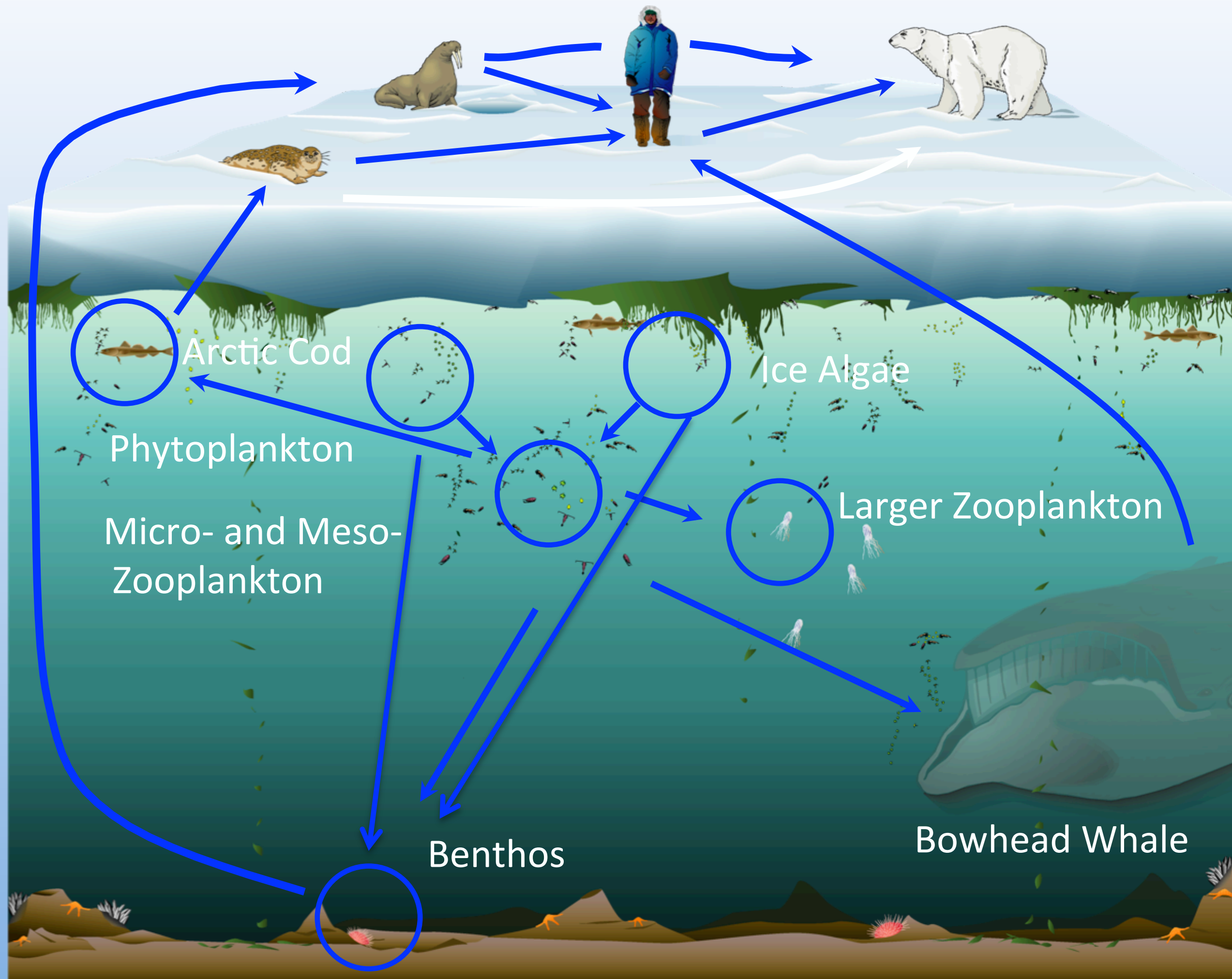
Arctic Marine Food Web



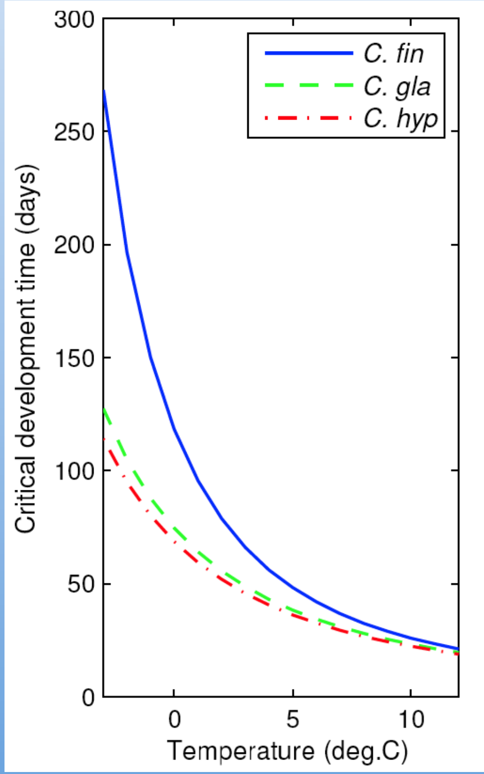
Not Shown:
Seabirds
Other fish

Difficulty in access, particularly in winter, means ecosystem is understudied
Few long term records so differentiating variability from change (climate) is difficult

What Controls Marine Ecosystems in the Arctic?

- Arctic marine ecology is profoundly impacted by the seasonal variations in temperature, light, and ice cover
- Life histories of organisms are timed to the seasonal cycles

  - Light: absent during winter
  - Temperature: cold, organisms ARE adapted to cold temperatures
  - Nutrients: strong pycnocline limits vertical mixing in Basin
  - Seasonal and Permanent Sea Ice: barrier to light and heat; critical substrate for organisms ranging from phytoplankton to mammals
  - Strongly seasonally varying food supply
    - Reproduction of organisms timed to coincide with availability of ice algal as well as phytoplankton food



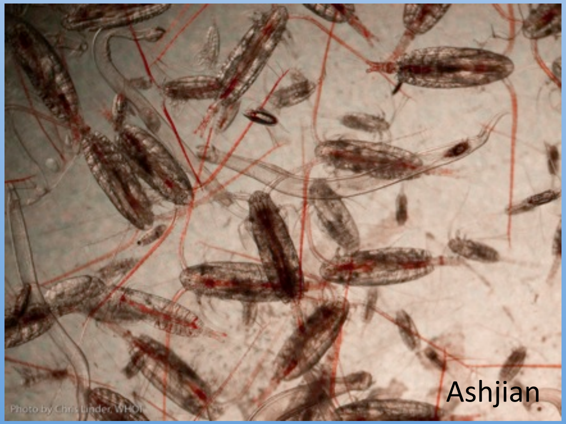
Ji et al. 2011

How might climate change impact this ecosystem?

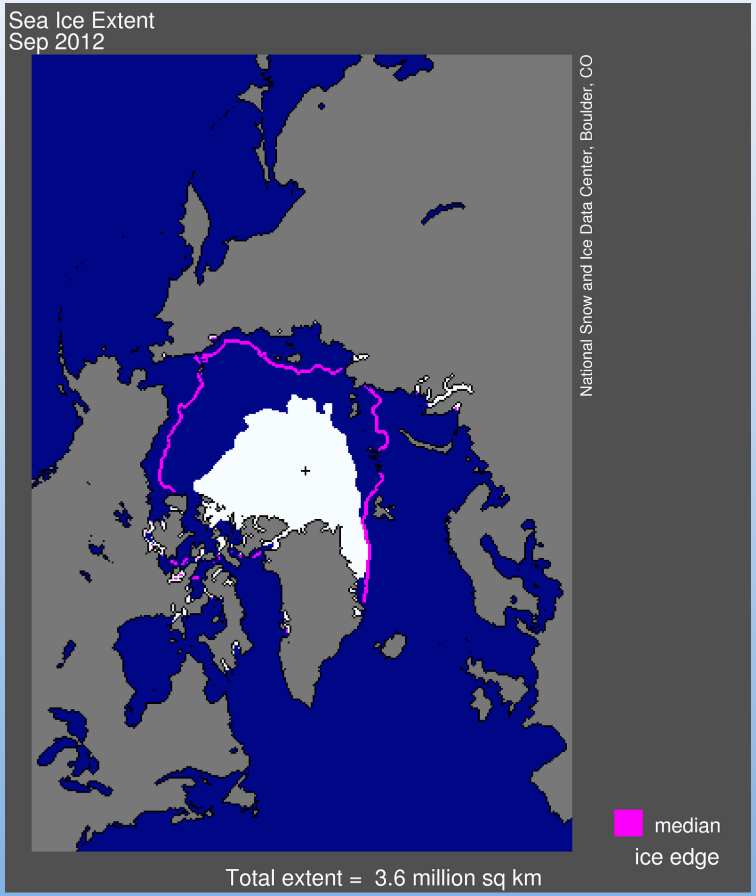
- Change in circulation, input of nutrients and heat, and biota
- Reduction/loss of seasonal sea ice
  - Serious consequences for ice obligate organisms that live in/on the ice
  - Changes the light environment
  - Changes in effectiveness of wind-mixing
- Changes in the ranges of organisms
- Changes in the marine food web
  - Changes in dominant organisms
  - Changes in food web linkages (e.g., more/less predation)
  - Changes in allocation of carbon between different components of the food web
  - Change from benthically dominated to pelagically dominated and vice-versa
- Changes in environmental seasonality
- Changes in weather
- Changes in ocean chemistry (acidification)

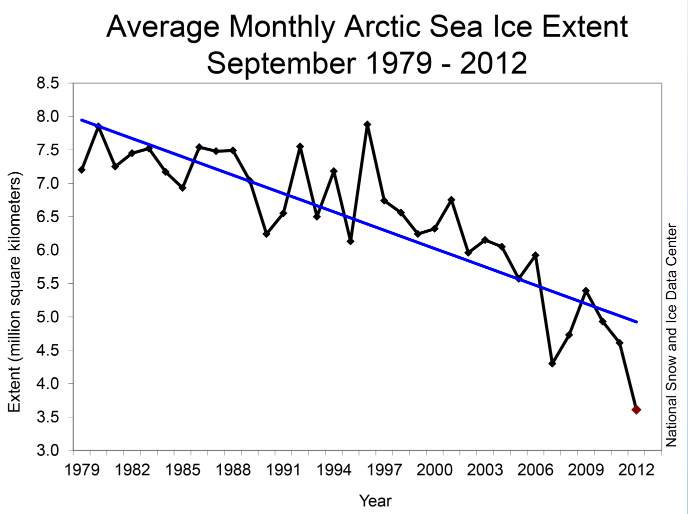
How do we study the Arctic marine ecosystem?

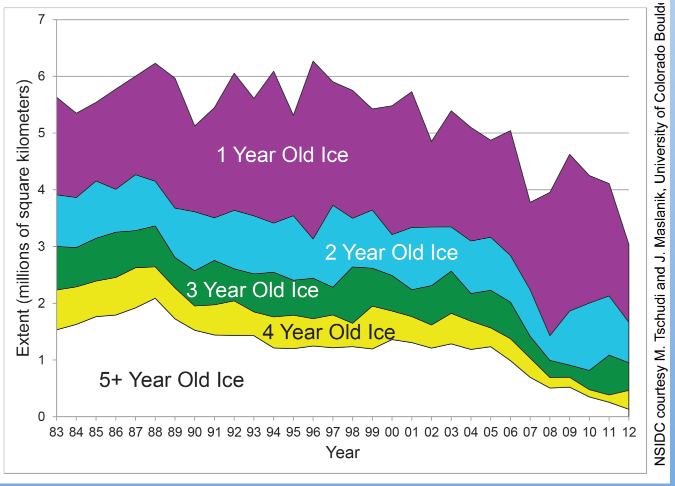
- Observing – Collection of organisms (determination of species, abundances, biomass), chemical and genetic analyses, observations of upper trophic level organisms, sensors on ships, moorings, ice-tethered profilers, AUVs, ROVs, submarines
- Experimentation – Determination of vital rates (grazing, egg production, growth, development, primary production, respiration)
- Modeling- to understand the ecosystem and to predict future conditions (the impact of climate change, management decisions)
    - Requires abundance/distribution/life history and vital rate data



Loss of Sea Ice is the Sentinel Feature of Climate Change in the Arctic





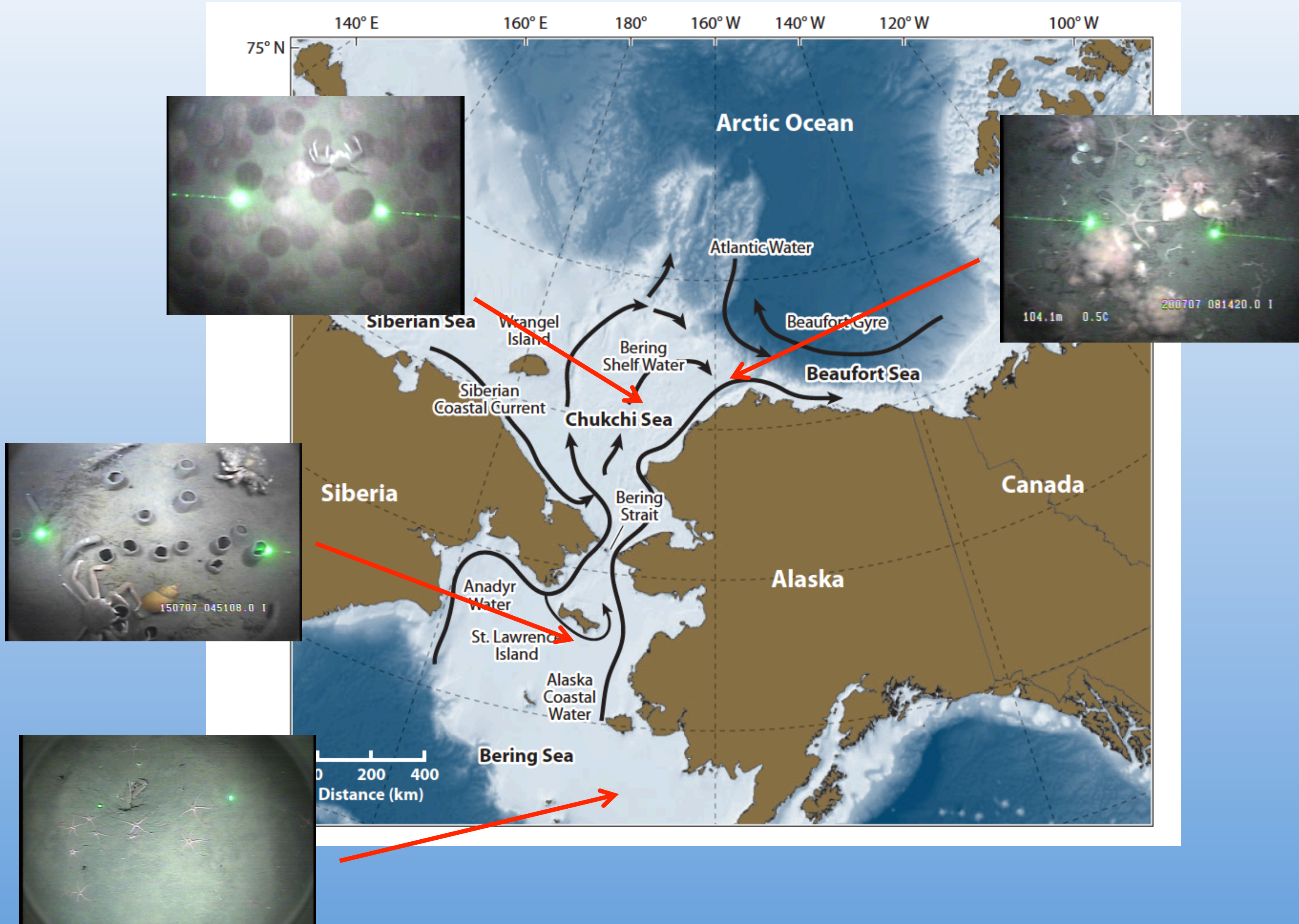


- Not only ice extent but also ice age and thickness is declining
- Summer sea ice may be gone by 2040 (Holland et al. 2006)

Some Changes Already have been Observed

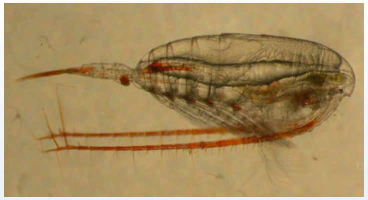
- Northward expansion of range of prominent animals – gray whales, salmon, fish
- Changes in phytoplankton standing stock and production in response to changes in sea ice (e.g., Arrigo et al., 1998; Grebmeier, 2012)
- Change in size composition of phytoplankton in the Canada Basin (Li et al. 2009)
- Changes in benthic biomass and community composition (Grebmeier et al., 2006; Grebmeier, 2012)
- Dramatic impacts of loss of sea ice for ice obligate animals (e.g., walrus, polar bears) (e.g., Monnett and Gleason, 2006; Cooper et al, 2006; Fishbach et al., 2007)

Region of Interest



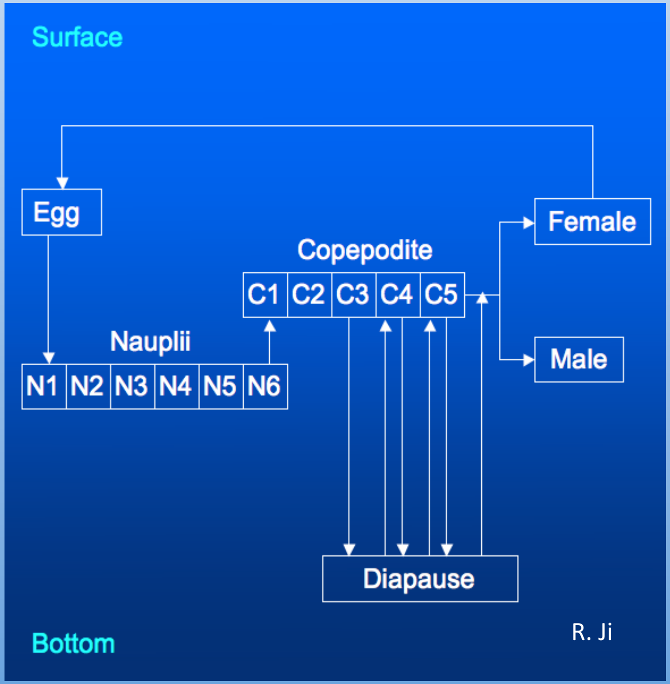
Map from Grebmeier et al. 2012

Images courtesy Lee Cooper and Jackie Grebmeier



What is going on with the biology in the Arctic seas during winter?

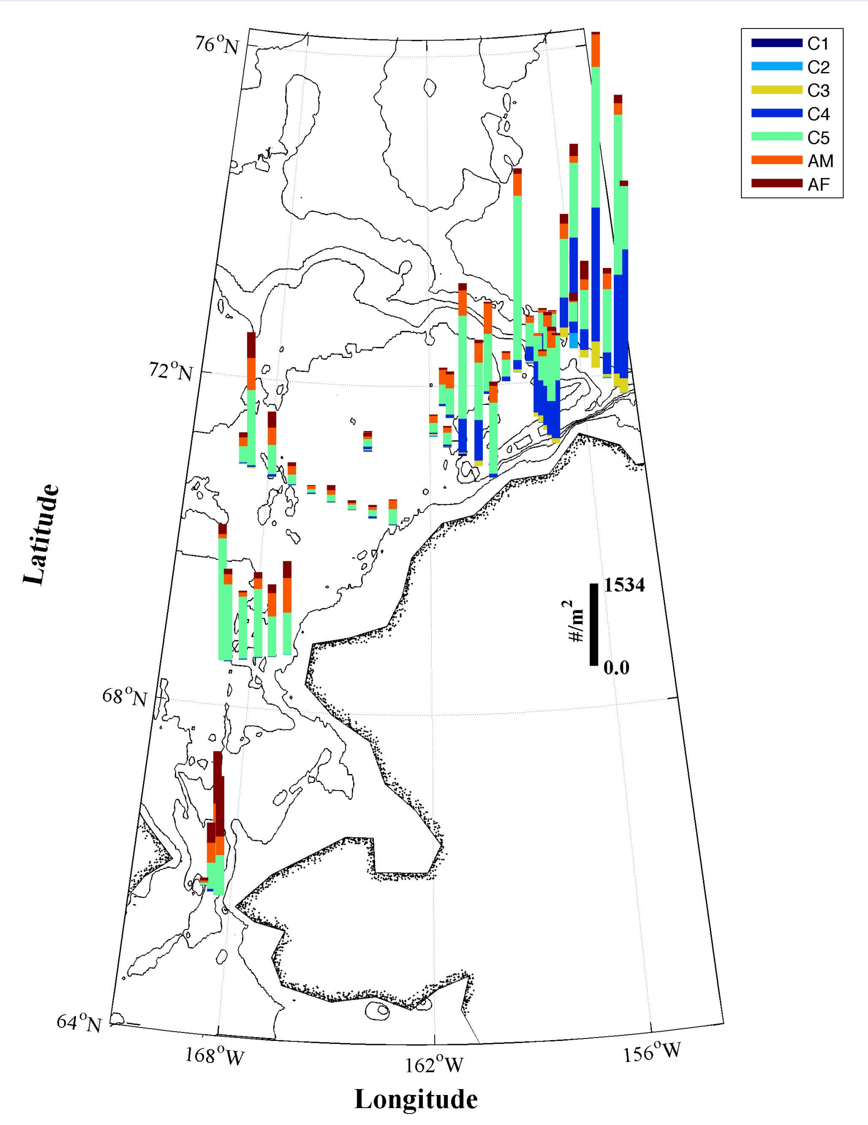
- Our understanding of Arctic ecology during winter is very limited. This has hampered our ability to model the ecosystems and to predict the impact of climate change
- In particular, we are interested in understanding how populations of the copepod *Calanus glacialis/marshallae* overwinter in the shallow Chukchi and Bering Seas (do they diapause/hibernate?)



- This species/genus follows a multi-stage, multi-year life history that includes diapause during unfavorable (winter) conditions, usually at depth
- *C. g/m* populations in the Chukchi Sea in particular are unable to consume all of the available primary production because the copepod biomass is too low (benthically dominated Chukchi Sea). Why? Is this because they do not successfully overwinter? Is the Chukchi Sea too shallow to permit successful overwintering?

How to do this? Take a ship (*USCGC Healy*) into the Arctic during early winter

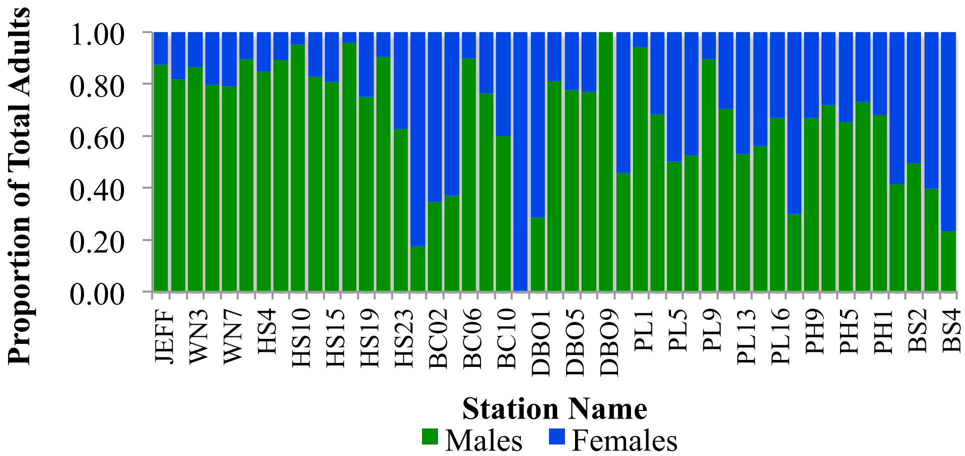
Abundance and Distribution of *Calanus glacialis/ marshallae*



- *Calanus* spp. were widespread in the Chukchi (and Bering, not shown) Seas
- Higher abundances were observed along the slope of the Chukchi Shelf Break and in the western Chukchi
- The dominant life stage was Copepodid 5 except in Barrow Canyon and on the Chukchi Slope– is this a population from the basin?
- Most had large lipid sacs ("Fat") for overwintering
- Animals appeared very active and not in diapause

Ashjian, Campbell, and Okkonen

Proportions of *Calanus* spp. Females and Males

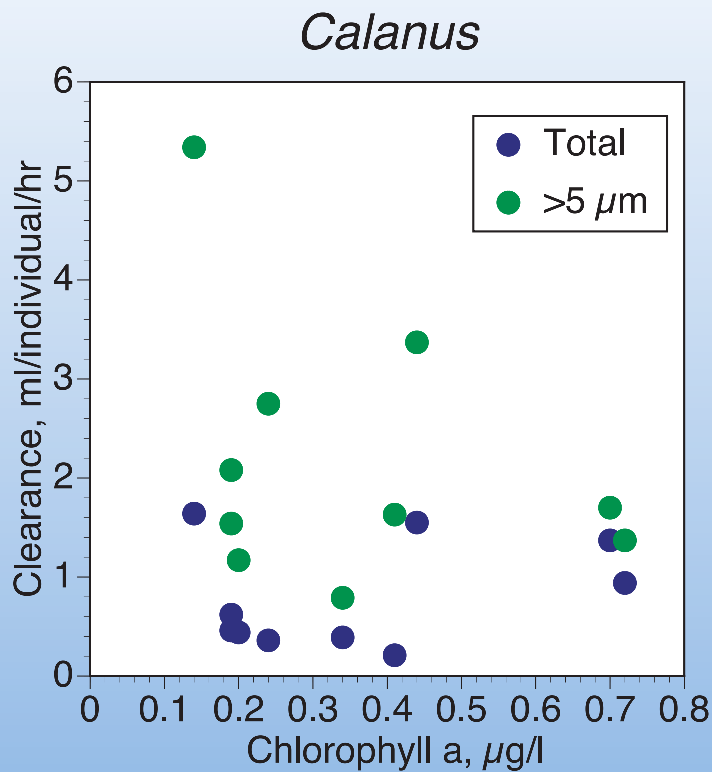


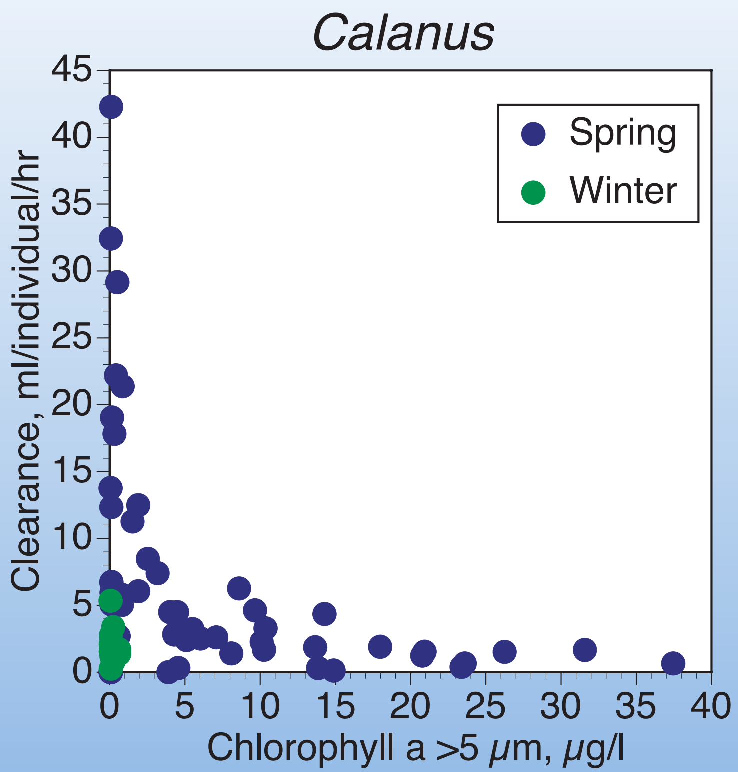
	% AM		
	Spring	**Summer**	**Winter**
Shallow Hanna Shoal	0 - <5	0 - <5	86
Hanna Shoal Slope	0 - <5	0 - <5	53
Head Barrow Canyon	0 - <5	0 - <5	77-84
Mouth Barrow Canyon	0 - <5	0 - <5	48

Comparison data collected during the SBI program in 2002 and 2004; Data from S.L. Smith, Campbell and Ashjian

- 50% or more of the adult *Calanus* were males at 36/47 (77%) of the locations
- Usually, we see males as a very small proportion of the adults – males are rare
- Males develop from C5 earlier than females
- The population was not remaining in the diapause stage but continuing to develop
- Female *Calanus* spp. did not have mature eggs but many had spermatophores attached

Copepod Grazing Rates



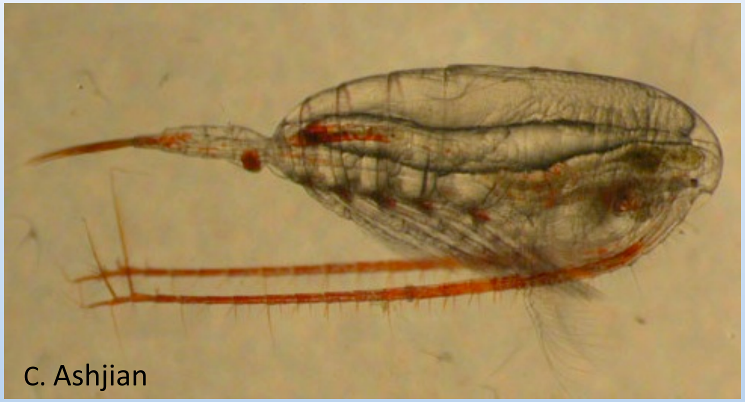


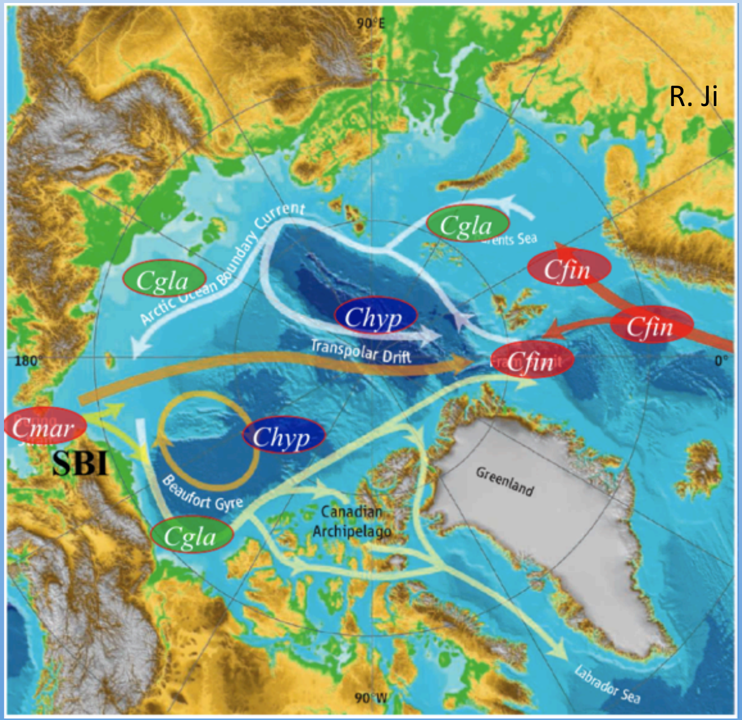
- Low but measureable grazing rates on chlorophyll
- Clearance greater on larger size fraction (>5 μm) indicating preference for larger cells
- *Calanus* spp. fed at lower rates during winter than during spring at similar low chlorophyll concentrations

Conclusions

- The Chukchi Sea in early winter is still biologically active
- Copepods of the genus *Calanus* are not in diapause, contrary to expectations, but are continuing to develop to older life stages
- Were we too early to see diapause? Or, does this population not diapause?

What determines the range of organisms and how might climate change change this?

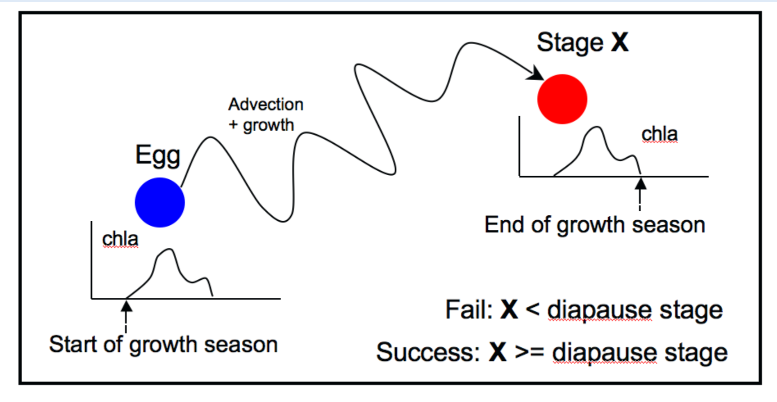


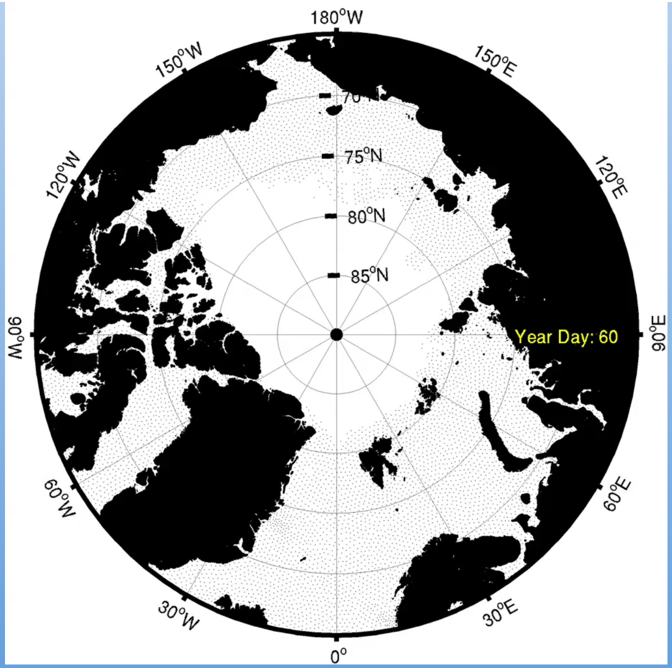


- Four species of the copepod genus *Calanus* are found in the Arctic and/or adjacent seas
  - Two in the northern Atlantic or northern Pacific, expatriate in the Arctic
  - Two endemic to the Arctic

- What maintains the persistent biogeographical patterns of distribution?
- Can species that are transported into the Arctic persist (reproduce successfully) and become endemic?
- Will climate change modify these patterns?

Modeling *Calanus* spp.





GOAL: Identify locations to which animals could be transported and successfully achieve an overwintering stage and thus persist

- Individual based modeling study
- Temperature and food dependent development rates
- Modeled circulation and water temperature
- Growth season length for each node point from satellite ocean color or from snow melt/radiation levels

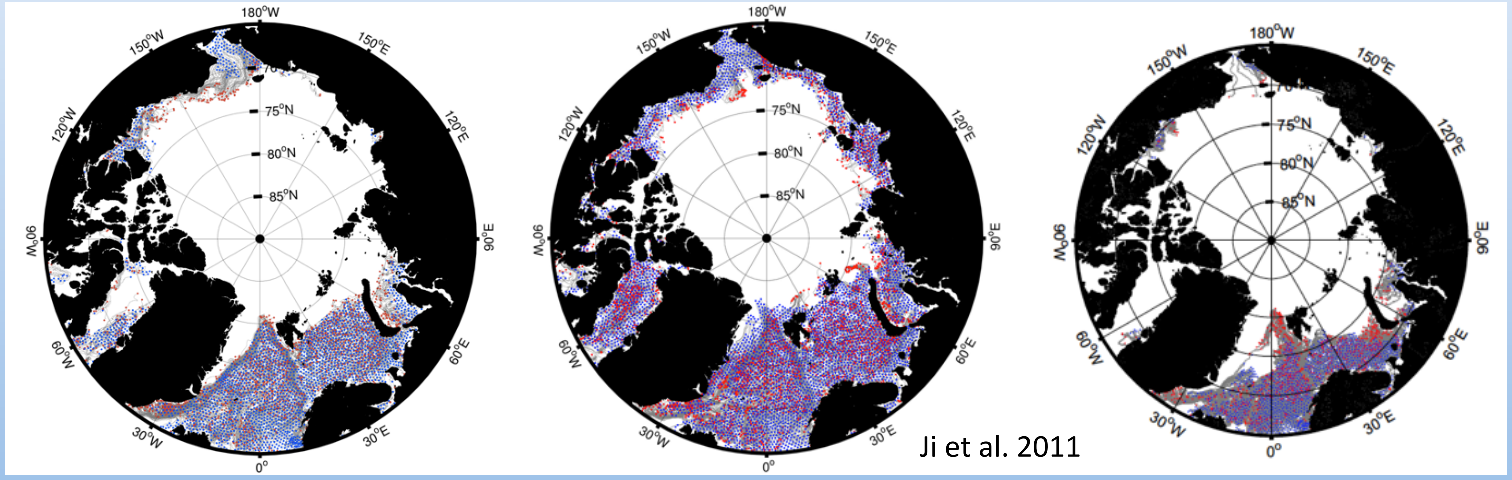
Ji, Ashjian, Campbell, et al. 2011. Progress in Oceanography

The Sub-Arctic Species (*C. finmarchicus* (Atlantic side) and *C. marshallae* (Pacific side)

Present Temperature and Growth Season Length

Temperature Increased 2°C

Growth Season Lengthened 2 Weeks



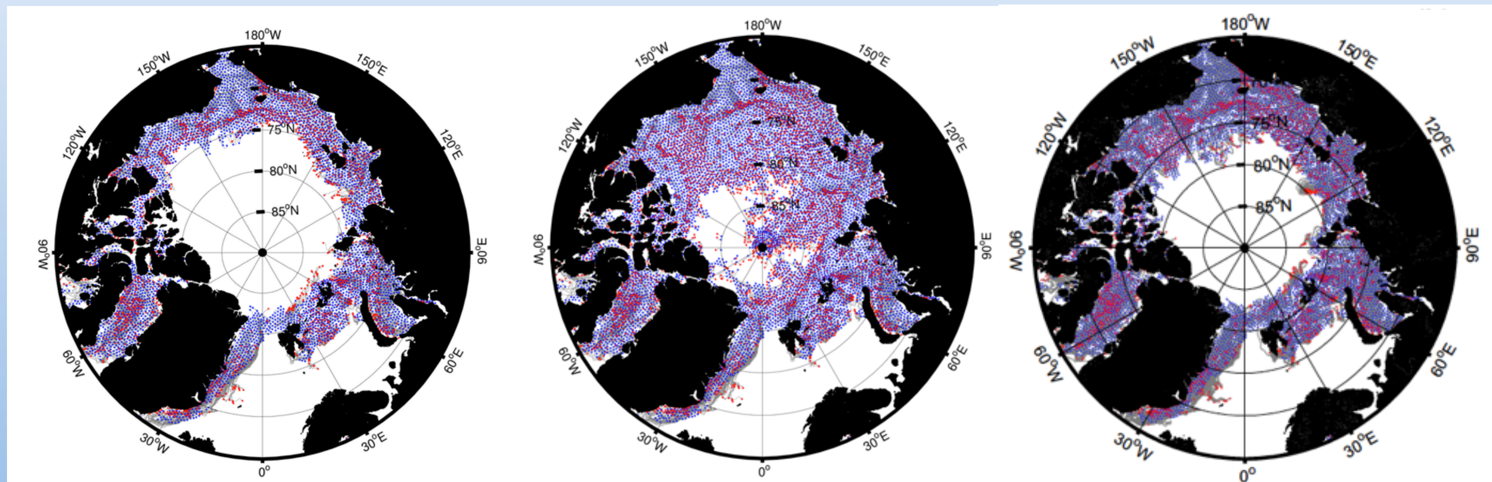
- Neither species can "make it" (achieve the diapause stage) in the Central Arctic at present because the growth season is too short to enable them to reach the overwintering stage at the ambient temperatures
- Even when temperature is increased by 2°C (and thus development rates are increased) and/or the growth season is lengthened by two weeks, these species still cannot persist in the Arctic

Arctic Species (*C. glacialis)*

Present Temperature and Growth Season Length

Temperature Increased 2°C

Growth Season Lengthened 2 Weeks



- Under present temperature and growth season length, distribution is restricted to shelves and slopes, consistent with observations
- A 2°C temperature increase greatly expands the potential range over which this species can persist. Lengthening of the growth season has a somewhat lesser effect

Conclusions from Modeling

- The observed biogeographic distributions of the species could be explained by life history characteristics and development rates coupled to water temperature, length of the growth season, and advection
- Both expatriate *Calanus* species cannot under present conditions colonize the Central Arctic because the growth season is too short to permit development to the diapausing stage
- Both endemic *Calanus* species can maintain viable populations in the Arctic marginal seas and Central Basin
- Only the Arctic endemics responded to increased temperature and the longer growing season, by increasing the range of where they could reach diapause, suggesting that even with moderate warming and changes in seasonality, the expatriate species will not be able to expand their range and colonize the Arctic

What next for Arctic ecosystems?

- Changes in ranges of prominent animals already have been observed (e.g., salmon, gray whales). However not all species may be so easily adaptable (e.g., *Calanus* spp.). The impact of climate change will depend on a complex mix of factors, including organism life history, changing seasonality, etc.
- The reduction of sea ice appears likely to continue and will have important impacts on the marine ecosystem, ranging from the obvious (loss of a critical substrate) to the more subtle (changing seasonality)
- Although we have increased our understanding of the ecosystem substantially in recent years, continued efforts to observe the ecosystem, particularly during winter, are critical
- Longer term records will permit us to recognize change. Ongoing efforts such as those through the Arctic Observing Network and the Distributed Biological Observatory should continue to provide the necessary assessment of variability