Consequences of Shrub Expansion in the Boreal Forest: Quantifying Alder's Seasonal Ecophysiological Dynamics

Samuel Dempster[1], Jessica Young-Robertson[1]

[1]Institute of Agriculture, Natural Resources & Extension, University of Alaska Fairbanks

ABSTRACT Shrub expansion has been occurring in northern latitudes, but the consequences of this change for larger scale processes such as permafrost stability, hydrology, and ecosystem production have been understudied in the boreal forest. Boreal shrub ecophysiological dynamics (such as water use and carbon flux of alder) are not well quantified and, therefore, limits our understanding of how shrub expansion will impact larger scale processes. This proposed research is a continuation of my URSA Spring 2022 project. The specific goals are: (1) quantify spring and summer alder water use, (2) determine the water sources that alder use, and (3) quantify summer carbon and water flux, water stress, water content, water use efficiency (WUE), and growth. I have been conducting measurements of water and carbon-related ecophysiological processes one to two times a week from spring to fall. To continue working toward these goals for the Fall 2022 URSA project, I have broadened the project's scope to include objective (4) quantify alder nitrogen use dynamics. Thus, this study has a suite of stable isotope analyses (dD, d18O, d15N, d13C) that will be compared to the ecophysiological data. I will also statistically analyze the data.

Introduction

- Shrub expansion has been occurring in northern latitudes
  - Alder (*Alnus* spp) is one of the shrub species expanding in range and is a nitrogen fixer
  - Often in areas that are experiencing disturbance, such as permafrost thaw. Thaw affects ecosystem processes, like water cycling, productivity, and ecosystem-climate energy balance
  - Research focuses on arctic regions; the boreal forest remains understudied
- Boreal shrub ecophysiological dynamics (water use and carbon flux) not well quantified
  - Deciduous vegetation can impact ecosystem processes through high rates of ecophysiological activity (water use, carbon flux, nitrogen use) and high growth rates
  - **Knowledge gap** in our understanding of the consequences of shrub expansion: seasonal ecophysiological dynamics of water, carbon, and nitrogen use of shrubs and the interaction with environmental variability.
    - Limits our understanding of how shrub expansion will impact larger scale processes, including feedbacks to climate and permafrost stability, in the boreal north.
- **Objectives**:
  - (1) Understand the impacts of shrub expansion on boreal forests by quantifying the seasonal dynamics of alder shrub water use and carbon gain, including the use of snowmelt water in the spring, utilization of summer rain events, and potential for shrubs to dry the soil over the summer via transpiration.
  - (2) Understand the relationship between physiological processes and environmental variability to eventually develop a predictive framework for shrub physiological function.
- Data collection over the growing season focused on: stem and leaf water content, use of different water sources over time (*not presented in this poster*), water and carbon flux dynamics, water stress, the impact of environmental drivers (air temperature, relative humidity, photosynthetically active radiation, precipitation, soil moisture/temperature). Data collection in the spring prior to leaf out focused on stem water content.
- This research was funded by two Undergraduate Research & Scholarly Activity (URSA) awards.
- Study site - University of Alaska Fairbanks (UAF) campus forest in a permafrost-free area.
- Specific objectives and hypotheses:

(1) Quantify alder water use in the spring throughout the growing season into autumn.
  - **Hypothesis**: Stem water content will increase with snowmelt and decline after budburst due to transpiration.

(2) Quantify photosynthesis, transpiration, water stress, leaf water content, growth, water use efficiency (WUE).
  - **Hypothesis**: Photosynthesis and transpiration will increase as the leaves develop. Water stress will be low at budburst due to wet soils but will increase as the soil dries. Stems will start elongating in the early summer. WUE will be higher under drier/hotter conditions.
- Note that this study occurred over one of the drier, hotter summers in Interior Alaska



Methods

- Installed a meteorological station at field site prior to spring breakup
  - Installed sensors that measure air temperature, relative humidity, precipitation, and photosynthetically active radiation when most of the snow had melted in mid-May
  - Soil moisture (0-12cm depth) and temperature (6cm depth) sensors installed when soil thaw permitted in late-June.
- Conducted measurements of water and carbon-related ecophysiological processes one to two times a week from spring to fall.
  - Since February 2022, measured weekly:
    - stem water contents including extracting water from stems.
  - Conducted the following weekly measurements beginning when leaves were large enough:
    - *Objective 1:* 5 replicates of leaf and stem water content, leaf area and stem volume on collected samples (standard protocol for gravimetric and volumetric water content).
    - *Objective 2:* midday photosynthesis, transpiration, stomatal conductance, WUE (CIRAS 3, PP Systems); water potential (midday and predawn); stem growth on 10 plants; specific leaf area (SLA) on 10 leaves
- Analyzed the data using multiple regressions (JMP) to evaluate the relationships between environmental parameters, ecophysiological processes.

Acknowledgements: I would like to thank Jessica Young-Robertson for her mentorship and guidance throughout my research project. Thank you to Matt Robertson for consultation of hardware and installation of field equipment, and the Forest Soils Lab for their continued support throughout my project. I thank my funding sources: travel grant from NSF EPSCoR Fire and Ice program at UAF, URSA for awarding me two semesters of funding and the URSA travel award, and USDA NIFA grant # ALK-23-04.

Results - *Environmental Data*

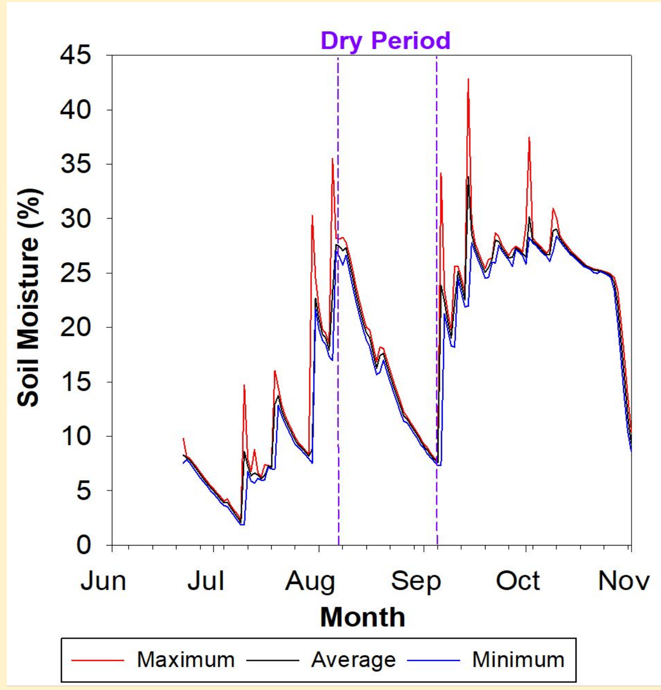

Figure 1. Soil Moisture. The summer was warm and hot compared to prior years, resulting in low soil moisture conditions (2-15%) until early August. Soil moisture increased in early August and then dried down considerably until early September ("dry period" - 8/6/2022 - 9/4/2022).

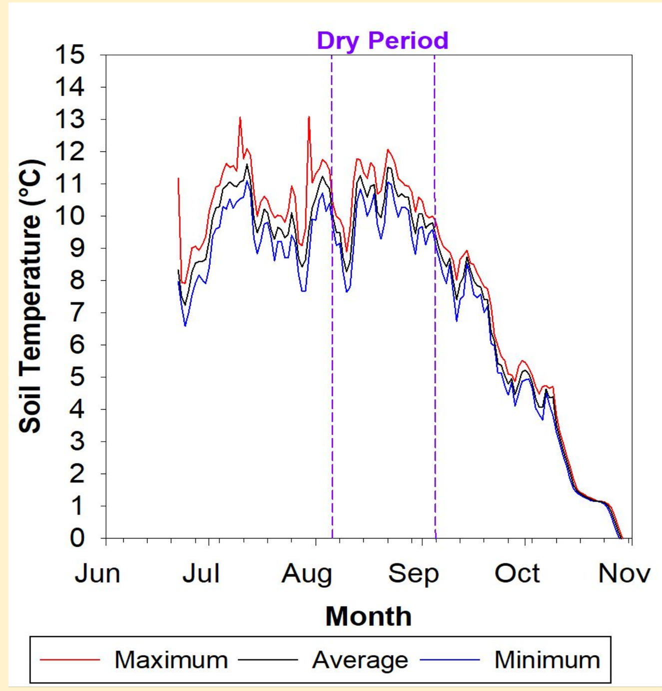

Figure 2. Soil Temperature. Soil temperatures ranged from 6.5 to 13°C over growing season. Soil temperature decreased in the beginning of the dry period most likely from the large rain events and subsequent evaporation as the soils initial dried until they became dry enough to maintain a consistent temperature.

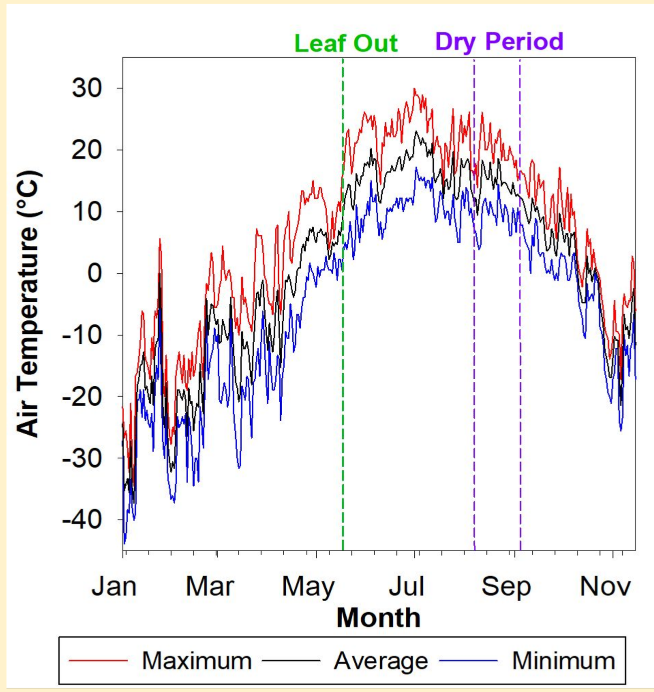

Figure 3. Air Temperature from January to early November. Growing season air temperature ranged from 5 to 25°C. Elevated air temperatures and reduced humidity (not shown) from Leaf Out through Dry Period contributed to higher VPD (Fig. 5).

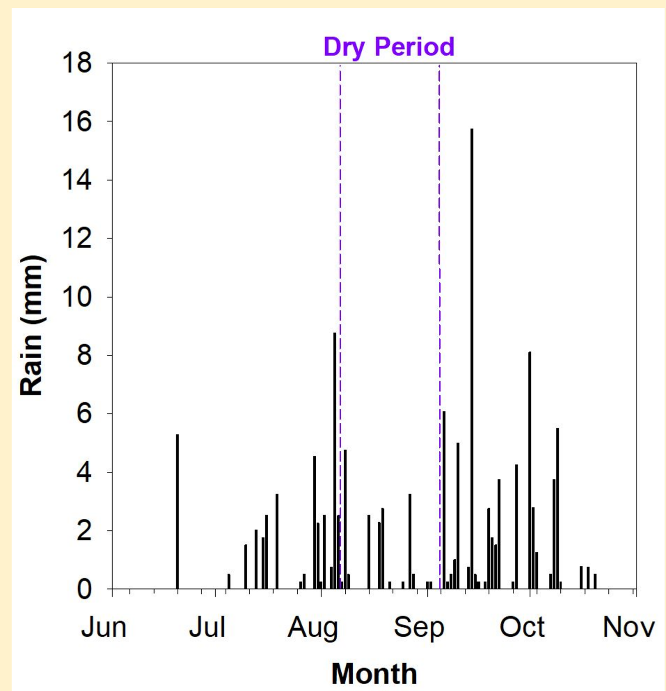

Figure 4. Precipitation events (rain) from late-June through early-November. Dry period marked by lower overall amount of rainfall resulting in decreased soil moisture and increased VPD. Significant amounts of precipitation occurred late in the growing season (early-September through early-October) compared to the beginning.

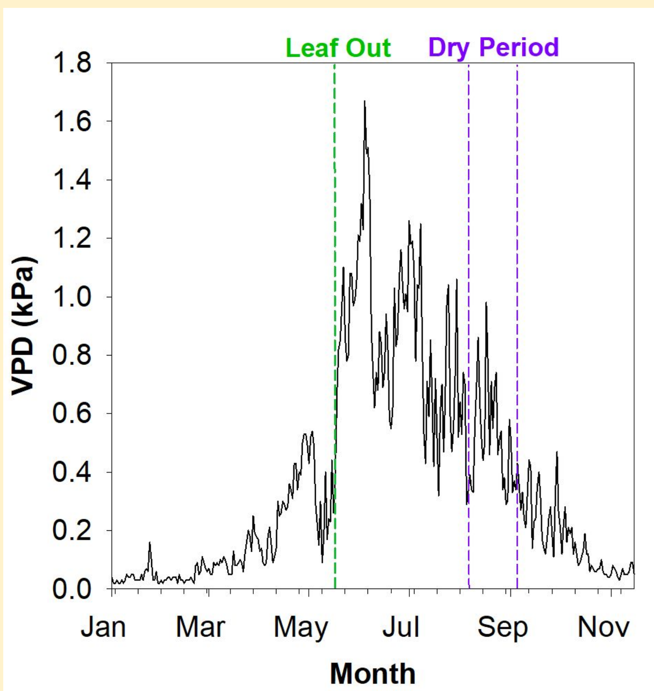

Figure 5. VPD spanning the dates of stem volumetric water content measurements. These data were calculated from data provided by UAF IARC/GI and Wunderground (Fairbanks International Airport). VPD ranged from 0 to 1.7 kpa during the growing season, with the peak occurring in June.

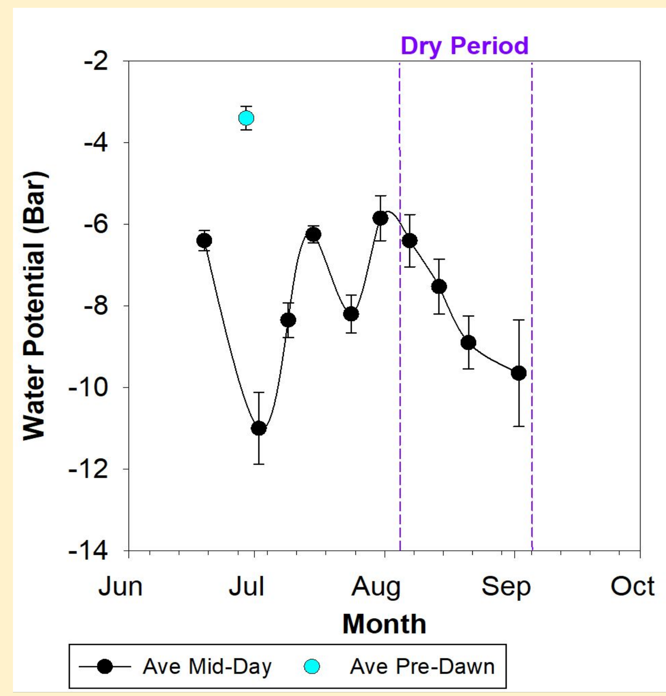

Figure 6. Midday water potential (water stress) with one predawn point around solstice in June. Water stress ranged from -6 to -12 Bar, with the more stressed values occurring in early July and early September (during hot and dry periods).

Results - *Physiological Data - Regression Analyses*

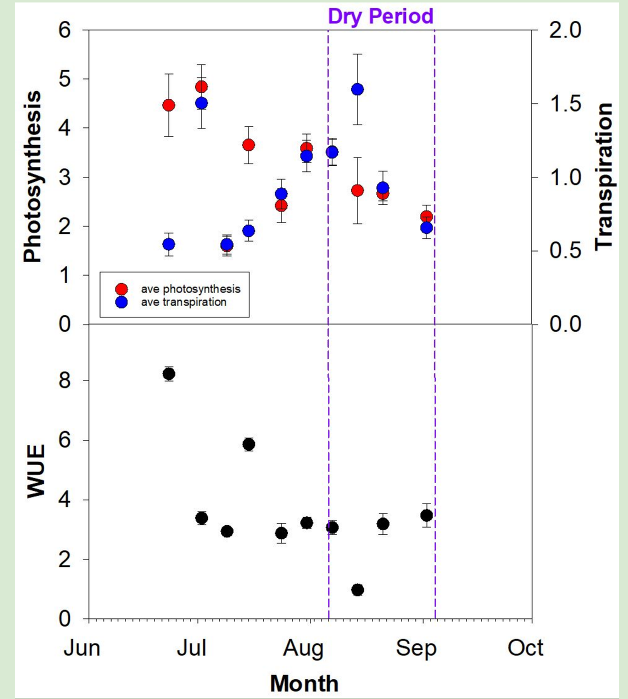

Figure 7. Mean (+/- s.e) photosynthesis (µmol CO_2 m^{-2}) and transpiration (mmol H_2O m^{-2}, top panel) and WUE (mmol CO_2 mol^{-1} H_2O, bottom panel). Photosynthesis decreased overall from mid-June through September while transpiration had a slight increase overall. Both trended downwards during the dry season, with the exception of one day in mid August that is associated with rain events. WUE trended downwards until early August and remained relatively constant with the one day of high transpiration reducing WUE in mid August.

- **Data analysis focused on WUE, integrates the responses of photosynthesis and transpiration,** R^2=0.786.
- **Higher WUE associated with**
  - **higher leaf water content** (p=0.0001) **& lower water stress** (p<0.0001)
    - highest WUE occurred when plants less water stressed, corresponding to higher leaf water content, occurred start of growing season and after rain events.
  - **warmer soils** (p=0.0009)
    - conducive to optimal plant physiological function
  - **lower RH & cooler air temperature** (negative interaction, p<0.0001)
    - VPD effect not significant. Less humid & cooler air temps typically occur under cloudy conditions, reducing photosynthesis (and WUE)
    - **lower stem water content** (p=0.0024)
      - Stem water content recharges (increases) when stomatal conductance declines (low gs reduces WUE)

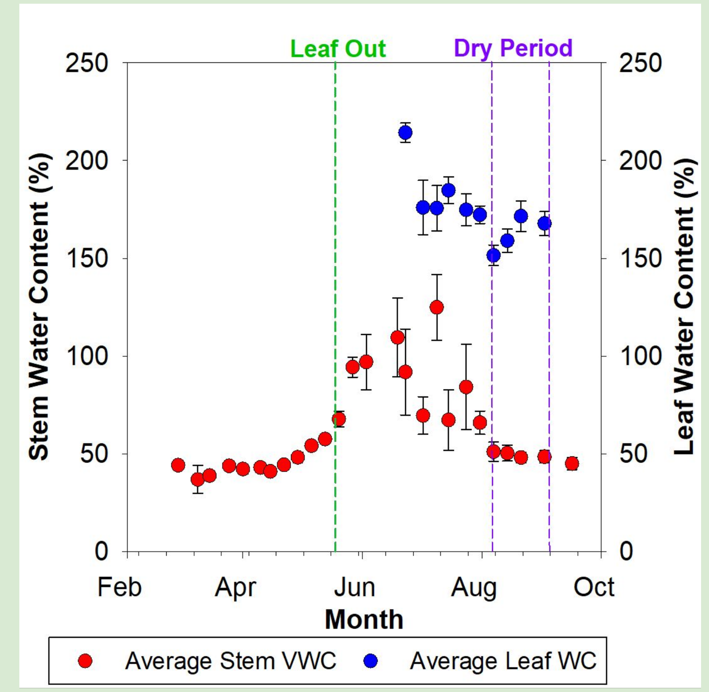

Figure 8. Stem volumetric water content (VWC) and leaf Water content (WC, g/g) from February through September 2022. Statistical analyses were divided between winter and summer measurements.

- ***Winter*** - 2/27/2022 - 6/19/2022 (day prior to first gas exchange measurements)
- ***Summer*** - 6/23/2022 - 9/16/2022

leaf out- May 17, 2022, breakup - 5/7/2022

Winter Statistics:

- **Stem volumetric water content (Stem VWC) greater with higher VPD** (p<0.0001), R^2=38.2
  - Relationship driven by dynamics around breakup (early May) -> Highest VPD levels occurred at this time, corresponding to highest stem water content as the shrubs took up snowmelt water from saturated soils

Summer Statistics:

- **Stem volumetric water content (Log Stem VWC) was greater with dryer soils** (p=0.0002), R^2=25.7
  - During dry periods, plants reduce stomatal conductance and stems recharge with water
- **Specific Leaf Area (SLA,** R^2=71.1**)** was higher with:
  - **higher leaf water content** (p<0.0001)
  - **wetter** (p=0.0060) **and warmer** (p=0.0009) **soils**
  - **warmer air temperatures yesterday** (p=0.0002).
  - All represent optimal conditions for overall plant growth and function
- **Leaf Water Content (Log Leaf WC,** R^2=74.6) was greater with
  - **greater SLA** (p<0.0001)
  - **drier** (p=0.0014) **and cooler** (p<0.0001) **soils**
  - **cooler air temperatures yesterday** (p=0.0009)
  - All can reduce stomatal conductance, increasing water content in the leaf as the plant recharges

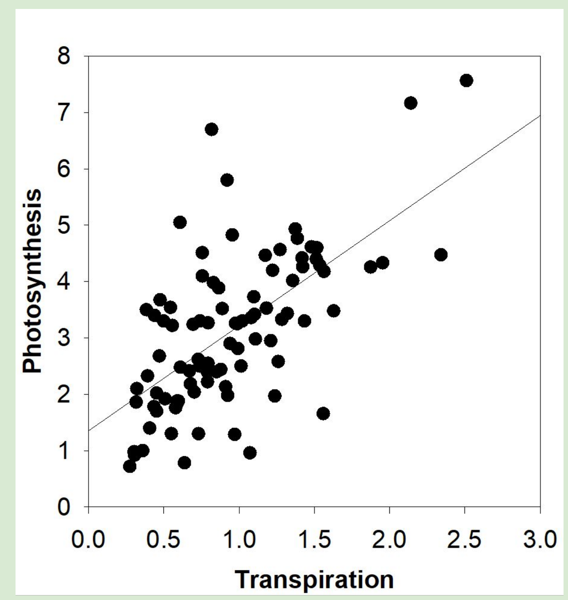

Figure 9. Photosynthesis (µmol CO_2 m^{-2}) vs. transpiration (mmol H_2O m^{-2}) showing the range of each process.

Discussion

- First hypothesis supported: stark increase in stem volumetric water content around leaf out (shrubs taking up snowmelt water for leaf production) and decline over the growing season to a consistent level (~50%).
- Second hypothesis supported: psn initially high, decreased as leaves matured. WUE high early in the growing season, which occurred during a period of little rain and high VPD, but decreased as it started to rain and VPD decreased. T increased slightly over the summer, potentially due to plants needing to expend more water to maintain leaf turgor and support physiological processes.
- Leaf water content decreased over the summer and slightly increased during the dry period. Could suggest plants are retaining more water in their leaves during the dry period. Stem water content remained fairly consistent around 50% during the time that leaf water was slightly increasing.
- Antecedent air temperature (the day prior to plant measurements) impacts leaf water content and leaf growth.
- This study provides evidence that expanding shrubs (particularly *Alnus* sp.) are able to cope with the more frequent extremes in weather Interior Alaska is experiencing due to climate change. Trees are competing with a species that are potentially more adaptable to these new rapidly changing conditions and also experience rapid growth coupled with large carbon and water fluxes.