Soil drying and active layer deepening decrease productivity across ecotypes of a dominant Arctic sedge

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November 24, 2022

Abstract

Arctic warming is outpacing the global rate of climate change, with up to 11 degrees C of warming projected by the year 2100 if greenhouse gas emissions follow their current trajectories. Increasing temperatures are expected to result in permafrost thaw, and the combined effects of precipitation changes, soil warming, and active layer deepening are expected to result in net soil drying. While there is widespread agreement that increasing temperatures and active layer depth will release carbon from soils, the effect on vegetative C cycling is less certain. In 2017, we conducted an experiment to examine the effects of soil drying and active layer deepening on primary productivity in Eriophorum vaginatum, a dominant circumpolar Arctic sedge, and the extent to which those effects vary across ecotypes. We harvested E. vaginatum tussocks from three sites along a latitudinal gradient in the Alaskan Arctic, placed them in pots filled with peat soil, and assigned each to one of three drying treatments. In one treatment, the soils were kept saturated with water through the growing season. In the second treatment, rain was excluded in alternating two-week cycles. In the third treatment, rain was also excluded in alternating two-week cycles, and the soil column was approximately doubled in depth to allow deeper drainage. We measured soil moisture, leaf water potential, leaf area index (LAI), leaf-level phenology, and photosynthetic capacity (Amax) in each of the tussocks. We found that the southern ecotype was affected most severely by drying, with reductions in LAI, maximum leaf length, and Amax. We found that effects were greater with rain exclusion and soil column deepening than with rain exclusion alone. However, we found no difference in leaf water potential between populations or treatments, suggesting that E. vaginatum leaves function within a fairly narrow range of moisture conditions. These results demonstrate that changes in soil moisture may affect carbon storage in Arctic vegetation, but that the magnitude of the effect may vary depending on region and ecotype.

B31F-2529: Soil drying and active layer deepening decrease productivity across ecotypes of a dominant Arctic sedge

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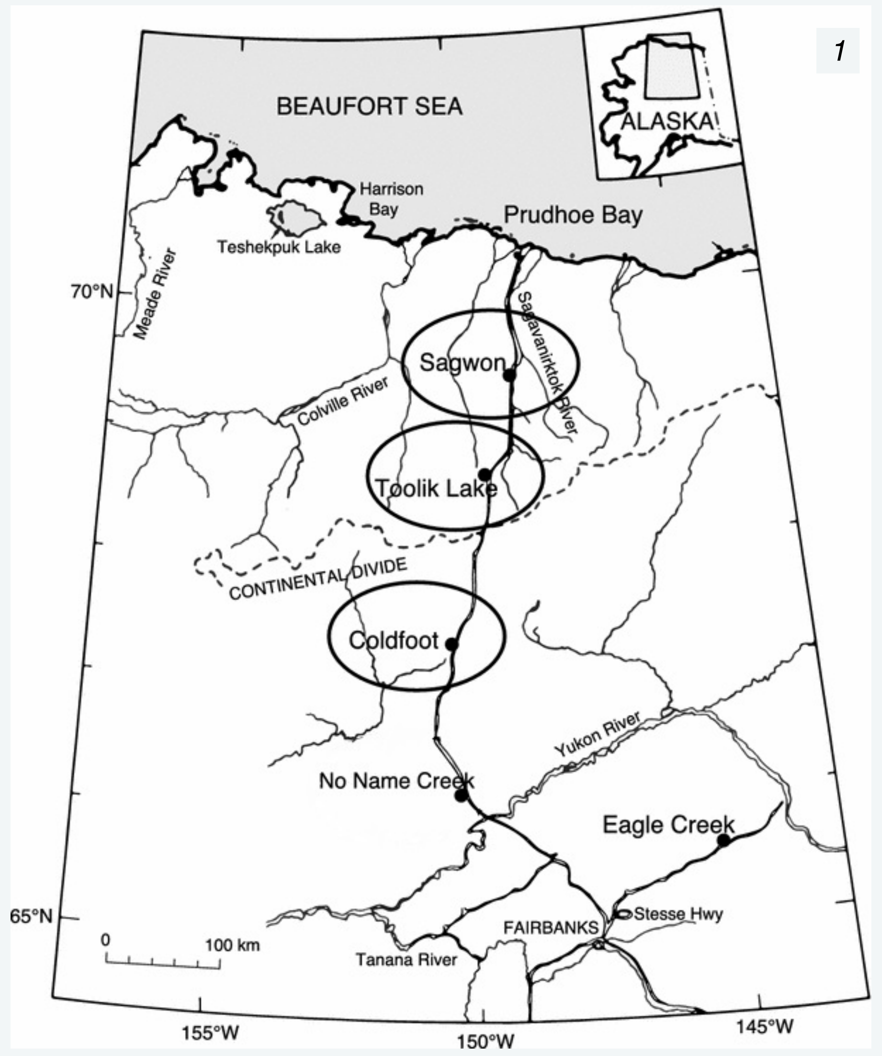
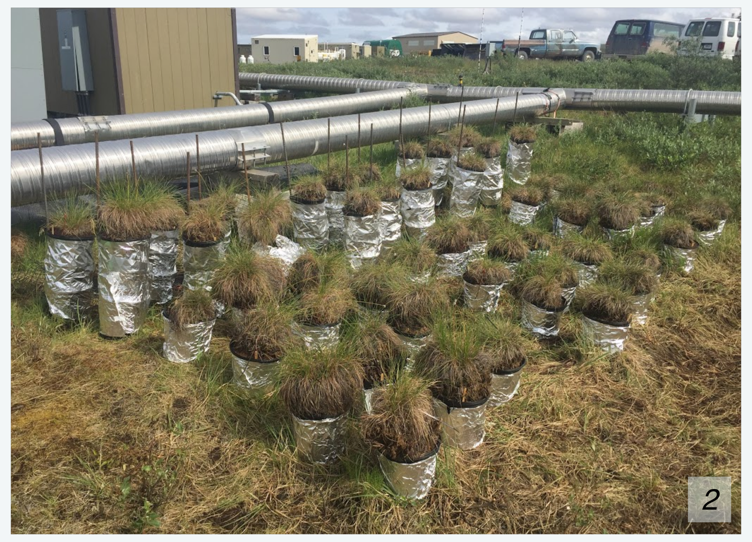
Motivation

Arctic warming is outpacing the global rate of climate change, with up to 11 degrees C of warming projected by the year 2100 if greenhouse gas emissions follow their current trajectories. Increasing temperatures are expected to result in permafrost thaw, and the combined effects of permafrost thaw and active layer deepening, precipitation changes, and soil warming, are expected to result in net soil drying. While there is widespread agreement that these changes will stimulate the release of carbon from soils[1], the effect on vegetative C cycling is less certain. Even less certain is how ecotypic variation within species will facilitate or inhibit plants' ability to adapt to rapid environmental change, In 2017, we conducted an experiment to examine the effects of reduced precipitation and active layer deepening on primary productivity in *Eriophorum vaginatum*, a dominant circumpolar Arctic sedge, and the extent to which those effects vary across ecotypes.

Methods

We harvested *E. vaginatum* tussocks from three sites along a latitudinal gradient in the Alaskan Arctic: Sagwon, (69.6° N), Toolik Lake (68.6° N), and Coldfoot (67.3° N). We placed them in pots filled with peat soil, and assigned them to three soil moisture treatments. In one treatment ("saturated"), the soils were kept saturated with water through the growing season. In the second treatment ("drought"), rain was excluded in alternating two-week cycles. In the third treatment ("drought + thaw"), rain was also excluded in alternating two-week cycles, and the soil column was doubled in depth to allow deeper drainage and simulate active layer deepening. We measured soil moisture, leaf water potential, normalized-difference vegetation index (NDVI), leaf area index (LAI), leaf-level phenology, and light-saturated photosynthetic capacity (A_{max}) in each of the tussocks over three months. We also harvested leaves and analyzed leaf $\delta^{13}C$ as a measure of intrinsic water use efficiency (iWUE).





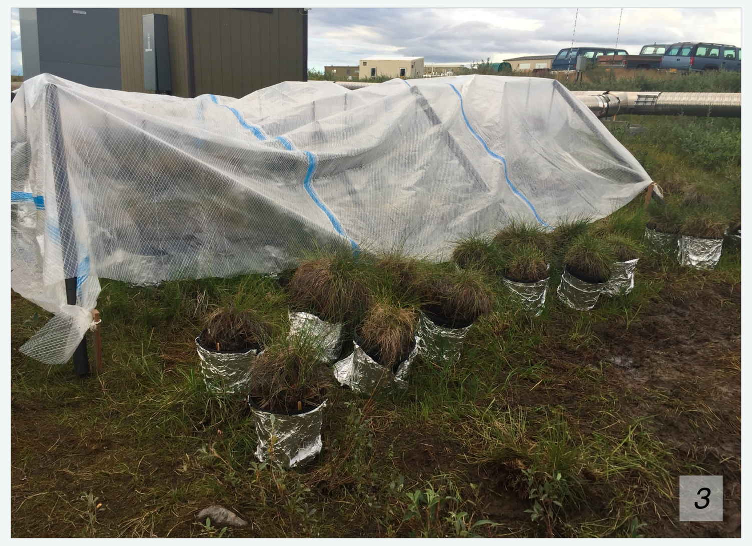
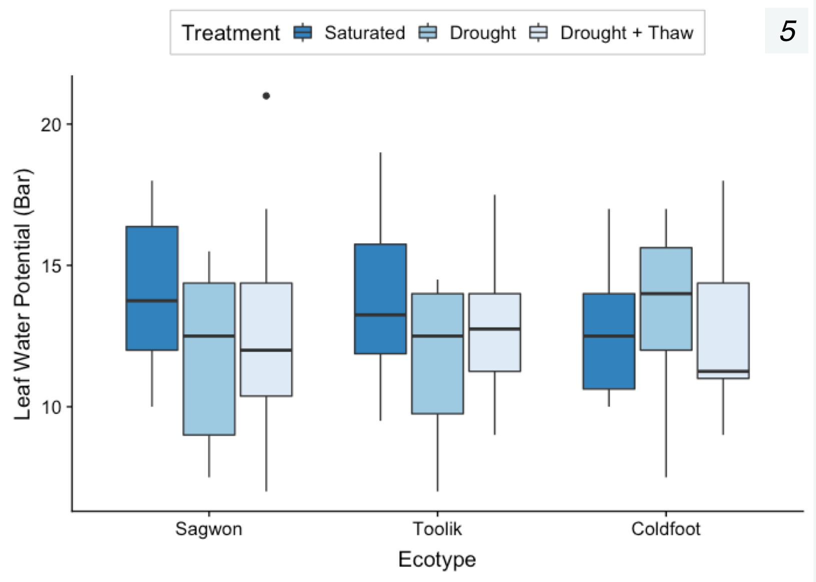
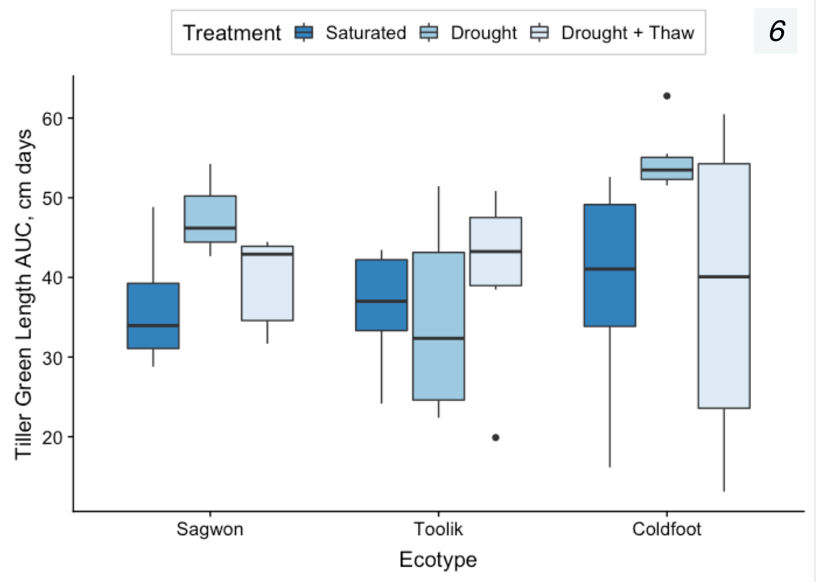
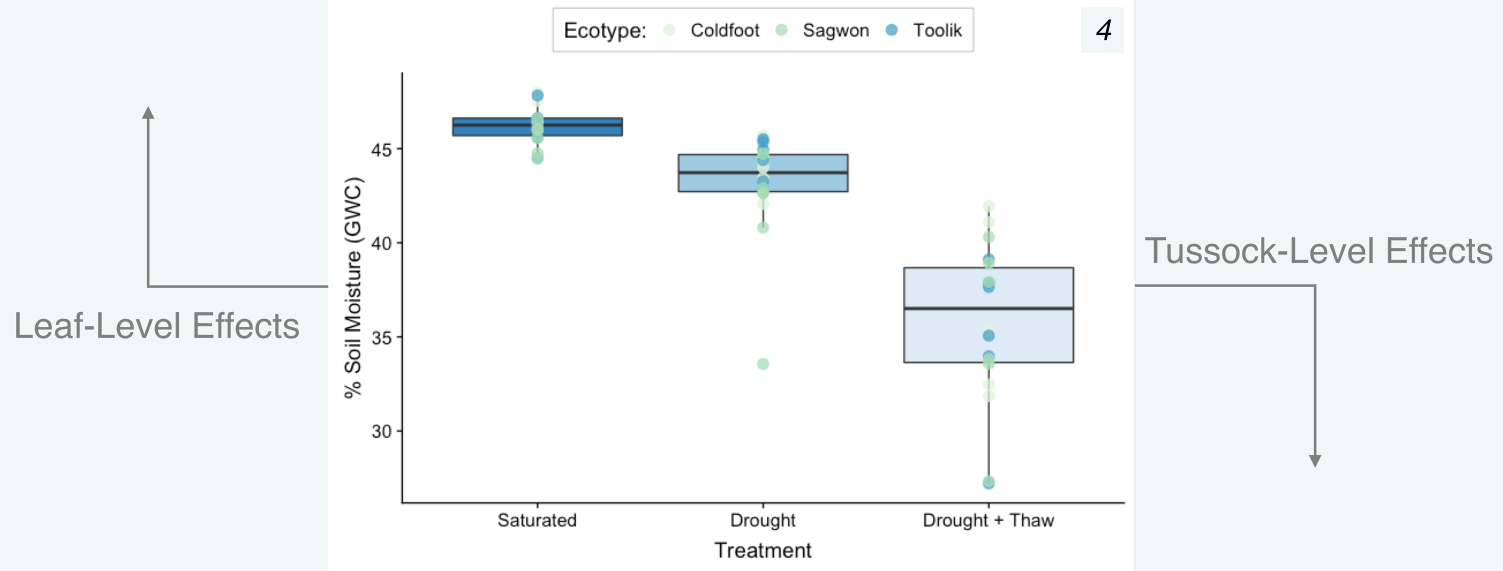
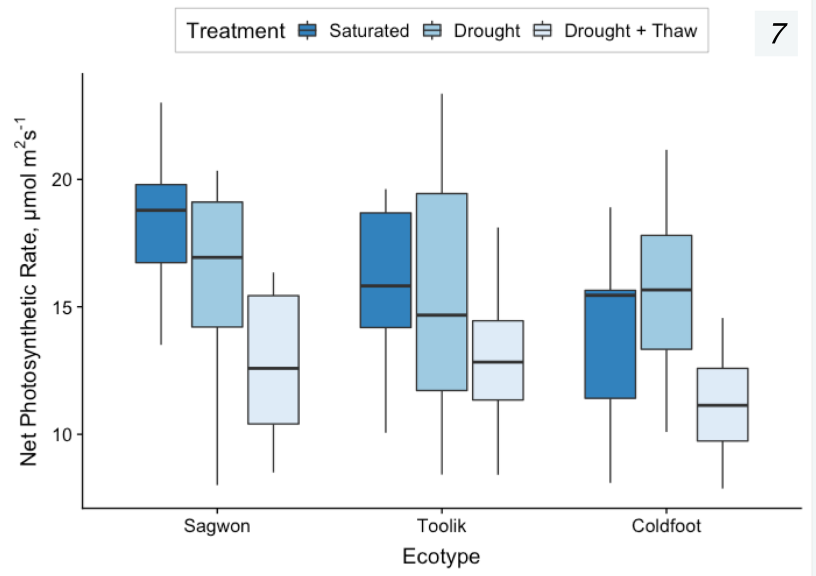


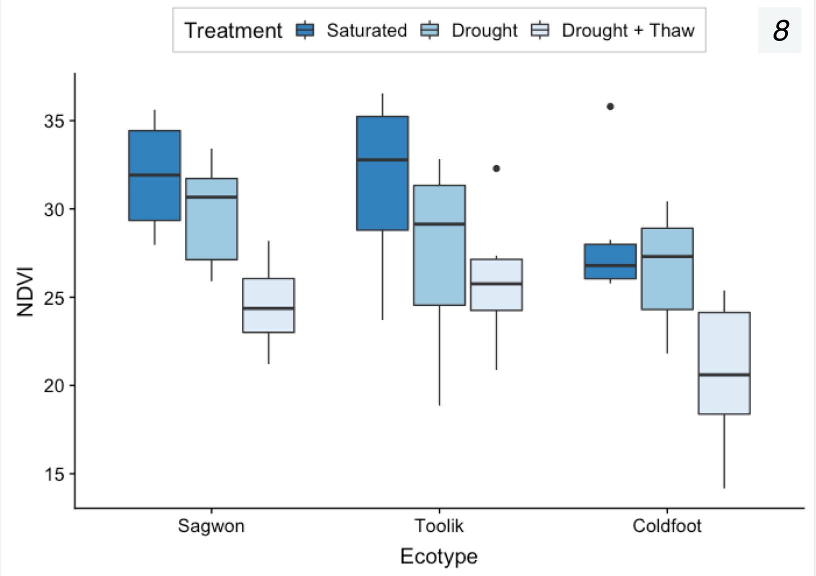
Figure 1: Study sites. Sagwon, Toolik, and Coldfoot are located along the Dalton Highway across ~2 degrees of latitude. **Figure 2: Experimental tussocks (uncovered) during dry conditions.** Tussocks from each site are placed in single pots with no drainage outlet, or in extended soil columns (back rows). **Figure 3: Tussocks covered during a precipitation event.** One group of single pots and the group of drought + thaw (extended soil column) pots had precipitation excluded on alternating two-week cycles.







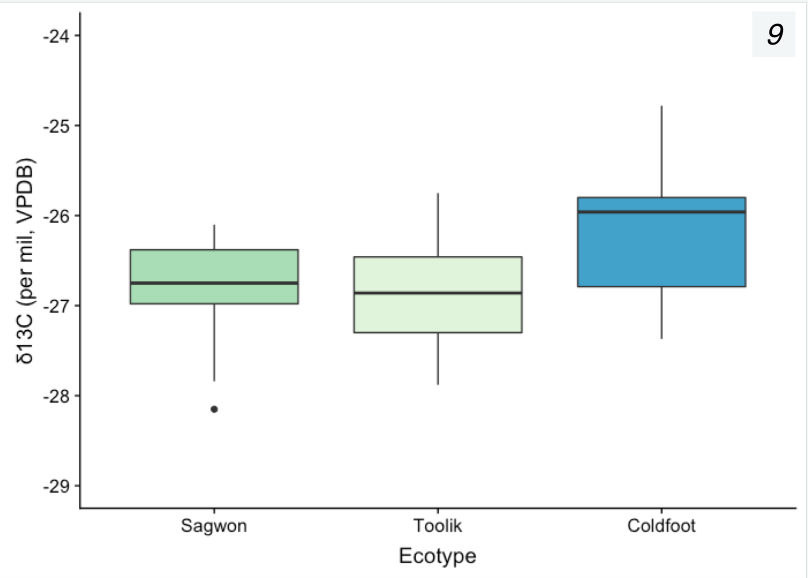


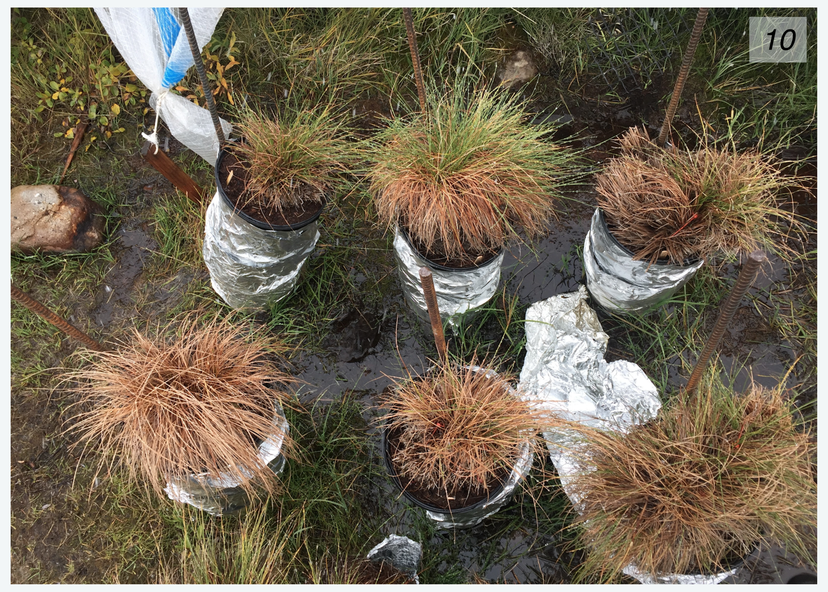


Results

As expected, rain exclusion and active layer deepening caused more severe soil drying than rain exclusion alone (Figure 4). We found no significant effects of soil drying on any metric of individual green leaf performance, such as water potential (Figure 5) or leaf length (Figure 6). However, we did find significant effects of soil drying at the whole-tussock level, where soil drying reduced A_{max} (Figure 7) and NDVI (Figure 8). We found that impacts were greater with rain exclusion and soil column deepening than with rain exclusion alone.

We further found that NDVI, LAI, and A_{max} varied by ecotype, with the Coldfoot (southernmost) ecotype exhibiting the lowest values in the "drought + thaw" treatment despite having slightly greater iWUE (Figure 9). However, there were no significant interactions between ecotype and treatment for any of our response variables, suggesting uniform responses to soil drying across ecotypes.





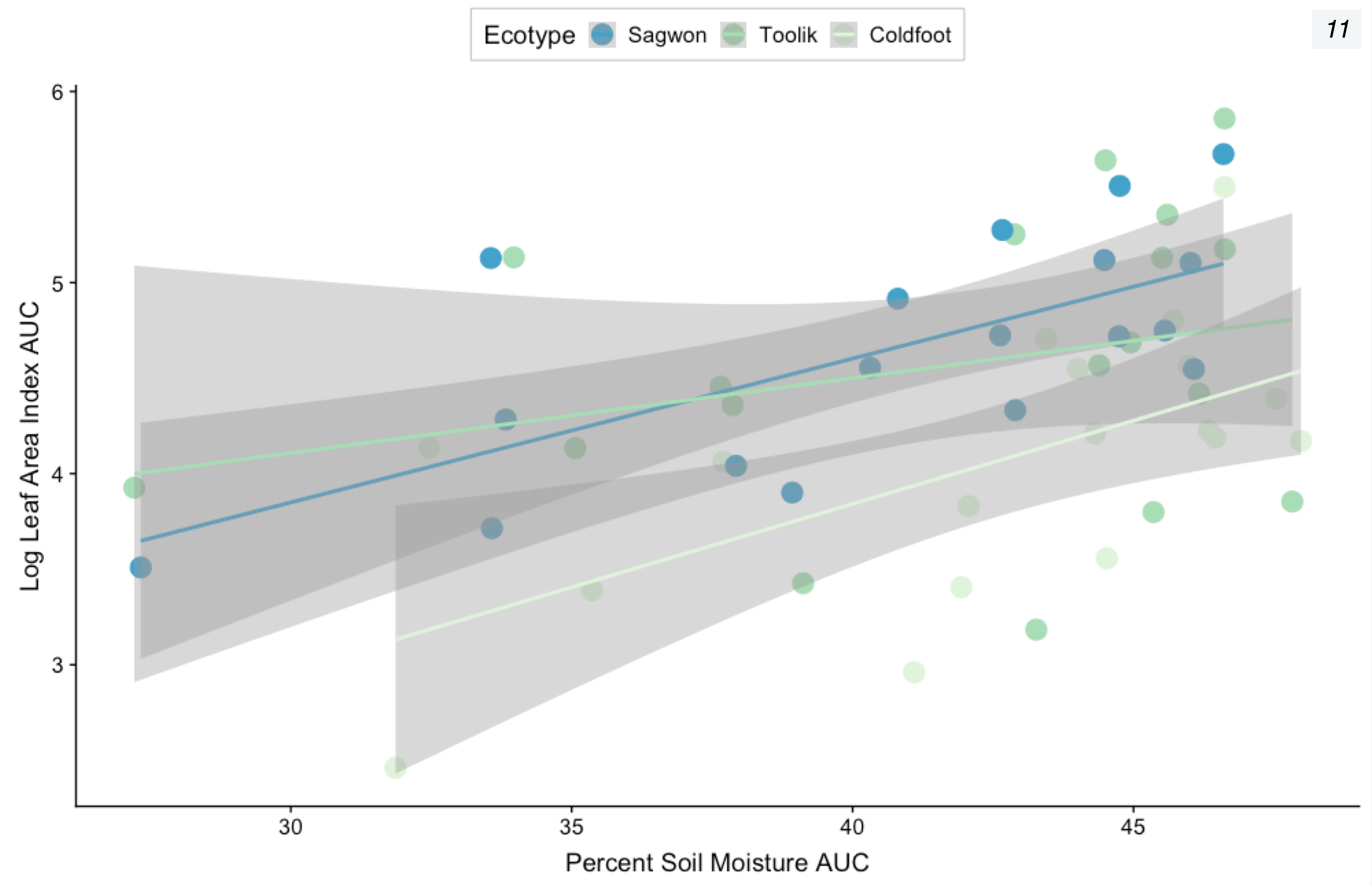


Figure 11: Relationship between soil moisture and time-integrated LAI. We calculated time-integrated soil moisture and time-integrated leaf area index for each plant as the area under the curve for each variable over time. Time-integrated LAI varied by ecotype (p=0.015) and time-integrated soil moisture (p=0.003), but there was no interaction between ecotype and soil moisture (p=0.841), indicating that tussocks reduce leaf area uniformly across ecotypes in response to soil drying.

Discussion

Previous research has established that *E. vaginatum* forms distinct ecotypes[2,3], with locally adapted traits such as stomatal density[4]. Here we find no effect of soil moisture on individual green-leaf performance (water potential or leaf elongation), but significant effects of both ecotype and soil moisture on whole-plant performance (NDVI, LAI, A_{max}). We infer that *E. vaginatum* leaves function only within a relatively narrow window of water availability, and reduce green leaf area in order to maintain the function of individual leaves under moisture-limited conditions (Figures 10-11). *E. vaginatum* plant productivity is thus reduced uniformly across ecotypes by soil drying.

These results demonstrate that changes in soil moisture may affect carbon storage in Arctic vegetation, and suggest that ecotypic variation in this dominant species does not regulate the magnitude of the effects.

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Acknowledgements

Thanks to all investigators and collaborators on the larger Ecotypes project within which this study was conducted. Thanks to Gus Shaver, Sal Curasi, Jeremy May, Kevin Griffen, Joanna Carey, and Jessica Schedlbauer for helpful suggestions in study design and analysis, to Robert Michener and the Toolik Field Station Environmental Data Center for lab assistance, and to Steven Unger, Alana Thurston, David Heinz, Matthew Simon, and Sofia Iglesia for field assistance. Funding was provided by NSF-OPP #1418010 to Ned Fetcher, NSF-OPP # 1417645 to Michael Moody, and NSF-OPP # 1417763 to Jim Tang.