Finding Grouping Schemes to Better Predict Tundra Plant Response to Warming

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Introduction

Tundra plant species are well-adapted to the Arctic. Low temperatures, in combination with a short growing season, create a harsh environment that limits the growth and success of plants (Bliss 1971). However, this harsh environment is changing. Warming has been documented in the Arctic at rates higher than those in other parts of the world site (Arft et al 1999, Hinzman et al 2005, Walker et al 2006). These changes are expected to continue and increase (IPCC 2007). Boreal forest, the biome adjacent to tundra to the south, will slowly replace tundra.

Predicting that boreal forest will replace tundra is an easy and succinct way to describe future changes, but articulating those changes and how they will happen is much more difficult. Even with dramatic warming in the Arctic, other challenges, such as light limitations in the spring and fall, will prevent plants from growing in the Arctic the way they grow at lower latitudes (Bliss 1971). It is not reasonable to expect the treeline to march homogeneously northward until it reaches the coast of the Arctic Ocean.

Overall warming is known to cause an increase in biomass; the warmer conditions are initially beneficial to almost all species (Hollister 2003, May 2011). However, indefinite expansion of all plant species is not possible, and competition will begin to direct community change. .Our objective is to identify those characteristics that could be used to predict species' responses to warming and the potential for a species to be successful in a more competitive environment.

Study Area

Fig 1. (above) Study location.

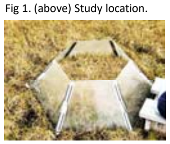
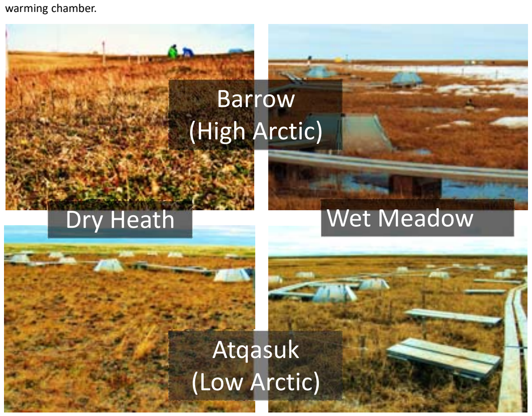


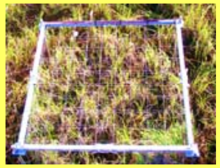
Fig 2. (above) An open-topped warming chamber.

Fig 3. (below) Four long-term study sites were established in Northern Alaska in 1994-1996 (Fig.2). Each of the four sites consists of 48 $1m^2$ plots, randomly designated as control plots or experimental plots. Experimental plots receive a warming treatment in the form of a passive open-topped warming chamber (Fig. 2). Chambers are placed over the plot for the duration of the growing season and removed over the winter. The chambers are designed to increase temperature of the canopy by an average of 1-3˚C while allowing precipitation, light, herbivores, and pollinators in and out of the plots (Hollister and Webber 2000).



Methods

Cover Assessment



Community data were collected using a point frame method in 2007 and 2008. A 75 cm x 75 cm grid (pictured above) was leveled over each of 96 control plots and 96 experimental plots. At each of 100 intersections of the grid, a ruler was dropped. Every time the ruler touched something, it was identified by species (or by abiotic material) and recorded as alive or dead. Each encounter was recorded, as well as the ground height.

Only encounters with live vascular plants were used in this analysis. The number of encounters in control plots was compared to the number of encounters in experimental plots.

"Grouping Schemes"

Grouping schemes were developed using information from the literature and from data from the sites.

Each species was labeled according to the group in which it belonged within the grouping scheme being tested. For example, one grouping scheme labels plants by growth form.

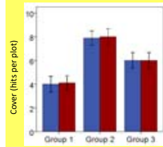
The number of encounters of all species in each group was summed for each plot.

Plot	Growth Form	# of Encounters
BDC01	Deciduous shrub	35
BDC01	Evergreen shrub	17
BDC01	Forb	5
BDC01	Graminoid	4
BDC02	Deciduous shrub	21
BDC02	Evergreen shrub	18
BDC02	Forb	4
BDC02	Graminoid	13
BDE01	Deciduous shrub	26
BDE01	Evergreen shrub	33
BDE01	Forb	5
BDE01	Graminoid	26
BDE02	Deciduous shrub	13
BDE02	Evergreen shrub	35
BDE02	Forb	4
BDE02	Graminoid	38

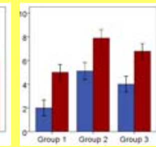
This is the "growth form" grouping scheme, see Table 1 and Fig 4, below.

Statistical Analysis

We used a two-way ANOVA to test each grouping scheme. Each grouping scheme was tested at each site individually. A significant result means that the groups within the grouping scheme do not respond to temperature change in the same way. If the groups respond differently, then the grouping scheme is useful in predicting change.

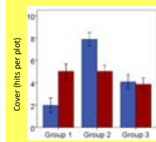


Example Grouping Scheme 1
The groups are statistically different from each other, but there are no differences between treatments.



Example Grouping Scheme 2
There is a response to warming, but the effect is the same for all groups.

These two example grouping schemes are **not** useful. The ANOVA would return a p-value that is not significant.



Example grouping scheme 3, to the left, shows a grouping scheme that would be useful. The direction or magnitude of change is different for at least one of the groups.

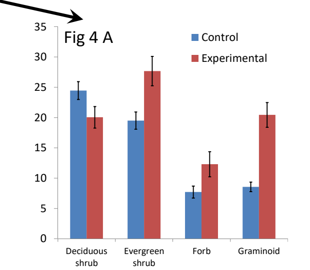
Twenty grouping schemes were tested. See Table 1 in Results section below.

Which characteristics of tundra vegetation are most useful for predicting response to warming?

Results

Grouping Scheme	Source	Number of Species	Barrow Wet	Barrow Dry	Atqasuk Wet	Atqasuk Dry
1. Growth Form	---	72/72		*		
2. Family	---	72/72		*		
3. Monocot/Dicot	---	72/72				
4. TDD$_{sm}$ / Julian Day	*Hollister 2003*	72/72				·
5. Raunkiær's Life Forms	*Sørensen 1941*	41/72				
6. Thawing Type	*Sørensen 1941*	41/72				·
9. Floral Wintering Stage	*Sørensen 1941*	41/72			*	
7. Wintering State of Leaves	*Sørensen 1941*	41/72		*	*	
8. Wintering State of Buds	*Sørensen 1941*	41/72		*		
10. Response to Warming	*Phenology BRW & ATK*	72/72				
11. Early / Late Leaf Bud Burst	*Phenology BRW & ATK*	52/72	*			
12. Early / Late Flower Burst	*Phenology BRW & ATK*	39/72	·			
13. Polyploidy	*Löve & Löve 1948*	35/72			*	
14. Young Zones	*Young 1971*	42/72		*		
15. High Arctic / Low Arctic	*Gould & Walker 1999*	40/72		*		
16. Biome Distribution	---	54/72		·		
17. Latitudinal Distribution	*Hultén 1968*	72/72			·	
18. Longitudinal Distribution	*Hultén 1968*	72/72		*		
19. Alaskan Distribution	*Hultén 1968*	72/72		*	*	
20. Greenland Distribution	*Sørensen 1941*	41/72	*		*	*

Table 2 (left) List of the twenty grouping schemes and their sources, if applicable. Asterisks and dots indicate a significant interaction between the grouping scheme and the warming treatment (*p<.05, · p<.10). The fraction represents the number of species out of the total 72 that were defined under each grouping scheme.



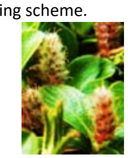


Fig 4 B

Fig 4 C

Fig 4 D

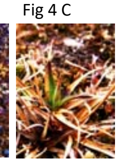


Fig 4 E

Fig. 4 (above). A shows the results for the "growth form" grouping scheme at the Barrow Dry site (p=0.0001). B (deciduous shrub: *Salix pulchra*), C (evergreen shrub: *Cassiope tetragona*), D (forb: *Pedicularis kanei*), and E (graminoid: *Luzula arctica*) show examples of the four broad growth forms used in this "grouping scheme."

Discussion

The high number of grouping schemes that were significant for at least one site is promising. This indicates that there are characteristics of plants that can be used to predict response to warming. The less promising aspect of these results is the amount of variation. Because none of the grouping schemes gave a homogeneous, significant result across the four sites (Table 1), we know that identifying useful characteristics is a complex task. A species may be expanding in the low Arctic, at the Atqasuk sites, but decreasing in the high Arctic Barrow sites.

Differences among the sites are responsible for much of the variation in the results. The Atqasuk dry site is a very open community with a lot of room for expansion; by contrast, the Barrow Wet site is a much more closed community. Species composition and diversity vary among sites, too. Though over sixty species are found in all the sites combined, none of the sites individually has half that many.

Some of the results of our analyses contradict the idea of highly adapted species suffering as conditions change. If this were true then the species with highly adapted traits would decrease in cover with warming. In the example above, northerly species are expanding with warming; northerly species are arguably better adapted to Arctic conditions than more southerly species, so we would expect southerly species to expand and northerly species to decline. This was not seen in our results.

While none of the twenty grouping schemes are copies of each other (each groups species in a unique way) the effects of key species may cause some repetition of results. Of common species, one species with dramatic change in cover was *Carex aquatilis* (Cyperaceae) (Fig. 5, left), a wet meadow sedge. Mean cover of *C. aquatilis* increased 22% in the warmed plots (p<0.05). This increase was reflected in the results of the grouping scheme analysis. For all but two of the significant grouping schemes the group that included *C. aquatilis* increased in cover, meaning that only in those two grouping schemes was *C. aquatilis* grouped with species that decreased in cover enough to mask the effect of the large increase of *C. aquatilis.* Several more rare species had large percentage increases or decreases in cover, but the changes in these species did not have the obvious impact of species like *C. aquatilis* because they were encountered 1-12 times per plot, compared to the 2-53 range of *C. aquatilis.*

Fig 5 (left) *Carex aquatilis,* a wet meadow sedge that responds to warming with a strong increase in cover.

Fig 6 (below). The US distribution of *Carex aquatilis.* This species can be found throughout the US and around the Arctic. (plants.usda.gov)

The power of abundant species to drive the changes in cover that we saw is important to remember when identifying groups that showed significant change. Also important to remember is that not all groups within a grouping scheme will define useful traits. The growth form grouping scheme at the Barrow Dry site was significant (Fig. 2). In this instance the species were sorted into four groups, but three of them responded in the same way, with an increase in cover. Only the deciduous shrub group showed a decrease in cover. When we examined the data more closely we found that the entire deciduous shrub group at the Barrow dry site was comprised of a single willow species (*Salix rotundifolia,* Salicaceae).

Improving the plant trait data used in the grouping schemes could change the result of the analyses. Filling in holes in the plant trait data and expanding the list of grouping schemes is recommended for future study. Testing these groups in combination could reveal the relationships among the traits.

Conclusion

No grouping scheme gave a significant result at all four sites. Our results indicate that different grouping schemes will be more or less useful under different abiotic conditions. The best way to accurately predict vegetation change will be to use the grouping schemes in combination with each other as appropriate for different habitat types. Further research is needed to expand the grouping schemes so more species can be included in the analyses.

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