Ranger Outline: We will come up with a better title when we feel more grounded in the results

Dan, Cat, Nacho and Lizzie

Figures to make:

1. Climate maps for species (some in supp. too)
2. Conceptual figure illustrating why variation in forcing should impact cue use
3. Results from cheapo models
4. some comparison of North America to Europe
5. Results from inter vs. intra specific model

Abstract

Introduction

For woody plants of the temperate zone, the phenology, or annual timing, of spring budburst influences a myriad of ecological processes including patterns of resource allocation (), trophic interactions () and biogeochemical cycling ().

1. Through budburst timing, woody plants balance the advantages of precocious growth resumption for resource gains with the risk of damage from late season frost ().
2. To navigate this tradeoff, woody plants have evolved complicated networks of sensory organs, hormone signaling, and physiological responses to sense environmental cues; changes in their physical environment, that signal the arrival of appropriate conditions for resuming growth.

Decades of research suggest that warming spring temperatures (forcing), cool winter temperatures (chilling) and day length (photoperiod) are primary environmental cues utilized by woody plants that determine the timing of spring phenological events .

1. These studies also demonstrate the there are substantial cue-use differences among species, with some species relying more heavily on some cues over others.

2. As anthropogenic climate change has already driven shifts in spring phenology () identifying these interspecific differences in cue use has emerged as a major goal of phenological research () as the differences have strong implications for both predicting the rate of phenological shifts as the climate continues to warm (), and anticipating the ecological consequences of these shifts ().

But the quantification of cue use difference among species offers even more—a novel opportunity to interrogate long-standing theories regarding the biology underlying cue-use difference among species.

1. One particular relationship that can now be examined this the relationship species' geographic ranges and phenological cue use.

Ranges and cues

Theoretical treatments of the evolution of phenological cues suggest that cue-use differences should reflect differences in the environment these species encounter ().

1. That is, the relative reliance on forcing, chilling and photoperiod for each species should be shaped by the unique environmental conditions across a species geographic range.
2. With the recent quantification for cue use of many species () and the accessibility of high resolution climate data it is now possible to rigorously test this theory with data.
3. Below, we briefly review the specific assumptions and predictions presented in the literature about the relationship between phenological cue-use and species' range characteristics. and then test these predictions using Bayesian models for a large suite of temperate woody species from North America vs Europe.

Assumptions and predictions for the relationship between the cue-use and species' ranges

0.0.1 Magnitude

1. The environmental condition must be present to be a cue.
2. For example, tropical species should lack a chilling cue.
3. For the temperate species of North American and Europe, this is not an issue **(Supplemental figure showing magnitude of chilling, forcing and photoperiod)** so our study will not focus on magnitude.

0.0.2 Relative reliance

1. Assumptions:

(a) Forcing is the predominant cure

(b) Photoperiod and chill reliance evolves when forcing alone is not a reliable cue of safe growing condition **Since Nacho is an author, maybe illustrate this with a beautiful conceptual figure?**

(c) Forcing is an unreliable cue where there is significant variation in it.

 i. Intra-annual variation: explain using our logic

 ii. Inter-annual (cite Zohner) and explain using their logic.

2. Predictions

 (a) Higher variation in GDDs to last frost should correlate with stronger chilling and photoperiod

 (b) Higher STV should correlate with stronger chilling and photoperiod

 (c) Larger ranges should correlate with more variation which should correlate with stronger chilling and photoperiod.

 (d) Macro-geographic patterns should also be detectable. Since spring climate is less stable in NA than Europe, we should see differences between the continents.

0.0.3 Species vs. Populations

1. All of the prediction above rely of the assumption that cue-use is conserved across species level. Yet there is some evidence cue use is locally adapted ().

2. if so: Predictions:

 (a) Not see strong relationships between species level traits and range characteristics.

 (b) Intra-specific variation should be high; similar or larger order than inter-specific.

 (c) Intra-specific should follow the same predictions for mentioned above (ie more forcing variation at a site should driver higher reliance on secondary cues.)

1. We tested these specific predictions using the OSPREE database, and climate data, and models.

2. Our interrogation of these relationships between climate and cue use not only clarifies the evolutionary drivers of cue use, but offers new insights regarding implications of climate change as both species' ranges and phenology continue to shift with warming.

Methods

Phenological data and cue-use estimates

Dan and/or Lizzie write:

- Introduce OSPREE
- Species selection
- Model description

Species' range characteristics

Cat and/or Nacho write?

- Climate data **(Figure of range maps with one climate variable, other could go to supplement)**
- note on temp vs. geographic variation
- calculation of GDD last frost
- STV
- range area

Statistical analysis

Variation and secondary cue use

Dan write description of cheapo models. Name them something cool.

Intra vs. interspecific models

Cat or Lizzie or Dan write

Results

Variation and secondary cue use

1. Nothing really here.(could do sub-subsection for each model (GGlf,are, STV, NA vs. EU))
2. Note that area doesn't correlate with variation so well.
3. **(Figure with Mu plots or linear regression from cheapo models)**
4. Note to self, should probably also check the converse (high variation in GDD to last frost drive weaker forcing response)
5.

Inter. vs. intra- specific variation

1. I can't exactly remember what our finding was. I think that intra-specific variation is high but not as high as interspecific. Cat probably knows the answer to this.
2. I also can't remember if this model can test the predictions at the population level or if we would need to write a different model, or if we already thought of this and ruled it out.
3. Either way this result should also have a **(figure)**.

Discussion

Question: where to attempt to reconcile our null results with Zohners

1. Summarize findings
2. Emphasize that these null results are informative because this is a common assumption.
3. We should stop using area as a proxy for variation.
4. Alternative hypotheses:
   (a) The relationship phenology cues and ranges are indirect: ie cues influence cold hardiness which influences ranges ().
   (b) too much noise in data to pick this up
   (c) Cue use reflects community assembly and other tradeoffs ie. traits
   (d) Cue use is highly constrained (phylogeny)
   (e) Modern range distribution do not reflect selection environment (ie ranges are not in equilibrium, glaciers and stuff
   (f) cues interaction in complex ways. Forcing and chilling can substitute for each other. We don't really understand how they work. Chilling is just a hypothesis etc.
5. Interestingly others have found a relationship between STV (reconcile our finding with Zohner. I could use help here but here are some ideas)
   (a) Noise in our data
   (b) the thing Lizzie asked me to check about 1 observation/continenent
   (c) STV windows are bad over geographic space because they can capture "spring" in all locations.
6. Explicitly address any differences between NA and Europe.
7. Bold claim 1: Does our work suggest phenological constraints to range shifts aren't as big a deal as some people think?
8. We need to explore the alternative hypotheses while improving our understanding and modeling of the physiology and genetics that underpin phenological responses to the environment.