Impacts of climate warming on mountain soils

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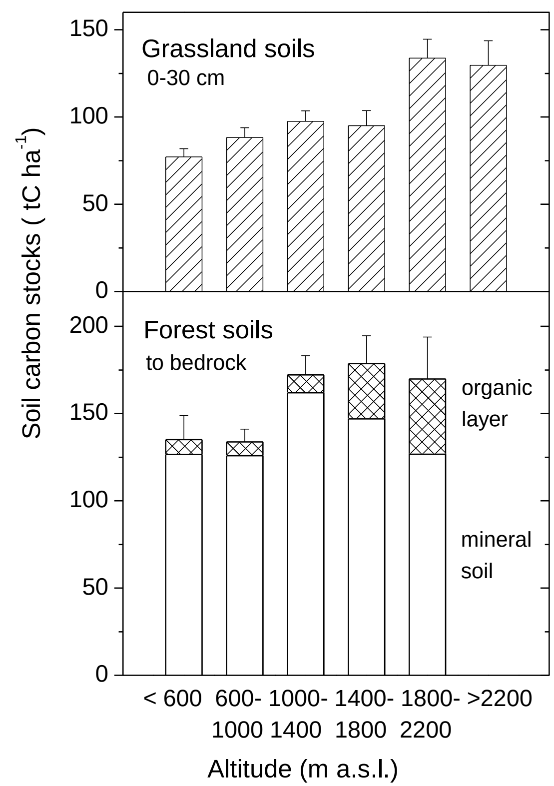
Why are we interested in carbon fluxes from soils in mountains?

- **Large stocks due to cold temperatures**
- **The carbon is relatively labile**
- **Climate change greater than average**
- **C inputs vary with altitude**

Carbon stocks in mountain soils

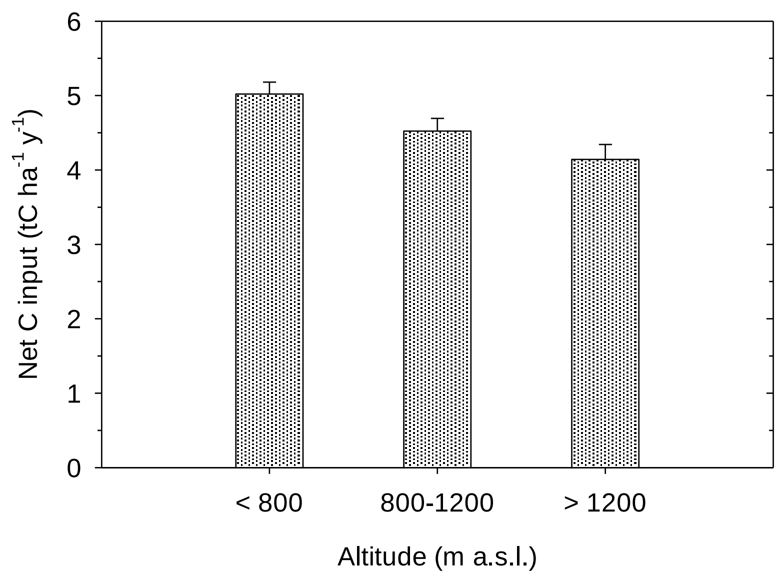
- Huge range - e.g. 4.5tC ha^{-1} in the Tatra mountains to 278tC ha^{-1} in the Swiss alps
- Soil C stocks increase with altitude
  - 3.1 t C ha^{-1} per 100 m for grasslands
  - 4.5 t C ha^{-1} per 100 m for forests
- The increase is strongest for the soil organic layer
  - which generally is the most labile fraction of the soil C.
- Swiss forests soils store about 4 times more (20 t C ha^{-1}) C in the Oh above 1400 m a.s.l. than below.



Total soil C stocks in mountain grassland, n=132 (central and southern Europe); and forest soils, n=258 for, total stock including mineral soils to bedrock, n=878 for organic layers (Switzerland).

Lower vegetation C inputs at higher altitude

- Trends with altitude for inputs of C and SOC stocks differ.
- The inputs of C to the soil from the vegetation drops with elevation.
- Importance of slow decomposition of SOC for C storage at high altitudes.
- Vegetation shifts will impact on the C inputs



Net C (above and below ground combined) inputs to the soil from the vegetation based on stand inventory data (Austrian forest Inventory 2009).

Warming trends in mountain regions

Climatic warming in Central and Northern European mountain regions is far stronger than anywhere else.

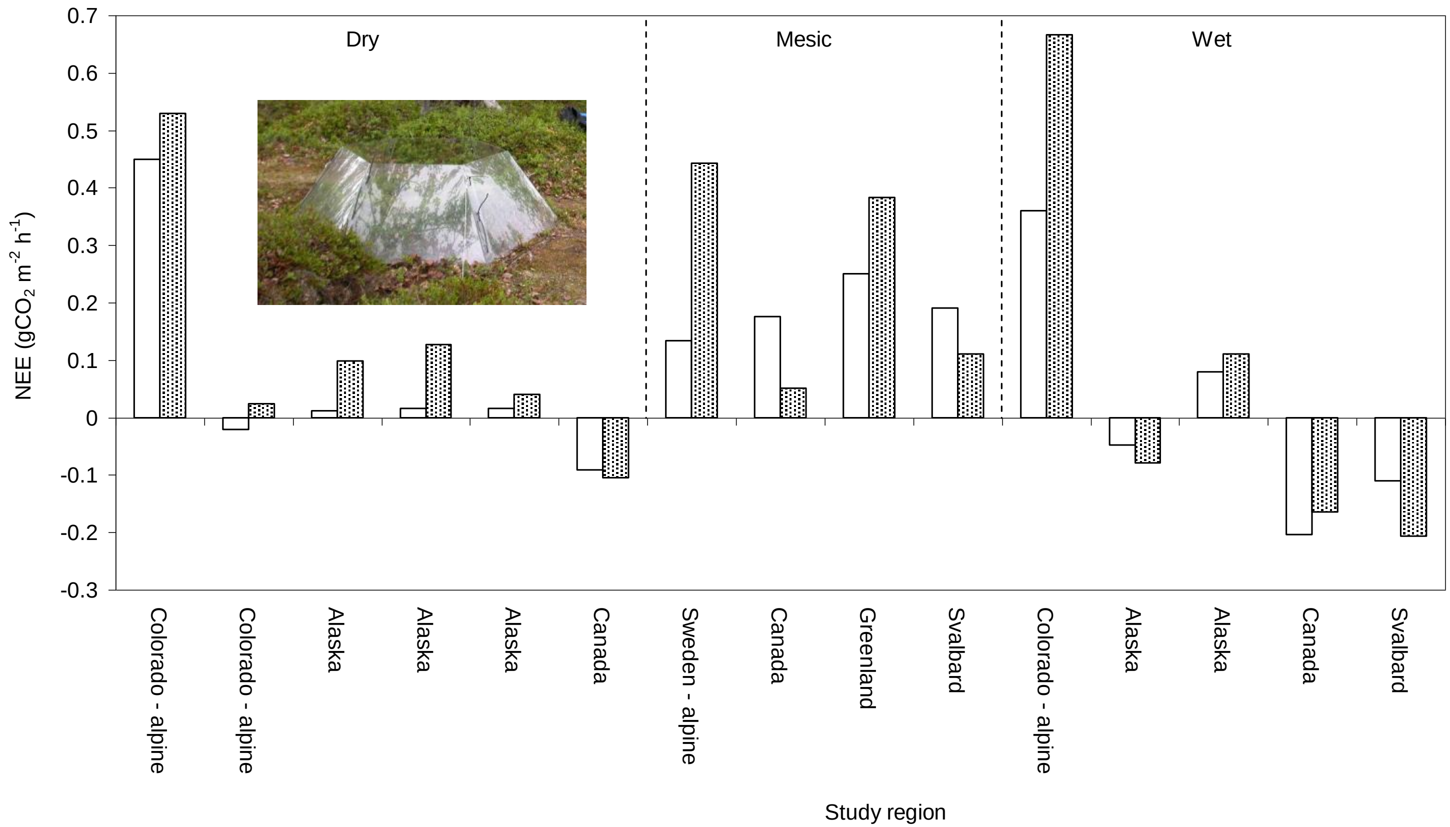
Decadal changes in temperature and precipitation during the last century in the Ural mountains (Devi *et al.*, 2008) and the Alps (Auer *et al.*, 2007).

	Temperature (C decade^{-1})		Precipitation (mm decade^{-1})	
	Summer	Winter	Summer	Winter
South Ural	n.s.	0.15 0.002***	n.s.	4.8 1.6**
North Ural	0.06 0.03*	0.25 0.004***	8.7 3**	12.1 2.7***
Polar Ural	0.1 0.03**	n.s.	4.7 2*	8.8 1.2***
			(% of 1901-2000 decade $^{-1}$)	
Alps SW	0.13’	0.15’	n.s.	n.s.
Alps SE	0.11’	0.11’	n.s.	n.s.
Alps NW	0.14’	0.16’	n.s.	2.4
Alps NE	0.13’	0.11’	n.s.	n.s.

Future predictions

- The predictions suggests continued greater than average warming in mountain areas in Europe (Nogués–Bravo *et al.*, 2007)
- With greater rates of warming than those that have been recorded to date.
- The climate change prediction for European mountains differs mainly between
  - the northern mountain ranges (i.e. the Scandes and the Urals) 3.4 and 5.9 °C
  - the Central and southern European mountains 2.9 and 5.4 °C
  - with greater rates of warming predicted at higher latitudes.

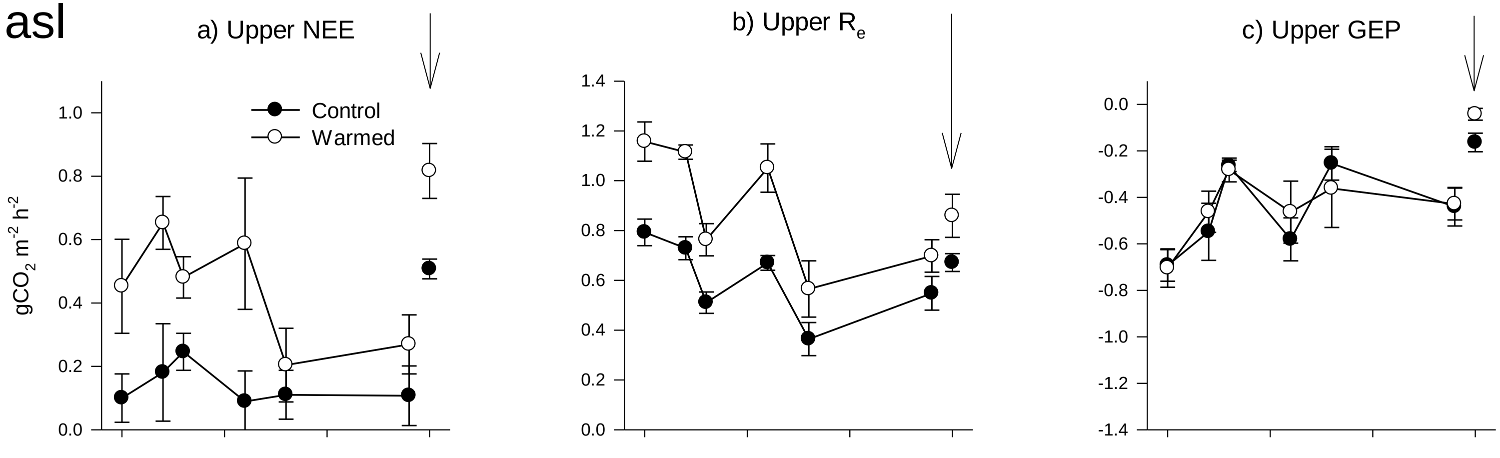
Impact of warming in different habitats



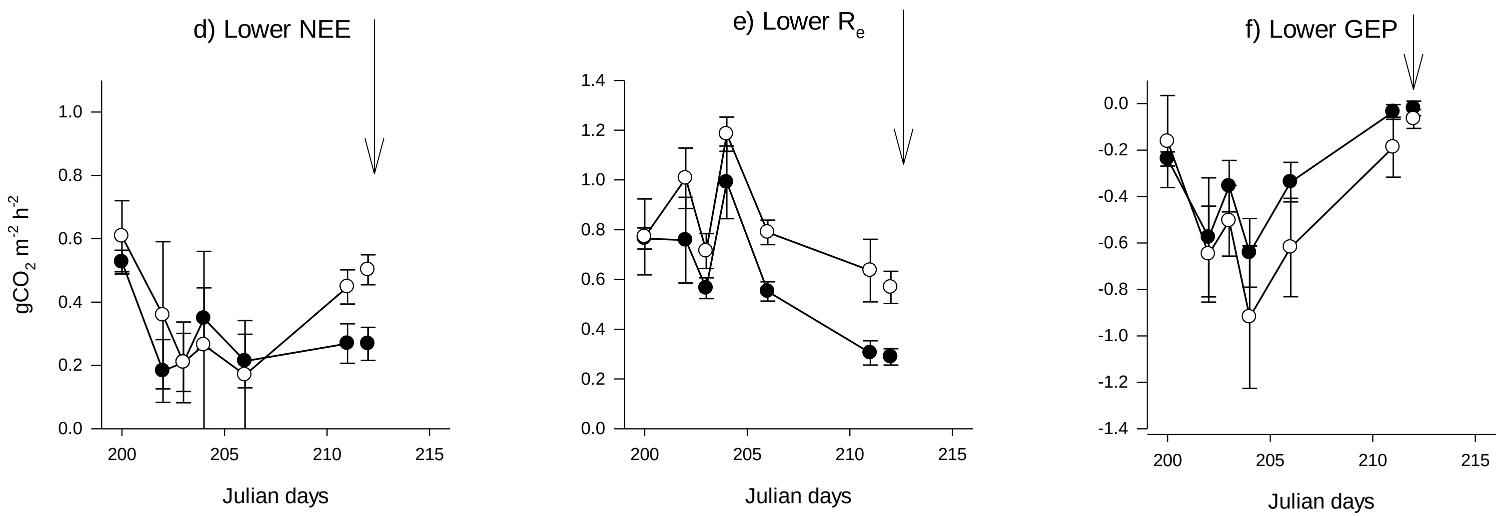
Warming effects on net ecosystem exchange (NEE) of CO_2 in different arctic and alpine (alpine sites indicated in the figure) study sites with different moisture status. Control and warmed plots are represented as white and grey bars respectively. All the treatment effects shown are significant on the P < 0.05 level. The values in the figure represent average treatment effects over the growing season.

Carbon balance after 4 yrs of warming in mountain sites at different altitudes

Ca 700 m asl



Ca 550 m asl



Impact of climate warming experiments on CO_2 fluxes during peak growing season at a higher and a lower elevation mountain heath.

Conclusion

- The strongest impact of climate change on SOC due to vegetation transitions.
- Management induced changes in SOC will be driven by vegetation shifts in response to land abandonment or altered herbivore pressure.
- Direct climate warming can also strongly alter the CO_2 losses from alpine ecosystems.
- It is not clear how long such a response would be sustained.
- Our understanding of C losses from mountain areas in response to climate change are limited by a lack of mechanistic understanding of the factors that control labile C accumulation in high elevation ecosystems.

Subarctic case study -Abisko

- Generally faster decomposition in forest compared to tundra
- Greater C storage in tundra
- Increased shrub cover of tundra
- Strong differences in decomposition between litter types
- Suggested negative feedback from litter decomposition i.e. lower quality litter is promoted by climate change

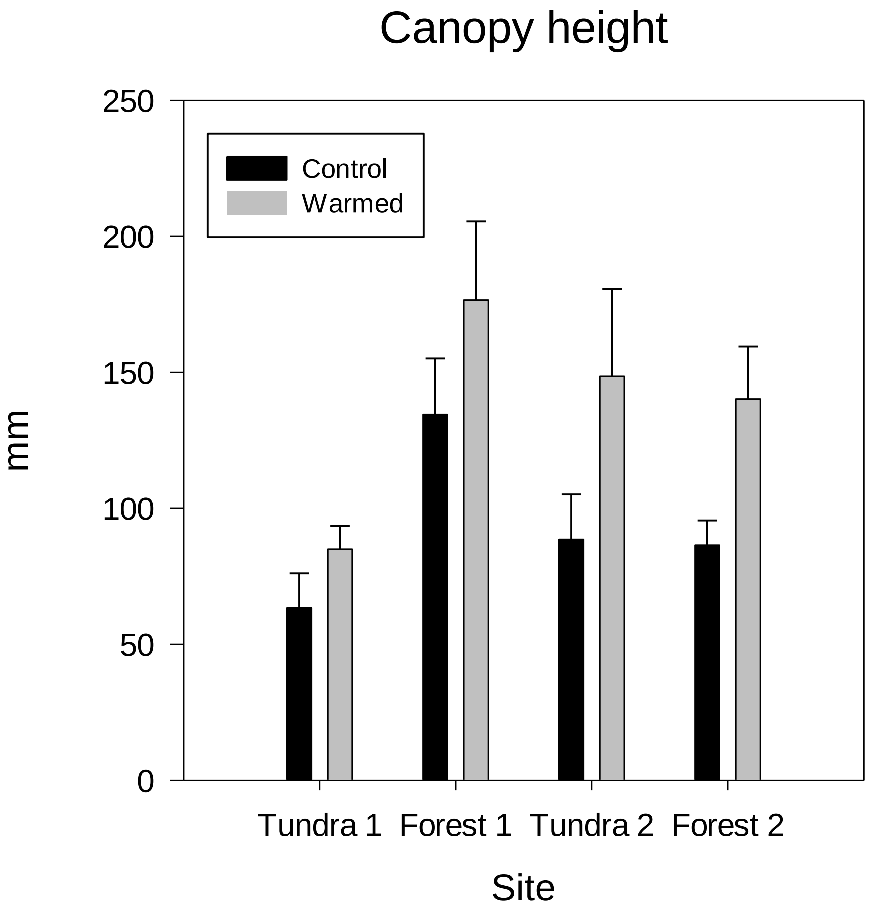
Does short term experiments reflect long term responses?

- 12 years of warming to test
  - if long term warming result in reduced carbon storage and increase C losses from the soil
  - if different habitats respond similarly using the sub arctic/sub-alpine tree-line as a sensitive model system

- Extension growth and canopy height data
- Soil temperature data
- SOM depth and soil respiration rates

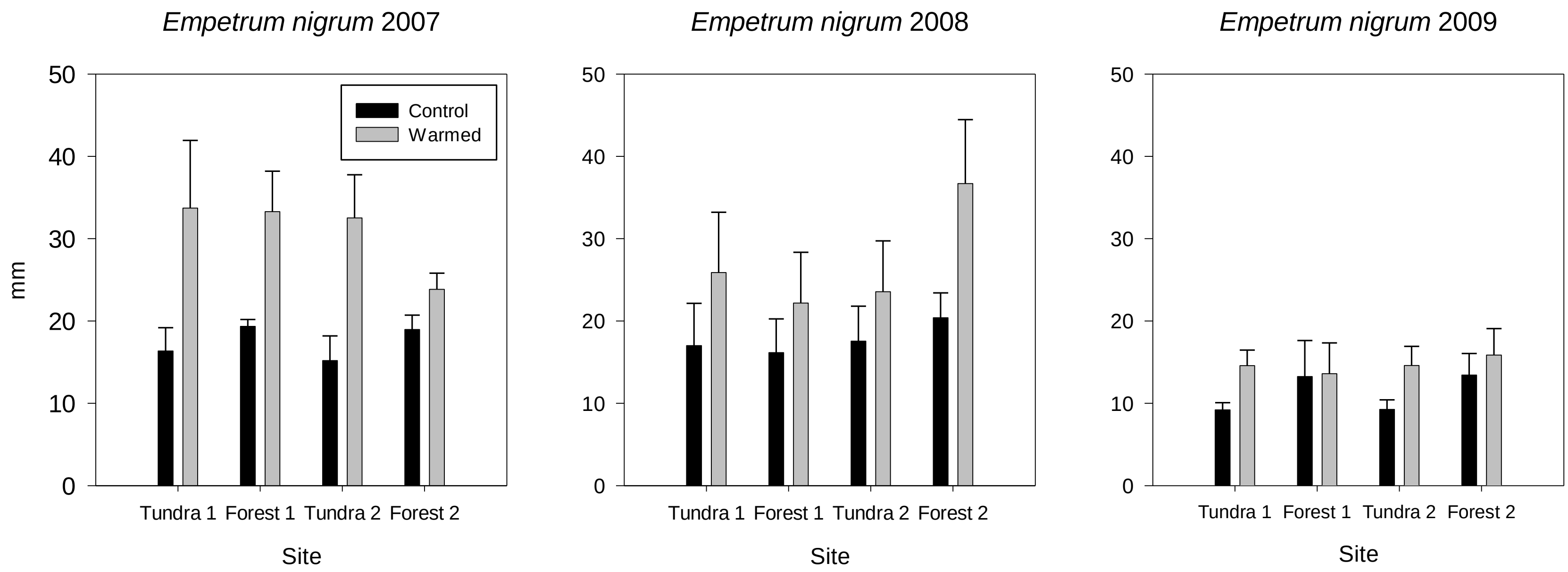
Extension growth of target species

Warming increased canopy height



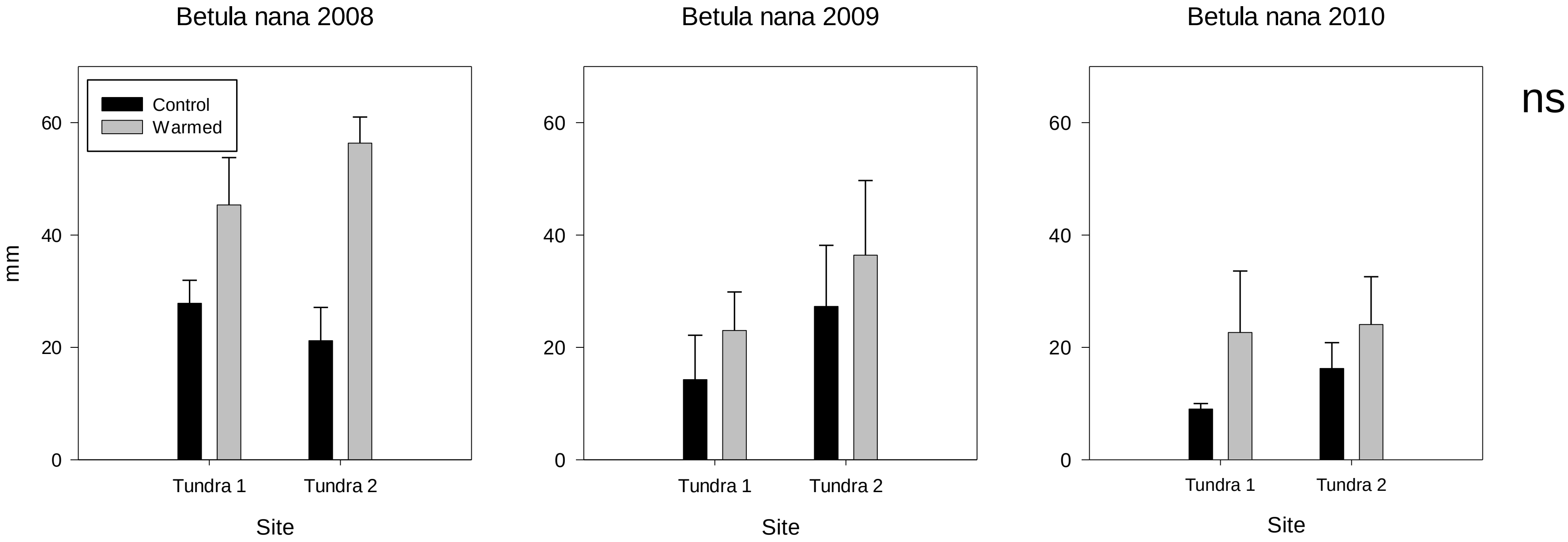
Treatment, $F_{1,32}$ = 9.70, $P < 0.01$

Warming increase growth in *E. nigrum*

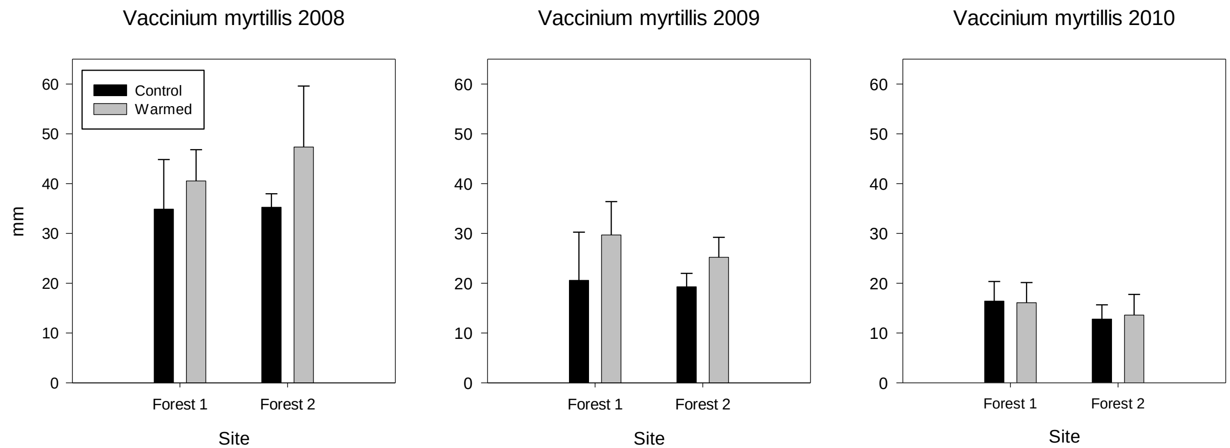


$F_{1,31} = 3.37, P = 0.076$

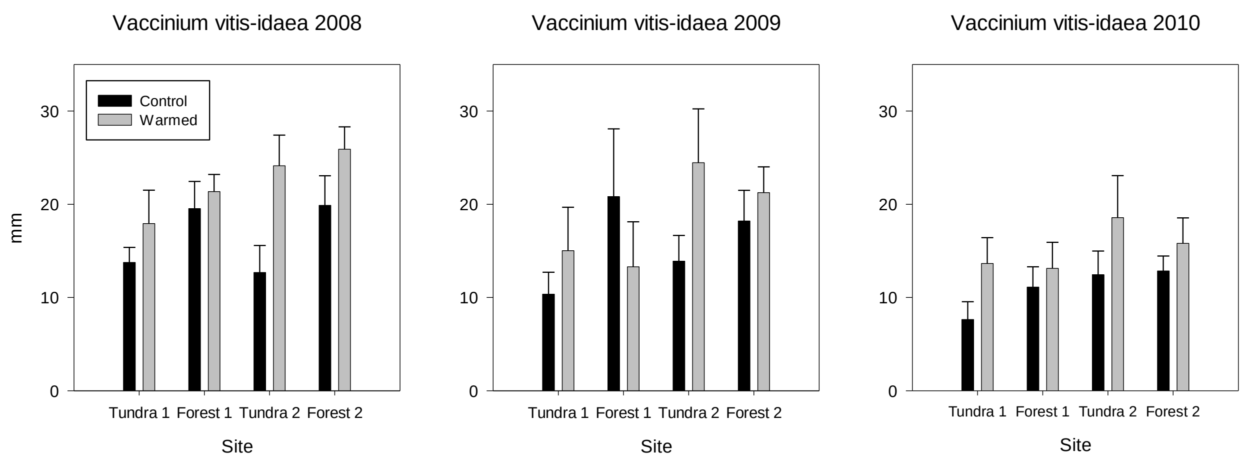
Temporally variable effect of warming on *B. nana*



Variable response of *Vaccinium* species

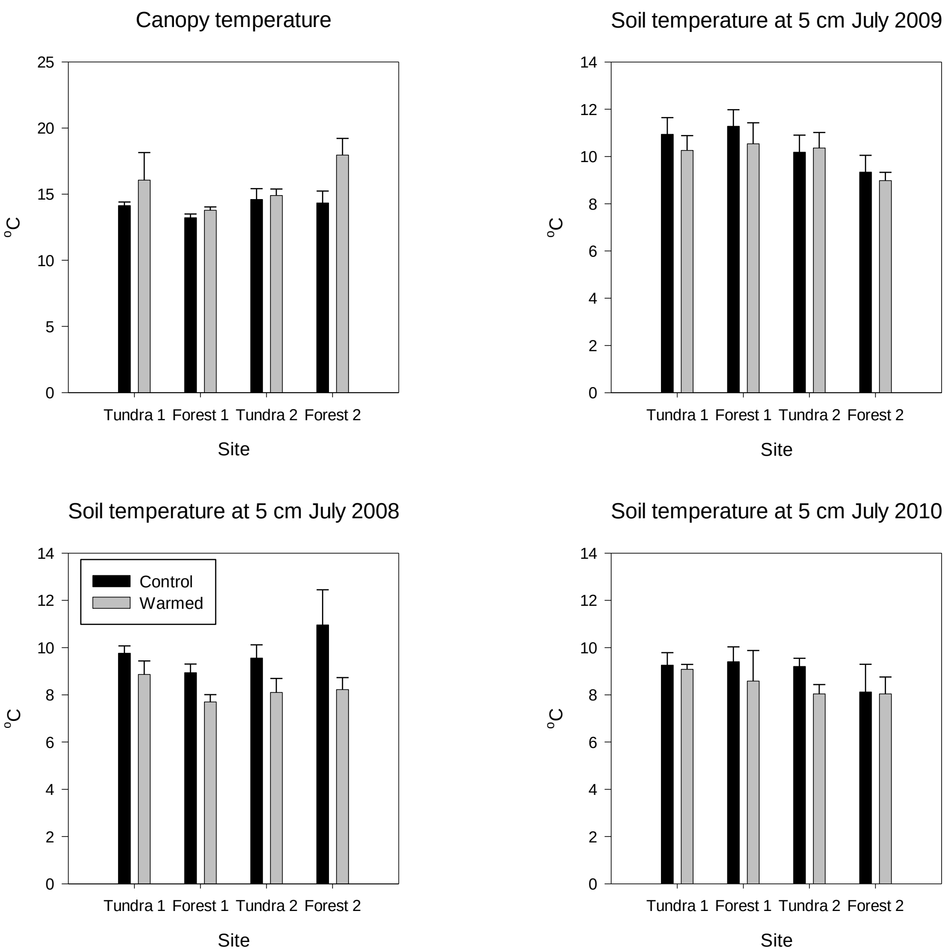


ns



$F_{1,32}$=4.81, P < 0.05

So what are the OTCs doing?



Warms the canopy layer with 1.5 C
$F_{1,32}$= 5.21, P < 0.05

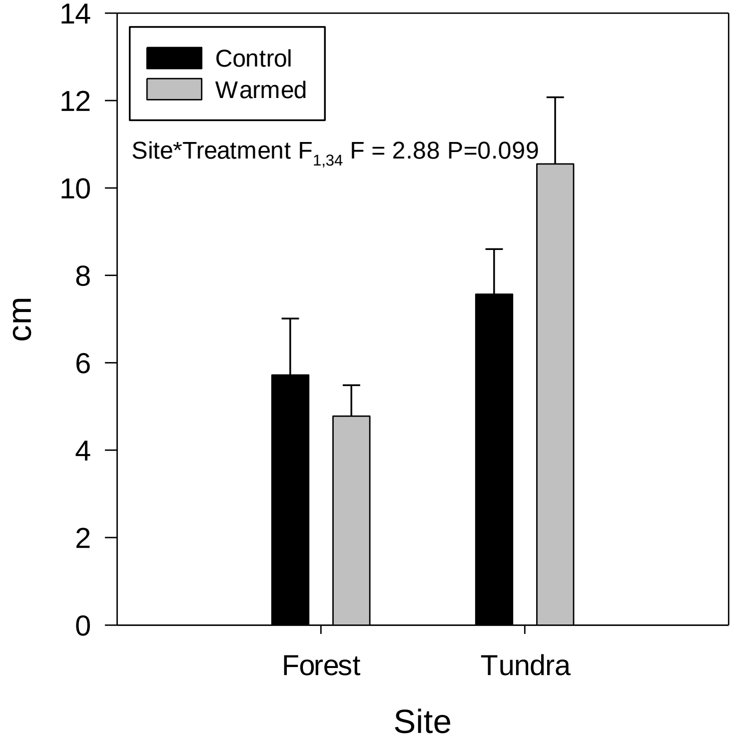
Cools the soil at 5 with between 0.5 and 1.6 °C
$F_{1,32}$ = 6.69, P < 0.05,
Cools the soil at 10 cm with between 0.4 and 1.1 °C
$F_{1,32}$ = 10.1, P < 0.01

So despite elevated air temperature in the OTCs their soils are cooler

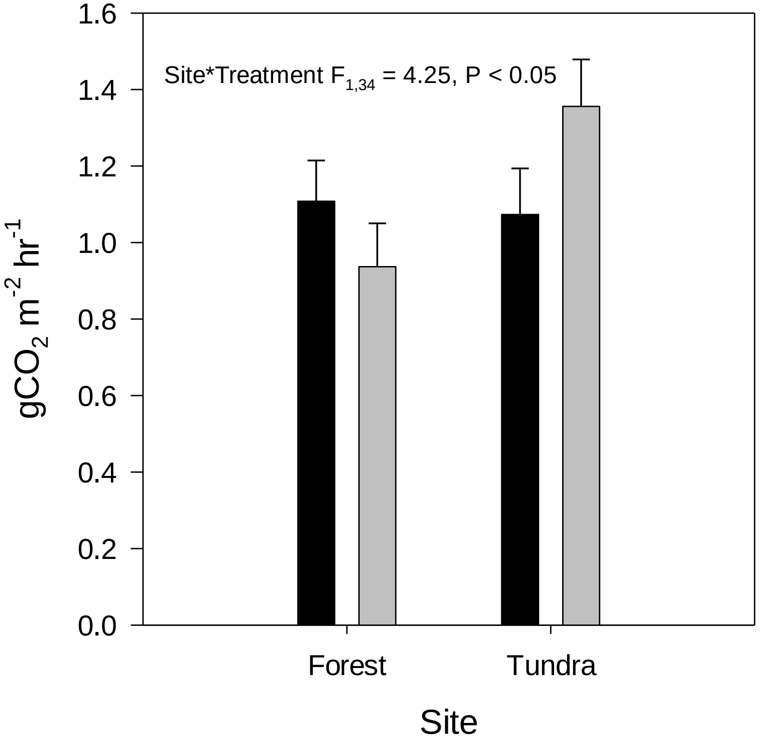
Link to the greater canopy height and increased insulation?

Differential warming responses in forest and tundra

Depth of the organic horizon



Soil respiration



Summary warming experiment

- Increased growth of *E nigrum* and *V vitis idaea*
- No signficant effect on *V myrtillis* and *B nana*
- Canopy height increased
- Temperature in the canopy is greater in OTCs
- Temperature in the soil is lower in OTCs
- Labile carbon has accumulated in warmed tundra soil but not forest soils

Conclusion

What will happen to carbon storage in mountains as the climate warms?

- Increased C losses initially
- But the increased canopy height may result in cooler soils which limits decomposition rates
- Increased C storage in tundra soil
- But shifts in the position of the tree line will reduce C storage