Microbial Communities and Climate Change in Alpine Ecosystems

Thanks to:

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More info at:
http://amo.colorado.edu/

Alpine Microbial Observatory

(http://amo.colorado.edu/)

Extreme variation in altitude, extent of snow cover, and plant community composition.

Sites:

1) Pine/Fir/Spruce Forests (el. 2700 meters, 9000 ft.)
2) Spruce and Subalpine Fir (el. 3000 m)
3) Alpine tundra:
   a. Wet Meadow (el. 3200 m)
   b. Dry Meadow (el. 3400 m)
4) Barren soils (up to >4000 m, 13,000 ft.)

Microbial Communities in a changing climate:

1) Microbial Community Succession in response to global warming

2) Microbial temperature responses - towards an understanding of Carbon and Nitrogen cycle responses to climate change.

More of this kind of stuff:

EBIO 4800/5800, Microbial Ecology, Fall 2009

1) Microbial Communities Succession in response to global warming

The Sub-Nival Zone = area between the ice-covered zone (Nival Zone) and the vegetated world.

e.g. Dry Valleys of Antarctica
Polar deserts of the high Arctic
"Barren" ice-free areas of high mountains
(very extensive in the Andes, Himalayas, Karakorams, Pamirs, Hindu Kush etc. etc.)

High-Altitude Environments are changing rapidly:

Expanding due to global warming - microbial succession in plant-free high elevation soils

Sub-Nival
Zone in the
High Andes

Nival Zone

"Snow Line" Approx 5400 m (17,700 ft) in 2007

Subnival Zone

~3 kilometers

5000 meters above sea level (3/2005)

Proc. Roy. Soc. B
275: 2793-2802

Zone of Continuous Vegetation

Lake that formed between August 2003 and March 2005
(5200 meters above sea level)

Succession of biogeochemical function and microbial diversity near receding glaciers

5000 meters el., note people approaching glacier

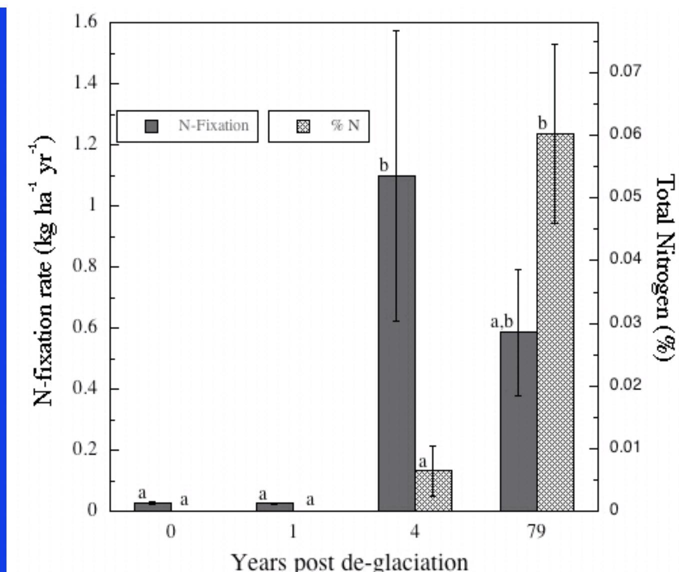
Nitrogen Fixation
(acetylene reduction)

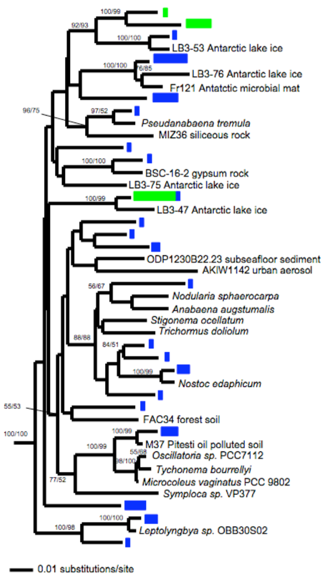
and

N pools increase with time since de-glaciation

Measured in the field

Proc. Roy. Soc. B 275: 2793-2802 (2008)





Cyanobacterial clone libraries from de-glaciated soils at 5000+ metres

Green = new soil (<1yr old)

Note closest relative from Antarctic Lake ice samples

(LB3 sequences from Priscu, J.C. et al. *Science* 280: 2095-2098)

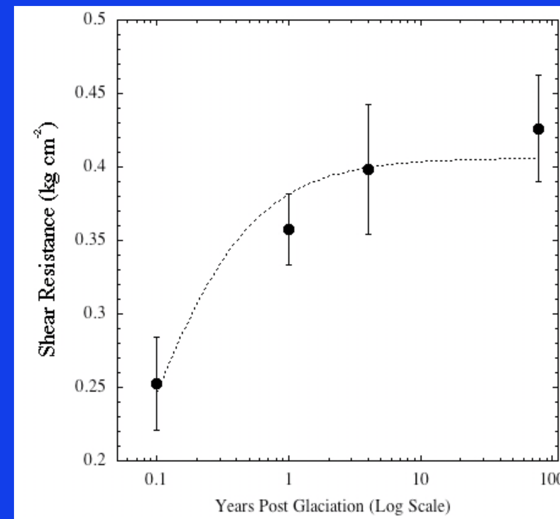
Blue = 4-5 yrs uncovered

Note broad diversity, many related to cryptobiotic crust and N fixers

Data from:

Proc. Roy. Soc. B 275: 2793-2802 (2008)

Cyanobacteria increase soil stability within the first several years after glacial retreat

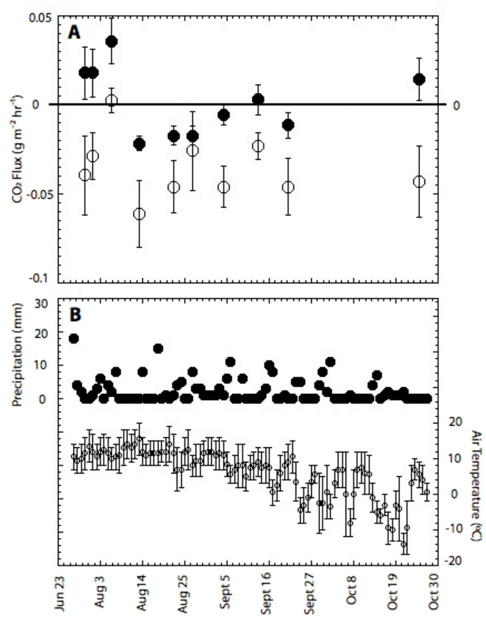


Proc. Roy. Soc. B 275: 2793-2802 (2008)

Barren Colorado talus soils show CO_2 fixation in the light

(data from 2002, similar results in 2007)

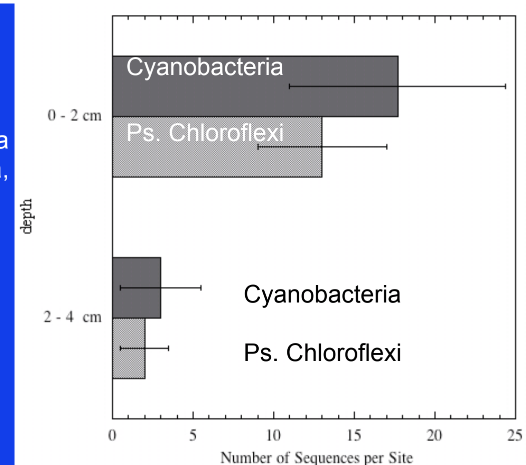
Freeman et al. 2009. *Environmental Microbiology* 11: 674-686.



These soils show vertical stratification in terms of photosynthetic microbes:

0 - 2 cm depth - dominated by a broad diversity of cyanobacteria, algae and chloroflexi

2 - 4 cm depth - significantly different community
(Also via Unifrac and P test)



Data from: Freeman et al. 2009. *Environmental Microbiology* 11: 674-686.

“sub-nival” zone soils

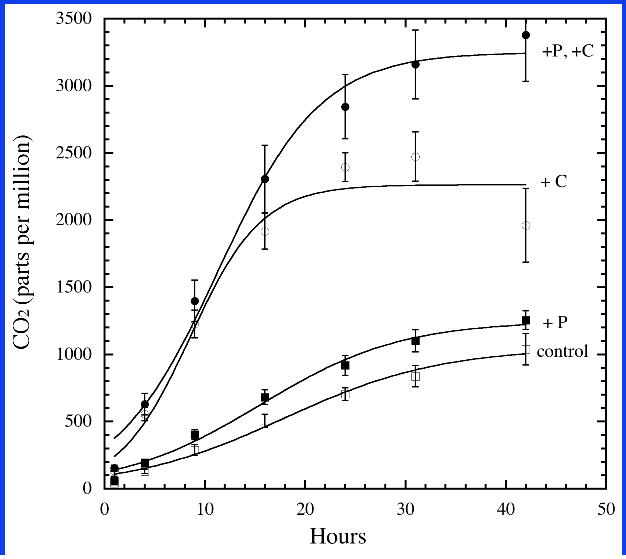
bacterial photosynthesis is probably the major C input

Next question:
Can we map environmental change in the sub-niavl zone?

Microbial activity and biomass are correlated with duration of snow pack and presence of invading plants…

- a powerful tool to monitor future environmental change

The highest enzyme activity in the talus was acid phosphatase, so Andrew did some substrate addition experiments and found P limitation:
King et al. (2008) *Soil Biology and Biochemistry* 40: 2605-2610.



Summary for “sub-nival” zone soils

-Bacterial photosynthesis is probably the major C input
-Cyabobacteria, Choroflexi, and Algal photosynthesis
- Rapidly expanding globally, esp. at high elevations

- Microbial ecosystems in a high state of flux - rapid succession

- Limited by: water, C, N & P (Andes)
water, C & P (Rockies)

- Plants are moving up as well, but it is unknown how high they can go

Nepal Talus sites el. 5100 to 5600 meters above sea level

Microbial temperature responses - Understanding microbial controls on soil respiration…

Important, but still not understood component of ecosystem and global change models

Under-snow microbes as drivers of ecosystem flux and nutrient retention.

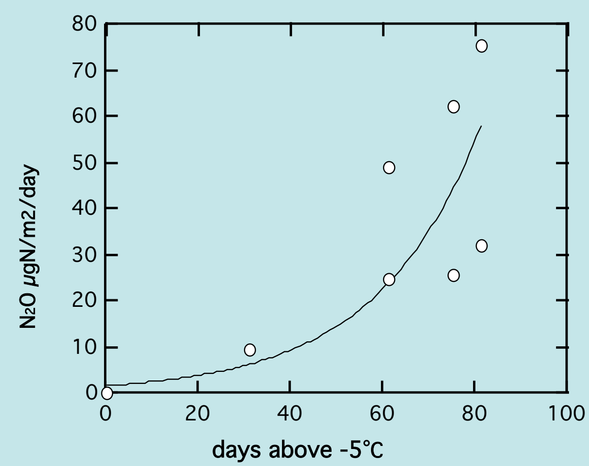
example of the dominant “snow molds” of sub-alpine forests

Biogeochemical background:

Measured year-round fluxes of CH_4, N_2O and CO_2 at our tundra sites…….

Highest N_2O fluxes occurred in the winter under the snow (see next slide)

N_2O fluxes showed annual peak in late winter, when soils warmed above -5°C.



Brooks, Schmidt & Williams Oecologia 110: 403-413

Other <u>under-snow</u> biogeochemistry

1) Protease & cellulase activities reach highest year-round levels in tundra soils leading to a large pulse of N from under the late winter snow pack - Microbial Ecol. 43: 307-314 (2002)

2) 50+% of forest carbon fixed each year is mineralized to CO_2 under the winter snow pack - more on this later……..
(Nature 439: 711-714, 2006)

The biologically produced “ionic pulse”

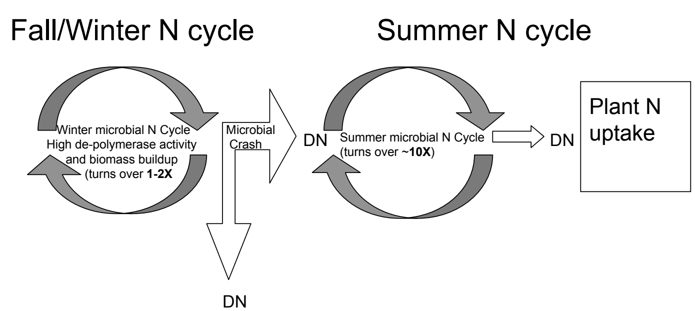
Where does most nitrogen comes from in ecosystems?…..

Breakdown of organic N (mostly proteins):

Protein -------> Amino Acids --------> NH_4^+ -------> NO_3^-

Undersnow pulse comes from the death of the cold-adapted winter microbes and the high levels of Proteolysis etc. that occur under the protective blanket of snow…

Year-round N cycle…



But, who’s there?

Early Work: estimate microbial biomass under the snow….

Used several methods…

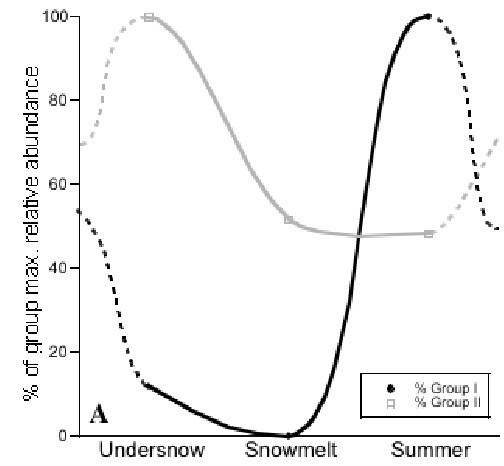
Seasonal dynamics of microbial biomass in *Kobresia* meadows

Science 301: 1359-1361 (2003)

SEASON	Biomass µg C / g soil	F/B Ratio
Under-snow	363 (18)	15
Snowmelt	244 (21)	7
Summer	125 (32)	7

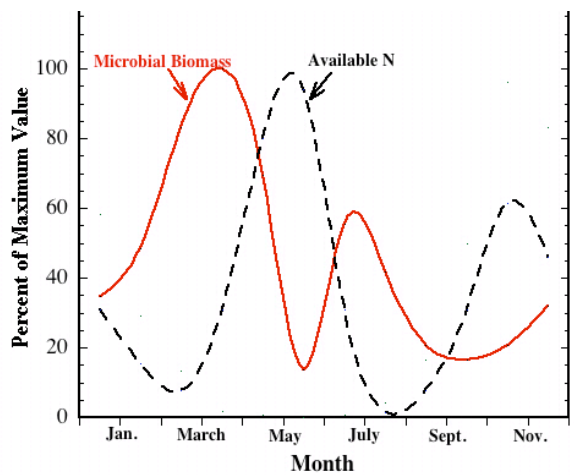
Seasonal succession of microbial groups

Novel group I dominates in the summer and Group II is more prevalent under the snow….



Ecology 88: 1379-1385 (2007)

Linking…. Seasonal fluctuations of microbial biomass and available N in alpine soils

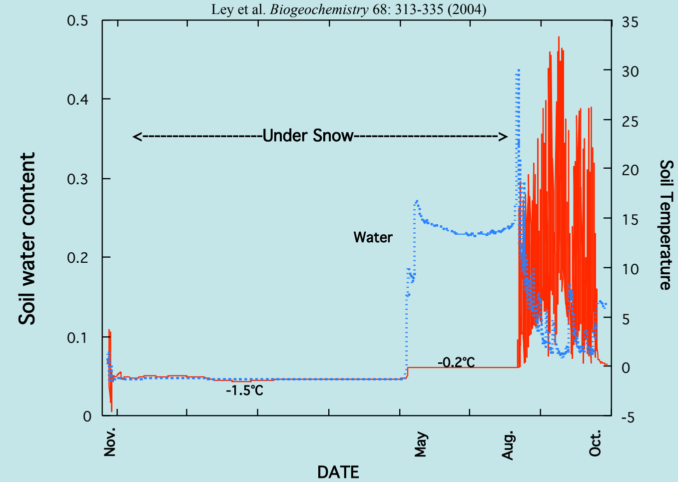


From: Schmidt and Lipson (2004) *Plant and Soil* 259: 1-7.

The late sub-nivian season is the mildest time of the year in alpine ecosystems

The Three Seasons Hotel at 3800 meters el.

Ley et al. *Biogeochemistry* 68: 313-335 (2004)



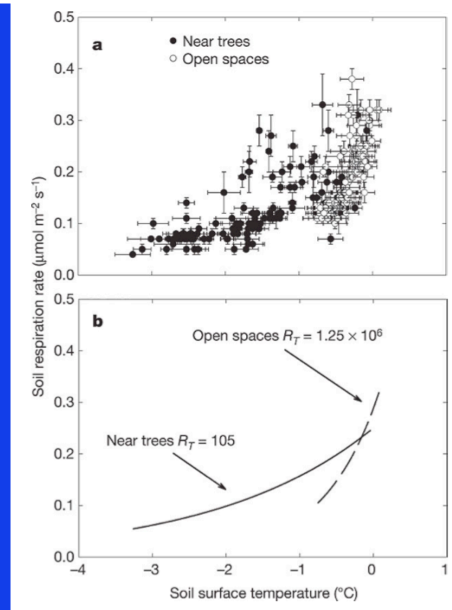
Understanding microbial controls on soil respiration in a pine/spruce/fir forest system:

1) As much as 50% of C fixed by this forest is respired back to the atmosphere through the snow pack and during snow melt at this site

2) Field rates of soil respiration are EXTREMELY sensitive to temperature as soils warm from -3 to 0°C (see next slide.).

2) Field rates of soil respiration are EXTREMELY sensitive to temperature as soils warm from -3 to 0°C.

Field measured "Q_{10}" values >> 100

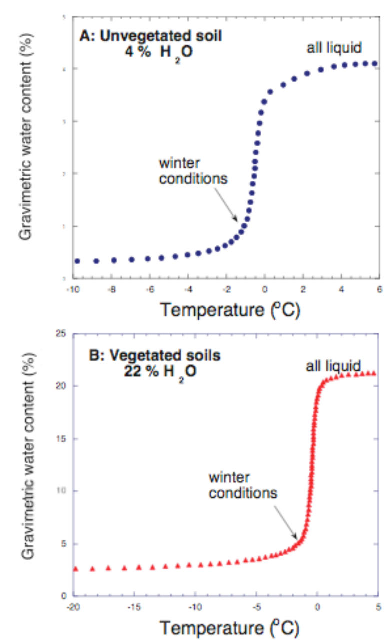


Monson et al. 2006. *Nature* 439: 711-714.

The "best" Explanation for for these amazingly high Q_{10} values is:
during the ice-water transition water availability increases exponentially and therefore DOC availability to microbes increases exponentially…

Romanovsky, V.E. & Osterkamp, T.E. 2000. *Permafrost and Periglacial Proc.* 11: 219-239.

Same sort of data from High Elevation sites in The Rocky Mountains



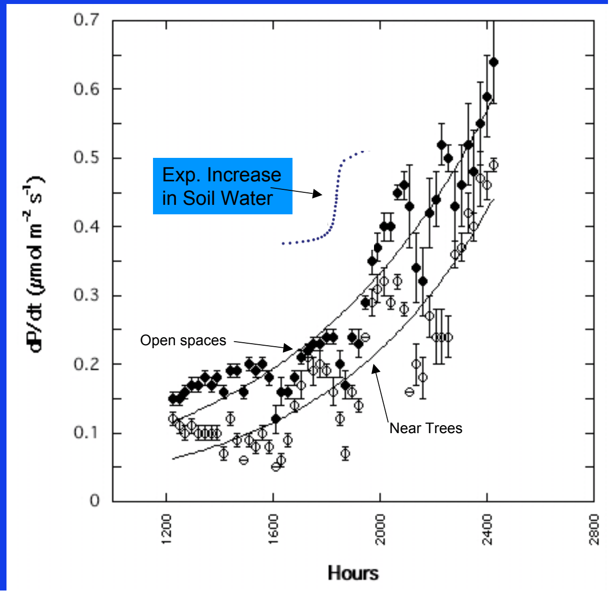
Ley, R.E. et al. 2004. *Biogeochemistry* 68: 313-335

But, the soil-water effect does not completely explain the sustained exponential increase of CO_2 flux through the snow..

Exponential increase of CO_2 flux as soil temps vary from -3°C to 0°C

(note - data now plotted vs. time not temp.)

Biogeochemisrtry (In Press)



Summary of last slide:

Exponential increase in H_2O occurred over a ~5 day period….

Exponential increase in CO_2 kinetics occurred over a ~50 day period…

?

Can the physiology of under-snow microbes explain the exponential CO_2 fluxes and the extremely high Q_{10} values for CO_2 flux?

We've been studying the physiology of under-snow bacteria (Lipson et al. 2008) and fungi (Schmidt et al. 2008) - today I'll just discuss the fungi…

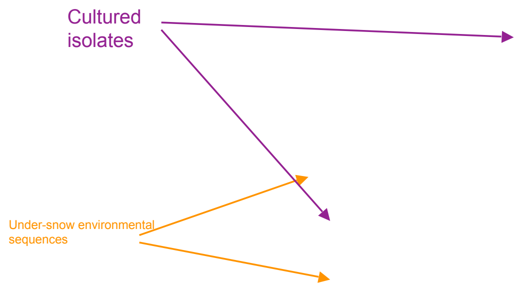
A mat of "snow mold" at the C1 site immediately after snow melt

Poster Child for the invisible majority of cold environments….

Ecology 88:
1379-1385 (2007)

"Snow molds" at bottom of snow pit, April 2007

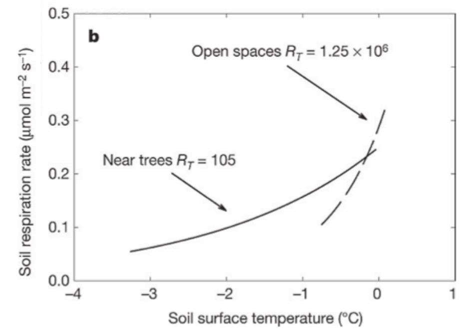
(photo by K. Wilson)

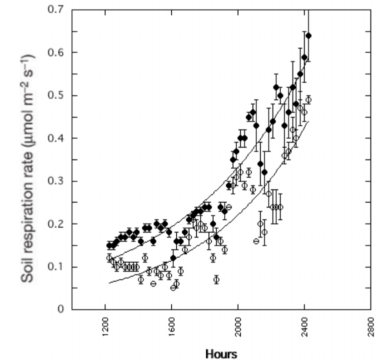


Schmidt et al. **2008**. Phylogeny and ecophysiology of "snow molds" from a sub-alpine forest ecosystem. *Microbial Ecology* (In Press)

The role of snow molds in CO_2 fluxes…
A more detailed look at the under-snow activity of some novel Zygomycetes

Remember, we're trying to explain high Q_{10} values and exponential increases in the rate of CO_2 flux through the snow…

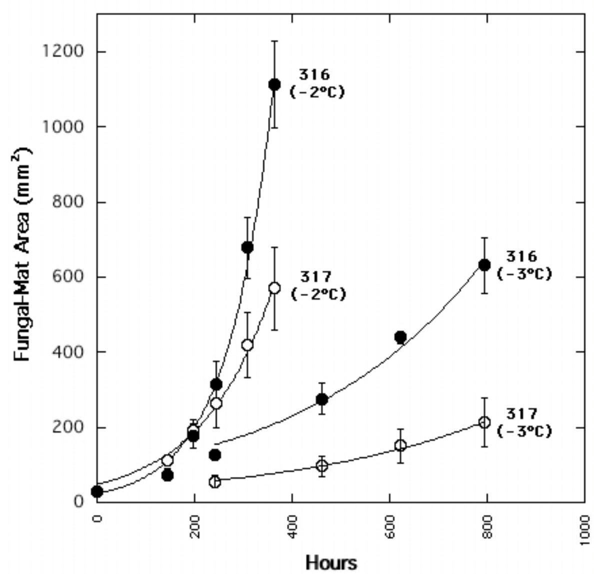




Isolated snow-molds grow exponentially at -3°C…..

Soil temps at C1 vary from -3 to 0°C during maximal CO_2 flux

Biogeochemistry (In Press)



Response of exponential growth rate (μ_{max}) to temperature increases near 0°C

Q_{10} values

isolate 317	
-2 to -0.3°C	330
-0.3 – 4°C	1.2
isolate 319	
-2 to -0.3°C	277
-0.3 to 4°C	2.0

Biogeochemistry (In Press)

Microbiological explanation for high field Q_{10} values:

Snow molds have intrinsically high Q_{10}s

+

And are increasing in biomass as soils warm from -3 to 0°C

= with only 2 doublings apparent Q_{10}s can reach as high as 10^6 due to the double exponential dependence of rate on biomass levels and intrinsic physiology….

Summary of snow mold work:

- Ubiquitous under late season snow packs, yet almost completely unstudied
- Have high Q_{10}s at low temps….
- Exponential biomass buildup under the snow (coincident with temp increases from -3 to 0°C) accounts for huge apparent Q_{10}s seen in field data…

Overall Summary:

- Global warming is rapidly changing mountain ecosystems throughout the world - microbial succession is rapid…….
- Many Unique Life forms (especialy in winter) with unstudied metabolic potential - "snow molds" as Poster Child for un-studied majority……

Thanks to:

K. Wilson, A. King, K. Freeman, S. Reed, E. Costello, D. Lipson, M. Weintraub, R. Monson, A. Martin, M. Williams, D. Nemergut, R. Ley, C. Schadt………….

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EBIO 4800/5800, Microbial Ecology, Fall 2009