The Effect of Increasing Temperature on Germination of Native Plant Species in the North Woods Region

Nicholas Dove
University of Vermont
ndove@uvm.edu
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Advisor: Margaret E. Mangan

ABSTRACT

Climate change, resulting from the anthropogenic release of carbon dioxide and other greenhouse gases, may globally increase temperatures between 2.5-4.5°C (IPCC 2007). This increase in global temperatures will likely affect future plant species distribution, and could influence the survivability of individual species because of the relationship between temperature, germination, and dormancy. The aim of our experiment is to determine if increases in temperature, predicted to occur in the North Woods region, will affect germination percentage and velocity of native species. Germination was monitored at two different temperature regimes: a control (5-15°C) and a simulation of a future climate (11.5-21.5°C). For germination percentage, it was found that seven of the thirteen species were positively affected by an increase in temperature. For germination velocity it was found that eight of the thirteen species were positively affected by an increase in temperature. Because species responded differently to an increase in temperature, this will most likely result in a change in species distribution favoring species that responded positively. This has widespread ecologic and economical effects for the North Woods region.

INTRODUCTION

Climate change, resulting from the anthropogenic release of carbon dioxide and other greenhouse gases, may globally increase temperatures between 2.5-4.5°C (IPCC 2007). This increase in global temperatures will likely affect future plant species distribution, and could influence the survivability of individual species because of the relationship between temperature, germination, and dormancy. Temperature has been shown to be the most important variable affecting germination (Milbau et al. 2009; Roberts 1988). For many species the optimal temperature for germination is 10-20°C (C. Baskin and J. Baskin 2001). Within this temperature range the germination rate is fastest (C. Baskin and J. Baskin 2001). Each individual species has a base and ceiling temperature that represents the extremes at which germination can occur. Below and above these extremes no germination can occur (Finch-Savage and Leubner-Metzger 2006). If climate change results in temperatures that exceed the ceiling for a species, then that species will not be able to germinate; thus, affecting its survivability.

Temperature affects germination in three primary ways: moisture, hormone production, and enzyme activity. For seeds to germinate, they need to imbibe water. For this to occur, sufficient moisture must be present. A warmer climate may increase evaporation and decrease moisture, which would negatively affect germination. Additionally, some climate change models predict greater variation in precipitation, which will directly affect the hydrologic cycle in many regions (IPCC 2007).

Two different hormones regulate germination: abscisic acid and gibberellins. Abscisic acid promotes dormancy and inhibits germination while gibberellins advance germination (Finch-Savage and Leubner-Metzger 2006). Through environmental cues, most importantly temperature, genes that control the production of gibberellins are up-regulated, dormancy is released, and germination occurs (Finch-Savage and Leubner-Metzger 2006). Germination occurs when the embryo elongates and the radical protrudes from the seed coat. For many species, enzymes are required to facilitate this process. For example, enzymes degrade endosperm tissue and rupture the seed coat (Finch-Savage and Leubner-Metzger 2006). Chemical signaling regulates production of enzymes, which is in turn regulated by temperature (Finch-Savage and Leubner-Metzger 2006). If the temperature window is breached, then these enzymes may become inactive (Peterson et al. 2007). Due to the temperature dependency of hormones and enzymes, a drastic change in temperature will significantly affect germination.

We are interested if germination of native species in the forests of the Upper Peninsula (UP) of Michigan and Northern Wisconsin (the North Woods) will be affected by the change in temperature projected for this region. If an increase in temperature negatively affects overall germination and germination velocity, persistence of individual species will be altered and species distribution could change. Similarly, if increasing temperatures have a differential positive effect on germination of some species, then these species will increase their fitness, also changing species distribution. This has incredible ecological and economic effects for the local ecosystems and surrounding areas.

This experiment tested the germination rates of thirteen different native plant species and evaluated how increasing temperatures impacts the germination velocity and success. We examined the potential effects on species distribution by evaluating multiple species that represent a variety of functional groups. We predict that increased temperatures will increase germination rates and percentages. However, any temperature past the optimum germination temperature (10-20˚C for many species) (Finch-Savage and Leubner-Metzger 2006) will negatively affect seed germination and species survivability.

MATERIALS & METHODS

Study Species

We purchased seeds of thirteen native species (Table 1). We selected three woody species, two sedges, and nine forbs. This represents about 3% of the vascular plants on the UNDERC property (underc.nd.edu). We selected species that had a northern distribution and represented multiple functional groups. Because there was a 10-week constraint on this project, we only used species that were easily available and required no cold stratification.

The species were ordered from three different seed suppliers (Sheffield's Seed Co., Michigan Wildflower Farm, and Prairie Moon Nursery). We talked with multiple seed distributors in the area near the University of Notre Dame Environmental Research Center (UNDERC) (where the study took place) because we wanted the species to represent the local ecotypes found in this area. Unfortunately, we were not able to order all of our seeds from local suppliers because of limited availability. Prior to germination the seeds were kept in total darkness, dry, and at constant room temperature (20°C). These conditions prevented the seeds from exiting dormancy before the experiment (C. Baskin and J. Baskin 2001).

Temperature

Two temperature regimes were chosen: 5-15°C and 11.5-21.5°C. These regimes had alternating temperatures that mimic diurnal fluctuations (J. Baskin and C. Baskin 2001). Seeds were subjected to the high temperature for 14 hours a day and the low temperature for 10 hours a day.

The first regime was the control temperature. It was designed by averaging the high and the low air temperatures in the UP for the month of May (National Weather

Service 2010). We then added or subtracted 5°C to obtain the high and the low temperatures, respectively. This gave us a temperature range of 10°C, which corresponds to previous studies (J. Baskin and C. Baskin 2001). Our control treatment was within the optimum range of temperatures for most species (J. Baskin and C. Baskin 2001).

The second temperature regime was based on a models developed by the Wisconsin Initiative on Climate Change Impacts (WICCI). Although the IPCC predicts a 2.5-4.5°C global increase in temperature, local temperatures may vary. The WICCI localized these global projections and downscaled them to various regions of Wisconsin. We used temperatures projected by the WICCI's A2 scenario of climate change. We decided upon this model because the A2 projection is the most fossil fuel intensive model and forecasts the most extreme change in climate (IPCC 2007). WICCI predicts that the A2 scenario will lead to an increase of 6.5°C by 2090 for our area (Figure 3**)**. Therefore, the second regime increased the high and low temperatures by 6.5°C from the control.

Experiment

The seeds were placed in 90mm diameter petri dishes with ample amounts of water. They were checked every other day for two weeks for radical protrusion. The seeds were placed in an environmental chamber and were subjected to 14 hours of high temperatures and light and 10 hours of low temperatures and darkness per day to mimic diurnal fluctuations of temperature and light (C. Baskin and J. Baskin 2001). Rate of germination was calculated using a modified Timson's index of germination velocity: Germination velocity=$\sum G/t$ where G is the percentage of seed germination at two day intervals and t is the total germination period (Khan and Ungar 1984). Germination velocity is one way to measure how fast a population of seeds germinates during a given time period. Additionally, percent total germination was calculated for each species at the end of the experiment.

Statistical Analysis

Percent germination and the germination velocity data were arcsine transformed prior to statistical analysis. For each individual species, a single-way analysis of variance (ANOVA) for total percent germination and germination velocity was conducted. Additionally, a two-way ANOVA was conducted to evaluate the effect of species and temperature on germination.

RESULTS

Percent Germination

Significant differences in germination were observed between species ($P < 0.001$; $F = 189.147$; $df = 11,48$). Germination was lowest with purple graceful sedge (*Carex gracillima*), which did not germinate and the highest for wild bergamot (*Monarda fistulosa*), which had an 81% germination percentage (Figure 1). Our results showed differences ($\alpha = 0.10$) in the total percent germination between temperatures for seven of the thirteen species **(**Table 2). All three of the woody plants (black spruce (*Picea mariana*), white spruce (*Picea glauca*), and tamarack (*Larix laricina*)) showed significant increases in percent germination. However, only four of the ten herbaceous species (zig zag goldenrod (*Solidago flexicaulis*), showy goldenrod (*Solidago speciosa*), common milkweed (*Asclepias syriaca*), and wild mint (*Mentha arvenisis*)) showed significant increases in percent germination.

Germination Velocity

Significant differences in germination velocity were also observed between species (P < 0.001; F =228.502; df =11,48) where again, purple graceful sedge did not germinate and wild bergamot had the highest germination velocity (.265) (Figure 2). There were significant differences in germination velocity for eight of the thirteen species tested (Table 2). Again, all three tree species had significantly faster germination velocities with the warmer treatment, while only five of the ten herbaceous species (same as before plus ear-leaved brome (*Bromus latiglumis*)) had higher germination velocities.

DISCUSSION

For all the species in this study, an increase in temperature had a positive or neutral effect on percent germination and velocity, and never had a significant negative effect on germination percentage or velocity. Therefore, the A2 scenario does not appear to approach a temperature ceiling for these species. Although overall climate change may negatively affect plant species and disrupt ecological systems, it seems as though temperature alone may have positive impacts on these species.

Our results indicate there is a differentiated effect of temperature on germination between species. Some species show a very positive response to increased temperature, while other species were unaffected. Therefore, those species, which are positively affected by increasing temperatures, will have higher fitness in a warmer climate. If certain species increase their fitness while others do not, this will lead to a change in botanical composition and species distribution in this area.

The study shows that trees may be more positively affected than forbs in a warmer climate. Therefore, it is likely that many ecosystems in the North Woods will be more dominated by trees. However, we only sampled three species and this does not represent the entire diversity present.

Unfortunately, due to time, I was not able to include plants requiring a cold stratification. The effects of increasing temperature on these species of plants could possibly be even more profound. In many species a cold stratification is needed to break dormancy (Shultz and Rave 1999). If the average winter temperatures were higher, then these species would experience shorter periods of cold stratification, and as a result may not germinate. This would lower their fitness, and may eliminate them from this area.

Our experiment focused on temperature as a primary control of germination because it is has been proven that temperature is the most important variable (Roberts 1988, Vleeshouwers et al. 1995, Probert 2000, Milbau et al. 2009). Although important, temperature does not regulate germination alone. Various other biotic and abiotic factors interact and have direct influence on germination successes. Paramount among these factors is soil moisture. When discussing affects of climate change, moisture (i.e water availability) is crucial as a warmer climate would most likely experience changes in precipitation patterns. This can be very difficult to predict with accuracy and the IPCC has not published any precipitation projections. However, it is challenging to make assumptions about germination if moisture is not accounted for. Thus, these results must be interpreted as an isolated temperature effect and should be reconfirmed under conditions of varying moisture availability.

Our results showed that warmer temperatures differentially affected species. These results were informative although only relevant to the species in this study. Since we used a relatively small number of species, thirteen, we cannot extrapolate results to the entire North Woods region. Many more species, representing different dormancy types, would have to be evaluated in order to make conclusions about the potential impact of climate change in this region. Therefore, the assumptions of change in the overall botanical composition of the North Woods may not be entirely accurate.

In the future more studies are required to address and evaluate botanical composition changes happening at the regional level. This is because not all regions will see the same increase in temperature with climate change. Therefore, it is imperative to know which regions need to plan for a large-scale change in species distribution. It is important that we have accurate regional temperature models for these studies. In addition to temperature models, precipitation models must be designed so scientists can better simulate a changing climate for plants.

Although germination is a key plant process, there are many other plant processes that will be affected by climate change. Therefore, more studies must be done so that we can more accurately portray what may happen with a changing climate. It is most likely that major disturbances will occur. Thus, it is imperative to know what these disturbances are so that we may plan and prepare.

BROADER IMPACTS

A change in plant species distribution could have widespread ecological effects and may result in an overall loss of biodiversity (Thomas et al. 2007). Animals are heavily reliant on trees and other plants to maintain a proper habitat, as well as for food resources. Additionally, some insect species rely on specific plant species as a source of food. If plant species were to change, then there may be cascading effects throughout the trophic levels and the entire ecosystem could be altered. This could have profound impacts on the migration of native animal species out of the North Woods and maybe even extinction of these species.

In addition to ecological effects, a change in species distribution of plants could affect the economy of the UP and Northern Wisconsin. This area is a place known for fishing, hunting, and other outdoor activities. Its economy is reliant on tourism. If the species distribution were to change, people may be less inclined to visit because the same ecosystems would not exist. If this were to happen, it could have disastrous effects for the local economies. Therefore, the North Woods area must plan and prepare for these effects.

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LITERATURE CITED

Baskin, C.C., & Baskin, J.M. (1998). *Seeds: ecology, biogeography, and evolution of dormacy and germination*. San Diego, CA: Acedemic Press.

Finch-Savage, W.E., & Leubner-Metzger, G. (2006). Seed dormancy and the control of germination. *New Phytologist*, *171*. doi: 10.1111/j.1469-8137.2006.01787.x

IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the*

Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Khan M.A. & Ungar I.A. 1997. Effects of thermoperiod on recovery of seed germination of halophytes from saline conditions, *American Journal of Botany* **84** (1997), pp. 279–283

Milbau, A., Graae, B.J., Shevtsova, A., & Nijs, I. (2009). Effects of a warmer climate on seed germination in the subarctic. *Annals of Botany*, *104*. doi: 10.1093/aob/mcp117

National Weather service. (2010). *Michigan's upper peninsula weather patterns*. Retrieved from http://www.michiganfilmoffice.org/cm/files/MFO_weather.pdf

Probert R.J. 2000. The role of temperature in the regulation of seed dormancy and germination. In: Fenner M, ed. *Seeds: the ecology of regerneration in plant communities.* Wallingford: CAB International, 261-292

Roberts, E.H. (1988) *Temperature and seed germination*. Symposia for the Society for Experimental Biology. 42:109-32

Shultz, W., & Rave, G. (1999). The Effect of cold stratification and light on the seed germination of temperate sedges (carex) from various habitats and implications for regenerative strategies . *Plant Ecology*, *144*(2), Retrieved from http://www.springerlink.com/content/mt2736004417006h/ doi: 10.1023/A:1009892004730

Thomas, C.D, et al. (2004) *Extinction risk from climate change.* Nature, 427 (6970). pp. 145-148. ISSN 0028-0836

Vleeshouwers L.M., Bouweester H.J., Karssen C.M. 1995. Redefining seed dormancy: an attempt to integrate physiology and ecology. *Journal of Ecology* 83: 1031-1037

WICCI. (2009). *Wicci: methods*. Retrieved from http://www.wicci.wisc.edu/climate-modeling-methods.php

TABLES:

Common Name	Seed Mass (mg)	Functional Type	Source	Location
Black Spruce	1.76	Tree	Sheffield's Seed Co.	New York
Common Bur Sedge	15.86	Sedge	Prairie Moon Nursery	Minnesota
Common Milkweed	5.84	Forb	Michigan Wildflower Farm	Michigan
Ear-Leaved Brome	3.28	Forb	Prairie Moon Nursery	Minnesota
Purple-sheathed graceful Sedge	0.92	Sedge	Prairie Moon Nursery	Minnesota
Showy Goldenrod	0.41	Forb	Prairie Moon Nursery	Minnesota
Sweetfern	10.90	Forb	Sheffield's Seed Co.	Wisconsin
Tall Thimbleweed	1.05	Forb	Michigan Wildflower Farm	Michigan
Tamarack	2.55	Tree	Sheffield's Seed Co.	Prince Edward Island
White Spruce	1.96	Tree	Sheffield's Seed Co.	New York
Wild Bergamot	0.30	Forb	Michigan Wildflower Farm	Michigan
Wild Mint	0.13	Forb	Prairie Moon Nursery	Minnesota
Zig-Zag Goldenrod	0.31	Forb	Prairie Moon Nursery	Minnesota

Table 1: The study species and their weight, functional type, source, and location of origin.

	Percentage			Germination Velocity		
Species	p-value	f ratio	df	p-value	f ratio	df
Black Spruce	0.085	5.196	1,4	0.015	16.643	1,4
Common Bur Sedge	0.374	1.000	1,4	0.374	1.000	1,4
Common Milkweed	0.002	50.695	1,4	0.009	22.305	1,4
Ear-Leaved Brome	0.345	1.144	1,4	0.014	17.358	1,4
Purple-sheathed graceful Sedge	-	-	-	-	-	-
Showy Goldenrod	0.001	72.824	1,4	0.007	26.464	1,4
Sweetfern	0.116	4.000	1,4	0.117	3.975	1,4
Tall Thimbleweed	0.374	1.000	1,4	0.374	1.000	1,4
Tamarack	0.020	14.146	1,4	0.009	22.743	1,4
White Spruce	0.001	68.426	1,4	0.000	114.975	1,4
Wild Bergamot	0.261	1.710	1,4	0.154	3.079	1,4
Wild Mint	0.001	88.402	1,4	0.001	93.405	1,4
Zigzag Goldenrod	0.003	41.954	1,4	0.001	64.083	1,4

significant

marginally significant

Table 2: The p-value, f ration, and degrees of freedom for each ANOVA between the two treatments.

FIGURES:

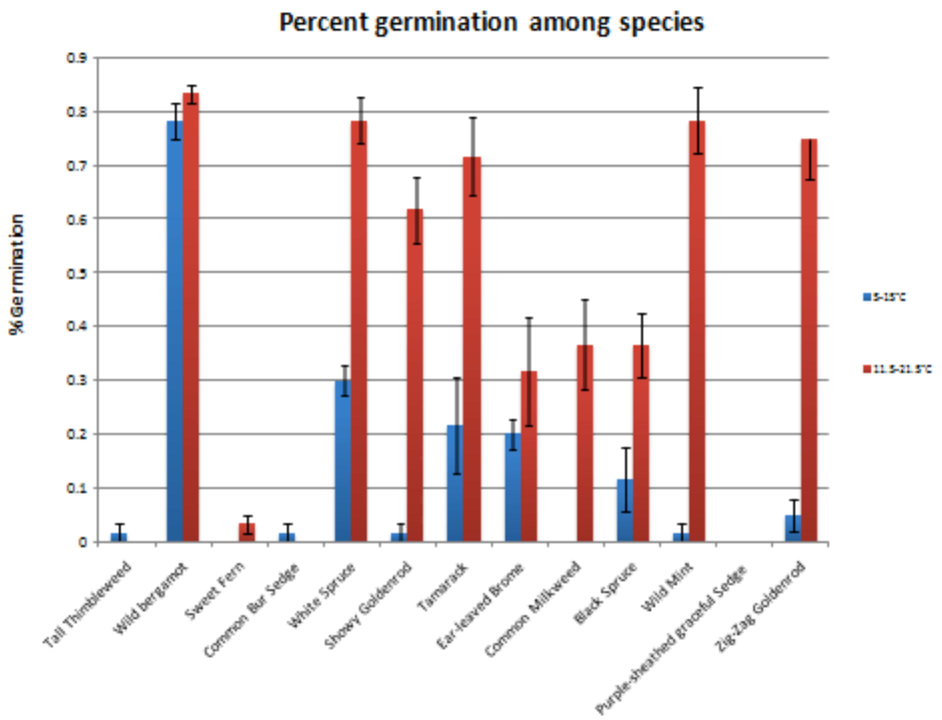

Figure 1: The germination percentages for each species and the two temperature regimes.

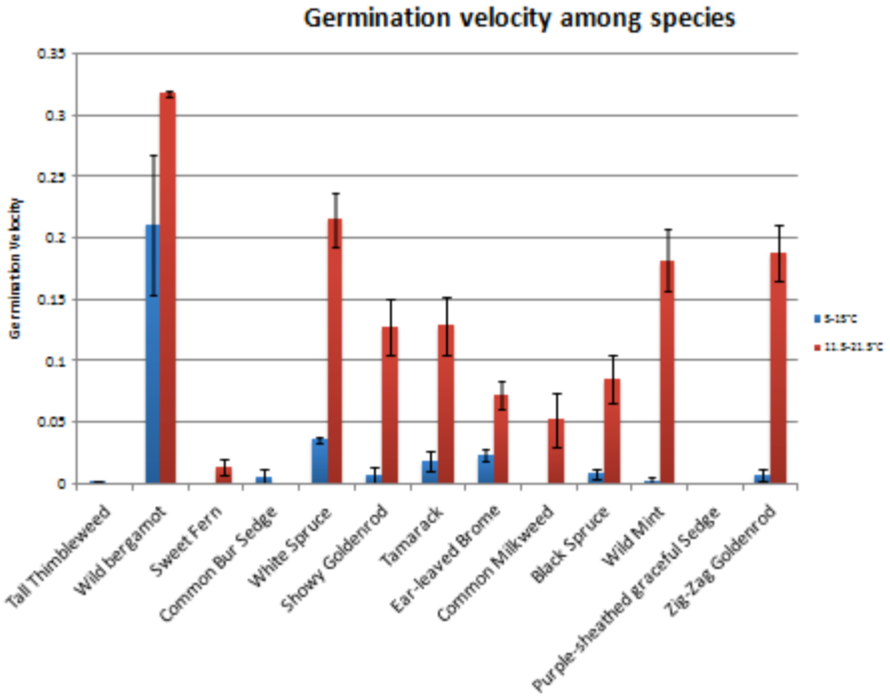

Figure 2: The germination velocites for each species and the two temperature regimes.

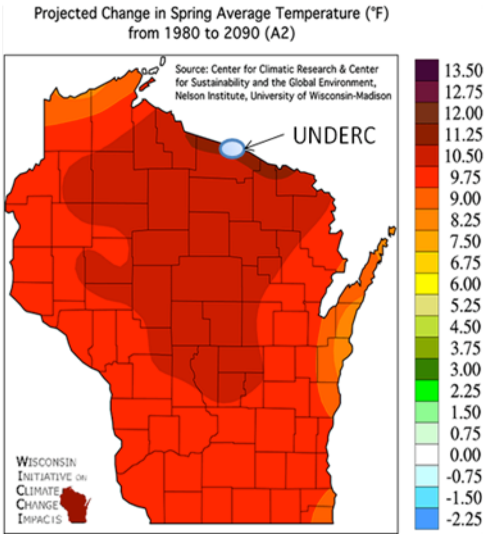

Figure 3: The WICCI predicts that in our study area we will see a 6.5°C (12°F) change in temperature by the year 2090.