UNDERSTANDING CLIMATE CHANGE-DRIVEN VEGETATION SHIFTS THROUGH A COMMON GARDEN EXPERIMENT IN THE YUKON TERRITORY

A Canadian field season: my experience, reflections, and preliminary project results.

Figure 1. The common garden experiment from above, and Kluane Lake in the background (photo credit: Iain Myers-Smith).

The Arctic is warming up to four times faster than the rest of the planet[1,2], driving vegetation change[3] and reshaping wildlife habitats[4,5]. As a response to climate warming, shrubs have been expanding within Arctic and alpine (high altitude sites) regions – a phenomenon colloquially known as “shrubification”[6,7,8]. Studying how different vegetation functional types are responding to such rapid temperature increases is critical for the management and conservation of northern ecosystems. Moreover, understanding the implications of climate-change-driven shrub encroachment is needed to predict future vegetation shifts and their implications for wildlife and human livelihoods.

This summer, I was lucky enough to be given the opportunity to fieldwork in the Yukon Territory (Canada) under the supervision of Prof. Isla Myers-Smith from the University of Edinburgh. Isla Myers-Smith is the lead of a research lab called Team Shrub, whose goal is to understand the drivers of shrub expansion and the consequences of this vegetation change for ecosystem functioning. As Team Shrub's research assistant, my job was to help the PhD students with their projects' data collection. The PhD students in the lab are studying a variety of topics including above and below ground plant phenology, functional diversity across elevational gradients and drivers of greening captured through satellite data.

I was delighted to be part of the field team. It was also my very first time travelling outside of Europe and seeing such incredible landscapes, colossal mountain peaks and vast lakes on Northern Canada. It was amazing to finally see the plants and landscapes that I had read about for my undergraduate dissertation project focused on Arctic vegetation dynamics. In the field, I was given the opportunity to carry out my own independent research project and collect my own data. My project was based in a common garden experiment (see Figure 1), set up by my supervisor in 2013 by Kluane Lake (see Figure 2), which was my home for the whole summer.

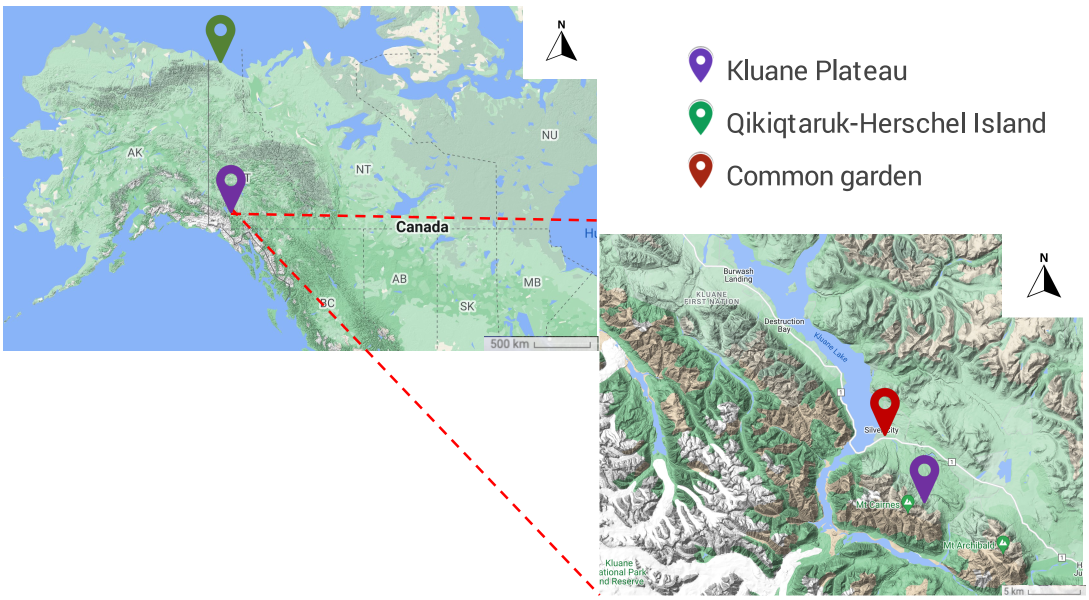

Figure 2. On the left: map of study sites in the Yukon Territory, Canada: Kluane Plateau (purple pin) and Qikiqtaruk-Herschel Island (green pin). On the right: zoomed-in map showing Kluane Plateau (purple pin) and Common Garden site (red pin). Maps made using Google My Maps 2022.

The common garden experiment

Common garden experiments are plantings of species collected from different geographical sites (Figure 2) and grown together under shared conditions[9]. In Kluane, the goal of the common garden experiment is to test for genetic differentiation in growth form of tundra willows (*Salix spp.)* across climate and latitudinal gradients. The underlying research question that the common garden is trying to answer is one about adaptation: Are tundra shrubs genetically adapted to their local environment - thus limiting future vegetation change as shrubs expand their ranges northward - or do environmental factors drive the 'plasticity' in shrub growth? In other words, the common garden experiment is designed to better understand the balance between genetic and environmental drivers of tundra shrubification.

In particular, the purpose of the experiment is to assess the growth of three different widespread tundra willow species (Richard's willow - *Salix richardsonii* (Hook.); Diamond Leaf willow - *Salix pulchra* (Cham.) and Arctic willow - *Salix arctica* (Pall.); see Figure 3) from Arctic and alpine source populations, under warmer temperature conditions. From 2013 - 2017, Arctic shrubs from Qikiqtaruk-Herschel Island (70°N) and alpine shrubs from the Kluane Plateau (61°N) – referred to as source populations - were transplanted into the warmer, common environment of the garden within the boreal forest (see Figure 2). The boreal forest site, where the common garden is located, has an average summer temperature of 14°C, which is approximately 3-5°C warmer than the source population sites with summer temperatures ranging from 0°C to 12°C (see Figure 4).

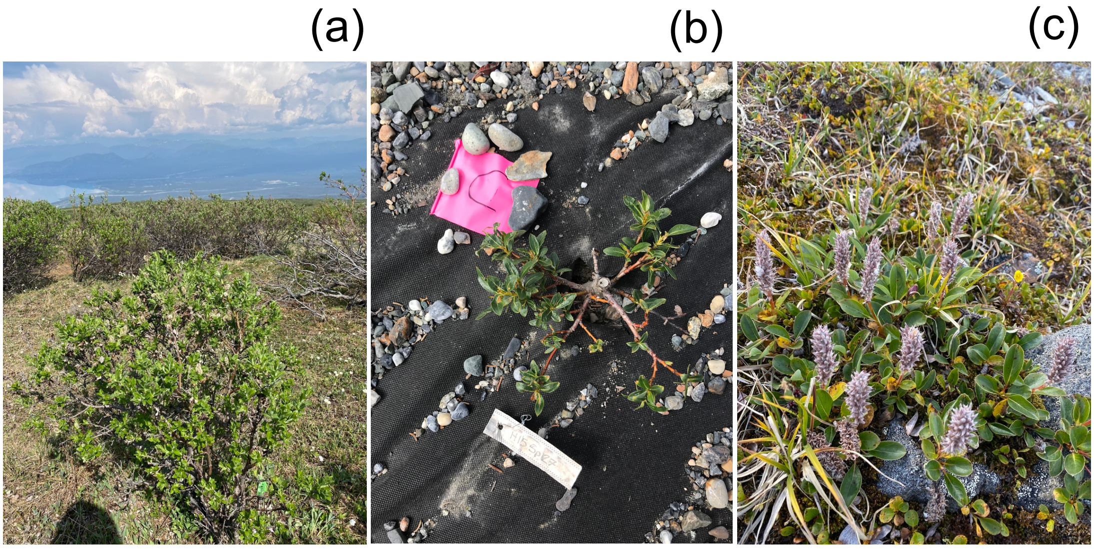

Figure 3. (a) *Salix richardsonii* on the Kluane Plateau (photo credit: Jiri Subrt, 2022), (b) *Salix pulchra* in the common garden (photo credit: Erica Zaja, 2022), (c) *Salix arctica* on the Kluane Plateau (photo credit: Jiri Subrt, 2022).

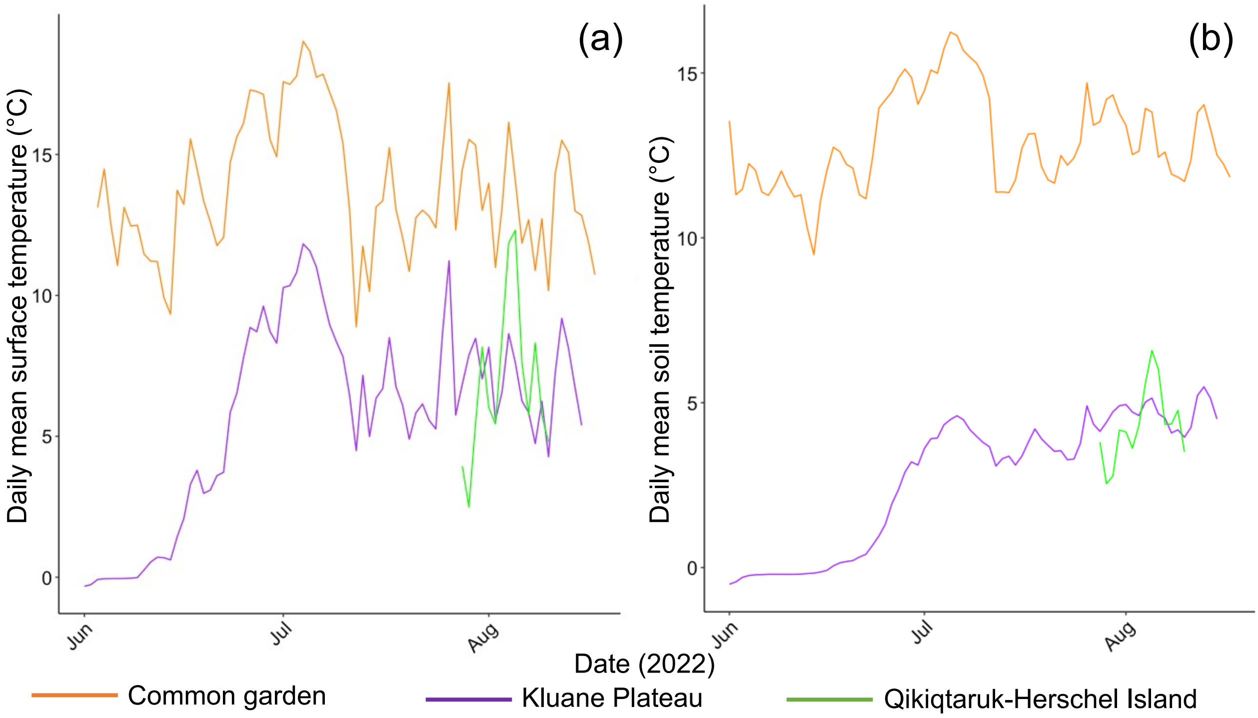

Figure 4. Daily mean surface (a) and soil (b) temperature (°C) for the three sites over the 2022 summer season (June-July-August) showing differences in temperatures. Common garden in orange, Kluane Plateau in purple and Qikiqtaruk-Herschel Island in green. Data from TOMST loggers that I installed and collected from the end of the summer 2022 field season.

Project aims and data collection

The common garden experiment has been ongoing since 2013, with shrub growth and phenology monitoring happening every summer season for nine years as of this summer. My project's aim was to continue the long-term monitoring of the common garden and to collect data from shrubs in alpine and Arctic source populations to compare to growth in the garden. Comparing the growth of shrubs in the common garden with the growth of shrubs in their respective source populations enables us to understand how the different shrub species respond when moved to a warmer environment. This comparison is allowing us to infer whether shrubs are showing strong genetic differentiation or whether they are responding to the local environmental conditions, with important implications for future climate-driven vegetation change.

Over the summer, I went to the common garden on a weekly basis and collected growth measurements including canopy height (cm), shrub width (cm), leaf length (mm) and stem elongation (mm). I also recorded shrub phenology – timing of lifecycle events including timing of green up, yellowing of leaves, leaf shed, and full senescence. To sample the growth of shrubs from the alpine source population I hiked up the steep trail of the Kluane Plateau (Figure 2) and tagged individuals of the three target *Salix* species, collecting growth measurements on a weekly basis as well. The round trip on the mountain was ~13km, and a 1000m elevation gain – which on a weekly basis (and 16 times in total over summer) was a great fitness workout! Finally, to sample the growth and monitor phenology of shrubs from the Arctic source population I designed a protocol for the other half of Team Shrub to follow to collect data on Qikiqtaruk-Herschel Island. At the end of the summer, I also downloaded the phenology pictures taken by time-lapse cameras over winter and summer 2022, and the environmental data (soil moisture and soil, air and surface temperature) recorded by TOMST loggers (Figure 5).

Figure 5. Me downloading data from a TOMST logger on the Kluane Plateau. Picture by Calum Hoad.

Preliminary results

Now, I am back in Edinburgh and I am working on data wrangling, data analysis and writing of my main findings. I have been adding the data that I collected this summer to the long-term nine-year monitoring dataset of the common garden. So far, through these analyses we have found that:

- Growth traits including canopy height, leaf length, and annual stem elongation show strong plastic responses to warming for the tall willows (*Salix pulchra* and *Salix richardsonii*) but not for dwarf willow *Salix arctica* (Figure 6).
- Willows from Kluane (southern population) show greater trait changes (canopy height change, leaf length and stem elongation increase) than willows from Qikiqtaruk (northern population) under warmer conditions (Figure 6).

When comparing data from the common garden with source population data, we find that:

- Shrubs at source populations are taller and have larger leaves than *Salix pulchra* and *Salix richardsonii* – but not *Salix arctica* - in the common garden (Figure 7).

- There is no difference between stem elongation values in the common garden and in source populations for any of the target shrub species (Figure 7).

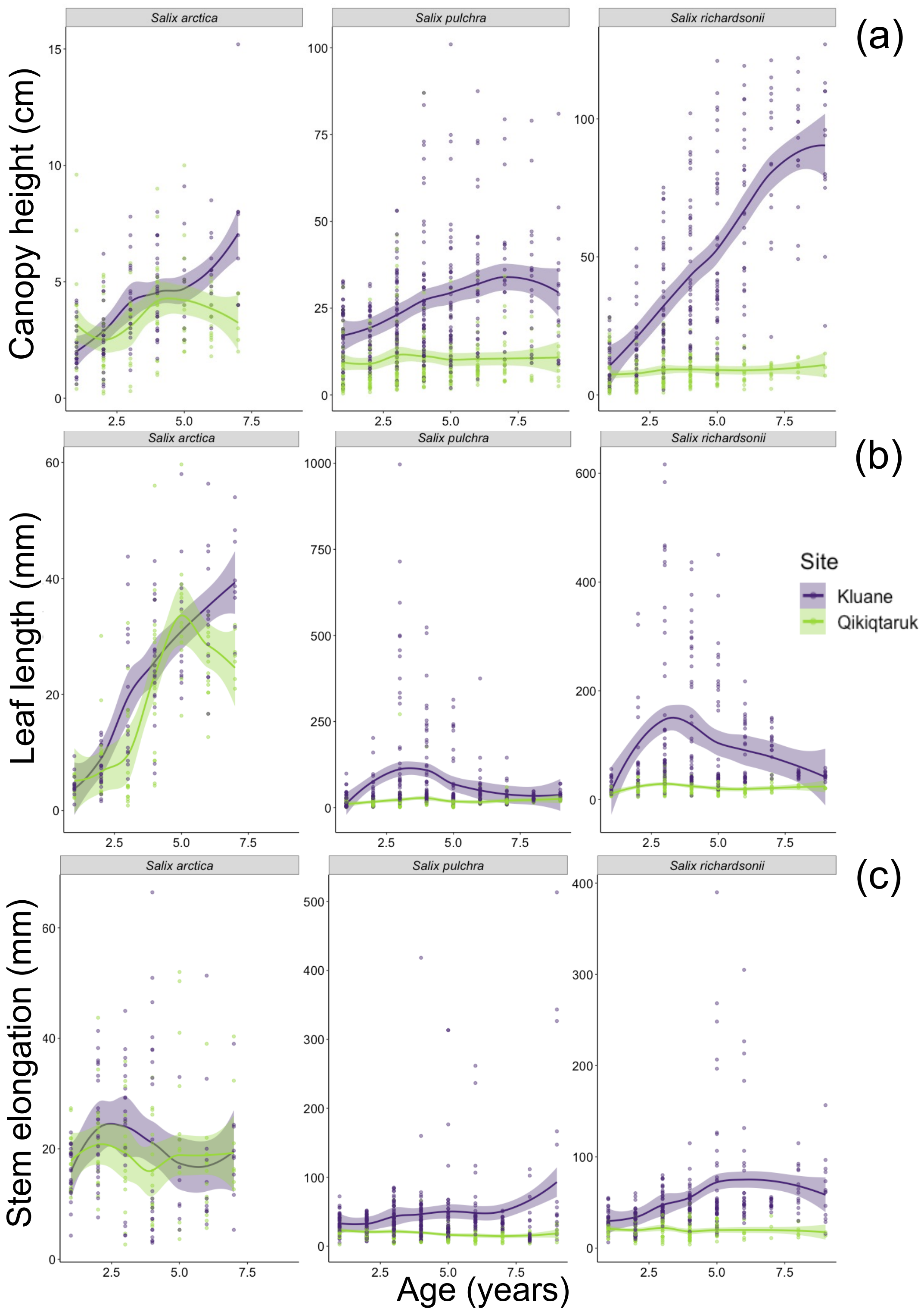

Figure 6. Canopy height (a), leaf length (b) and annual stem elongation (c) differ between alpine (purple) and Arctic (green) shrubs in the common garden over nine years. Lines are generalised linear mixed models and 95% confidence intervals. Colours indicate different shrub source populations: purple for Kluane and green for Qikiqtaruk (Sample size = 260 individuals).

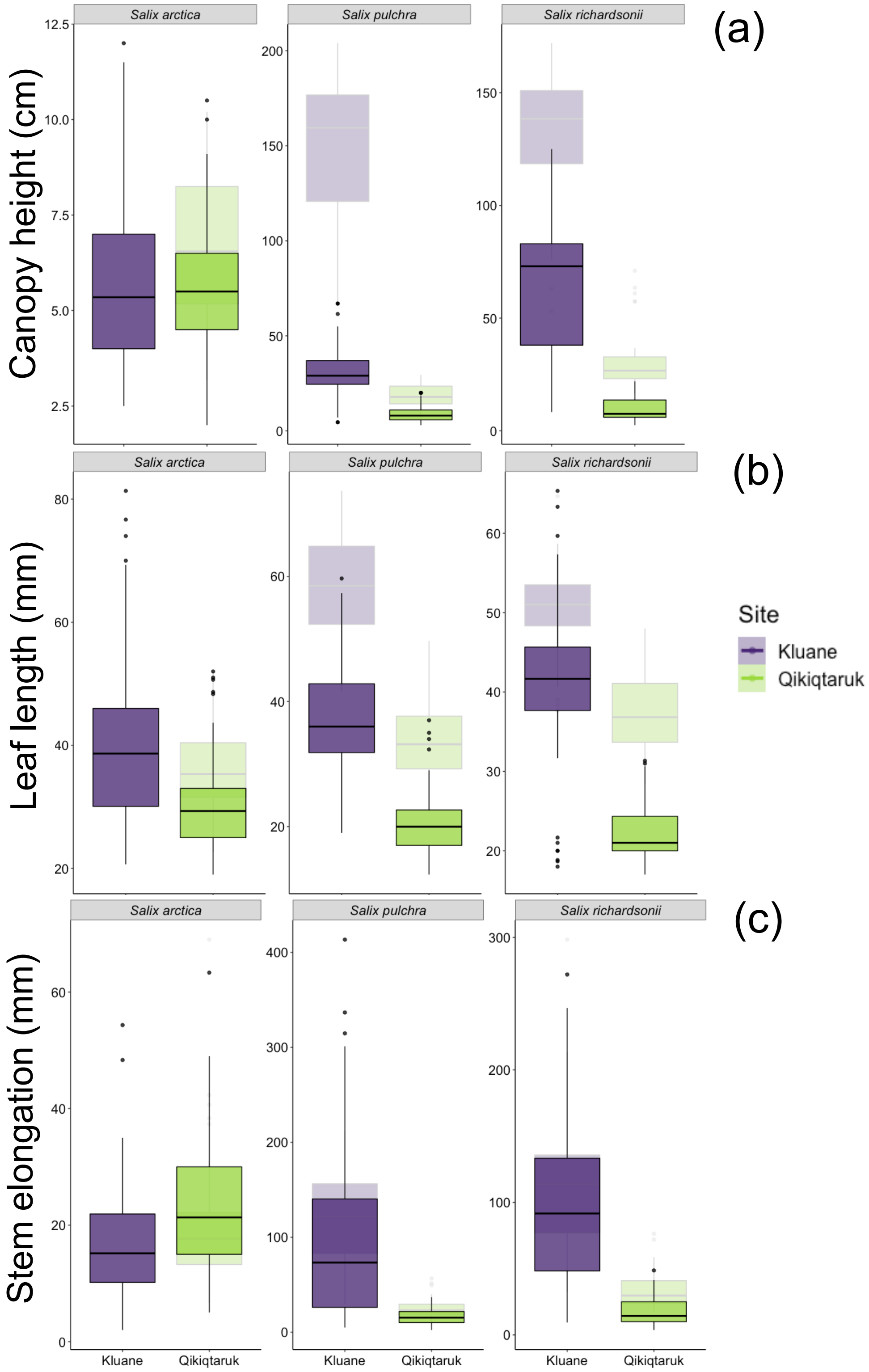

Figure 7. Differences in canopy height (a), leaf length (b), stem elongation (c) between alpine (purple) and Arctic (green) shrubs in the common garden, compared to data from source populations. Kluane source population in faded purple and Qikiqtaruk source population in faded green. Boxplot showing mean values from data I collected over summer 2022 (Sample size = 127 individuals).

Implications of my findings

Overall, preliminary findings indicate that tundra shrubs grow rapidly under warmer conditions, but alpine shrubs (southern population) respond at a faster pace than Arctic shrubs (northern population). These findings suggest that there might be strong genetic differences between populations that constrain trait changes as response to warming, although willows do demonstrate high plasticity potential to warmer growing conditions. In summary, these preliminary results suggest that local adaptation may constrain tundra shrub growth responses to future warming, especially at northern sites, and that we should expect rapid - but not uniform - shrub encroachment with future warming across the tundra.

Next steps

- Explore maternal effects to understand differences in canopy heights. Do taller parent shrubs (shrubs from source populations from which cuttings were taken and transplanted to the common garden) produce taller offspring in the common garden?
- Process phenocam pictures and compare timing of different phenophases between common garden and source populations. Do northern willows senesce earlier than southern willows, being adapted to a shorter growing season?
- Explore environmental drivers of shrub growth and phenology. Do warmer temperatures and wetter conditions favour shrub growth and alter the timing of phenophases?

What this field season has taught me

This summer has taught me really important scientific skills and lessons that I will benefit from throughout my career. Meeting First Nations Peoples and communities and learning about their lands, plants, wildlife, and culture was the highlight of my summer. I learnt how to identify many of the native plant species of the region, I practiced field sampling techniques and I met interesting researchers working on a variety of different topics from glaciology to pika habitat conservation. Having the opportunity to spend so long in a place so far from my own home and experience is something I will always be grateful for. The three most important things this field season has made me value more are: living in close contact with nature, the beauty of tundra plants and boreal forests, and my luck as an early career ecologist to be able to travel to such amazing places.

Acknowledgements

Thank you to the Kluane First Nation, Champagne and Aishihik First Nations for allowing us to work on their lands. Thank you to all the people that worked so hard over the years to set up and maintain the common garden experiment, including Gergana Daskalova and Mariana García Criado. Thank you to this summer's field team (Calum Hoad, Diana Jerome, Joseph Everest and Jiri Subrt) for helping me collect the data in the common garden and on the Kluane Plateau. Thank you to this summer's Arctic team (Elise Gallois, Madelaine Anderson, Clara Surprenant, Zabrina Leslie) for collecting data on Qikiqtaruk.

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