Consistency of Graminoid Response to Warming in the Alaskan Tundra

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Introduction

The effects of global climate change have been most pronounced in the Arctic, and recent warming has been linked to shifts in arctic plant communities (Elmendorf et al., 2012). Tundra plants impact many ecosystem processes globally (IPCC 2007). Many studies suggest that plant response to warming varies over time and location (Arft et al., 1999). Also, it has been shown that there may be differences in short-term and long-term responses to warming (Hollister et al., 2005a). The objective of this study was to determine the consistency of the response of graminoids to warming in Northern Alaska. The study examined the impact of experimental warming and natural temperature variation at ITEX (International Tundra Experiment) sites at Barrow and Atqasuk, Alaska (**Figure 1**) **.** Species were classified into temperature response types as in Hollister et al. (2005b) in order to compare short term (1994-2000) and long term (2007-2011) responses across sites, species, and growth forms (grasses, rushes, and sedges, **Figure 2**).

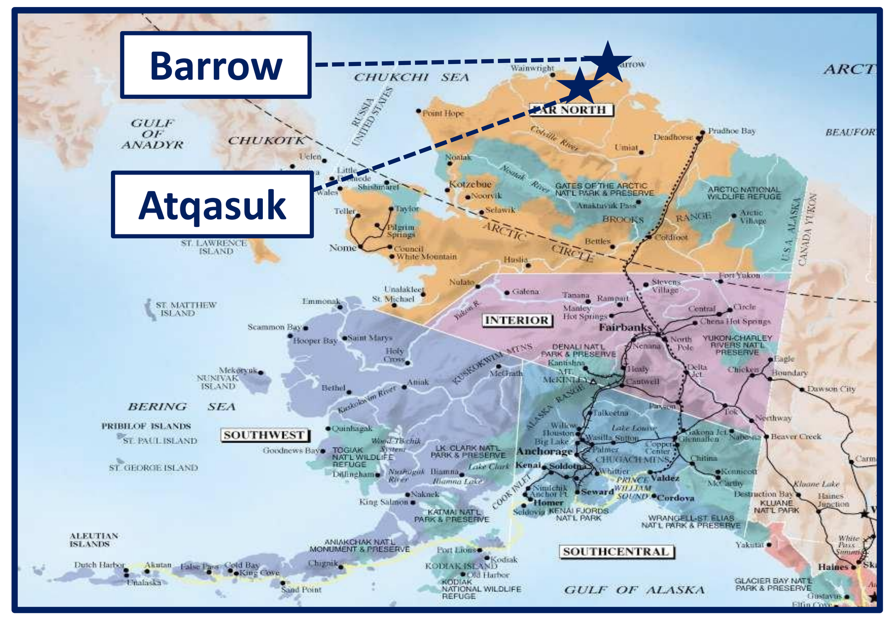

Figure 1 (ABOVE): Location of study sites in Barrow and Atqasuk

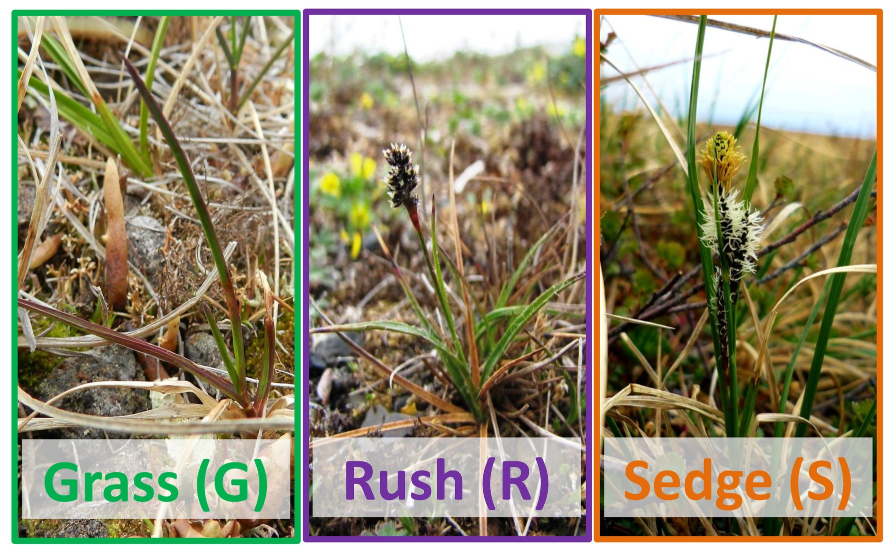

Figure 2 (ABOVE): Examples of growth forms analyzed: (from left to right) *D. fisherii* (G), *L. confusa* (R), and *C. aquatilis* (S).

Methods

Sites were established at Barrow in 1994 and 1995 and at Atqasuk in 1996. Plots of vegetation (1m²) were warmed on average 1°C to 3°C over the summer using open-top fiberglass chambers. This increases the thawing degree day after snow melt (TDD_{sm}) in the experimental plots. TDD_{sm} is the cumulative amount of degree days (which relate time and temperature). Each location contains a dry heath and a wet meadow site (Figure 3) with 24 control and 24 experimental plots each, for a total of 48 plots per site at four sites. The response of leaf length, inflorescence height, and number of inflorescences for 13 graminoid species from 1994-2011 is reported in this study (Figure 4). Data were collected June through August in each control and experimental plot containing the species. A species was only included if it was present in more than 5 control and 5 experimental plots for a given year. Correlation with TDD_{sm} and the response to warming were used to classify graminoid species into temperature response types (Figure 5), as in Hollister et al. (2005b).

Temperature Response Types (from Hollister et al. 2005b):
For each species, a linear regression relating response to TDD_{sm} and a 2-way ANOVA relating response to 'treatment x year' was conducted. If the trait was significantly correlated with TDD_{sm}, then temperature was considered to control the response and was a "dominant factor". If the trait responded to the warming treatment but was not significantly correlated with TDD_{sm}, then temperature was considered a "subordinate factor". Relationships were considered significant if P<0.05. If there was no overall correlation with TDD_{sm} and no significant response to warming treatment, then the trait was classified as "unresponsive" to temperature. The response was then classified as positive or negative based on the direction of change. If there was a significant interaction between treatment and year, the response was classified as "inconsistent".

The analysis including years 1994-2000 was considered the "short-term" response (ST), while the analysis including years 2007-2011 was considered the "long-term" response (LT). Data from all years combined (1994-2011) is also presented. Response types for all graminoid species are shown in Table 1.

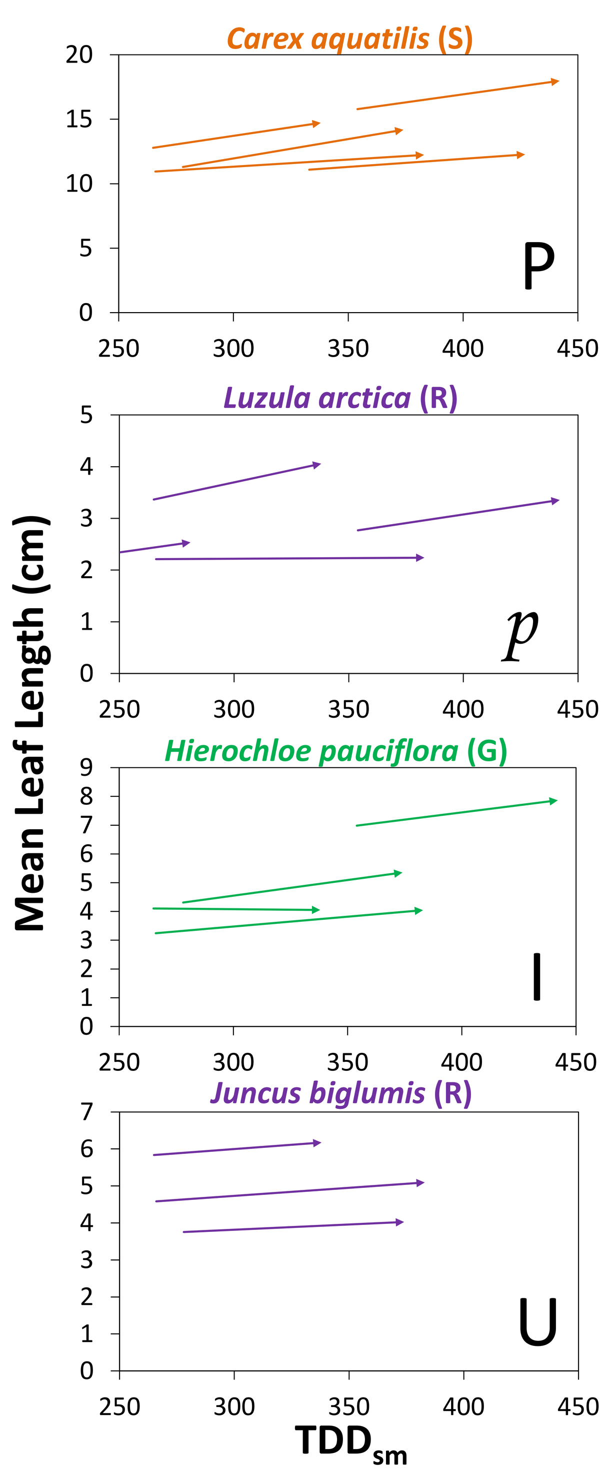

Figure 5 (RIGHT): Examples of temperature response types for Barrow wet, short term response. Positive dominant (P), positive subordinate (*p*), unresponsive (U), and inconsistent dominant (I) responses are shown. Arrows represent change between control and experimental plots. Each arrow represents a different year. Sedges (S), rushes (R), and grasses (G) are included.

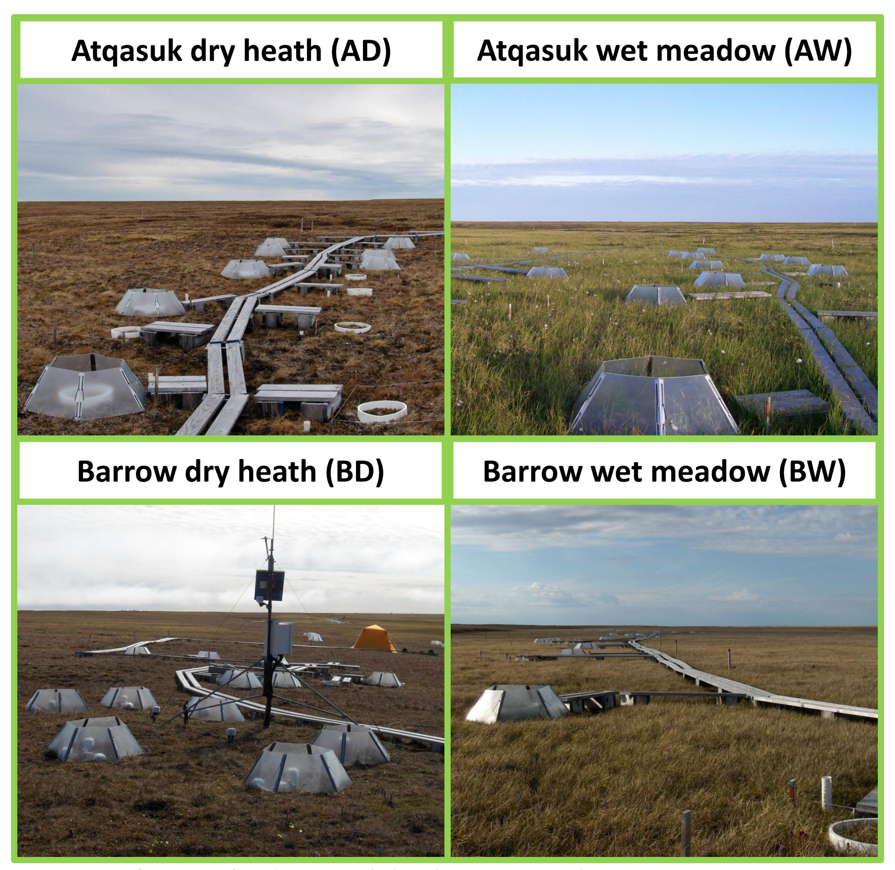

Figure 3 (ABOVE): Photos of the four research sites.

Figure 4 (LEFT): Diagram of growth measures used in this study. Leaf length was only included for vegetative individuals. All inflorescences in a plot were counted .

Results

The response of leaf length to temperature is very consistent from short term to long term (Figure 6).
- Little change (1%) in the percent of responsive species
- Little change (2%) in the percent of positively controlled species
- Little change (2%) in the percent of inconsistent species

The response of the number of inflorescences to temperature is very inconsistent from short term to long term (Figure 6).
- Increase in the percent of responsive species
- Increase in the percent of dominantly controlled species
- Decrease in the percent of positively controlled species
- Increase in the percent of inconsistent species (17%)

Leaf length and inflorescence height tend to be positively controlled by increased temperature (Figure 6).
- Very high percentage of species are positively controlled (>85%)

Number of inflorescences is the trait least influenced by temperature (Figure 6).
- Majority of species unresponsive
- Majority of responsive species subordinately controlled

In general, rushes were the least responsive to increased temperature for all traits (Table 1).
- For leaf length and inflorescence height, less than 75% responsive.
- For number of inflorescences, 0% responsive

Sedges showed the greatest changes between short term and long term response types (Table 1).
- For leaf length, percent of responsive species decreased by 77%, percent dominantly controlled and percent positively controlled decreased by 50%.
- Also large changes for inflorescence height and number of inflorescences.

The short term response for leaf length is the most consistent trait between sites (Table 2).
- 71% of species were consistent

The short term response for inflorescence height is the least consistent trait between sites (Table 2).
- 0% of species were consistent

The change in percent of consistent species between short term and long term varies between traits (Table 2).
- Decreases for leaf length
- Increases for inflorescence height
- Consistent for number of inflorescences

Species by Site	Leaf Length			Inflorescence Height			Number of Inflorescences		
	Short term	Long term	**All years**	Short term	Long term	**All years**	Short term	Long term	**All years**
Atqasuk dry heath									
Hierochloe alpina (G)	P	*p*	**P**	P	P	**P**	*p*	U	**U**
Luzula arctica (R)	U	U	**U**	U	…	**U**	U	…	**U**
Luzula confusa (R)	U	P	**P**	U	U	**U**	U	U	**U**
Atqasuk wet meadow									
Dupontia fisherii (G)	*p*	P	**P**	…	…	**U**	…	…	**P**
Carex aquatilis (S)	*p*	U	**U**	*p*	*p*	***p***	U	P	**P**
Eriophorum angustifolium (S)	P	I	**P**	i	*p*	***p***	*p*	P	**P**
Eriophorum russeolum (S)	P	U	**P**	i	…	***p***	*p*	…	***p***
Barrow dry heath									
Arctagrostis latifolia (G)	*p*	U	**P**	P	P	**P**	U	U	**U**
Poa arctica (G)	P	P	**P**	*p*	P	**I**	U	U	**…**
Luzula arctica (R)	U	*p*	**U**	*p*	*p*	**P**	U	U	**U**
Luzula confusa (R)	*p*	P	**P**	P	P	**P**	U	U	**U**
Barrow wet meadow									
Dupontia fisherii (G)	U	P	**I**	P	P	**I**	n	n	**n**
Hierochloe pauciflora (G)	I	*p*	**P**	U	U	**i**	U	n	**U**
Poa arctica (G)	U	U	**U**	…	*p*	***p***	…	U	**U**
Juncus biglumis (R)	U	…	**U**	P	…	**P**	U	…	**U**
Luzula arctica (R)	*p*	…	***p***	P	*p*	**P**	U	U	**U**
Luzula confusa (R)	U	…	**U**	P	U	**I**	U	U	**U**
Carex aquatilis (S)	P	*p*	**P**	P	*p*	**P**	U	i	**U**
Eriophorum angustifolium (S)	U	U	***p***	*p*	*p*	***p***	U	*p*	**U**
Eriophorum russeolum (S)	*p*	U	***p***	*p*	…	***p***	U	…	**U**

Table 1 (ABOVE): Assigned temperature response types of species at the four study sites. Response types are positive dominant (P), positive subordinate (p), negative dominant (N), negative subordinate (n), inconsistent dominant (I), inconsistent subordinate (i), and unresponsive (U). "Long term" response types include data from 2007-2011, while "short term" response types include data from 1994-200.

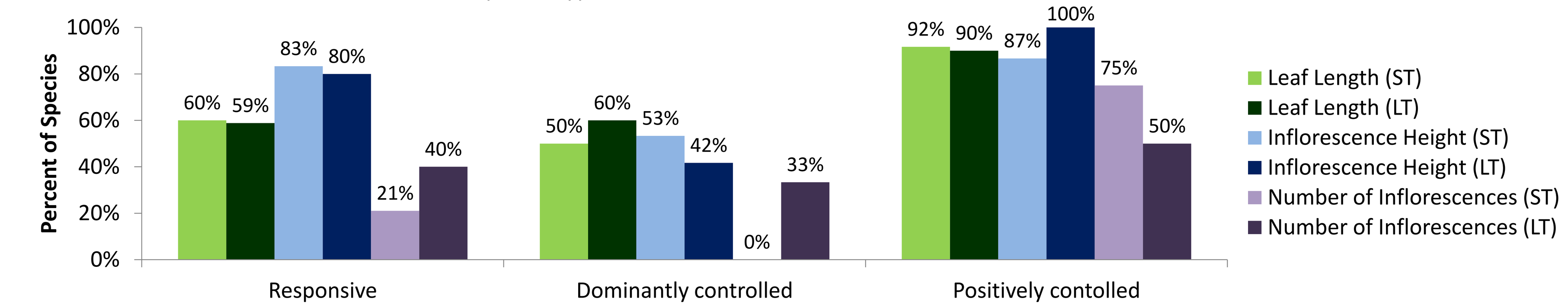

Figure 6 (ABOVE): Percentages calculated from Table 1 for short term (ST) and long term (LT) response types for all traits analyzed. Values for "dominantly controlled", and "positively controlled" were calculated out of the total number of responsive temperature response types ("U"s were not included).

Species	Leaf Length			Inflorecence Height			Number of Inflorescences		
	Short Term	Long Term	**All Years**	Short Term	Long Term	**All Years**	Short Term	Long Term	**All Years**
Dupontia fisherii (G), (AW, BW)	C	C	**I**	…	…	**I**	…	…	**I**
Poa arctica (G), (BD, BW)	I	I	**I**	…	I	**I**	…	C	**…**
Luzula arctica (R), (AD, BD, BW)	I	I	**I**	I	C	**I**	C	C	**C**
Luzula confusa (R), (AD, BD, BW)	C	C	**I**	I	I	**I**	C	C	**C**
Carex aquatilis (S), (AW, BW)	C	I	**I**	I	C	**I**	C	I	**C**
Eriophorum angustifolium (S), (AW, BW)	C	C	**I**	I	C	**C**	I	I	**I**
Eriophorum russeolum (S) (AW, BW)	C	C	**I**	I	…	**C**	I	…	**I**
Percent Consistent	71%	57%	**0%**	0%	60%	**29%**	60%	60%	**50%**

Table 2 (ABOVE): Change of response types across sites for species that occurred in more than one site. If the temperature response type was different for at least one site the species was present at, it was assigned an "I" for "inconsistent". If the temperature response type for the species was consistent across all sites it was present in, it was assigned a "C" for "consistent".

Conclusions

The consistency of graminoid response to warming varies between traits, with inflorescence height being the most consistent trait from short term to long term. The number of inflorescences produced is the least responsive to temperature. This suggests that a specific trait may be more impacted by warming than others, and some traits may be more consistent over time. Consistency and responsiveness also vary between growth forms. Rushes tend to be less responsive to warming, and sedges tend to respond less consistently over time. Furthermore, the consistency of the response to warming across sites also varies with time and between traits. Overall, the consistency of graminoid response to temperature varies between species, traits, growth forms, across sites, and over time. This variation should be taken into consideration when attempting to predict how tundra vegetation will be impacted by global climate change. Long term monitoring of tundra vegetation over a wide range of habitats is crucial in order to keep track of how the tundra is changing with changing temperature.

References and Acknowledgements

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