**INTRODUCTION**

*Introduction*. The Introduction should present an overall framework for your research by reviewing the literature, discussing what is currently known about the particular subject (as well as perhaps how this knowledge may have evolved historically), identifying relevant questions or debates that exist in the field, and detailing the specific question/s that you investigate in the thesis. The Introduction often reads like a mini review article on your topic. It should be very obvious to the reader what specific scientific questions you aim to address with your work. If you introduce the background well, the reader should also understand why your specific work is an important and obvious next step for your particular field or laboratory. You should end your introduction by clearly stating (or perhaps restating) your objectives and rationale for the thesis. This provides a starting point for the thesis and tells the reader what to expect in the forthcoming sections. Throughout the introduction you should supply sufficient information to allow the reader to understand the forthcoming results without her/him needing to read previous publications. When in doubt, explain briefly. Include schematic figures or diagrams in your Introduction that illustrate the details you are introducing. If it is something crucial for the reader to understand, a figure is always a good idea. It improves your overall presentation and also helps the reader to focus on the important points they must understand for the remainder of the thesis. Throughout the Introduction and all subsequent sections, you should include in-text citations of all relevant published work. References serve multiple purposes. Beyond their most important role in giving credit to previous work, references also serve as resources for the reader to learn where s/he might find further reading on a particular subject. Be sure to include relevant reviews or even textbook chapters that you found helpful as you learned about your topic.

**INTRODUCTION**

I. Range extremes and community ecology

* 1. Community assembly as an ecological sorting process (Ackerly 2003)
     1. plants in saturated communities occupy optimal or near-optimal environments
     2. distribution is due to abiotic and biotic factors
     3. plasticity within a species alters functional traits

Range extremes have long been a core concept in community ecology. The assembly of a community of species is an ecological sorting process; the final demography of a species and its community composition is the result of interplays between a combination of abiotic and biotic factors (Ackerly 2003). In saturated communities, a species is forced to occupy an environment conducive to its success, and so it occupies a (near-)optimized environment. On the edges of its range, species sees either biotic and/or abiotic factors forcing it out in habitat filtering (Weiher 1998). Range limits are predetermined by Yet it remains unclear whether

* 1. Range limits as predetermined by environment/strength of biotic factors (Pigot and Tobias 2013; Sexton et. al 2009)
     1. Environment biogeographical history as more important than species interactions—all references cited in Pigot and Tobias 2013 (Shmida & Wilson 1985; Pearson & Dawson 2003; Cavender-Bares et al. 2009; Peterson et al. 2011; Wiens 2011), and that contiguous distributions mainly reflect autoecological differences rather than competition (Case et al. 2005; Sexton et al. 2009).
     2. Unclear how much of range limits are due to biotic or abiotic factors
     3. Likely that it varies among species due to different dispersal capabilities, competition (varies on local scale), and freezing tolerance (Louthan et. al 2015)
     4. Mixture of abiotic external factors that constrain traits appearing within limits and biotic internal forces that keep coexisting species from being too similar (Weihar et. al 1998)
  2. Climate change’s influence on range extremes

(1) Poleward range shifts observed in many well-studied species (Parmesan 2006)

(a) Linked to global climate change through historical data and observation

(2) Population’s responses to changing environments (Ackerly 2003)

(a) Shifts in the optimal environment: microhabitat and/or altitude

(b) Large-scale shifts in geographic distribution (range expansion and extirpation at “trailing edge”)

(3) Parmesan 2006: species expected to migrate towards poles

(4) Chen et. al 2011

b) Plants at their edge at a disadvantage -> how does this become apparent in their functional traits and competitiveness?

i) Trailing edge hypothesis – climate change’s rate affects how prevalent adaptive responses are (Ackerly 2003)

(1) Historically, species replacement (migration) outpace local adaptation

(2) Leading edge will become either site of extinction or site of migration

(3) Plants at range extremes outside optimal environment

(a) can’t track preferred environment simultaneously in multiple dimensions, thus effective dispersal will cause species to track preferred conditions

ii) Importance of trait-based and phylogenetic-based models in isolating species interaction signals (Pigot and Tobias 2013)

c) Altered opportunities for trees at their range extremes

i) Look at range extremes to predict future responses to climate change

ii) Competition slows advance of colonists into new environments when combatting the changes in environment due to global climate change (Urban et. al 2012)

d) Hypotheses

i) H1: Less competitive as you approach (climatic and/or latitudinal) range limit (plant at disadvantage) – niche grows smaller as plant approaches range limit (Sexton et. al 2009)

(1) A1: More competitive as you approach (climatic and/or latitudinal) range limit due to fewer competitors, greater realized niche

(2) A2: Competition not predicted by position in (climatic and/or latitudinal) range

a. They differ across and within the range – local factors matter more, community composition and local adaptation determine competitiveness (not position in range limit)

b.

(b) Local community composition around each tree is most predictive

ii) H2: Trees at their range extremes exhibit altered suites of functional traits from trees in the range interior (Weiher et. al 1998)

(1) A1: Trait variation increases as plants approach their range extremes (indicates plants trying many different combinations of traits)

a. Edge populations more frequently experience strong, limiting factors (Sexton et. al 2009)

b. Varying environment that is outside of individual tolerance might contribute to increased phenotypic plasticity (Sexton et. al 2009)

(2) A2: Trait variation decreases as plants approach range extremes

a. One combination of traits functions well in specific (limiting) environment

(3) A3: Trait means vary across range

e) Prediction given data!

**MATERIALS AND METHODS**

To understand community composition and functional traits in response to range limits, we examined the immediate vicinity of six deciduous tree species. We collected data on the community composition of the understory species, as well as current competitive environment for each focal tree. Data on functional traits for some of the same individuals were collected the year prior across all four sites through the summer.

***Species selection*** *-* We sampled six different species of deciduous woody plants that are abundant across the latitudinal range of our sites in the Eastern US. The species’ ranges vary, though all reach a range extreme near one of our four sites. The species in question are: *Acer pensylvanicum, Betula papyrifera, Cornus alternifolia, Fagus grandifolia, Hamamelis virginiana,* and *Sorbus americana*. Four of the six species reach their northern range extremes within or just outside of the latitudinal range covered by our four sites. Two species, *Betula papyrifera* and *Sorbus americana,* reach their southern limits just below our southern-most site at Harvard Forest. *Hamamelis virginiana*, on the other hand, reaches its northern limit near our second southern-most site in the White Mountains.

Each species was selected based on (a) which species had been included in past studies at the four sites as part of the Wolkovich lab’s work, and (b) the location of its range limits with relation to the four sites. We found each species’ latitudinal range limits through the websites bonap.org, plants.usda.gov, and gbif.org. This was to account for records of tree species that were recorded outside their latitudinal limits (as evidenced by highly decreased abundance), but had still been recorded as appearing in different counties.

***Sites*** - We collected data at four sites, all spaced approximately one latitudinal degree apart from each other. Individuals of the six species had previously been tagged for past lab work. All sites were temperate deciduous forests with a small amount of human disturbance. The southernmost site was Harvard Forest, an LTER in Petersham, Massachusetts. The Harvard Forest spans approximately 3000 acres, and lies 110 kilometers west of Boston. The second site was located in the southern White Mountains in New Hampshire, off the Kancamagus Highway. As the southernmost part of the White Mountains, the site does not lie within a protected research area. However, as part of a national forest, it is fairly protected from human intrusion. The third site was in the Dartmouth College Second Grant, a site maintained by Dartmouth College for some recreational use and scientific research. The Grant in northern New Hampshire, near the border of Maine. Finally, the northernmost site was located at the Station de biologie des Laurentide in Quebec. The Station de biologie des Laurentide is slightly larger than Harvard Forest, spanning 4000 acres, and is 75 kilometers northeast of Montreal. Due to the varying latitudes, the northern-most sites see a climate of colder winters and shorter growing seasons. All follow mild summers.

All four sites had previously been used by the Wolkovich lab for research in temporal ecology into the species used for this experiment, thus ensuring the presence of suitable individuals at each site. Nearly all sampling sites occurred in closed canopy forests, except for some sampling plots of *Cornus alternifolia* and *Sorbus americana* which frequently appear on forest edges.

***Competition and community data*** *-* For each of the six species, we tagged six (or found some previously tagged) individuals at each site that the individuals were present in. We compared total basal area of the focal individual with trees in the competitive environment around each focal individual. The direct competitive environment was estimated as being within a 5-m radius around the focal tree. We recorded the DBH of all trees falling within this circle. We took note of the presence and absence of species in the understory, including species of saplings appearing under 1.3m. To determine competitiveness of our focal individuals, we used the percentage of total basal area attributable to the focal individuals as a proxy for competitive advantage in each plot.

***Functional traits***- For functional trait data, we used the data collected the previous summer by Harry Stone during the Harvard Forest REU Summer Program in 2015. The height of individuals not measured summer 2015 was measured through a clinometer. Additionally, we measured the DBH of any newly-tagged individuals (in cases where an individual is too close to another focal plant). Functional traits for newly-tagged individuals were not measured, but instead the traits measured in 2015 served as a representation of the traits of all species within that site.

Data on the functional traits Specific Leaf Area (SLA), Leaf N%, leaf dry matter content, and height were all collected for at least six individuals of the six species across the four sites (when applicable). Samples were processed in the John Torrey laboratory at the Harvard Forest. When possible, leaf samples were collected near the center of the tree canopy. Leaf size was measured using the LI-COR 3100 leaf area meter. To account for variation within an individual, a wide range of leaf sizes were measured to achieve a representative average size. Specific leaf area (SLA) was determined by the leaf size divided by dry mass of the leaves (Cornelissen 2003). The leaves were weighed after drying for than 24 hours at 60 OC.

We measured leaf dry matter content by comparing the fresh mass of the leaves, determined immediately after removal from the individual and the dried weight. Height of the individual was measured using a clinometer from 15 meters away from the tree. Stem specific density was measured by comparing the volume of the stem sample to the dried mass. The volume of the stem was calculated by submersion in a container of water and the volume of the water displaced is equivalent to the volume of the stem. Then the stems were dried in excess of 24 hours in the drying oven at 60 OC.

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