**draft title: Multiple mechanisms can explain patterns of shrubification in a warming Arctic**

**Introduction**

* **Arctic warming is triggering shifts in plant communities across the tundra biome.** The most commonly observed pattern is an increase in tall, deciduous shrubs - called shrubification. However, there is heterogeneity observed in patterns of vegetation change and shrubification across the Arctic. Despite strong greening (20%) and browning (10%) trends in some places, 70% of Arctic vegetation remains unchanged, or a mix of positive and negative trends.
* **Despite great progress in characterizing patterns of vegetation change, the mechanisms driving these changes (or lack of change) remain unclear.** Multiple literature reviews have had difficulty in pulling out what exactly shrubs are increasing or not across the Arctic. Common narratives include (a) increasing in photosynthetic rate, (b) increases in nutrient availability, (c) increases in growing season length.
  + **Fig 1:** 
    - **Panel 1. Conceptual Diagram: Common Narratives behind Shrubification**
    - **Panel 2. Empirical evidence for Shrubification / trends in Arctic vegetation**
* **Understanding mechanisms can help explain heterogeneity observed in vegetation change.** 
  + MAYBE
* **In other systems, mechanistic models have helped clarify patterns of vegetation change.**
  + Introduce methods of this type of mechanistic model and how it can help us. [write this section next]
* **Briefly describe set-up of tundra model:**
* Frame important components of the shrubification model in the tundra system, paralleling common narratives of shrubification.
* **Describe goals of paper:** using this model, we can explain,
* Why isn’t the Arctic all shrubs today?
  + Model allows the coexistence of multiple species with diverse sets of traits on the tundra
* Why patterns of shrubification are the most commonly observed in a warming Arctic
  + Any increase in productivity should lead to shrubification
* Why increases in productivity in some areas are NOT leading to shrubification AND/OR identify resilient/at risk tundra communities
  + ??? not sure about this yet
* **Briefly describe what we do in this paper.**

**Methods**

Brief/clean description of model

* **Fig 2: Model Diagram**
  + **Plant life cycle**
  + **Description of light environment / competition**

Description of model simulations

* + Photosynthetic rate (for all species)
* + Nutrient availability (for all species)
* + Growing season length (for all species)

Description of trait change analysis

* Model Simulations
* Comparison w/pan-arctic trait databases

Description of comparison of model results + case studies

* Process for “parameterization” of the model for each case AND/OR location
* Description of check of model w/data from the field

**Results**

* **Fig 3: Community-level Model Results**
  + Coexistence outcomes w/Global Change Simulations
* **Fig 4: Trait-level Model Results** 
  + Simulations: Trait Change in Model Simulations
  + Empirical: Extant Trait Distributions of Tundra Plants + Trait Change with warming
* **Fig 5: Model meets tundra reality: Case study of 3 different mechanisms / outcomes / locations w/data on shrub expansion**
  + **Option 1: Organize by dynamical outcomes**
    - No Shrubification
    - Shrubification: no extinction cascade
    - Shrubification triggers extinction cascade
      * (+ what happens after shrubs… but maybe that’s a later project)
  + **Option 2: Organize by mechanisms**
    - +N => Shrubification
    - +Season Length => Shrubification
    - +Warming Alone => Shrubification
  + **Option 3: Organize by Locations and/or Experiments**
    - Somewhere in Alaska (Arctic LTER, +N additions, Alaska)
    - Somewhere in Canada?? (Kluane, Team Shrub Salix site)
    - Somewhere in Scandinavia?? (Abisko, Sweden)

**Discussion**

Why isn’t the Arctic all shrubs today?

* Model allows the coexistence of multiple species with diverse sets of traits on the tundra

Why patterns of shrubification are the most commonly observed in a warming Arctic

* Any increase in productivity should lead to shrubification
* **It turns out “which mechanism” doesn't matter: all should shift tundra communities towards shrubification.** We use a mechanistic model of tundra vegetation to show that any increase in productivity through these mechanisms or others, should favor a shift towards shrubification (taller species).

Why increases in productivity in some areas are NOT leading to shrubification AND/OR identify resilient/at risk tundra communities

* ??? not sure about results for this yet

Other questions I want to be able to address:

* Is your part of the Arctic at risk for shrubification with warming? If so, what is going to happen to other species?
* If shrubs are increasing in your system, can we identify why?
* Does this matter? Are there different biodiversity and carbon storage implications of different shrubification mechanisms?

⇒ Identify specific strengths of this approach (what are we able to explain now that we were not able to before?) and limitations (what happens if you break certain model assumptions?)

⇒ Something more substantial/specific to say about what relevant next steps can lead to a better understanding of tundra plant community dynamics.

⇒ (AT THE END, CHECK IF TRUE) This points towards further efforts to use mechanistic models to model communities of species, with implications for biodiversity and ecosystem function on a changing planet.