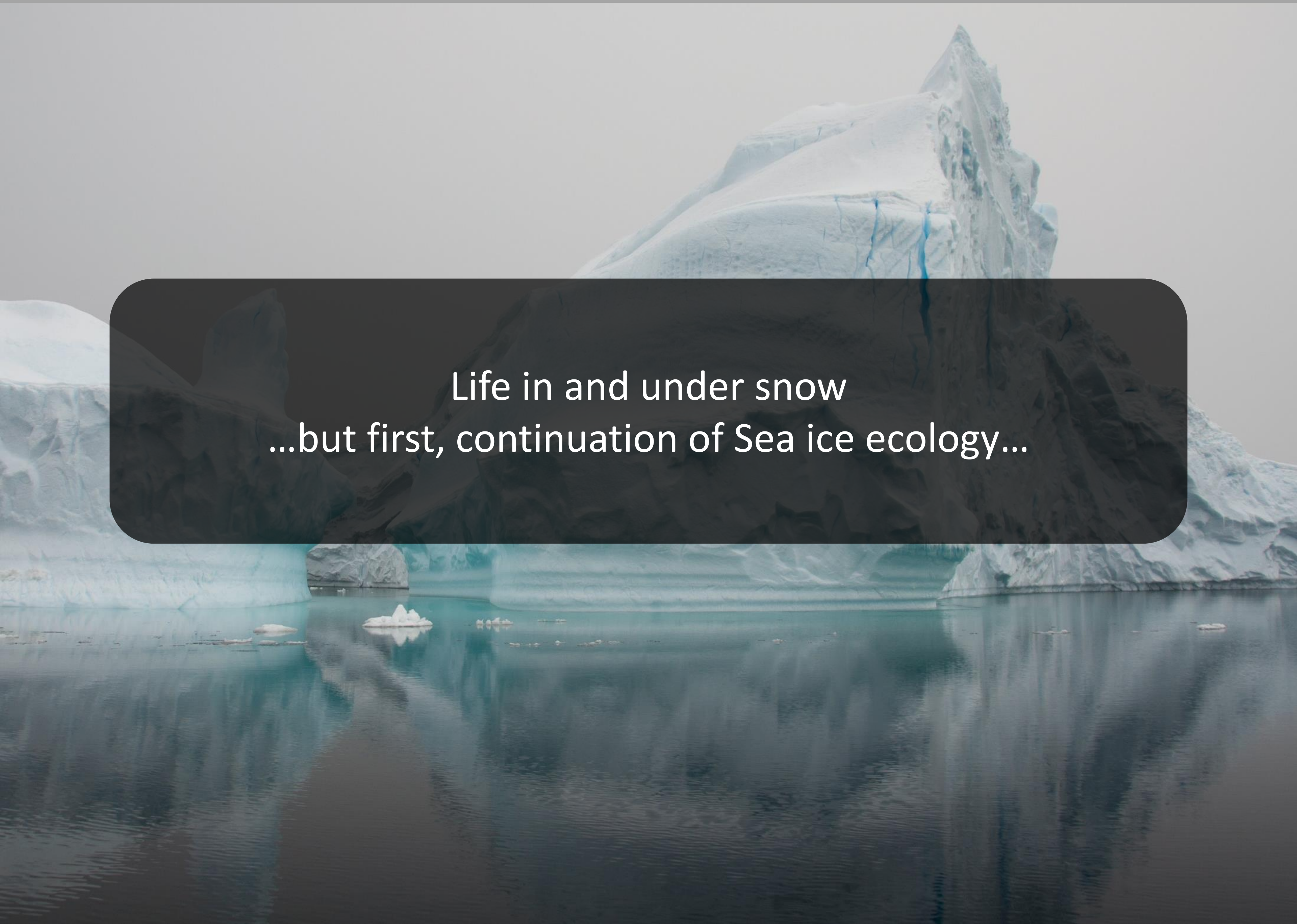


Life in and under snow
…but first, continuation of Sea ice ecology…

Announcements

- Presentations, rubric
- Group gets one grade for presentation
- Organization, content, presentation
- Make it organized, make it accurate, make it look nice!

1. Permafrost is a significant reservoir of…?

   Organic carbon

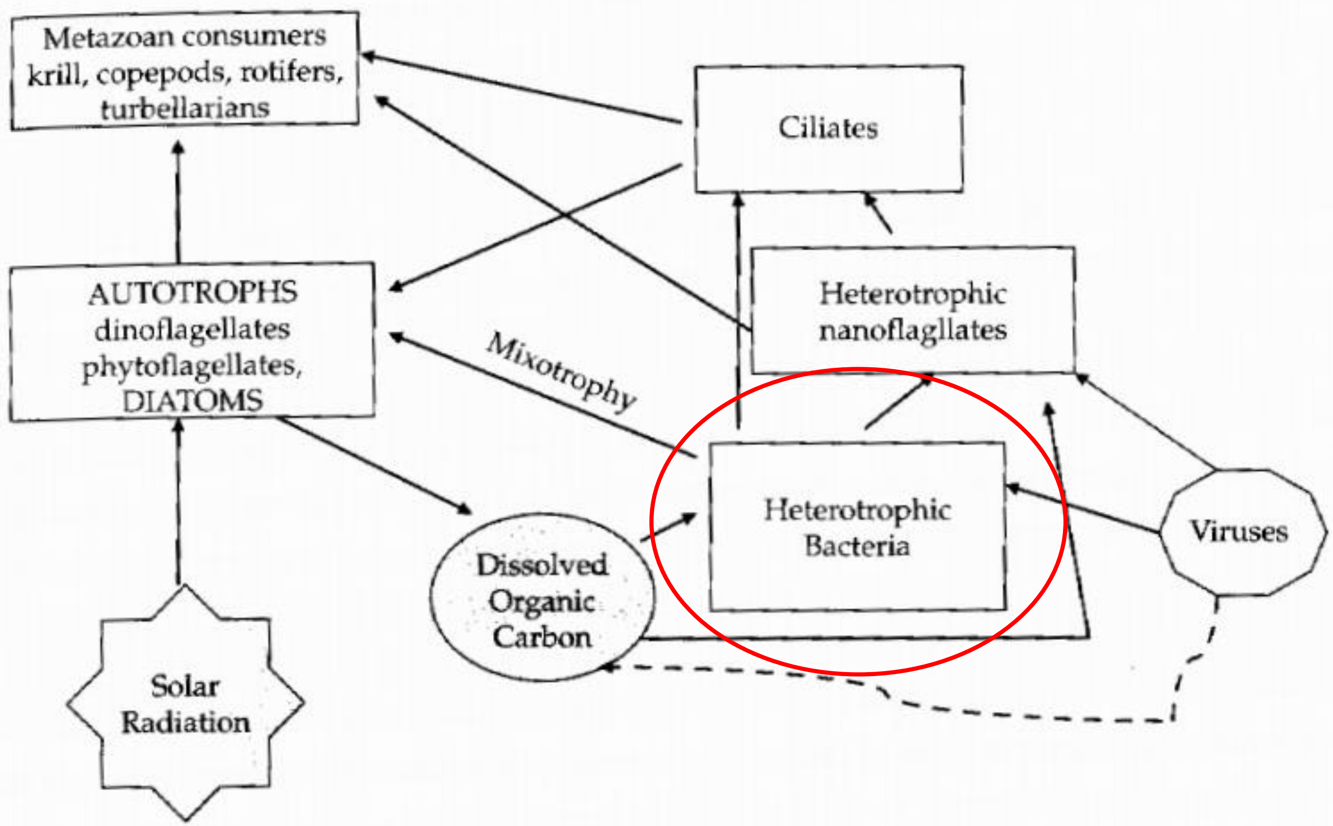
2. What thing(s) determine the moisture content of snowpack?

   Temperature and solute concentration

3. Diatoms have which two general morphologies?

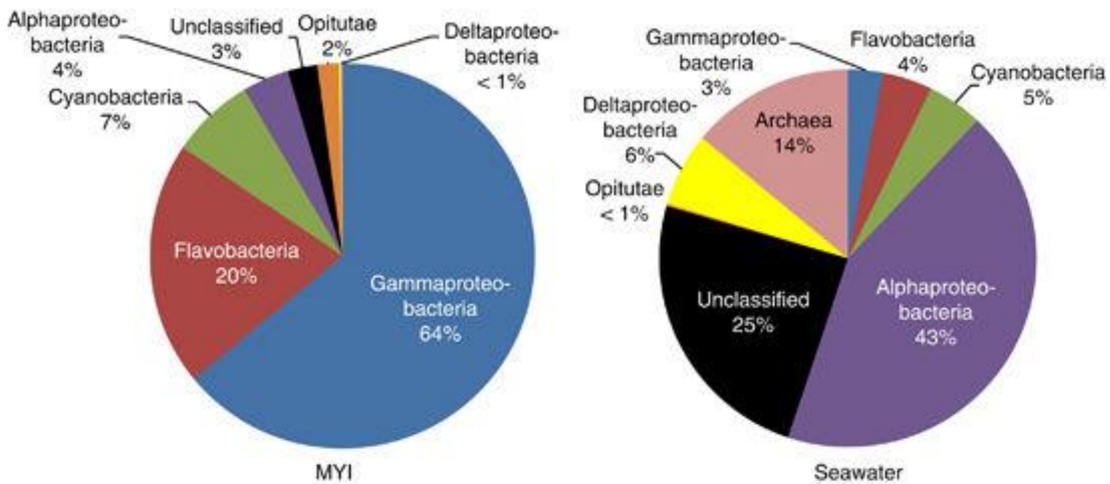
   Pennate and centric

1. Which of the following organisms are potential mixotrophs; diatoms, dinoflagellates, ciliates?
2. DMS, a byproduct of DMSP catabolism, does what in the atmosphere?
3. Which of the following undergo respiration: bacteria, diatoms, dinoflagellates, ciliates?


Metazoan consumers
krill, copepods, rotifers,
turbellarians
Ciliates
AUTOTROPHS
dinoflagellates
phytoflagellates,
DIATOMS
Heterotrophic
nanoflagllates
Mixotrophy
Heterotrophic
Bacteria
Viruses
Dissolved
Organic
Carbon
Solar
Radiation

"Typical" multi-year sea ice and seawater from the central Arctic

- Bacteria in sea ice are dominated by the Gammaproteobacteria and Flavobacteria
- These clades are optimized to fast growth under high organic carbon conditions
- This means that they are *copiotrophs* as opposed to *oligotrophs*

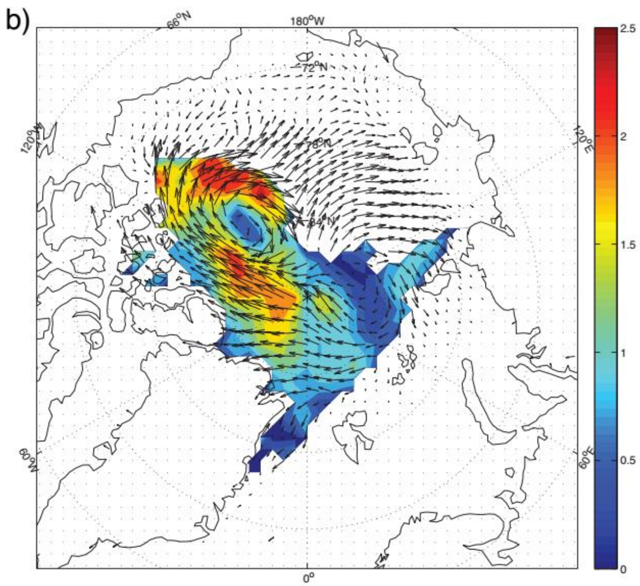


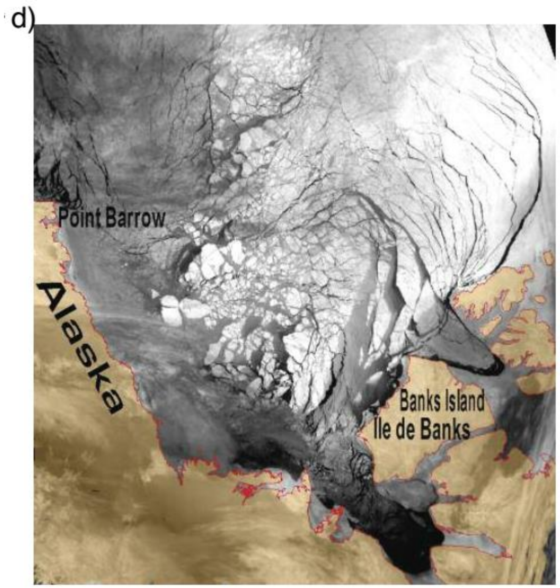
Bowman et al., 2012

How does this system establish?

- In the fall the seawater microbial community becomes the sea ice microbial community during ice formation
- This community persists through the winter – early spring population looks like the fall population

- Seasonal succession is very import in sea ice, but difficult to observe!





The Canadian icebreaker Amundsen during the Circumpolar Flaw Lead study

SIO 121, Lecture 6: Sea ice ecology cont'd: Heterotrophic bacteria

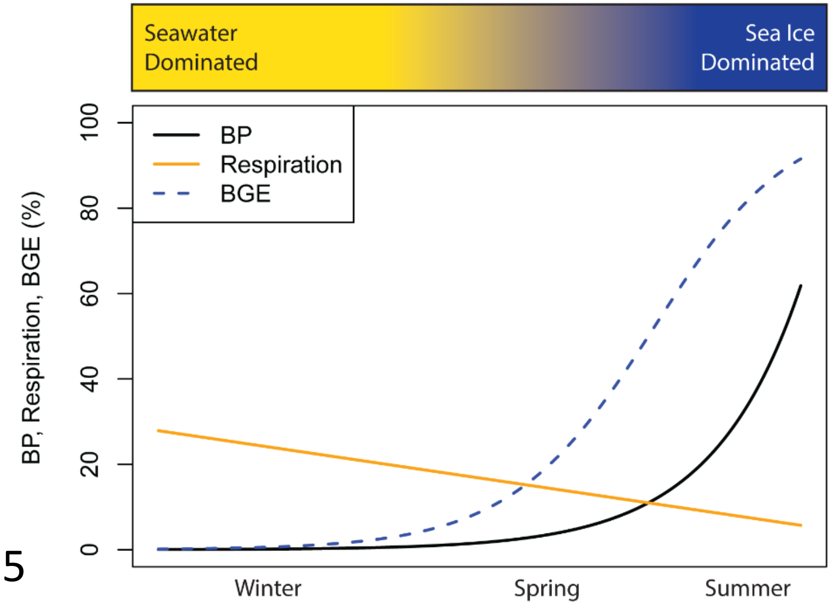
Table 1. Bacterial ARISA OTUs in Franklin Bay (FB) sea ice horizons I–III (representing depths of 25, 45 and 65 cm below the ice surface) and under-ice seawater (SW).

	FB I			FB II							FB III	FB SW		
	24	60	74	24	31	38	53	60	67	74	31	88	% height	Phylotype of best clone library match
683	•	•	•	•	•	•	•	•	•	•	•	•	37.3	SAR11: B1-a, B2, B3-a, B17-a
786	•	•	•	•	•	•	•	•	•	•	•		7.1	*Polaribacter*: B28-a
666	•	•	•	•	•	•	•	•	•	•	•	•	6.5	SAR11: B1-b
702	•	•	•	•	•	•	•	•	•	•	•	•	6.3	*Alphaproteobacteria*: B13-b; OM182: B20
237	•	•	•	•	•	•	•	•	•	•	•		3.1	–
738	•	•	•	•	•	•	•	•	•	•	•	•	2.8	–
860	•	•	•	•	•	•	•	•	•	•	•	•	2.6	*Polaribacter*: B28-d
391	•	•	•	•	•	•	•	•	•	•	•		2.3	–
704	•	•	•	•	•	•	•	•	•	•	•	•	2.3	*Alphaproteobacteria*: B13-b; OM182: B20
661	•	•	•	•	•	•	•	•	•	•	•		1.7	SAR11: B1-b, B9, B10; *Cryobacterium*: B42
688	•	•	•	•	•	•	•	•	•	•	•	•	1.7	–
856	•	•	•	•	•	•	•	•	•	•	•	•	1.5	*Polaribacter*: B28-d
539	•	•	•	•	•	•	•	•	•	•	•	•	1.2	–
756	•	•	•	•	•	•	•	•	•	•	•	•	1.1	–

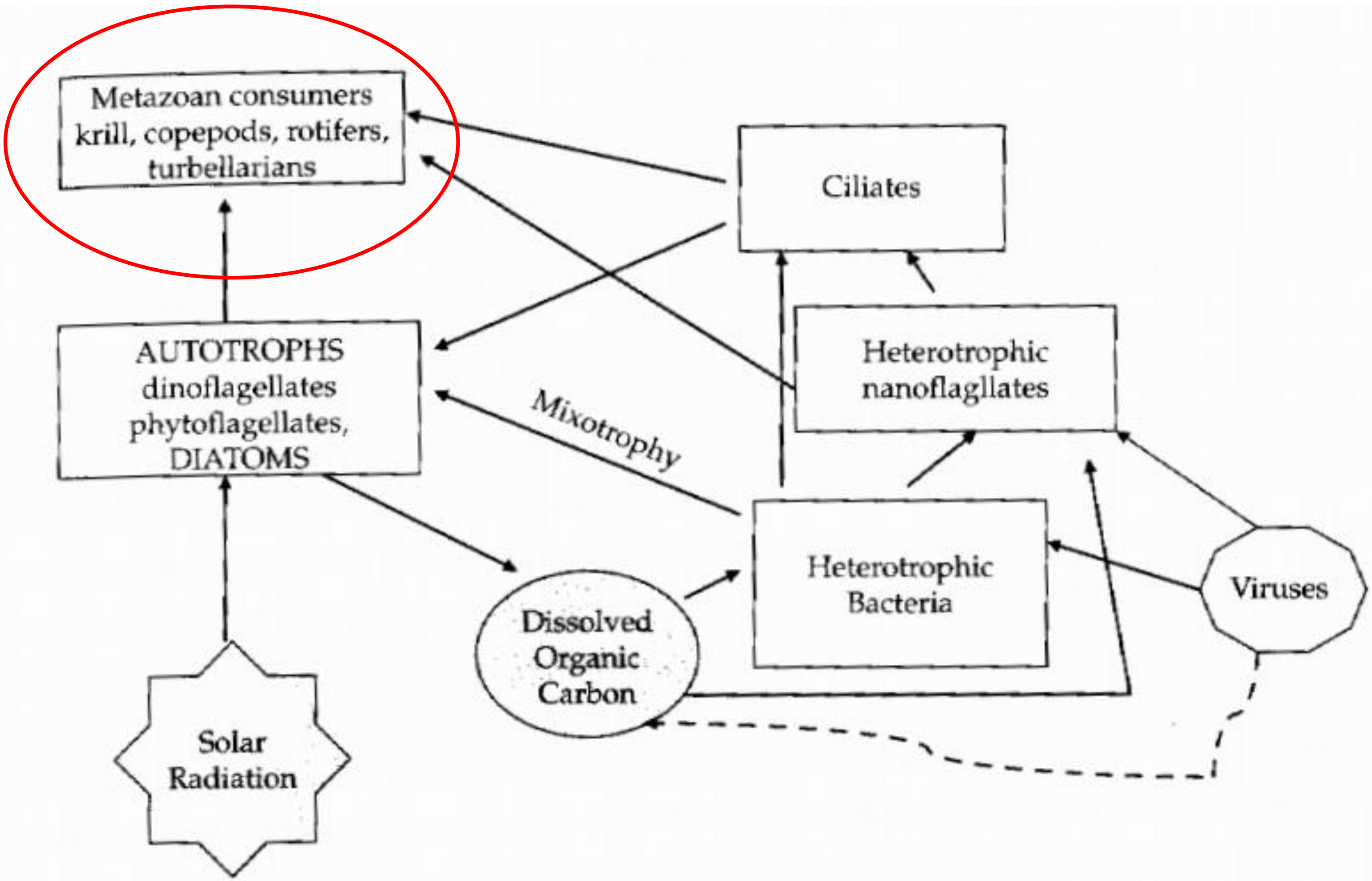
Each horizon is ordered by calendar day (left to right). Shown are OTUs present in every sea ice sample; additional OTUs are presented in Table S1. A black dot indicates the presence of a peak; alternating grey and white rows are used for clarity. '% height' indicates the percentage of the total global peak height in each OTU.

Collins et al., 2010

When we describe the "sea ice microbial community" we are generally narrowly focused on the highly productive spring and summer sea ice environment



Bowman, 2015


Metazoan consumers
krill, copepods, rotifers,
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Ciliates
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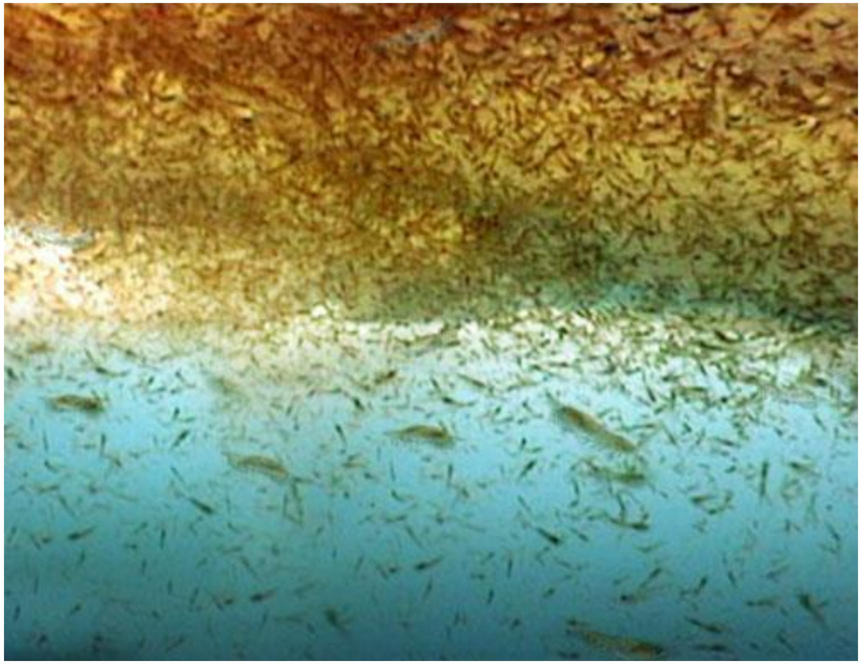
phytoflagellates,
DIATOMS
Heterotrophic
nanoflagllates
Mixotrophy
Heterotrophic
Bacteria
Viruses
Dissolved
Organic
Carbon
Solar
Radiation

- High levels of primary production are important for the rest of the foodweb
  - Amphipods, copepods, krill graze at the sea ice-seawater interface
  - Secondary consumers graze at the sea ice-seawater interface
  - Sea ice-derived POC can feed rich benthos



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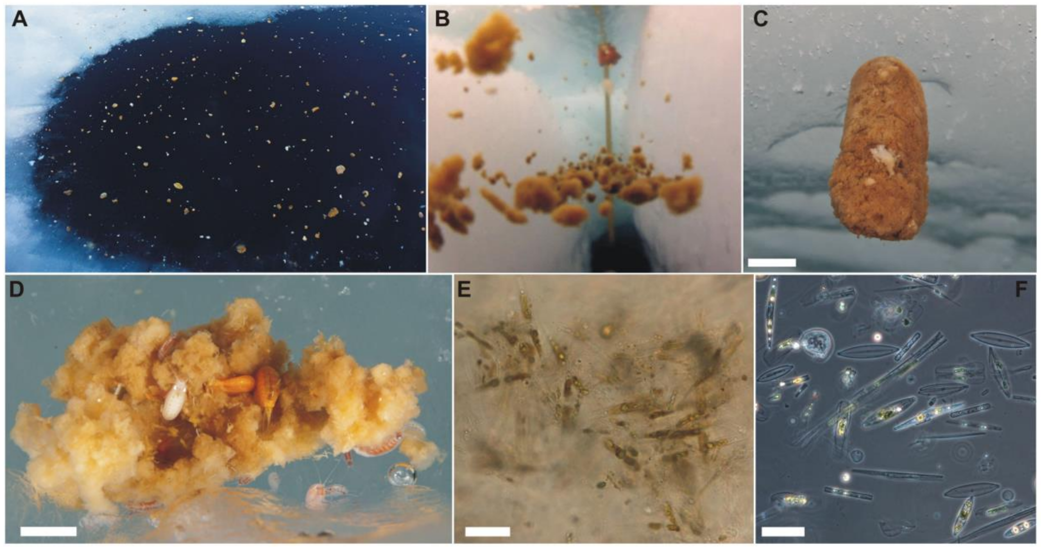
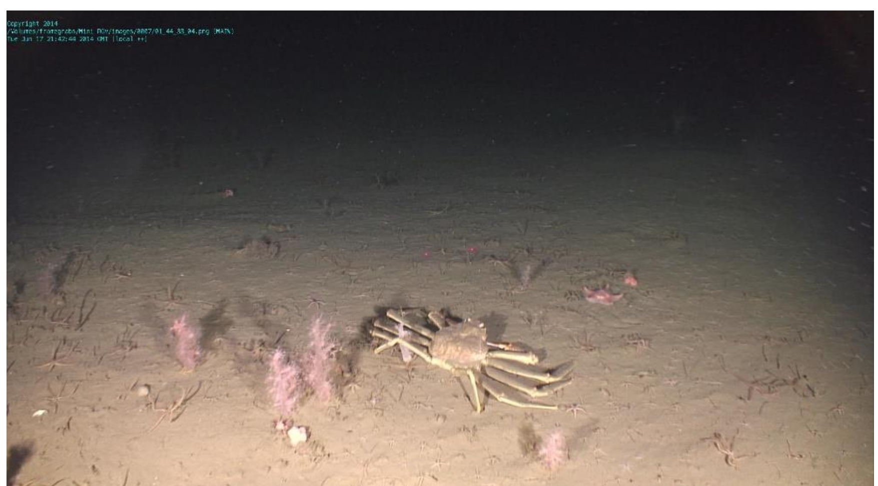


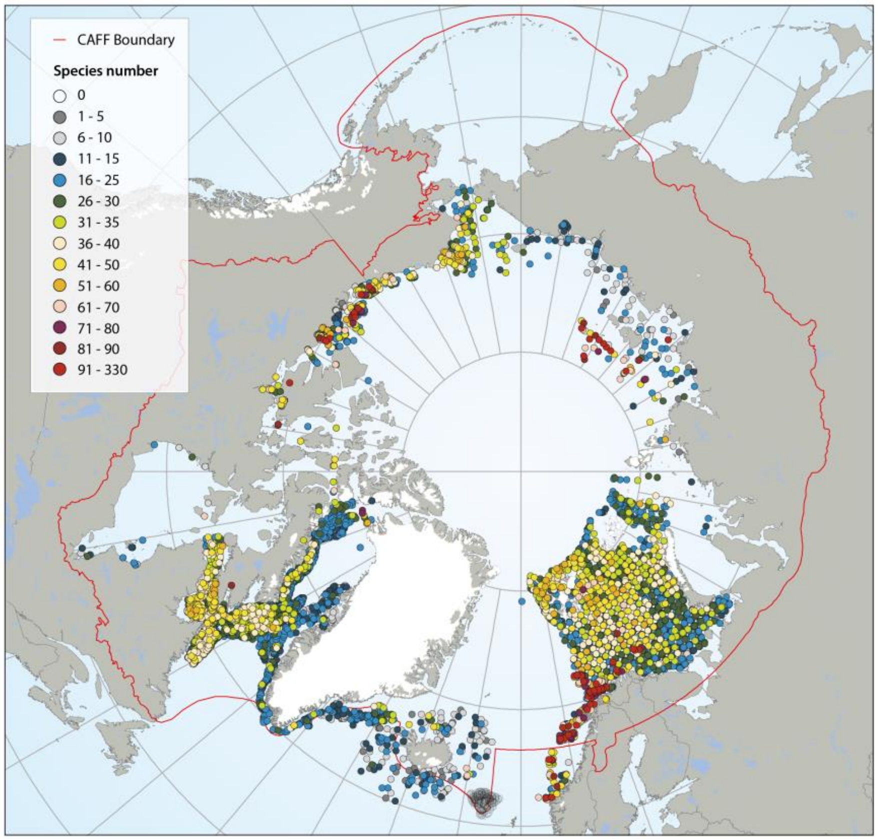


Chionoecetes opilio, Snow crab

Box 3.3.2: Benthic megafauna

Pan-Arctic taxon richness in trawl benthos

More than 100 megafaunal species/taxa have been recorded at trawl stations (red) in the eastern Beaufort Sea, the deeper parts of the Laptev Sea, and the west coast of Norway. The lowest numbers (blue/grey) have been recorded in around Greenland and Iceland, in the southeastern Barents Sea and southern Chukchi Sea, as well as the shallower parts of the Kara, East Siberian, and Laptev Seas. Intermediate species/taxon richness (yellow) have been recorded in the Baffin Bay-Davis Strait/Hudson Complex, the central and northern Barents Sea, the western Beaufort Sea, the northeastern Chukchi Sea, and the Canadian Archipelago.



Box figure 3.3.2 Number of megafauna species/taxa in the Arctic (7,322 stations in total), based on recent trawl investigations. Stations with highest species/taxon number are sorted to the top, meaning that dense concentrations of stations (e.g. Eastern Canada, Barents Sea), with low species numbers are hidden behind stations with higher species numbers. Also note that species numbers are somewhat biased by differing taxonomic resolution between studies. Data from: Icelandic Institute of Natural History, Iceland; Marine Research Institute, Iceland; University of Alaska, Fairbanks, U.S.; Greenland Institute of Natural Resources, Greenland; Zoological Institute of the Russian Academy of Sciences, St. Petersburg, Russia; Université du Québec à Rimouski, Canada; Fisheries and Oceans Canada; Institute of Marine Research, Norway; and Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia.

- The Arctic and Antarctic are both well known for high benthic diversity and high benthic biomass
- This is a direct result of sea ice primary production

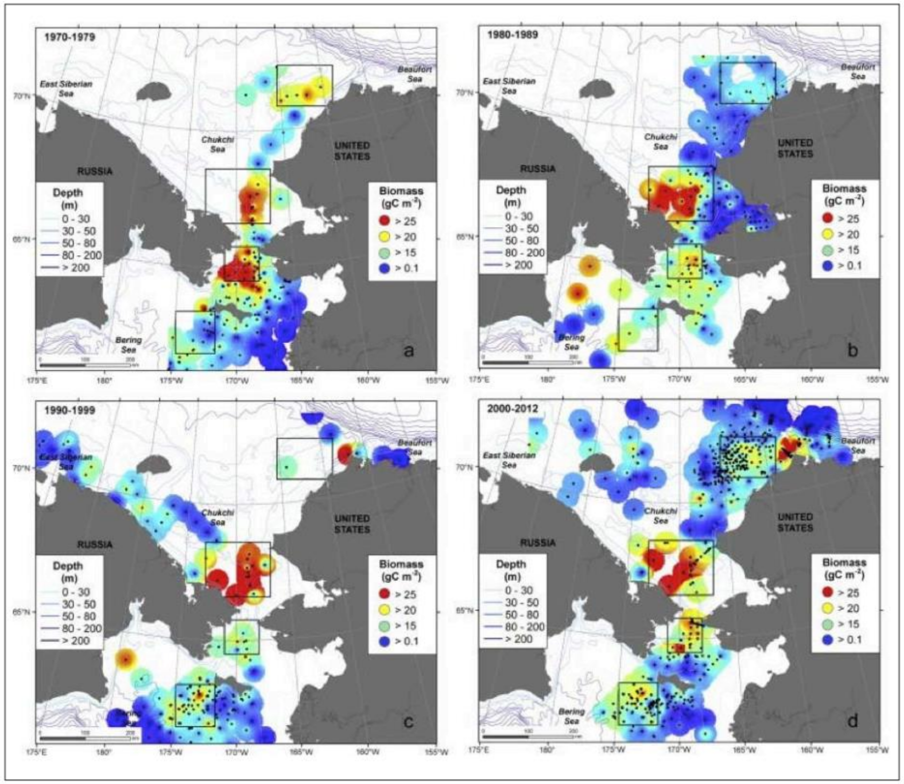


Figure 3.3.6: Benthic macro-infauna biomass in the northern Bering and Chukchi Seas from 1970 to 2012, displayed as decadal pattern Adapted from Grebmeier et al. (2015a) with permission from Elsevier.

State of the Arctic Marine Biodiversity Report, Chapter 3.3

- Hypothesis: Sea ice-derived POC feeds rich benthos
- Can test using stable isotope methods that are analogous to primary production assay

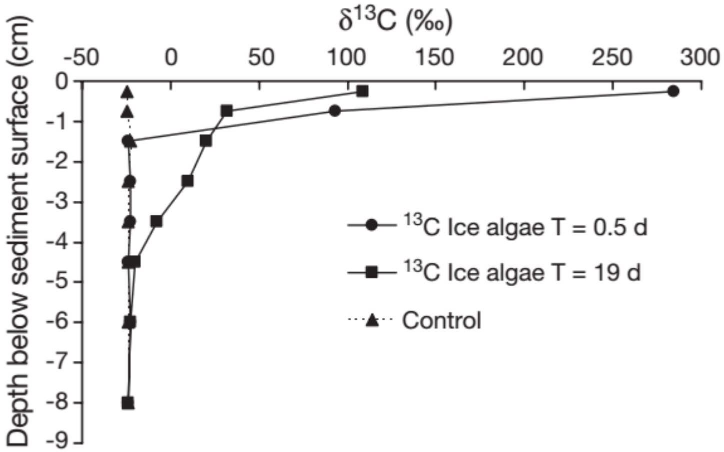
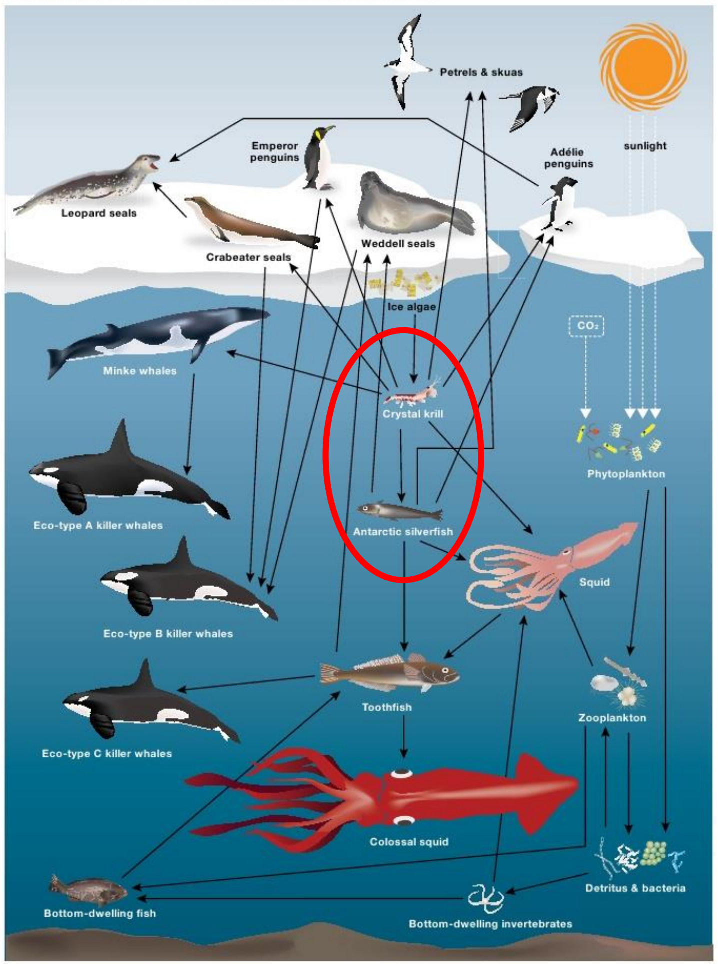


Fig. 3. Down-core profiles of mean sediment $\delta^{13}C$ signatures in sediment cores inoculated with ^{13}C-enriched ice algae and a no food addition control after 0.5 and 19 d of incubation at 4 to 5°C. N = 2 replicate sediment cores

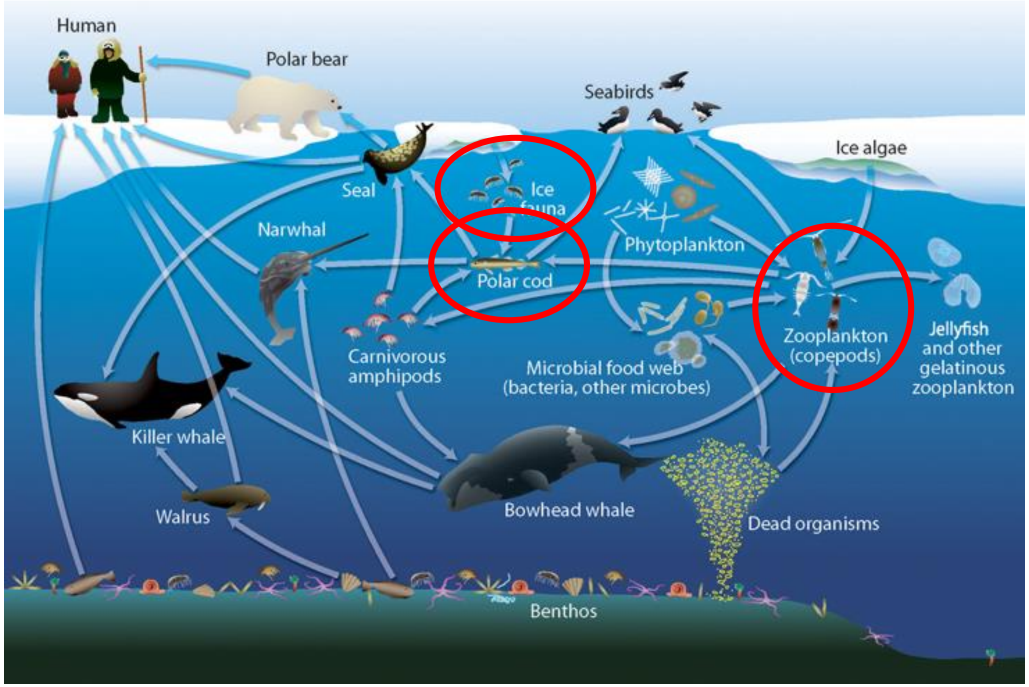
McMahon et al., 2006

- As with all networks, look for the nodes with the most connections
- In food webs, also look for nodes that connect across trophic levels
- Arctic and Antarctic both have critical species that serve as links between sea ice primary production and higher trophic levels

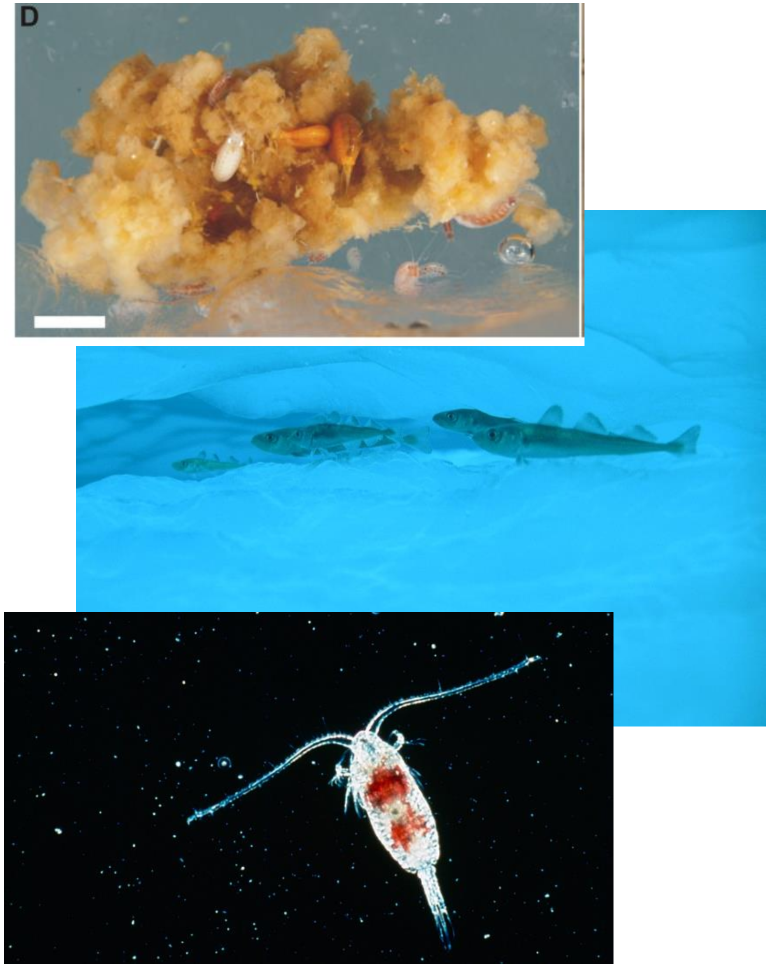
Figure 3 A simplified representation of the key species in the Ross Sea food web.

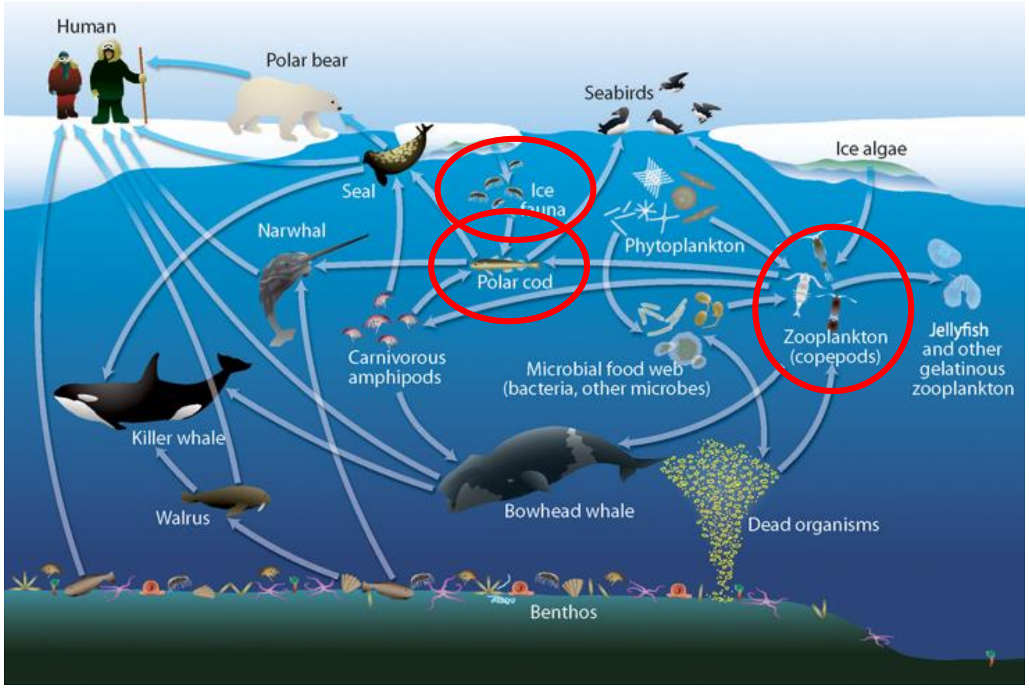


18 Defending the last ocean



- Polar cod are an ecologically significant species in the Arctic
  - Not ice dependent, but probably thrives best when ice present
  - Small enough to feed on copepods, but large enough to be fed on by everything else

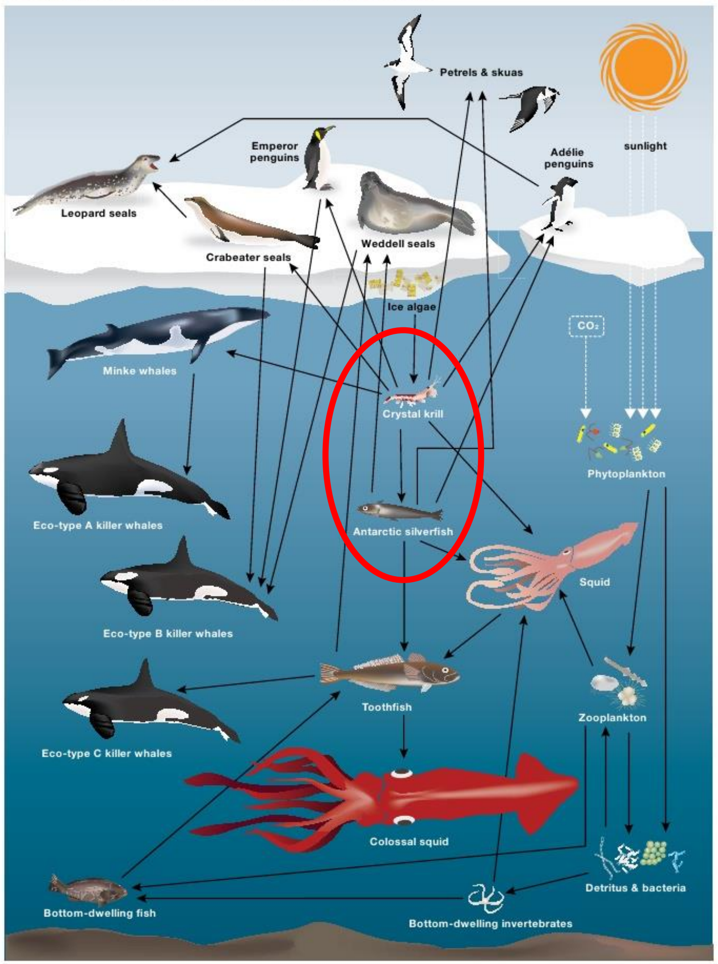




SIO 121, Lecture 6: Sea ice ecology cont'd: Primary and secondary consumers

- Polar cod are an ecologically significant species in the Arctic
  - Not ice dependent, but probably thrives best when ice present
  - Small enough to feed on copepods, but large enough to be fed on by everything else
- Antarctic krill and silverfish fill a similar niche in the Antarctic
  - Both are considered ice dependent species
  - Juveniles are closely associated with sea ice

Figure 3 A simplified representation of the key species in the Ross Sea food web.



18 Defending the last ocean

- Prey quality matters – foraging can be an expensive activity!
- Eating silverfish is better than eating krill

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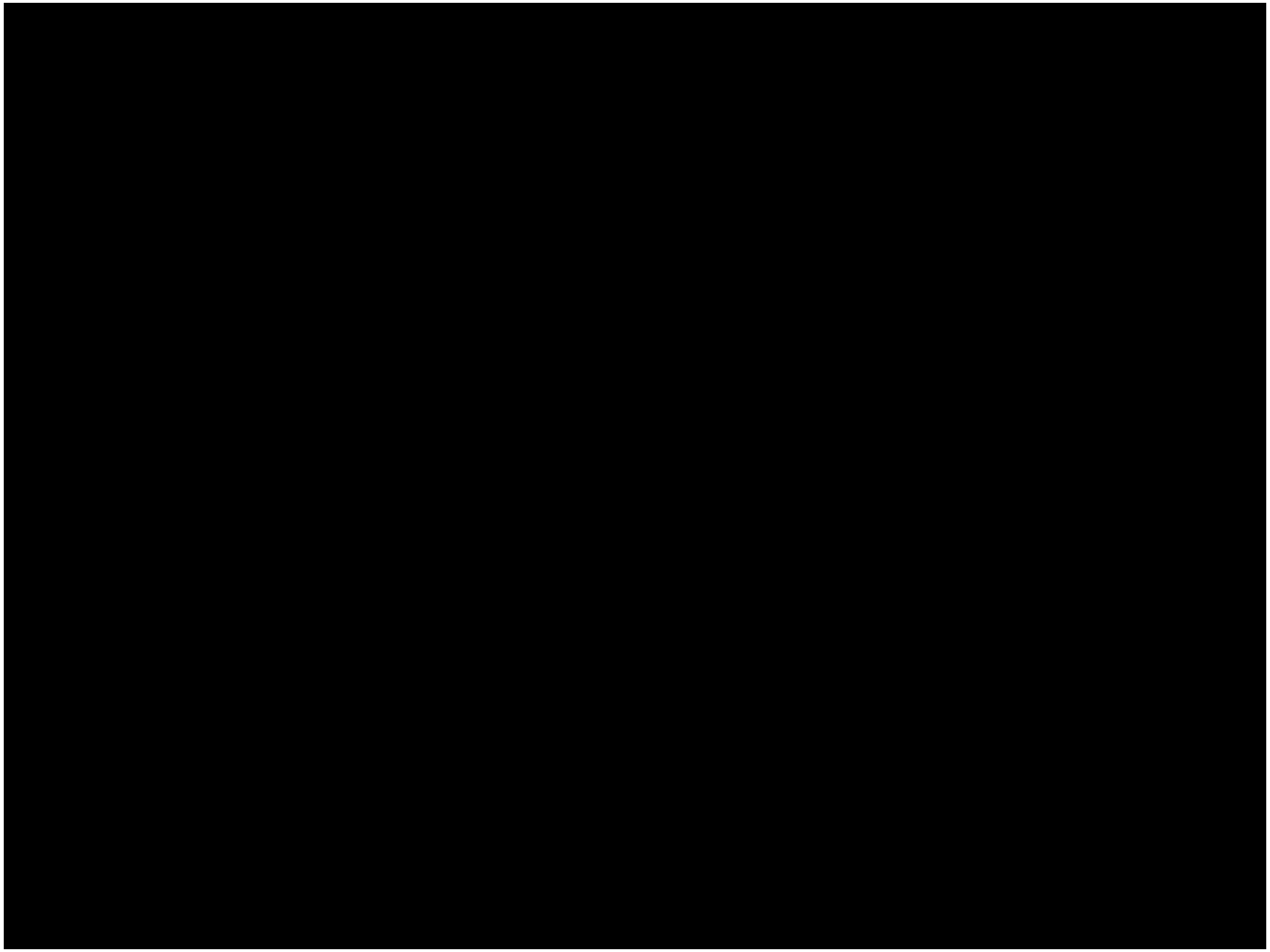
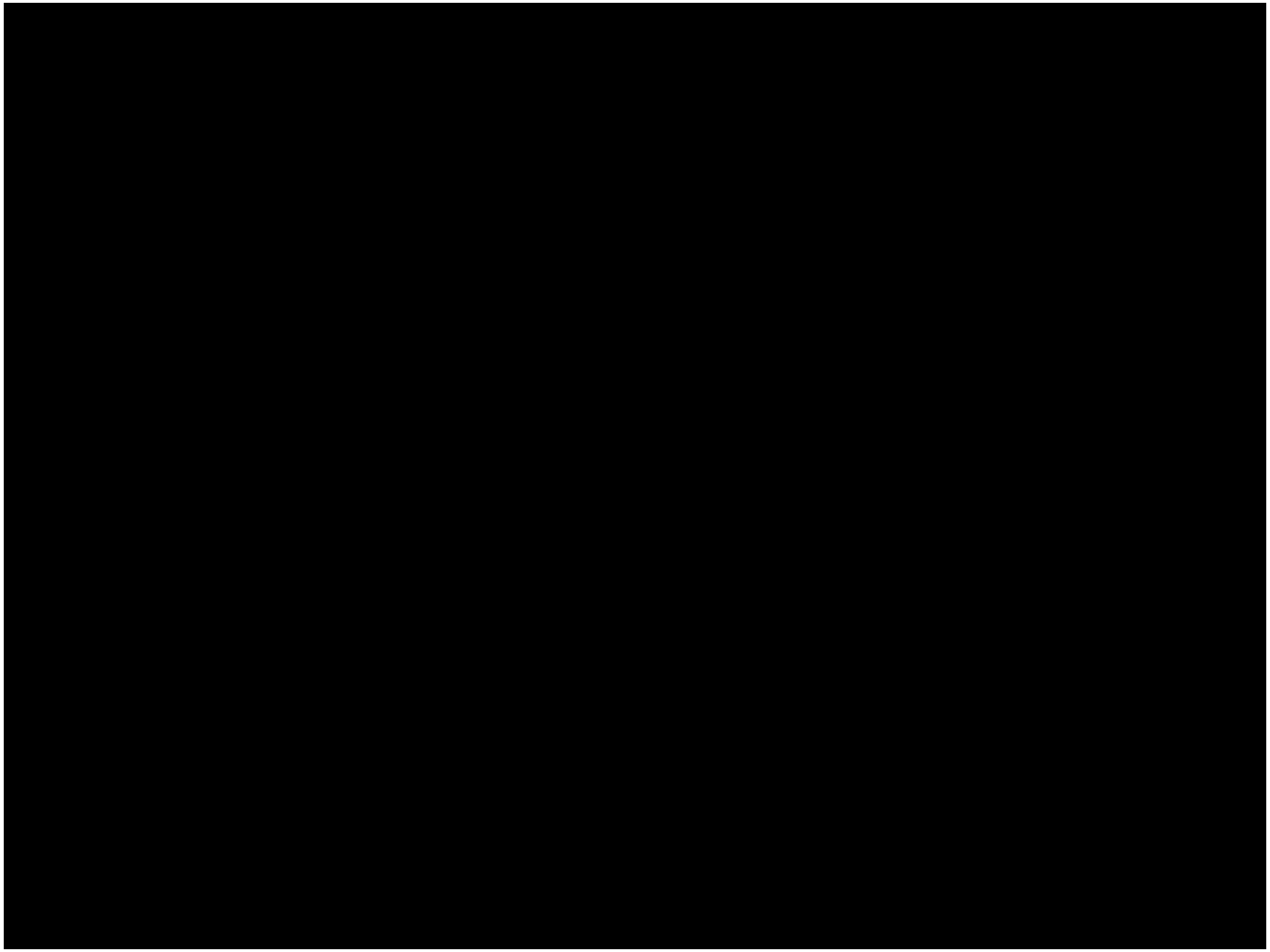
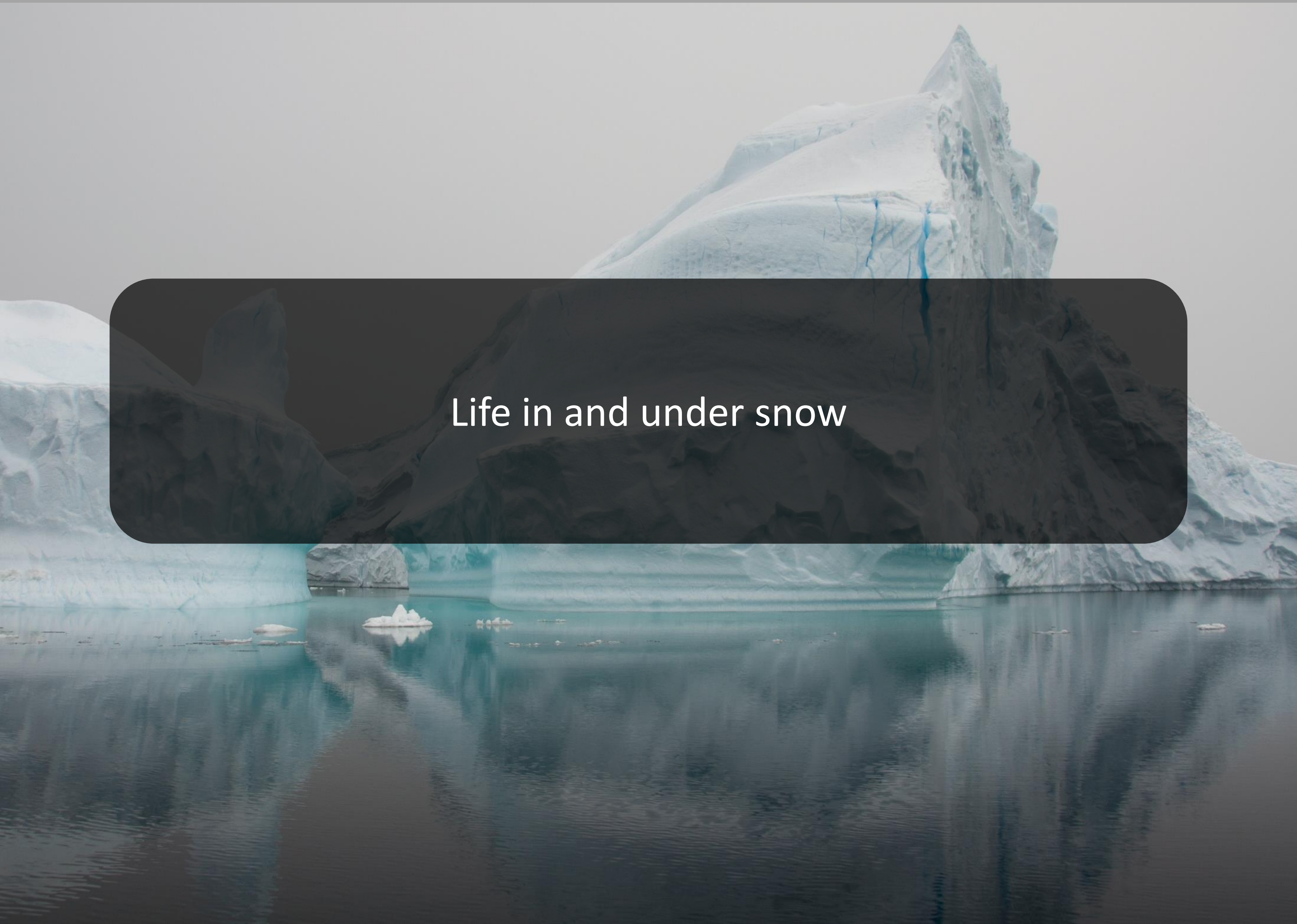


- Prey quality matters – foraging can be an expensive activity!
- Eating silverfish is better than eating krill



Life in and under snow



Challenges and opportunities in snow

Challenges

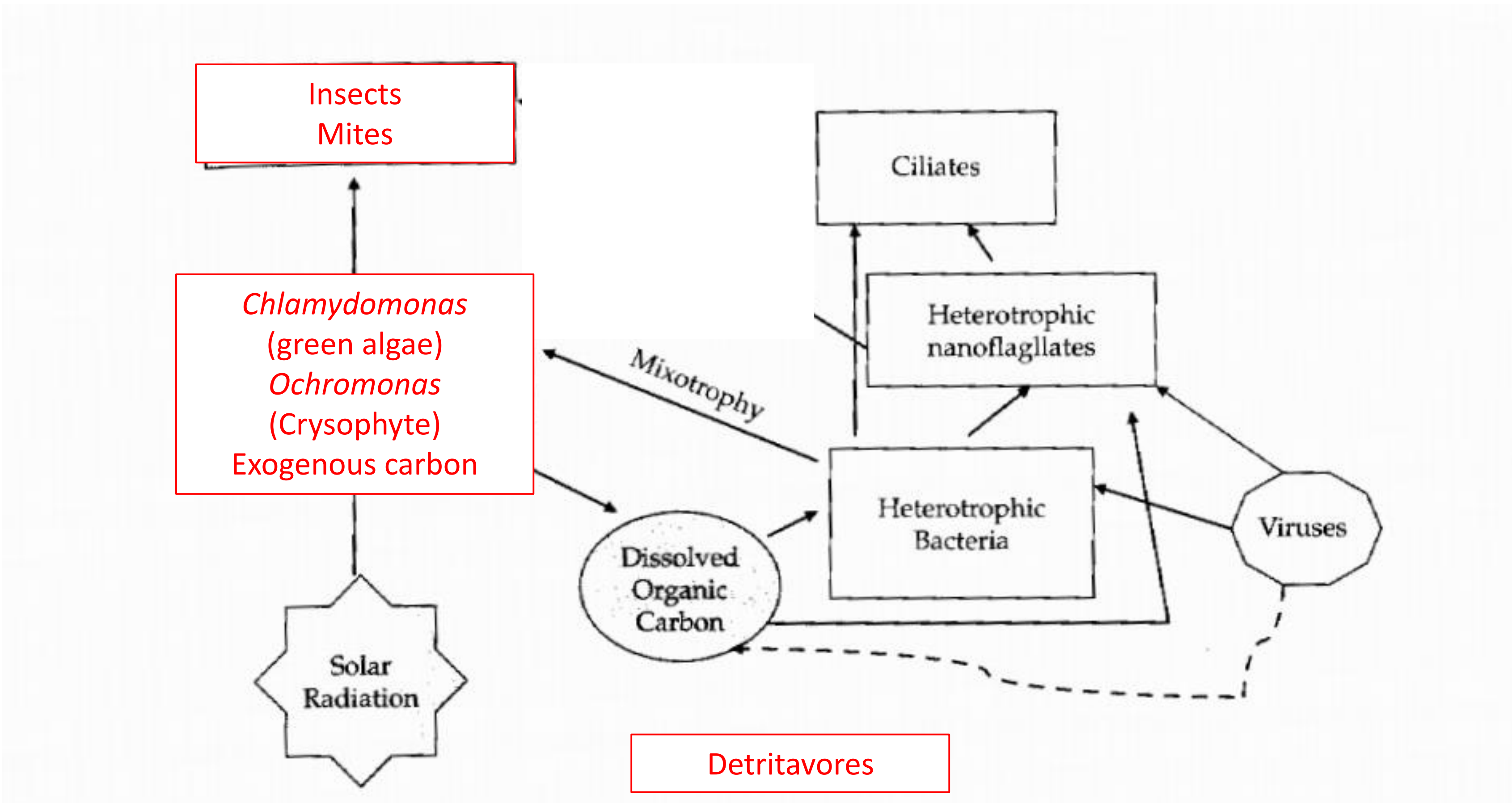
- Low temperature
- Extreme temperature fluctuations
- Low water activity
- Low nutrients (interior and surface)
- Low carbon (interior and surface)
- Intense radiation (surface)

Opportunities

- Adequate light for photosynthesis
- Liquid water, where thermodynamics allow
- Nutrients and carbon at the base of the snowpack

Based on the availability of carbon, nutrients, and energy, life is concentrated at the snow surface and at the base of the snowpack (*subnivean* zone).

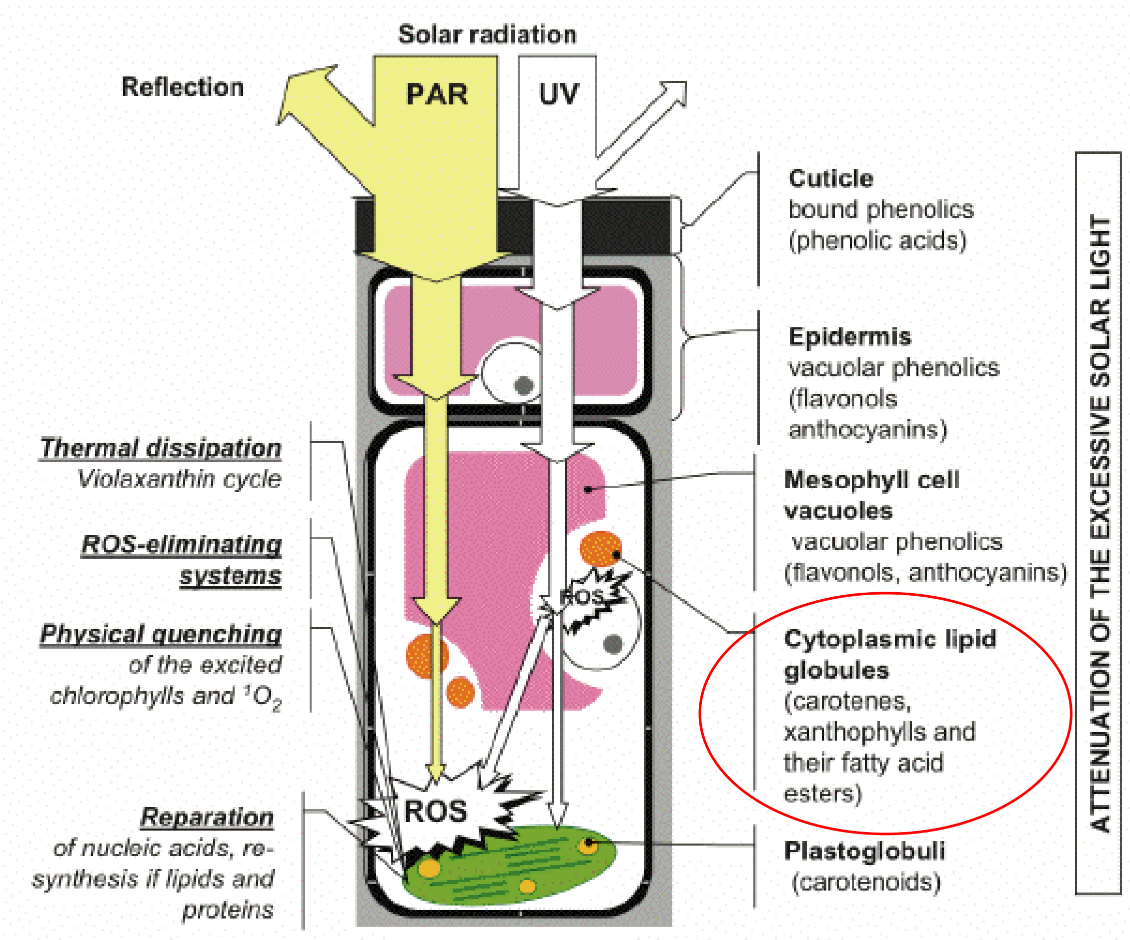
Foodweb at the snow surface



SIO 121, Lecture 7: Life in and under snow

Chlamydomonas nivalis

Q: Why pink?
A: High proportion of carotenoids, specifically astaxanthin, a pigment that does not participate in photosynthesis and serves to limit the amount of light reaching the photosynthetic apparatus



http://photobiology.info/Solovchenko.html

Chlamydomonas nivalis

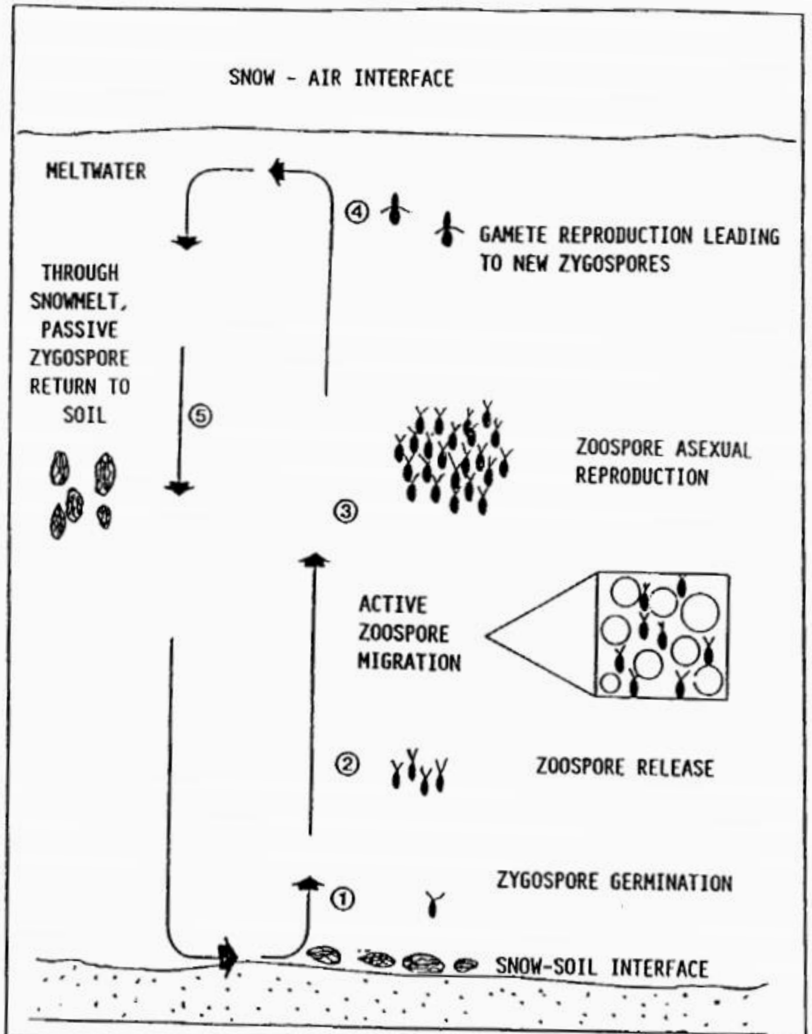
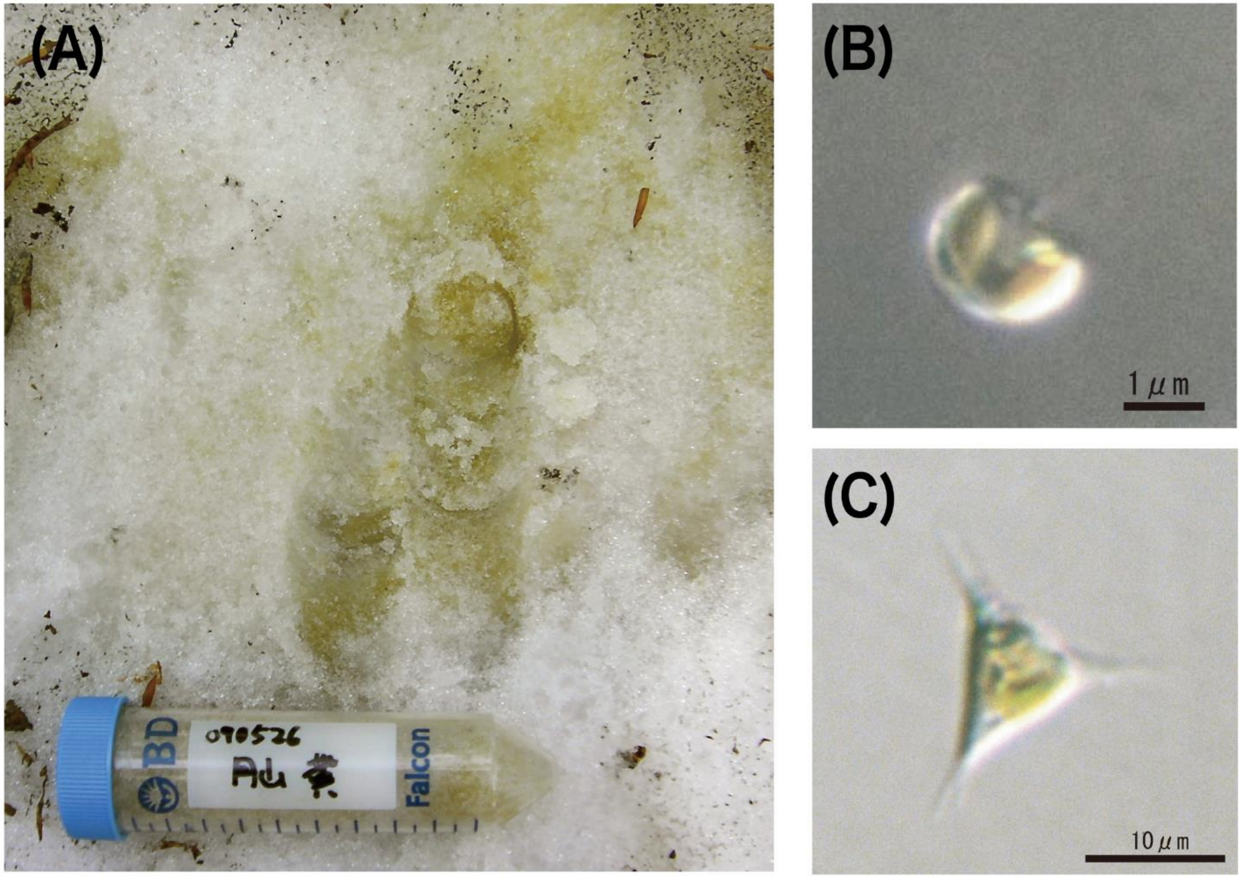


Figure 1. Life cycle of snow algal flagellates such as *Chloromonas* and *Chlamydomonas*. Zygospores germinate releasing zoospores (1 & 2), zoospores become active vegetative cells (3), the latter produce gametes when nutrients become limiting (4) and new zygospores (5) do not germinate until the following year (modified after Gamache, 1990).

Q: Where do they come from each year?
A: Soil! Complex lifecycle involving motile and nonmotile phases.

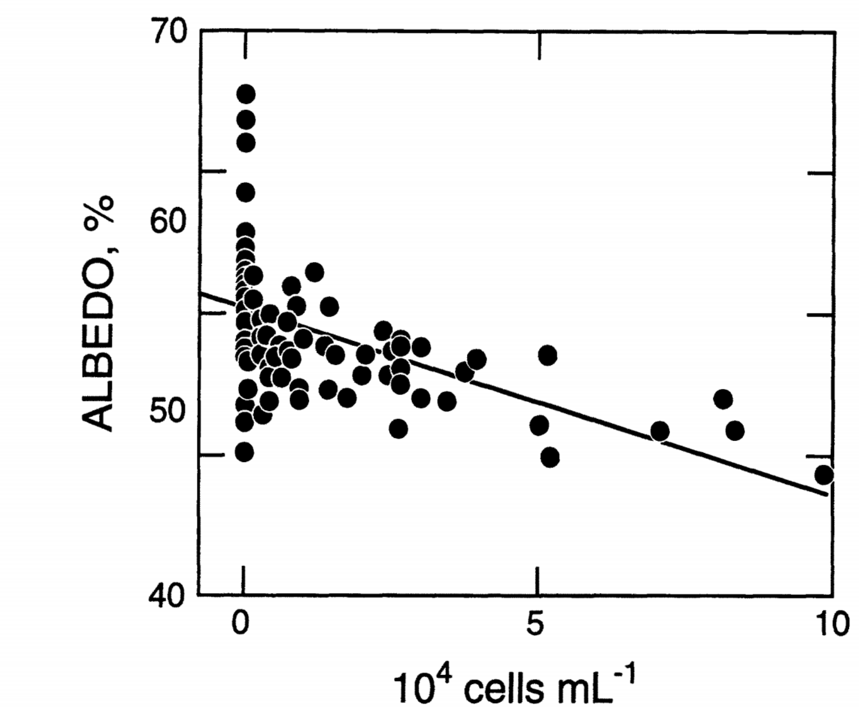


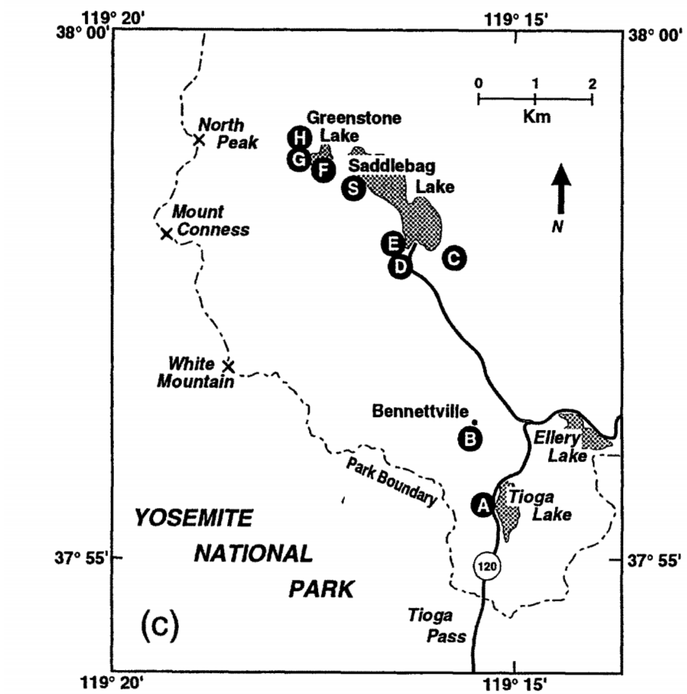
Tanabe et al., 2011

Ochromonas smithii, common at the snow surface in late spring and early summer

- Motile
- Mixotrophic

- We can see snow algae, but how much is really going on there?



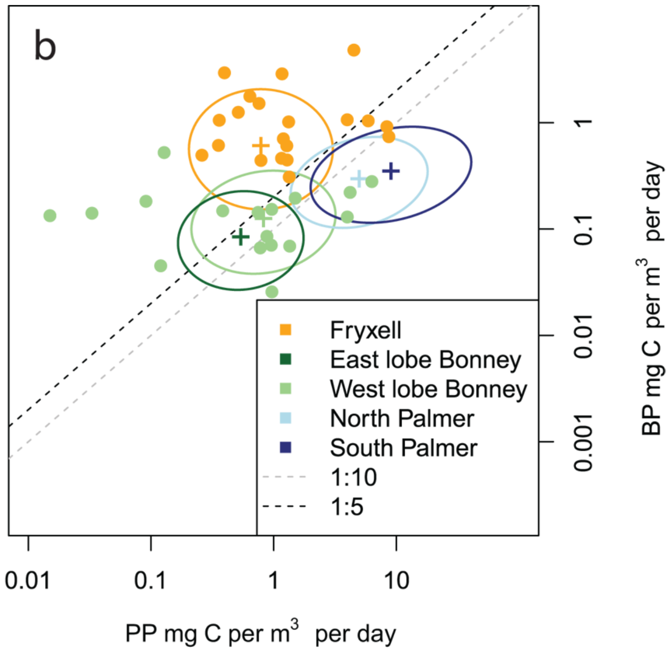


Standing crops of algae and bacteria in red and white snow from the Tioga Pass Area, Sierra Nevada, California, August 1993

		Red snow			White snow		
Date	Site	Algae[a] (10^2 cells mL^{-1})	Bacteria[a] (10^3 cells mL^{-1})	Biomass ratio (Algae/bacteria)	Algae (10^2 cells mL^{-1})	Bacteria (10^3 cells mL^{-1})	Biomass ratio (Algae/bacteria)
5 August	E	1270	546	4433	1.68	98	32.4
9 August	E	998	648	2919	1.80	228	15.1
25 August	F	8.8	356	47	0.42	126	6.3
30 August	G	408	338	2292	0.60	40	28.6

[a] Numbers of algae and bacteria are expressed as cells mL^{-1} of meltwater.

Thomas and Duval, 1995



10^{-2} µg C ml h^{-1} = 240 mg C m^{-3} day^{-1}

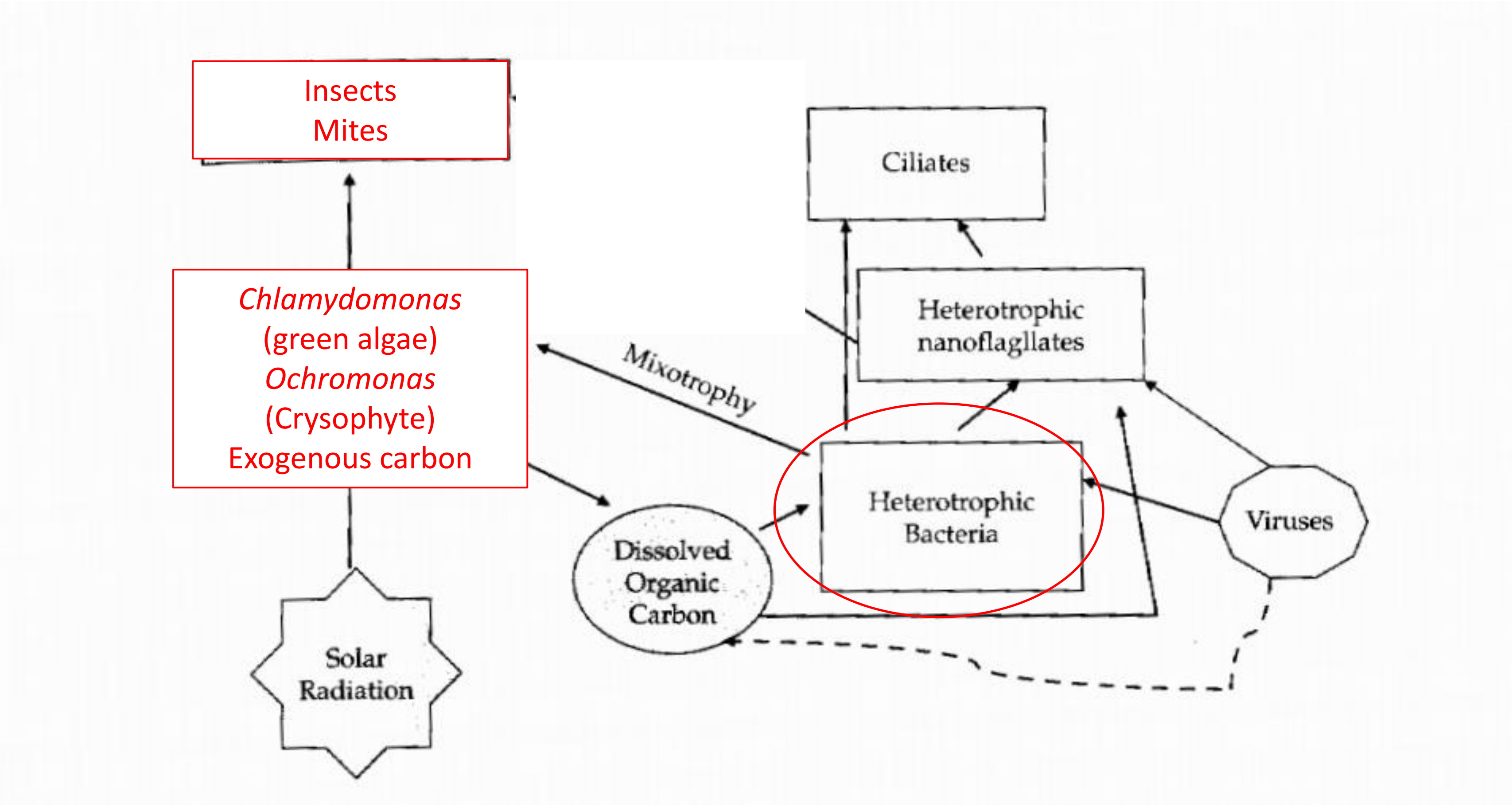
Organic production rates of algae and bacteria in red and white snow from the Tioga Pass Area, Sierra Nevada, California, August 1993[a]

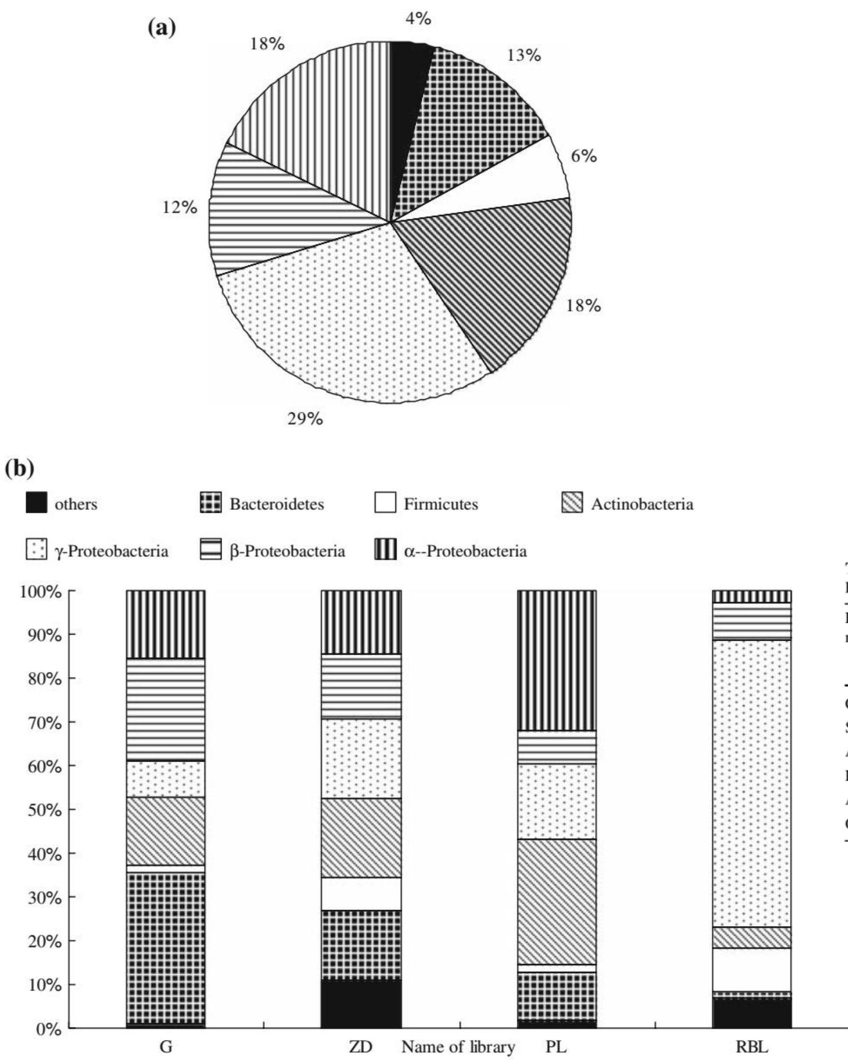
		Red snow			White snow		
Date	Site	Algal production (10^{-2} µg C mL^{-1} h^{-1})	Bacterial production (10^{-4} µg C mL^{-1} h^{-1})	Production ratio (Algae/bacteria)	Algal production (10^{-2} µg C mL^{-1} h^{-1})	Bacterial production (10^{-4} µg C mL^{-1} h^{-1})	Production ratio (Algae/bacteria)
6 August	E	7.20	4.00	180	0.000	0.070	—
8 August	E	24.6	17.44	141	0.300	0.894	33.6
26 August	F	2.32	2.26	103	0.034	1.82	1.9
31 August	G	4.38	1.48	295	0.160	0.690	23.2

[a] All production rates are expressed as mL^{-1} of meltwater.

Thomas and Duval, 1995

Foodweb at the snow surface





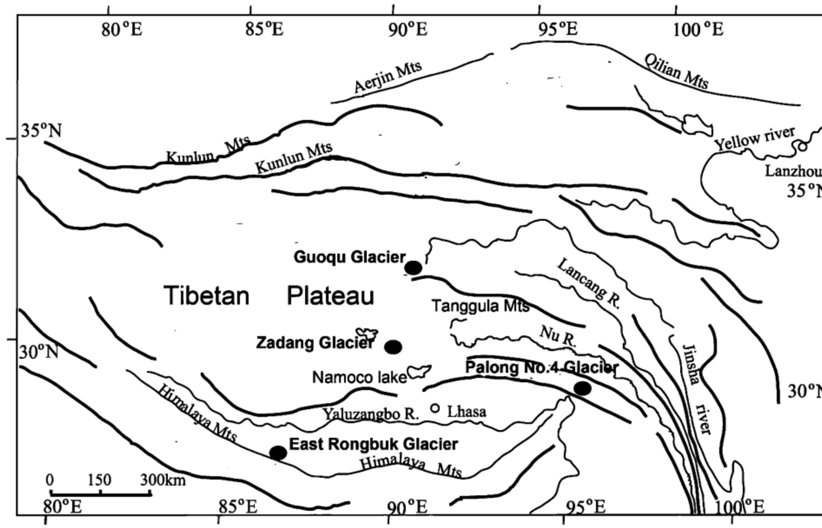


Table 3 Classification of the environment of the nearest neighbor of snow bacteria at the Guoqu (G), Zadang (ZD), East Rongbuk (RBL) and Palong No. 4 (PL) Glaciers

Environment of the nearest neighbor	Total		G		ZD		RBL		PL	
	Sequences (%)	Clones (%)	Sequences (%)	Clones (%)	Sequences (%)	Clones (%)	Sequences (%)	Clones (%)	Sequences (%)	Clones (%)
Cold environment	33	43	41	71	37	39	36	16	28	55
Soil	30	25	41	17	29	33	16	26	29	20
Aquatic environment	18	24	14	6	17	14	44	58	19	12
Plant	5	4	3	5					14	9
Air	6	2			10	6			3	1
Others	7	3			8	8	4	4	7	2

- Snow microbial diversity is not nearly as well-studied as sea ice or glaciers
- Snow-algae associated communities are similar to sea ice bacteria
- But many transient organisms from soil, etc.

What is the limit of respiration in snow?

Bacterial Activity in South Pole Snow

EDWARD J. CARPENTER,[1] SENJIE LIN,[2] AND DOUGLAS G. CAPONE[3]*

Marine Sciences Research Center, State University of New York, Stony Brook, New York 11794[1]; Department of Marine Sciences, University of Connecticut, Groton, Connecticut 06340[2]; and Wrigley Institute for Environmental Studies, University of Southern California, Los Angeles, California 90089[3]

Received 8 May 2000/Accepted 29 June 2000

Large populations (200 to 5,000 cells ml^{-1} in snowmelt) of bacteria were present in surface snow and firn from the south pole sampled in January 1999 and 2000. DNA isolated from this snow yielded ribosomal DNA sequences similar to those of several psychrophilic bacteria and a bacterium which aligns closely with members of the genus *Deinococcus*, an ionizing-radiation- and desiccation-resistant genus. We also obtained evidence of low rates of bacterial DNA and protein synthesis which indicates that the organisms were metabolizing at ambient subzero temperatures (−12 to −17°C).

APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Oct. 2003, p. 6340–6341 Vol. 69, No. 10
0099-2240/03/$08.00+0 DOI: 10.1128/AEM.69.10.6340–6341–000.2003

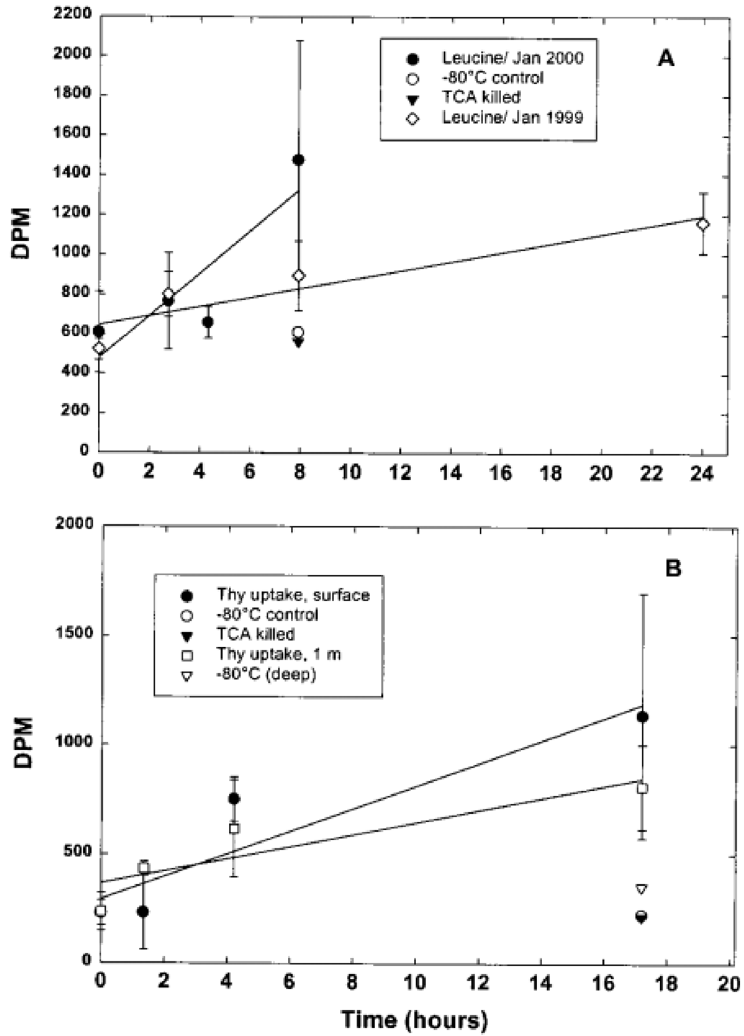
Letters to the Editor

Bacterial Activity in South Pole Snow Is Questionable

Authors' Reply

We appreciate the thoughtful comments of Drs. Warren and Hudson regarding our AEM paper "Bacterial Activity in South Pole Snow." Warren and Hudson largely base their criticism of our research on their theoretical calculations of the physics of water and ice. Their main point concerns the predicted lack of sufficient liquid water in the snow to allow bacterial metabolism at the subzero temperatures at which our experiments were conducted. They also suggest that the injection of our isotopic tracer may have provided sufficient liquid water to cause melting of the snow core and to permit the observed uptake.

What is the limit of respiration in snow?



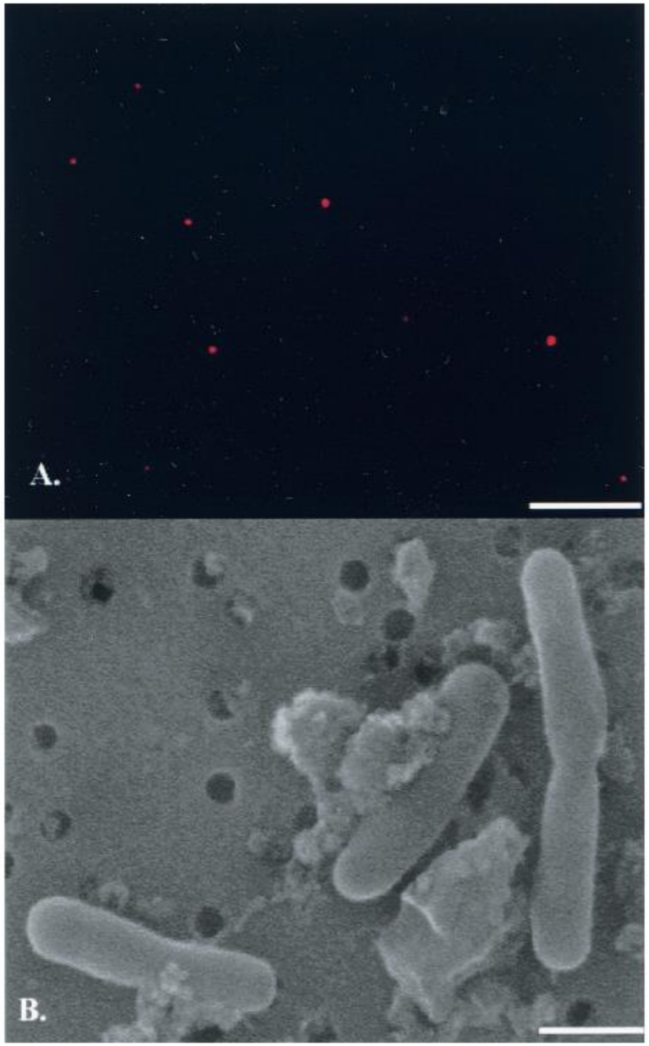
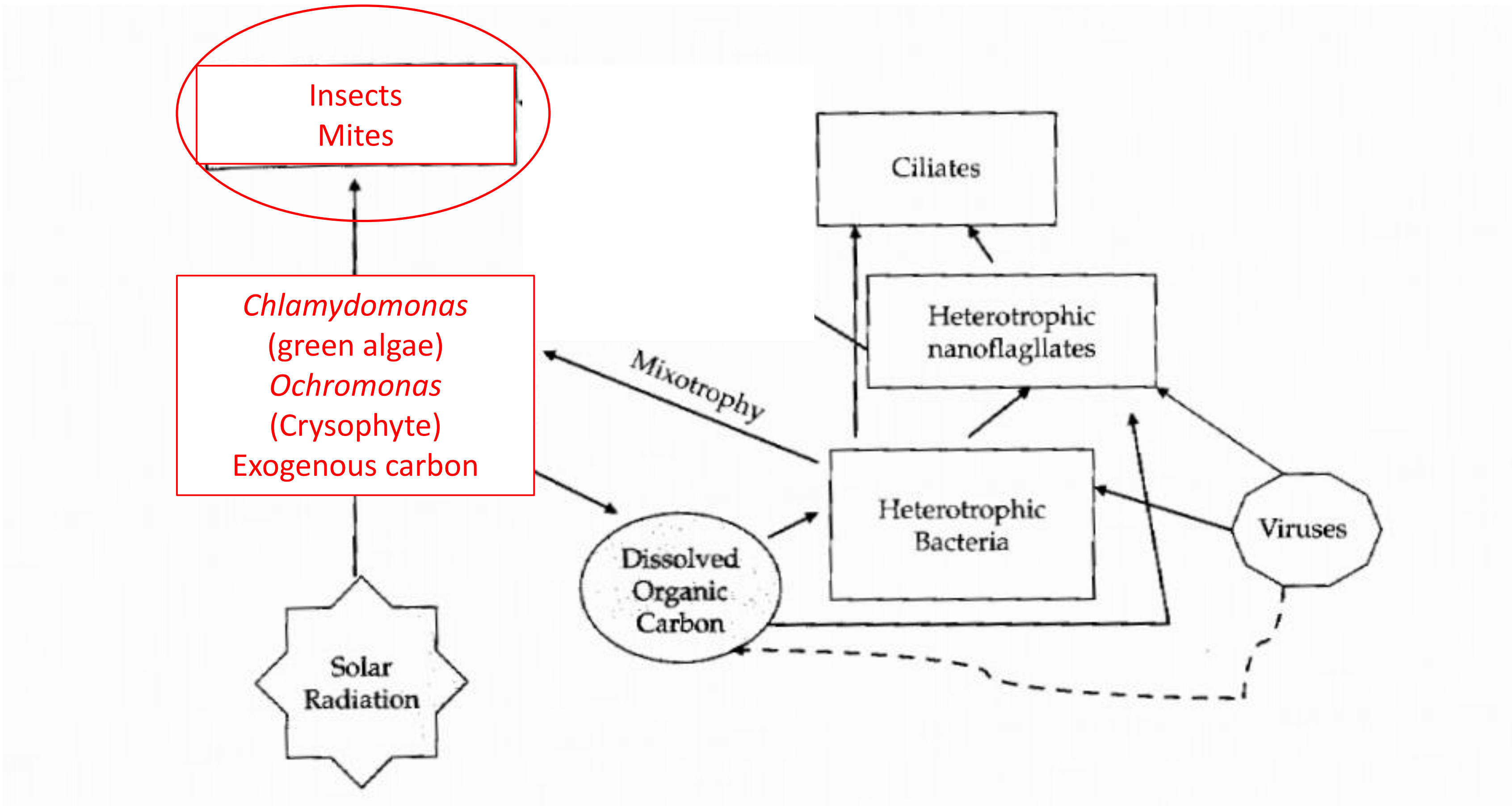


FIG. 1. Micrographs of fluorescent in situ hybridization (A) and SEM of bacteria from south pole snow. Bar = 10 µm (A) and 1.0 µm (B).

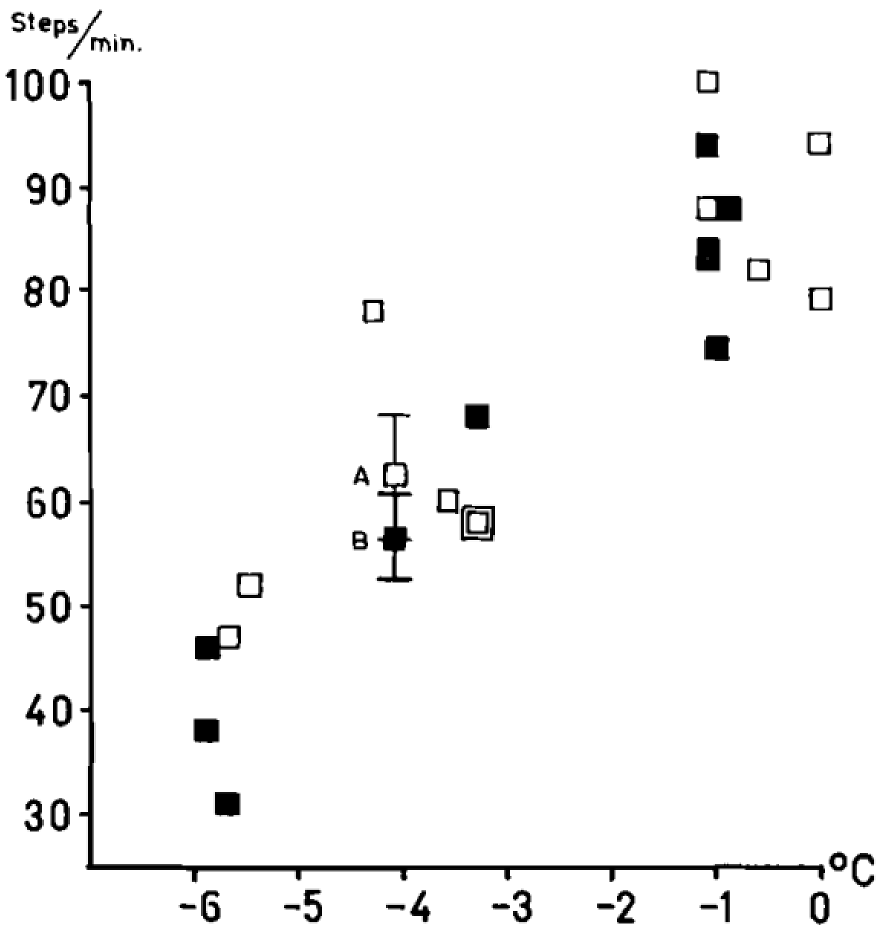
Foodweb at the snow surface



Snowflea (springtail)

Snow scorpionfly (non-feeding adult)

- Much harsher environment than marine arthropods have to deal with (why?)!
- All of these use the adaptations that we already know about
  - Compatible solute formation
  - Ice binding proteins
  - Cold active enzymes



Walking speed of *Chionea araneoides*
Hagvar, 1971

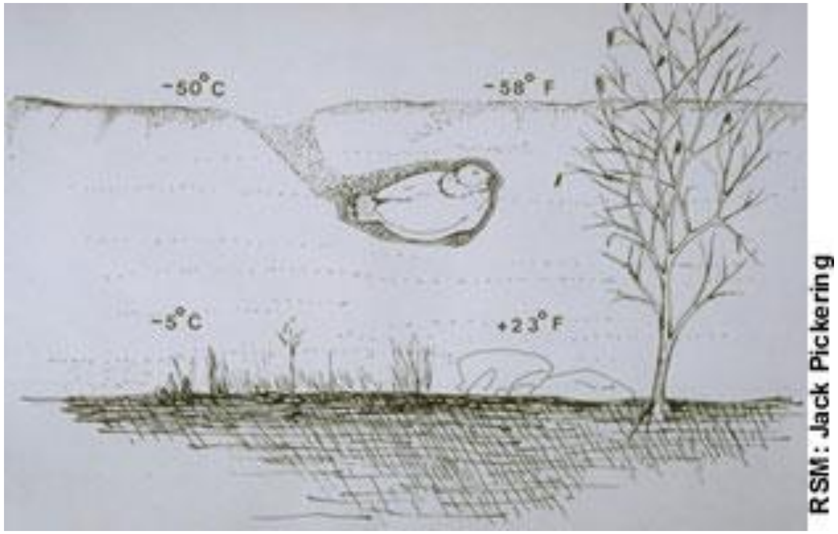
- Metabolic rates strongly controlled by temperature
- Can you estimate Q_{10} from these data?

$$Q_{10} = \left(\frac{R_2}{R_1}\right)^{\left(\frac{10}{T_2 - T_1}\right)}$$

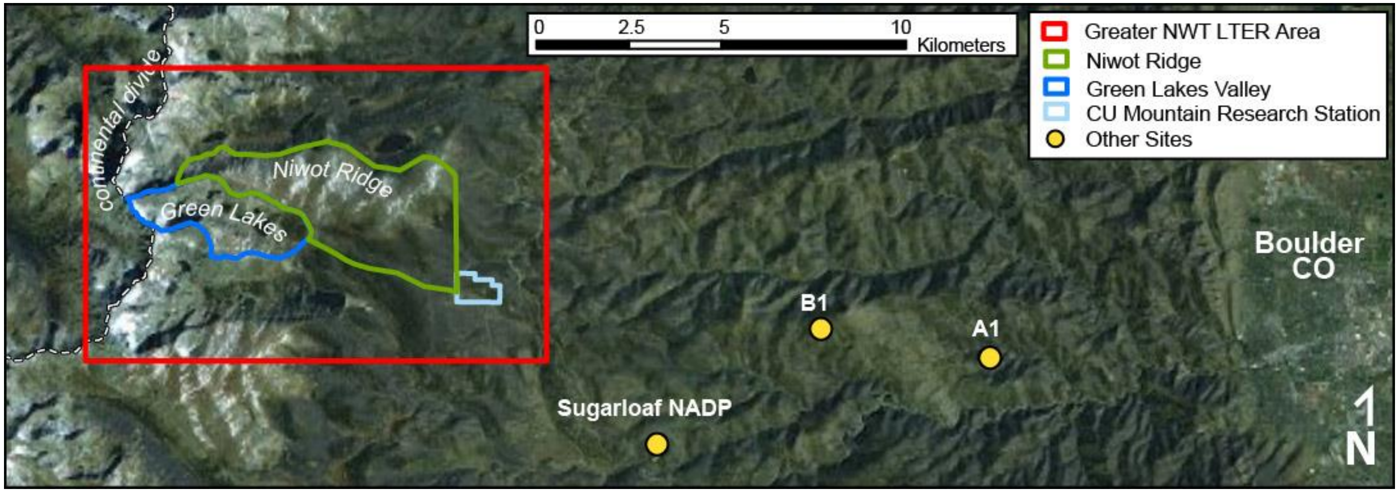
$$Q_{10} = \left(\frac{30}{90}\right)^{\left(\frac{10}{^-6 - ^-1}\right)}$$

$$Q_{10} = 0.33^{^-2} = 9.2$$

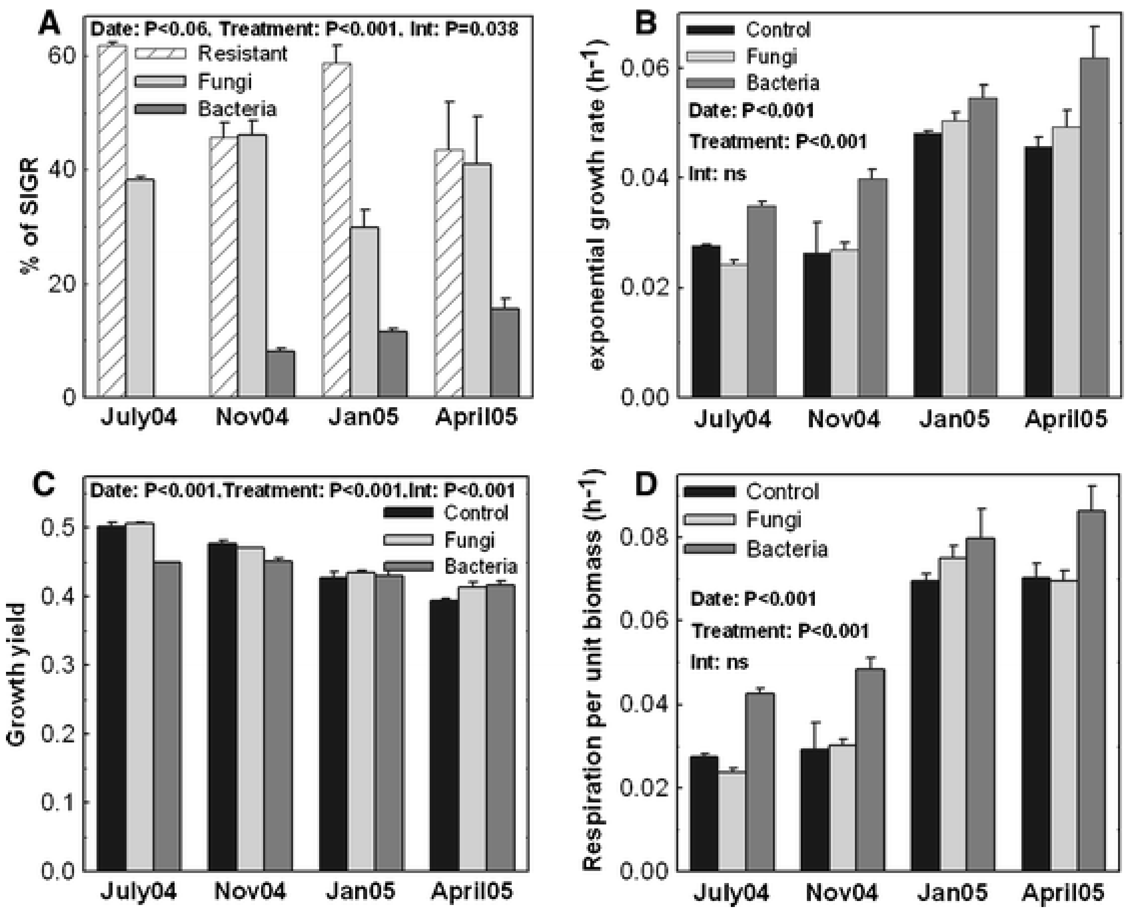
Subnivial environment



- The base of the snowpack is comparatively warm, and high in nutrients and organic matter
- These trends extend to the soil below the snowpack, which remains biologically active throughout winter

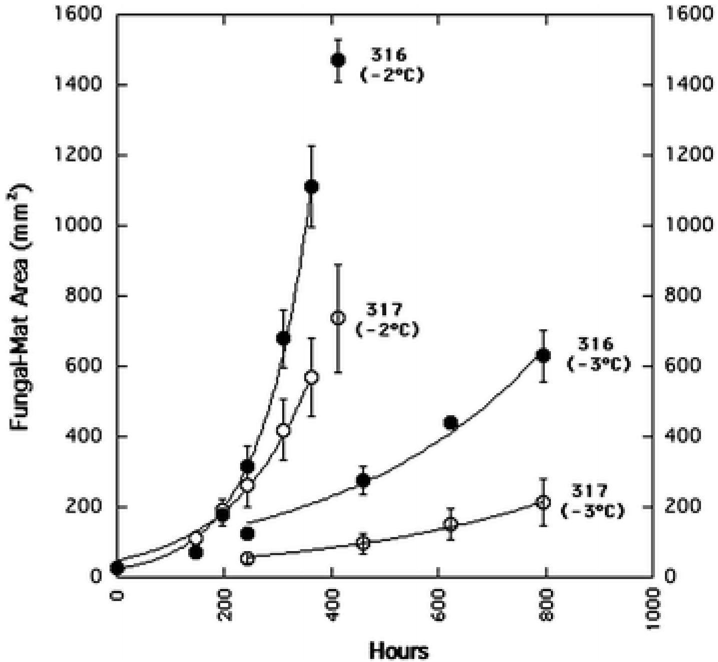


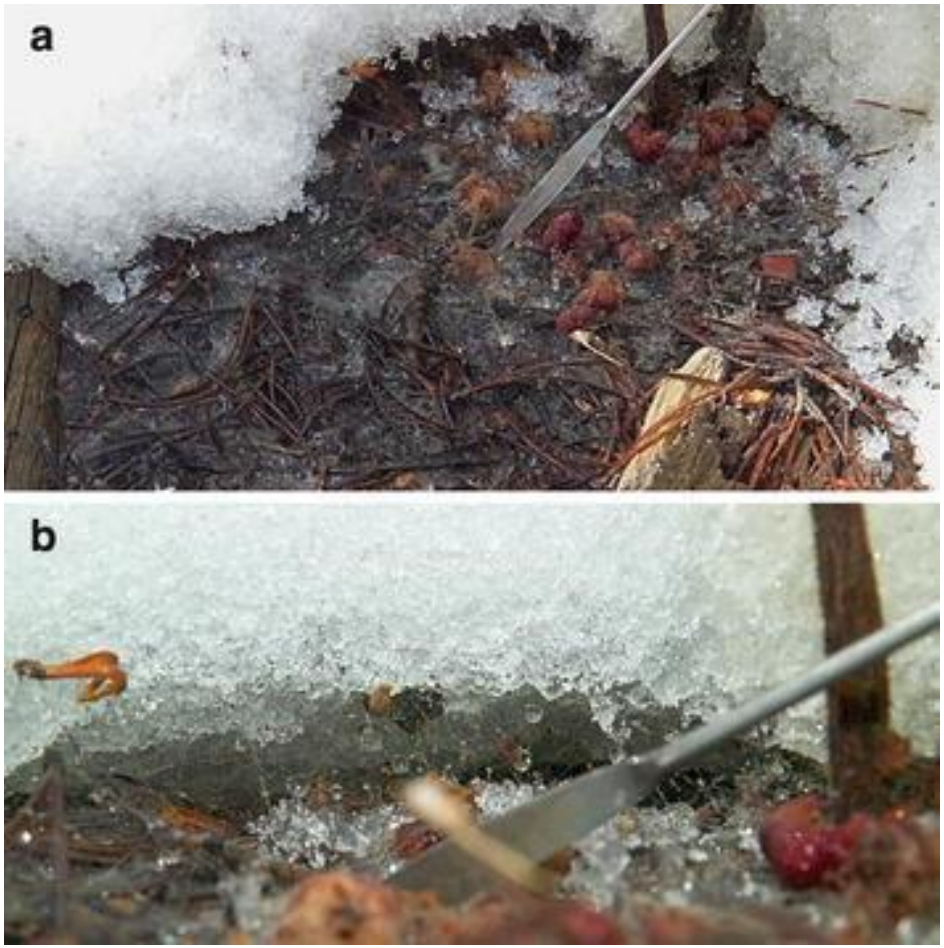
- The Niwot Ridge LTER site in Colorado is one of the best-studied temperate snow ecosystems
- Eddy-flux covariance towers at the site allow observations of the inorganic carbon exchange between the atmosphere and soil/biomass



Lipson et al., 2009

- Fungal and bacterial respiration remains high during winter





Lipson et al., 2009

- Fungi are a major component of the subnivial enviroment

- Hair ice caused by the fungus *Exidiopsis effuse*
- Fungal metabolites inhibit ice recrystallization similar to ice binding proteins
- The process is still not well understood…

Hoffman et al., 2015