1 Introduction

- Phenology, the timing of seasonal life cycle events such as leafout, seed germination etc, is important for lots of things, especially species interactions, and helps give rise to the rich community biodiversity we observe today.
- Phenology is shifting due to climate change, but shifts vary among species.
- These shifts are sure to affect interactions altering patterns of competition/coexistence, but exactly how is unknown, because eco-physiological underpinnings of phenology are not yet well integrated with models of long-term community dynamics.
- This limits our ability to forecast community change and manage the biodiversity crisis.
- First, we provide empirical about germination phenology and environmental cues to demonstrate how phenological differences contribute to community coexistence and how phenological sensitivity—differences in how species respond to climate variation—-alters these differences. Then we adapted a common model of community dynamics (often conceptualized for two competing species of plants with a seedbank) to explicitly model the timing of germination over the season depending on winter climate conditions to assess how the tradeoff between phenological sensitivity and competitive ability changes under alternate climate conditions. Finally, we provide some future directions.
- **probably need to specify we are talking competition/same trophic level, and maybe in general be more specific about limiting the scope of our inquiry**

How phenology mediates species interactions/competition

- Phenological differences among competitive species can serve as a stabilizing mechanism (define) between species.
- By being active at different times increases strength of intraspecific vs. inter specific competition. Also serves as a seasonal priority effect- allowing earlier species a head start, niche modification etc.
- If superior competitors are also earlier active the can rapidly exclude competitors. ie this is what we think some invaders do. Priority effects can can allow weaker competitive to exclude stronger ones (Figure 1).
- Priority effects can lead to coxistience if the weaker competitor is earlier, and the difference in phenology is proportionate the the difference in competitive ability. For example, we found that the two species we studies had an average overall phenological differences of appx. 7 days (Fig 2a). Therefore, assuming a specific (slope) of the relationship, they would coexist if there difference in competitive ability was X (Fig 2b).
- However, phenological timing is not an intrinsic species trait—in most ecological systems, phenology is strongly controlled by climate cues (e.g., temperature, light and moisture) making phenological differences among taxa the variable product of an interaction between species unique sensitivity to environmental variation and the annual environmental conditions they encounter. Considering phenology sensitivity is key to understanding the efffects of climate change on coexistence.

How phenology sensitivty mediates phenological differences

- Temperature, light, moisture cue phenology, but species respond differntly to these cues.

- In general, higher levels not only advance spring phenology, but also reduce differences amoung species.
- This is apparent in our germination study (Figure 3a).
- This is the tricky part to describe: This suggest the differences in competitive ability necessary for coexistence are conditioned on (evolved?) long term climate patterns. For example if community received on average 12 weeks of chilling phenological differences between aster and smart weed would be X, but in lower chill (6 weeks), it would be Y (Fig 3b). This is impossible (assuming here R*s are an intrinsic species traits). This suggest species that coexist under one climate condition will not be able to if the average climate conditions shift. You'd need a species with different sensitivty to produce the same phenological differences.
- But how while this relationship between sensitivity and competition shift?

Predicting the tradeoff under climate change

- All these things, are hard to observe (germination, competition, coexistence) and experiments are limited in the timescale in their ability to link them. But combining empirical experiments with models can allow to get a better sense of this.
- Plagiarized from my esa abstract: We adapted a common model of community dynamics (often conceptualized for two competing species of plants with a seedbank) to explicitly model the timing of germination over the season depending on winter climate conditions (Methods S1). We parameterized this model based on estimates of phenological sensitivity to environmental variation from a series of germination assays performed with herbaceous plant species of eastern temperate forests. By running our simulations under both contemporary and future (warmer) conditions, we were able to parse how the phenology-competition tradeoff of coexistence is likely to shift with climate change.
- Under both high and low chill scenarios, the relationship between phenolgical differences and competition was the same (as expected). However, these relationship between phenological sensitivity and competition shifted. The slope got steeper and coexistence less frequent with lower chilling (Fig. 4).
- Why you might ask? As we saw indicated in the case study above with aster and smart weed, under high chilling, species tended to germination at the same time (Fig 4b), but under lower chilling the same sensitivity differences resulted in larger phenological differences (Fig 4a,b).
- Some speculative implications in real communities? Increased diversity of physiological mechanisms that affect sensitivity. For example, communities with different kinds of dormancy, or ones that use different cues. Phylogenetically more diverse?
- But there are some step we probably need in order to actually begin to understand this.

2 A path forward

Our model is only the beginning, and while it is a noteworthy advance worthy of being published in a nature subsidiary or equivalently high impact journal, there is still a long way to go to forcast these dynamics. Here are some critical aspects. **I think I need help here. All of my thoughts are pretty germination/chilling specific. I could use some idea for contextualizing this more broadly in phenology, and coexistence**

1. Germination phenology as a response curve. We do a good job of modeling quantitative responses to forcing and water potential. Bad job for stratification of seeds, which is super critical in alot of parts of the work.

2. Longer term. Experiments with seasonal cary-over. Most SPE studies only apply the priority effect once. When in reality, communities reassemble each season.

3. Seasonal priory effects and other germination variation. In this study we were super focused on phenology so we held germination % steady. Future model extension could include both.

Figures

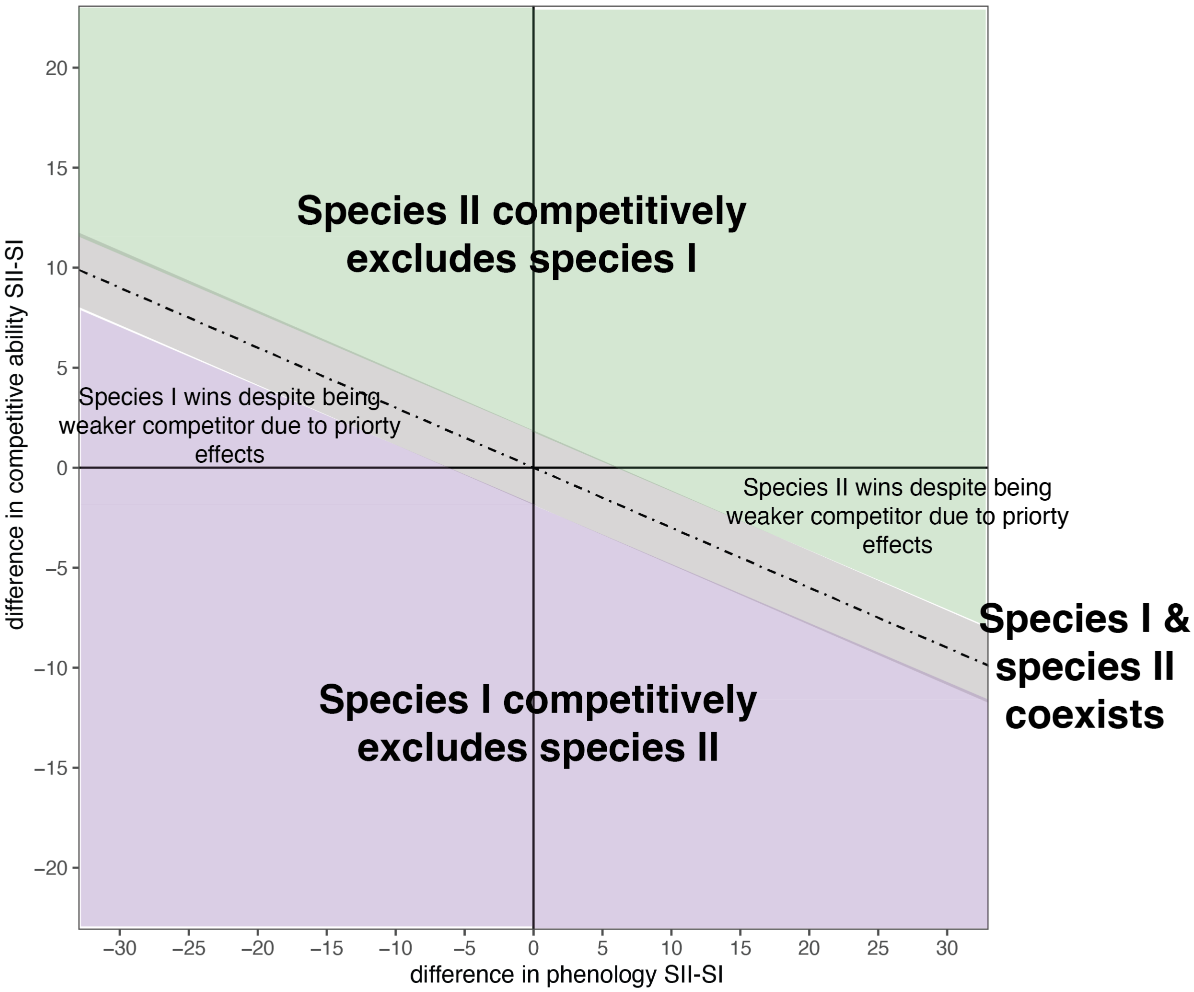

Figure 1: Concept

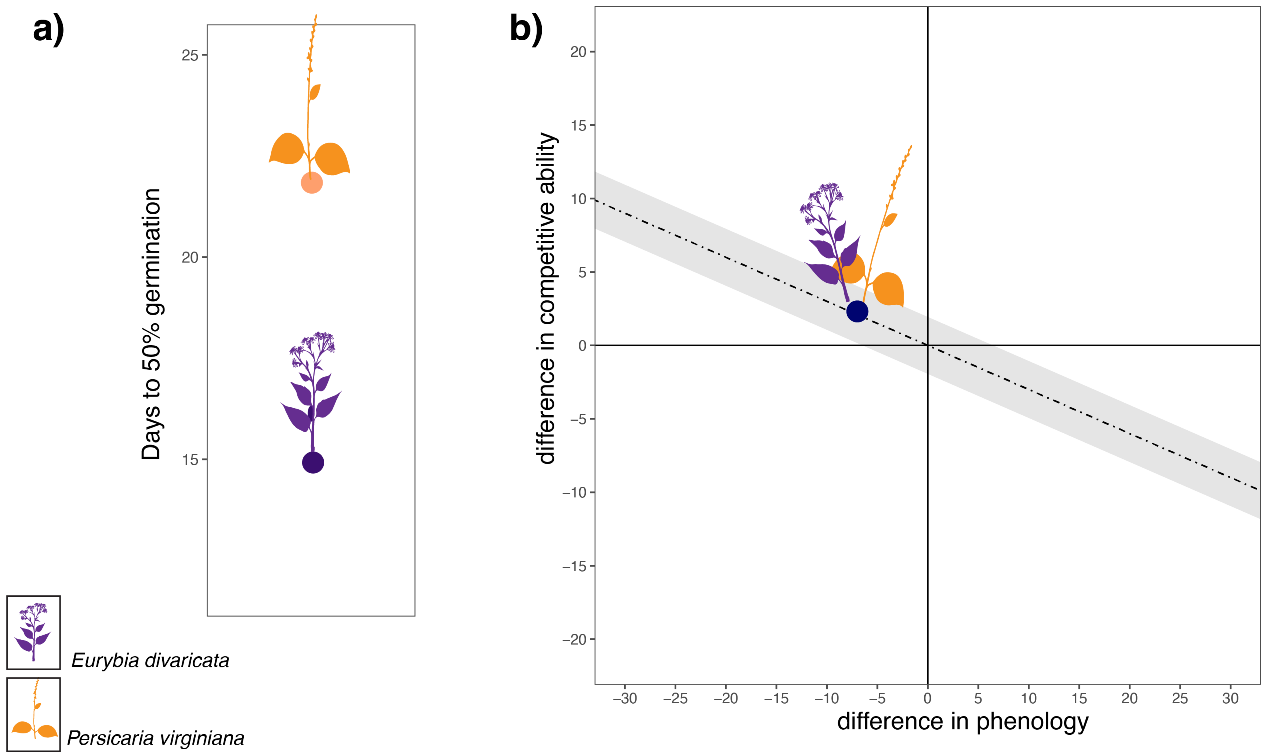

Figure 2:

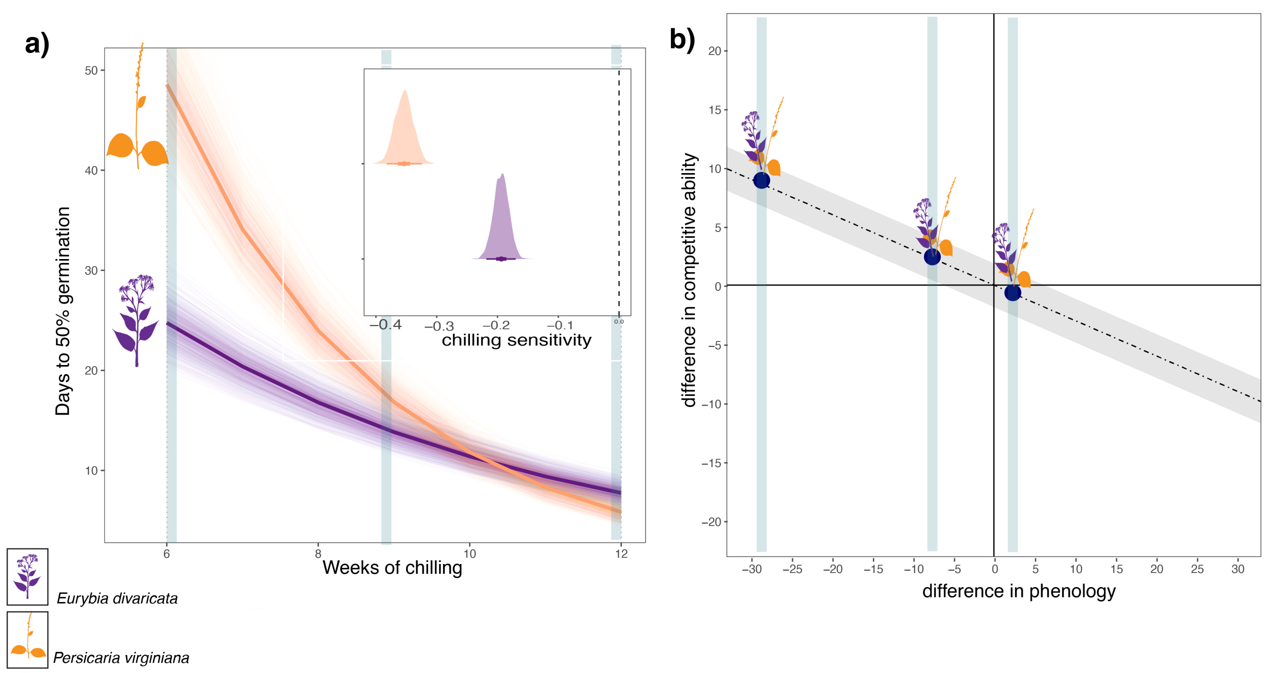

Figure 3:

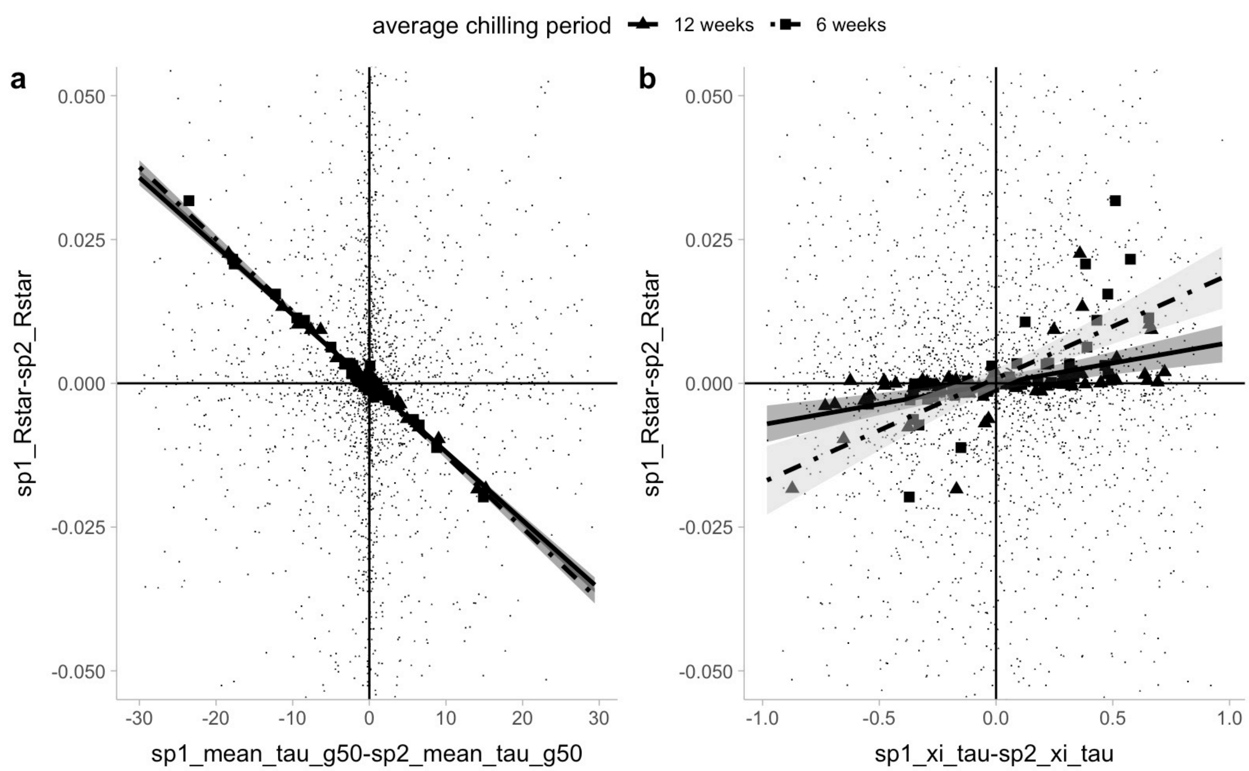

Figure 4:

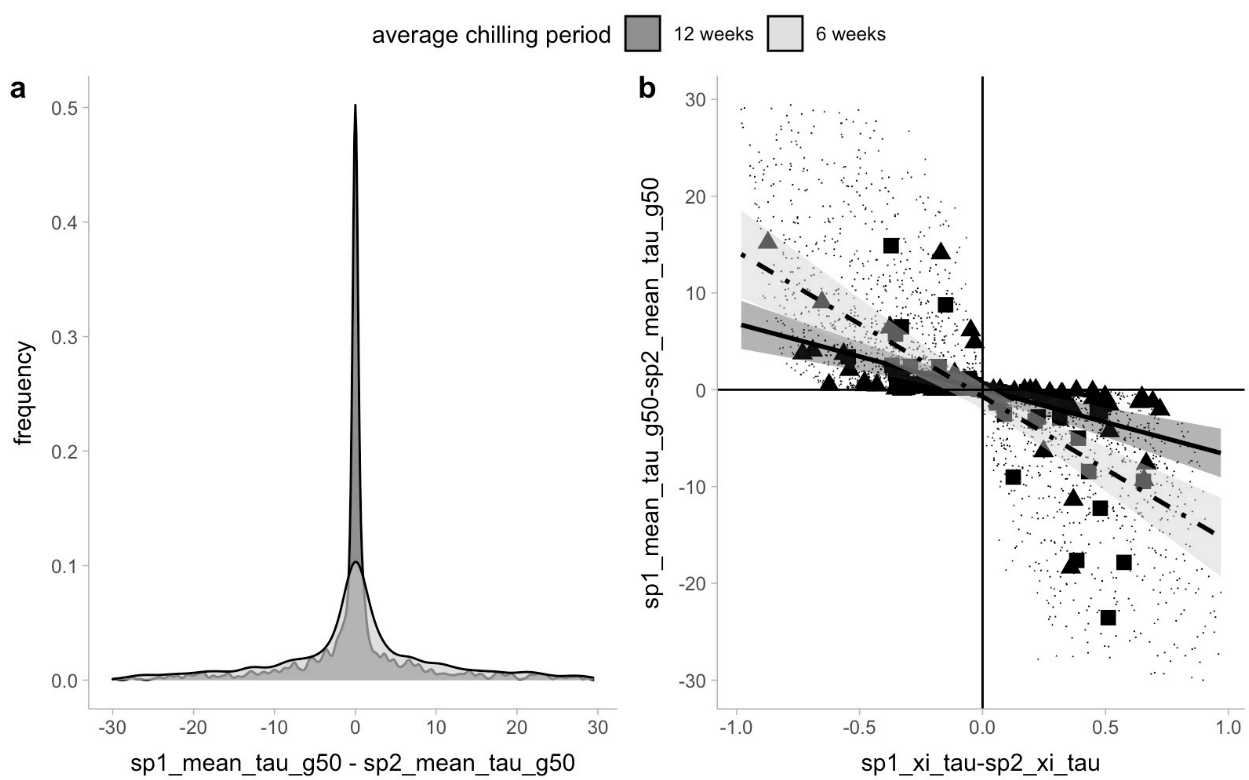

Figure 5: