Climate as a Driver of Shrub Expansion and Tundra Greening

Interim Report - April 2018

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Project Title: Climate as a Driver of Shrub Expansion and Tundra Greening (NERC)

This interim report provides a summary of the research conducted by Dr. Isla Myers-Smith and her work group (Team Shrub) from the University of Edinburgh, Scotland (UK) on Qikiqtaruk - Herschel Island over the summer of 2017 (for more information see https://teamshrub.com/).

Premise: Vegetation changes in a warming Arctic

Global warming is changing environments all over the world, but the changes are particularly pronounced in the Northern Latitudes[1]. The Arctic is warming at twice the rate than the rest of the globe[2] and the higher temperatures associated with longer growing seasons are causing notable changes in the vegetation of the Arctic tundra: the plants are becoming more productive and the tundra is getting "greener"[3,4]. Particularly, shrubs are increasing in height and abundance[5,6] (Fig. 1).

Plants are an essential source of food for animals living in the tundra, but they also influence decomposer activity in the soil and the regional climate by changing snow cover and the reflection of solar light from the landscape[7]. The latter have potentially strong influences on the global climate[7] and the changes in vegetation are therefore of interest to both people living in the Arctic and around the world.

Research on Qikiqtaruk – Understanding vegetation changes

The aim of our research on Qikiqtaruk is to better understand vegetation changes, their causes and the effect they have on the tundra and the regional climate. To do so we carry out a variety of experiments and surveys, including vegetation monitoring, decomposition experiments and herbivory monitoring.

A large majority of our work forms part of ongoing long-term projects (more than 15 years) that allow us to draw meaningful conclusions of the changes over time. In the far north-west of the Yukon, Qikiqtaruk is at the end of the distribution of large shrubs, which usually would grow further south. The unique setting at the latitudinal shrubline within the Arctic makes Qikiqtaruk particularly interesting to both our research and to global studies.

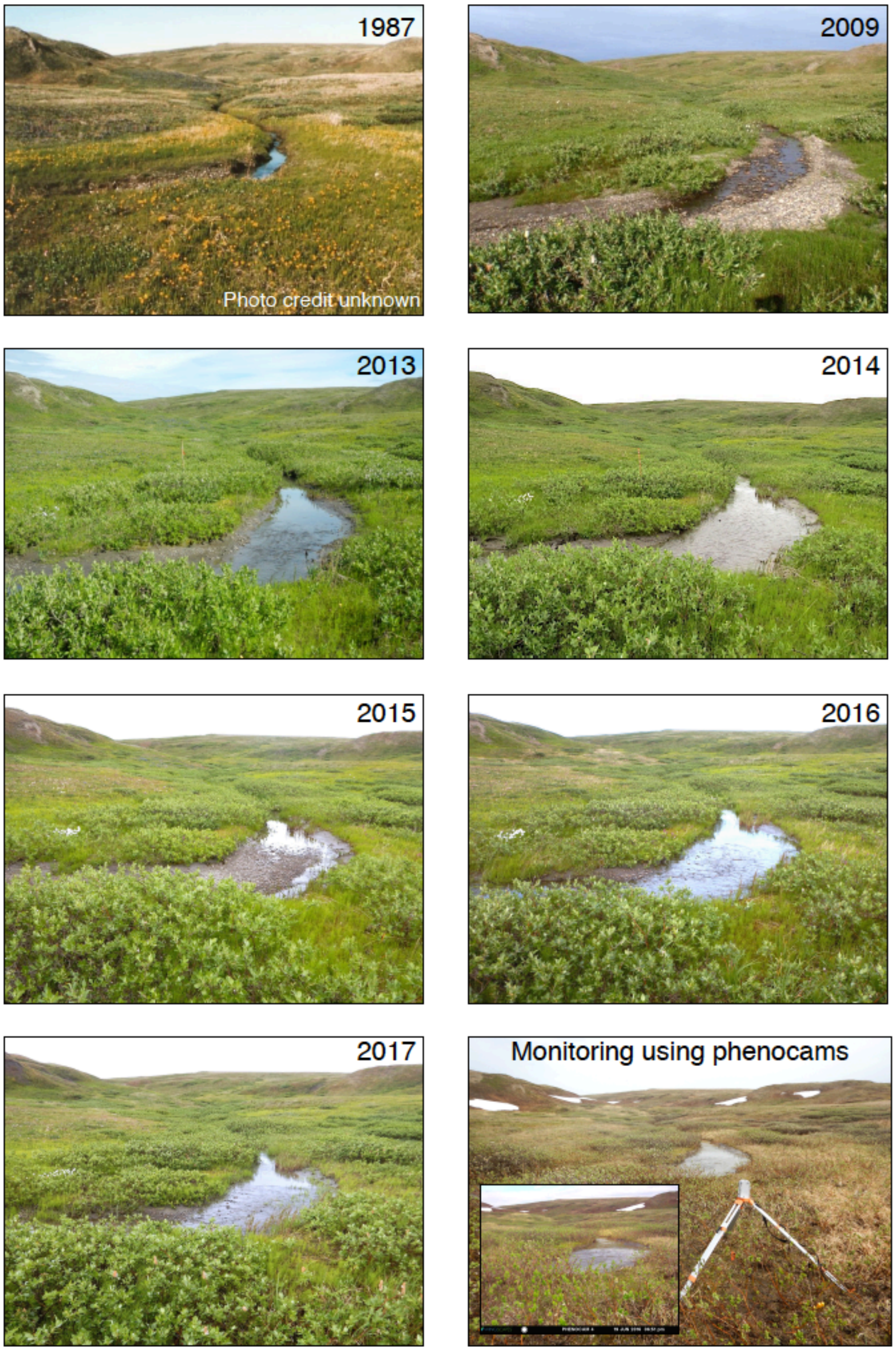

Figure 1. Shrub cover is increasing on Qikiqtaruk. Change in shrubs in Ice Creek on Qikiqtaruk over the last 29 years shown by repeat photography. We have additionally added phenocams – time laps cameras to monitor plant growth at this and four other sites.

Vegetation Monitoring

1. Changes in spring leaf out, flowering and senescence

The Yukon Government Territorial Park rangers have been monitoring the annual date of leaf bud burst, flowering and senescence (autumn leaf fall) for 20 individuals of three plant species on Qikiqtaruk (mountain avens or *Dryas integrifolia*, arctic willow or *Salix arctica* and tussock cottongrass or

Eriophorum vaginatum). We are currently analysing the data collected over the last 16 years (2001-2017, Fig. 2). Our findings show that:

- Arctic willow leaf buds burst earlier in spring and mountain avens flowers appear earlier.
- Snow melt seems to govern the dates of leaf emergence and flowering in both species.

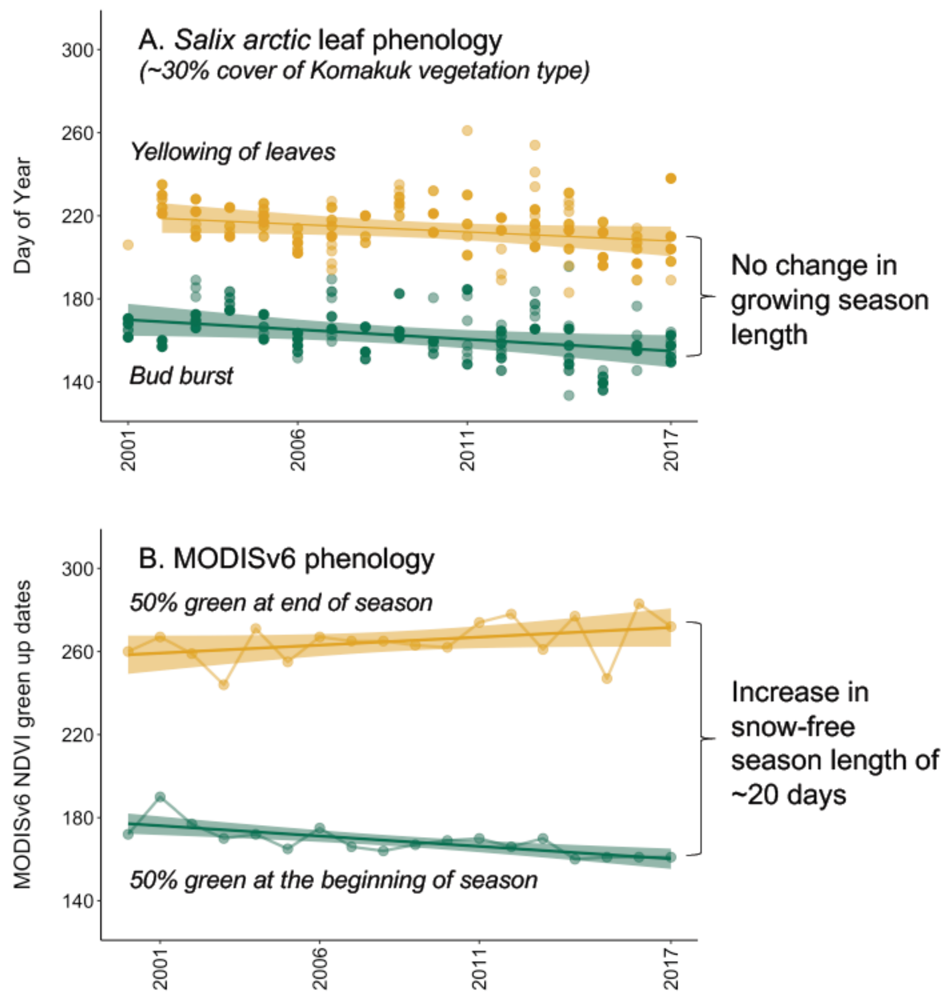

Figure 2. Plants are greening up earlier and senescing earlier and satellite data indicate a lengthening of the snow-free period. Advancement of leaf bud burst and yellowing of first leaf of arctic willow (*Salix arctica*) monitored by the Yukon Park Rangers on Qikiqtaruk (A) and the timing of green up and browning in the same region as the phenology transects as indicated by the satellite data (MODIS v6, Moderate-resolution imaging spectroradiometer) satellite greening dataset.

2. Tundra plant composition and plant height

To find out whether certain plants are becoming more abundant or are increasing in size, we're continuing measurements on the composition of two areas with distinct groups of vegetation common on Qikiqtaruk. The initial measurements were started in 1999, allowing us to investigate changes over 18 years. Combined with the most recent data that we collected in summer 2017, our analyses demonstrate that:

- Plant height is increasing across the patches of monitored tundra (Fig. 3).
- Certain plant species are becoming more abundant including *Eriophorum vaginatum* (cottongrass) and *Salix pulchra* (diamond leaf willow).

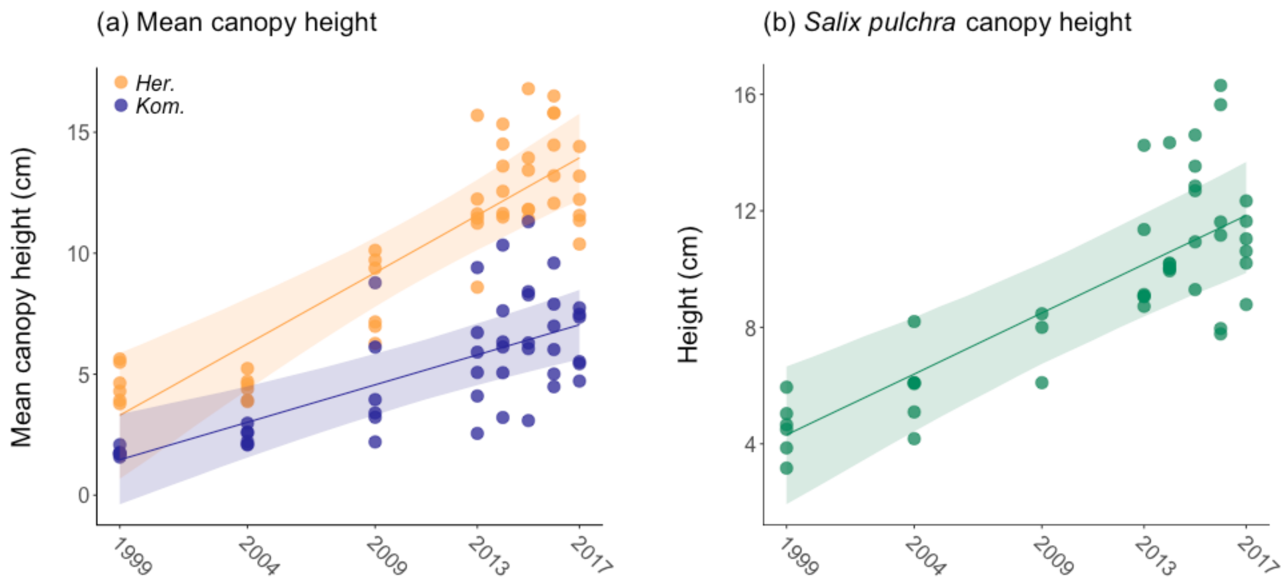

Figure 3. Plants are getting taller on Qikiqtaruk-Herschel Island. Variation in growth and climate sensitivity of growth of the entire canopy in the two vegetation types (A), for *Salix pulchra* (B).

To find out which plant species might colonize the long-term monitoring plots in the future, we surveyed the local species pool around the community composition plots in 2017 following the International Tundra Experiment species pool monitoring protocol. We identified the plant species found in 100 m radius from the plots and noted their distance from the center plot (Fig. 4).

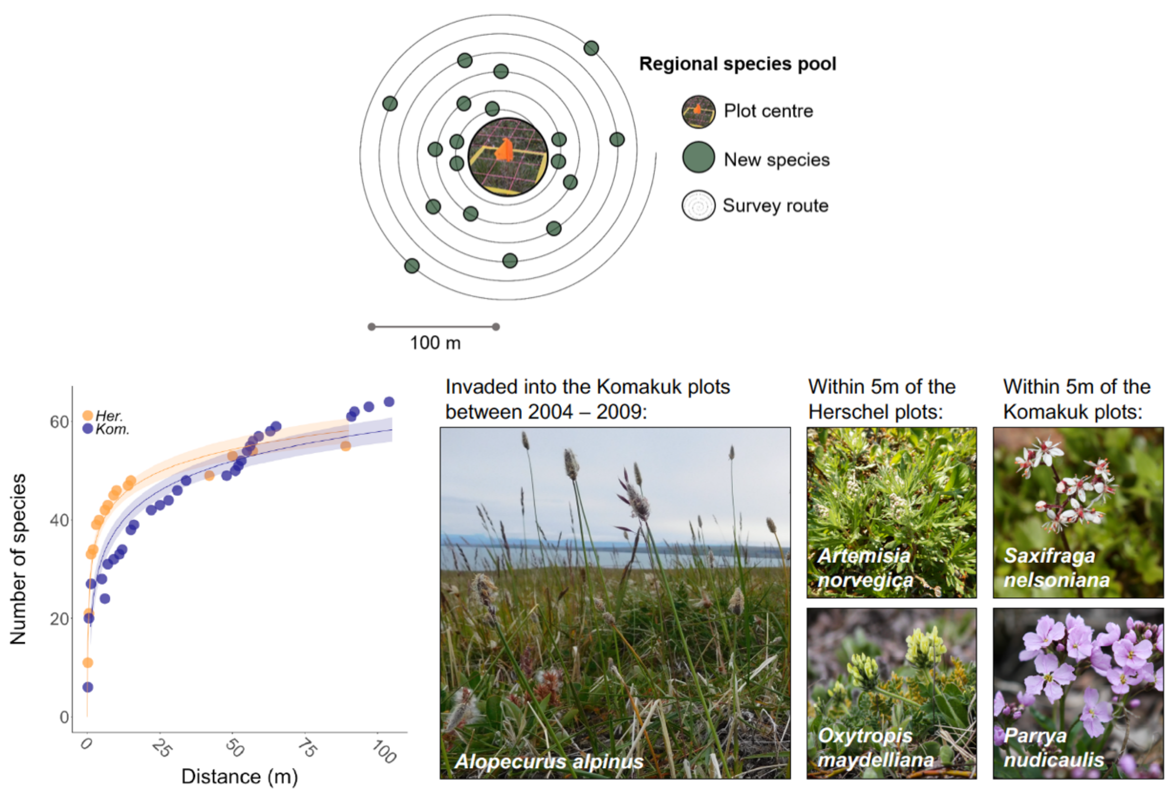

Figure 4. Plant species, currently unrecorded in the community composition plots, occur in close proximity to the plots and might invade them in the future, leading to more vegetation composition changes in the Herschel and Komakuk vegetation types. Survey methods (A) and number and identity of observed species in 2017 (B).

We tested how close new species were that could potentially occur in the monitoring plots in future, and found that:

- The number of species near the Herschel vegetation type plots was greater than those near the Komakuk vegetation type plots (Fig. 4).
- There were 13 plant species within 100 m of the Herschel vegetation type and 26 within 100 m of the Komakuk vegetation type that have not yet been observed in the long-term monitoring plots (Fig. 4).

3. Plant traits

We collected leaf, seed and stem cuttings from plants on Qikiqtaruk. These samples were used to measure plant characteristics (traits) that indicate different growth strategies and environmental responses among species. These data are being contributed to global analyses across the global tundra of how plant traits vary and are influenced by the environment.

Our analyses indicate that:
- There is very large variation within individuals and species, in some cases larger than the differences between species.
- Some traits, such as height, correlate well with environmental characteristics such as temperature, indicating strong links between how plants grow and their environment.
- Some plant communities are showing changes in their traits as the tundra warms, for example, towards taller canopies.

4. Decomposition

Decomposition is important for transferring nutrients from the plants to the ground and back into plant growth and as a factor that influences the storage of carbon in soils. To assess whether different parts of the tundra biome decompose plant material at different rates, we buried red and green tea bags at range of locations across Qikiqtaruk and at over 350 other sites around the tundra biome. This ‘Tundra Teabag Experiment’ will allow us to see if there are large differences in decomposition along environmental gradients and around the pole.

In addition, in 2015 we collected leaves, flowers and stems from common plants on Qikiqtaruk. These were buried in a warming common environment for one year in the Kluane Region to investigate differences how quickly different species decompose. The results of this experiment are telling us how the change in plant communities will increase or decrease decomposition rate overall.

Initial results indicate that:
- Despite changing vegetation, the rate that below-ground decomposer communities break down plant litter has likely remained relatively stable over the last 25 years.
- Decomposition is different between sites, but this difference is small compared to the differences between different plant litters.
- Moisture is just as important as temperature in explaining tundra decomposition rates.

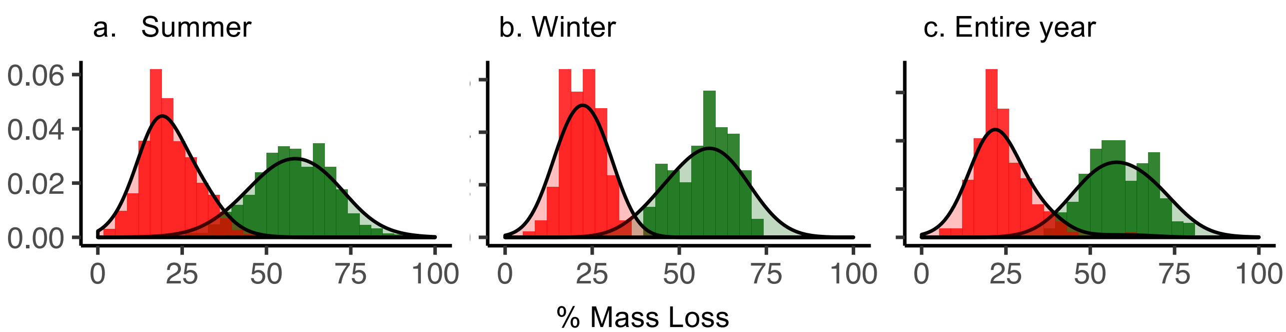

Figure 5. Our results indicate that tea decomposes faster at warmer and wetter sites and that more deciduous plant leaves decompose faster than more tough plant leaves and wood across sites and that this difference is maintained across different experiment lengths including just the summer, just the winter or the entire year.

5. Mapping landscape vegetation with drones

Much of our understanding of changes in tundra vegetation across regions and around the pole comes from satellite data. However, the satellite images are coarse compared to our fine-scale observations on the ground. Our areal imagery obtained with drones in 2015 and 2017 tracks vegetation greenness over the growing season (spring green-up to fall senescence, Fig. 5).

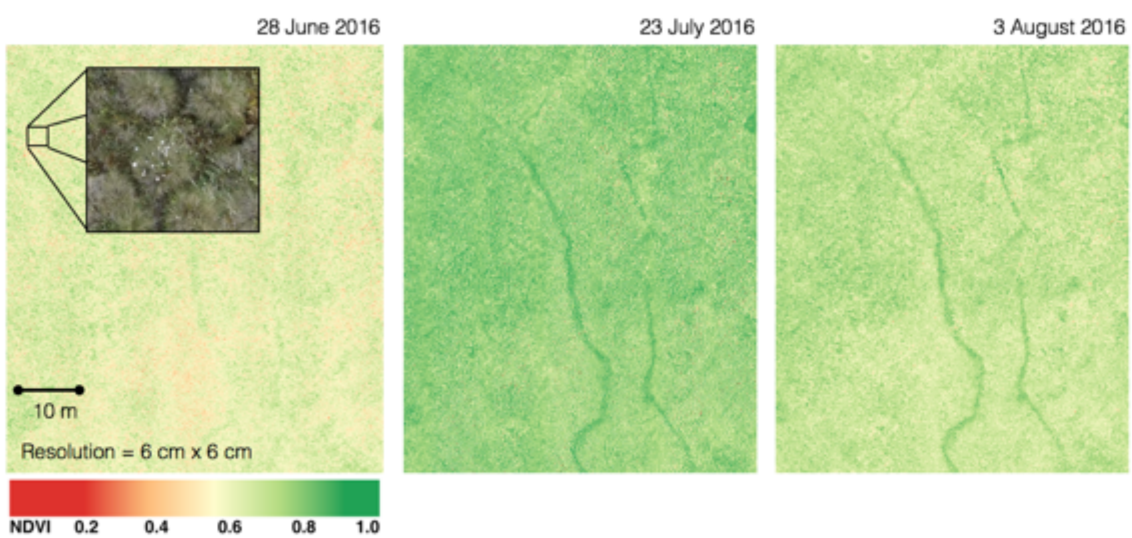

Figure 5. Imagery of vegetation on Qikiqtaruk – Herschel Island and NDVI imagery of the "greenness" of the tundra. Areas that are very green and have lots of plant biomass are indicated as green in this figure and areas that have no plants – bare ground are indicated as red.

Initial results indicate that:

- Drone data capture the same seasonal trends as records from plots on the ground and from satellites, but they better capture the landscape level variability, including the parts of the landscape that change earlier versus later or contain more or less biomass.

6. Competition and climate sensitivity of shrubs on Qikiqtaruk

Rates of shrub expansion vary from site to site and among species across the tundra[8], because non-climatic factors also control vegetation dynamics. One factor that could mitigate the climate response of shrubs is competition for resources such as water and nutrients. This is supported by studies at the treeline, but had previously never been tested further north in the tundra. As vegetation gets taller and denser on Qikiqtaruk, it is possible that stronger competition for resources could have a dampening effect on shrub expansion in the future.

We tested whether competition alters the climate sensitivity and the expansion potential of four shrub communities in the Canadian Arctic, including Qikiqtaruk. We mapped all shrubs within 10 m by 10 m plots, then harvested the base of every shrub to measure annual growth rings in the woody root collar (Fig. 6).

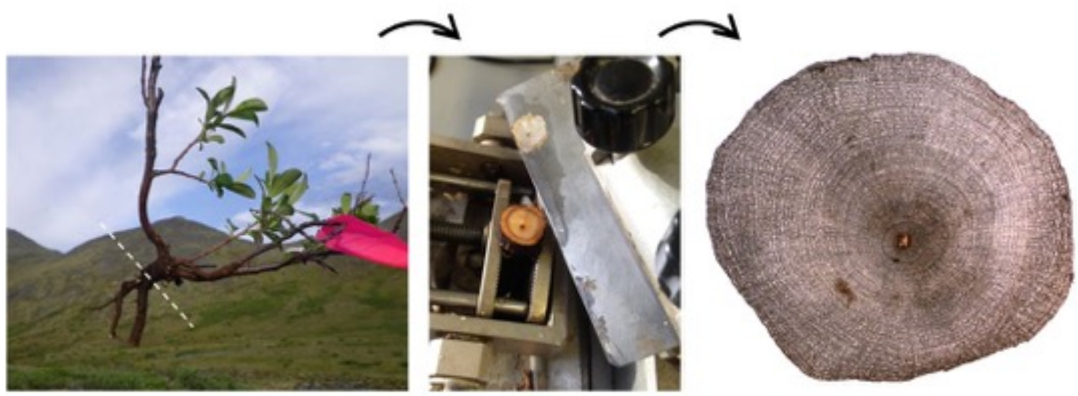

Figure 6. Preparation of samples for growth-ring analyses, from sampling (left) to preparation of thin sections (center) that can be photographed under the microscope (right). Growth rings can then be measured on the computer.

Initial results indicate that:

- By linking annual growth to annual mean summer temperatures, we found that shrub growth is promoted by warm temperatures, although many shrubs only show weakly positive climate-growth relationships (Fig. 7a).

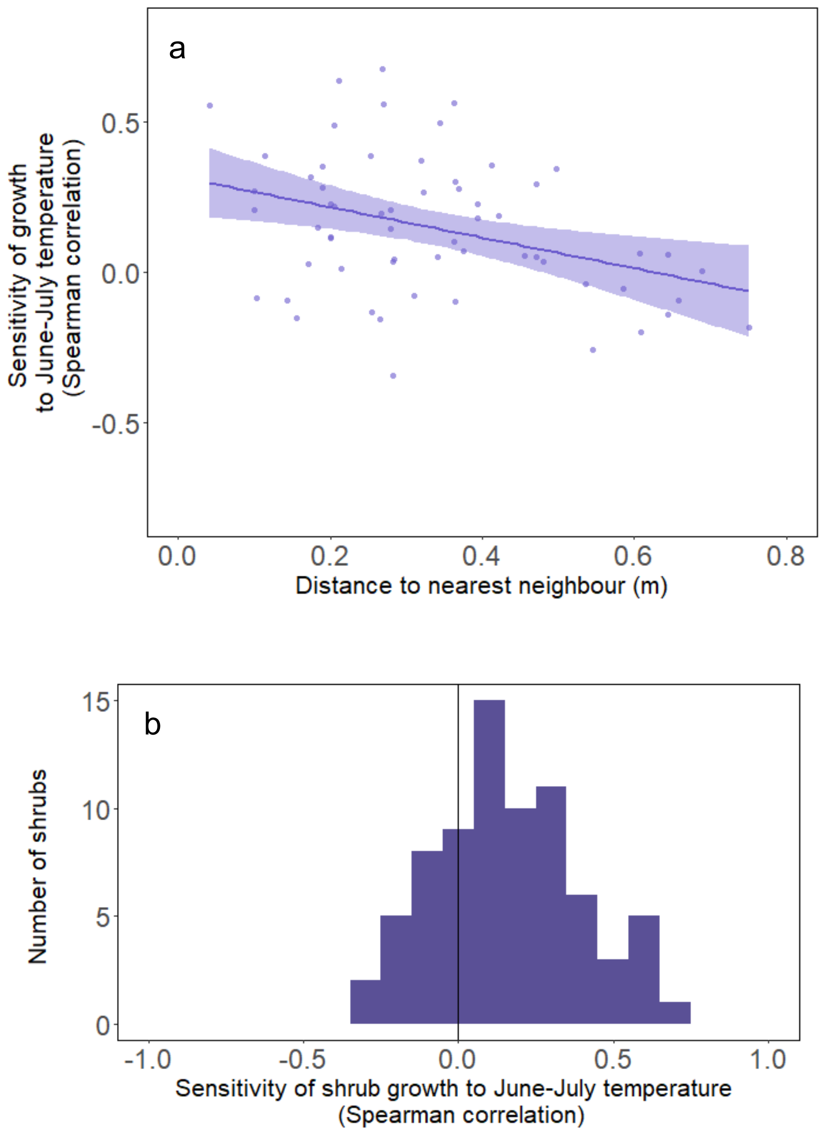

Figure 7. Annual growth of willow shrubs on Qikiqtaruk is positively associated with warmer summer temperatures for the period, with the majority of shrubs sampled showing weak positive correlations (a). Shrubs with closer neighbours tend to better track summer temperature in their annual growth (b).

For each shrub in our study plots, we calculated the distance to the nearest neighbour as an indicator of the intensity of competition. We then tested our hypothesis that the climate sensitivity of shrubs was negatively affected by the proximity of competitors. Contrarily to our expectations, we found a slight trend of higher climate sensitivity for shrubs with closer neighbours (Fig. 7b). Because resources are often patchily distributed in the landscape, this could be indicative of shrubs clustering in spots where nutrients are more locally abundant, which would in turn improve their ability to respond to climate fluctuations. We could not find evidence that competition exerts a strong control on shrub, suggesting that shrubs are likely to continue expanding on Qikiqtaruk in the near future.

7. Carbon stored in tussock tundra

The arctic landscape is projected to change from a tussock- to a shrub-dominated tundra with ongoing climate warming. The carbon stored in the tussock landscape is presently poorly quantified and the fate of these carbon stores, in the event of tussock loss, is largely unknown. Tussocks change their soil microenvironment and a vegetation community shift may have indirect effects on the soil carbon stocks as well.

As a part of the Carbon in Arctic Tussock Tundra (CATT) Network, lead by Adrian Rocha, Notre Dame University, Team Shrub carried out the CATT protocol to help quantify arctic tussock carbon stores. Dissertation student Sam Kellerhals calculated the carbon stored across the landscape on Qikiqtaruk using drone imagery.

Initial results indicate that:

- The tussock tundra vegetation type stores approximately double the carbon than the grass and flowering plant dominated vegetation type.
- That above-ground carbon storage in plants may have as much as tripled on Qikiqtaruk in the past 18 years.

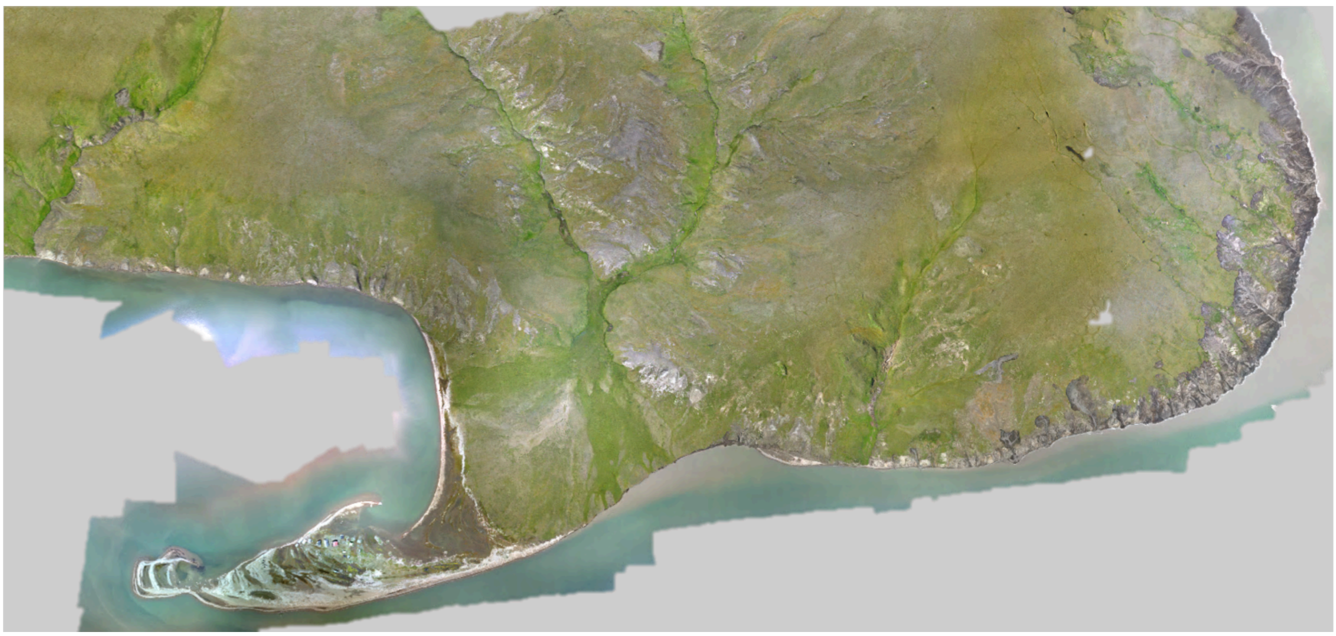

Figure 9. Drone imagery has been collected over the past three years on Qikiqtaruk to quantify vegetation across the landscape, to monitor disturbances such as permafrost thaw slumps and coastal erosion and to estimate above-ground carbon storage.

9. Coastal erosion and permafrost thaw

In 2017 using drone imagery, we observed approximately 15 m of coastal erosion on a 500 m coastal reach between Kuvluraq - Simpson Point and Nuvuruaq - Collinson Head. This rapid rate of coastal erosion was surprising to the Park Rangers and researchers and was covered by media (http://www.cbc.ca/news/canada/north/yukon-herschel-island-erosion-1.4253948). Our drone imagery is also being used to quantify rates of permafrost thaw in retrogressive thaw slumps on Qikiqtaruk.

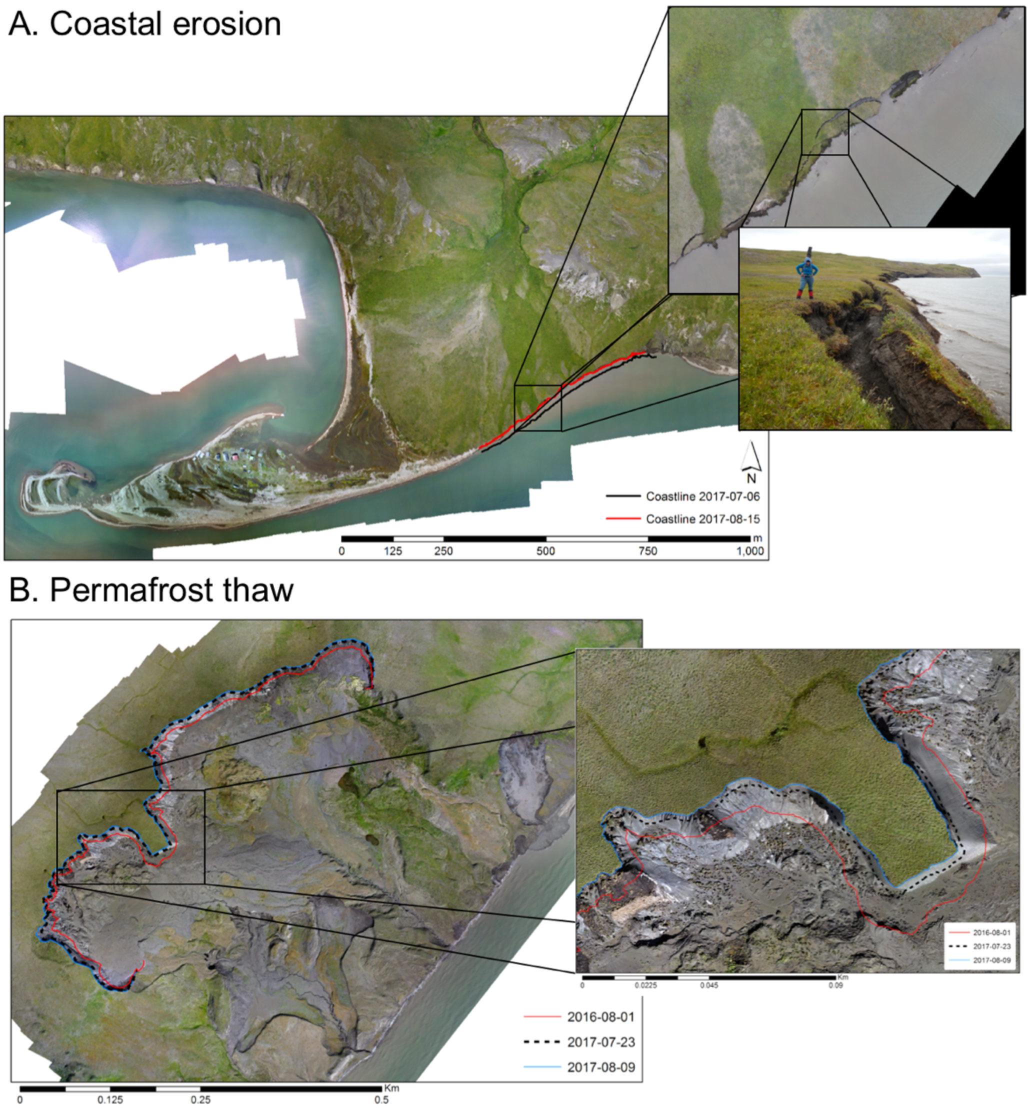

Figure 10. Changes in coastal erosion and permafrost thaw are being quantified using the drone imagery collected in 2016 and 2017.

8. Herbivory monitoring

One of the reasons that plants such as shrub species could be increasing in tundra ecosystems might be a reduction in the number of animals feeding on those plants over time. Large mammal populations of caribou and muskox have been relatively stable on Qikiqtaruk over the past 18 years, apart from the decline to three male muskox in recent years residing on the island in the summer (*Pers. Comm.* Herschel Island – Qikiqtaruk Territorial Park Rangers, Cameron Eckert). We do not know the exact impact of herbivores in the area where the long-term ecological monitoring occurs on the island over time.

In order to assess the role of herbivory, animals eating plants at these sites, we surveyed for animal signs such as feces, nests, wool (qiviat), and leaf damage from animals such as caribou, muskox, lemmings, ptarmigan and insects. We have been conducting these protocols over the past couple of years to contribute to assessments of herbivore densities and impacts on plant communities around the tundra biome coordinated by the Herbivory Network (http://herbivory.biology.ualberta.ca/).

Additional information:

Team Shrub at the University of Edinburgh https://teamshrub.com

The High Latitude Drone Ecology Network https://arcticdrones.com

The Tundra Tea Bag Experiment https://tundratea.wordpress.com/

The Global Tea Bag Index www.decolab.org/tbi

International Tundra Experiment http://ibis.geog.ubc.ca/itex/, https://www.gvsu.edu/itex/

Herbivory Network http://herbivory.biology.ualberta.ca/

Carbon in Arctic Tussock Tundra (CATT) Network
https://www3.nd.edu/~rochalab/wordpress/?page_id=509

References:

1. IPCC. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. (2014).
2. Susan Joy Hassol. *Impacts of a Warming Arctic*. (Arctic Climate Impact Assessment (ACIA), 2004).
3. Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G. & Nemani, R. R. Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature* **386,** 698–702 (1997).
4. Guay, K. C. *et al.* Vegetation productivity patterns at high northern latitudes: a multi-sensor satellite data assessment. *Glob Change Biol* **20,** 3147–3158 (2014).
5. Myers-Smith, I. H. *et al.* Shrub expansion in tundra ecosystems: dynamics, impacts and research priorities. *Environ. Res. Lett.* **6,** 045509 (2011).
6. Tape, K. D., Strum & Racine, C. H. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. Glob. Change Biol. 12, 686–702 (2006). *Global Change Biology* **12,** 686–702 (2006).
7. Pearson, R. G. *et al.* Shifts in Arctic vegetation and associated feedbacks under climate change. *Nature Clim. Change* **3,** 673–677 (2013).
8. Myers-Smith, I. H. *et al.* Climate sensitivity of shrub growth across the tundra biome. *Nature Clim. Change* **5,** 887–891 (2015).