BRINGING BROADER IMPACTS TO THE COMMUNITY VIA UNIVERSITY K-12 PARTNERSHIPS: GROWTH IN AND SEED QUALITY OF *BETULA NEOALASKANA* SARGENT

By

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Abstract

Betula neoalaskana Sargent is the most abundant birch species in Alaska. All parts of the tree can be used in creating timber and non-timber products, and birch stands provide high-value ecosystem services for ecotourism and outdoor recreational purposes. For these reasons, the OneTree Alaska program of the University of Alaska Fairbanks uses Interior Alaska white birch as the centerpiece of its work.

This M.S. thesis is a contribution to OneTree Alaska's goal of raising the public's understanding of the effects of Interior Alaska's lengthening growing season on the growth and reproduction of the local birch resource. Specifically, the thesis relates to the growth and reproduction of the offspring of the original "one trees" harvested on Nenana Ridge in October 2009.

The saplings have been growing in the Generation OneTree Research Plot in the T-field, north of the Smith Lake on the University of Alaska Fairbanks campus, since June 2011 and represent half-sibling families reared from the seed of 8 maternal trees. As seedlings, they were reared for growing seasons of variable length, both by students at the Watershed Charter School of the Fairbanks North Star Borough and by OneTree personnel in a University of Alaska Fairbanks growth chamber.

Prior to this study, end of year measurements had been taken of the young trees in the T-field for all but one year and established that the length of the first growing season persistently affected the number of stems and the diameter at breast height (DBH) of the main stems. New findings in this thesis show that the elevation difference among trees impacts the number of infructescences and germination rates but not the number of male catkins. At least for the 2018 seed crop, seeds from trees planted at higher elevations in the T-field showed higher germination

rates than those planted at lower elevations, while they produce fewer infructescences at up slope.

Other findings demonstrate that sibling family does not have an effect on either vegetative or reproductive growth. Instead, the length of the first growing season provides for a diversity of canopy shapes across sibling families. The most significant finding is the effect of elevation on female reproductive growth: It suggests a number of next steps, tools, and analysis to better understand environmental variables that work alongside elevation in determining growth and reproductive success. Soil moisture and pH (H_2O), Carbon/Nitrogen ratio, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine micronutrient composition, sensors to capture wind speed/direction and solar radiation, photosynthetic traits, and chlorophyll concentration measurements could all be valuable in further elucidating the hypotheses being advanced by this research regarding the interactions between changing environment and reproduction.

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Chapter 1. Introduction

1.1. *Betula neoalaskana* Sargent: boreal forest and birch in Alaska

The boreal forest is the most widely distributed forest type in the world, as it "extends from Manitoba west through Alaska, from elevations near sea level to about 1000m" (Pojar, 1996). "In Alaska, the boreal forest zone is essentially intermontane, between the coast, Alaska and Brooks ranges" (Hogg, 1994). The boreal forest consists of both coniferous trees such as *Picea, Abies, Pinus*, and *Larix* and hardwood trees such as *Populus*, *Betula*, *Alnus*, and *Salix*.

Betula, colloquially known as birch, covers a wide area in the boreal forest (Figure 1 *Geographic range* of Betula neoalaskana Sarg.), especially in areas where disturbance has created large cleared spaces either through natural or artificial causes. Its seeds are widely distributed to open spaces by wind, and its strong photosynthetic ability under bright sunshine makes it a successful early successional species (Kanie, 2018). Because of these characteristics, birch helps with the process of reforestation.

Figure 1 Geographic range of *Betula neoalaskana* Sarg. (Flora of North America)

The shaded area represents the only natural range of Betula neoalaskana in the world. The habitat is from the west coast of Alaska to the middle of the state of Ontario. The study sites of this research are inside the Tanana watershed which is in the natural range (Furlow, 1997).

Until recently, *Betula neoalaskana* was classified as a subspecies of *Betula papyrifera* Marshall (paper birch) (Furlow, 1997). Distinct from *B. kenaica* and *B. papyrifera*, *B. neoalaskana* Sargent is the most common birch species in Alaska. Interestingly enough, *Betula neoalaskana* is closely related to birch species in Asia, for example, *B. japonica* Siebold and in Europe (*B. pendula*).

In terms of human use, birch has both high-end and low-end value as a timber species. It is an inexpensive hardwood when used to make chopsticks, popsicle sticks, and edge glued panels (Nicholls, 2010). Edge glued panels were introduced by United States Department of Agriculture (USDA) for *Betula papyrifera* Marsh. with an advantage of "lower cost of equipment, flexibility of the product size, and needs in local markets." In addition to using *B. neoalaskana* as a timber species, it has many non timber forest products (NTFPs) values: bark, chaga, and sap are just few of them used all over the world (State of Alaska Department of Natural Resources Division of Mining, 2008). Furthermore, birch adds value to the recreational use of the forest such through eco-tourism and other outdoor activities which are valuable components of ecosystem services (Costanza et al., 1997; Maher & Anne, 2013; Бояр & Boiar, 2004). In the OneTree Alaska program, birch is respected as an educational inspiration for STEAM (Science, Technology, Engineering, Art, and Math) and life-long-learning (Belle, 1982; Watson, Watson, & Ramaley, 2013).

As we can observe in Alaska and the rest of the circumpolar region, climate change impacts the forest and its ecosystem in various ways (Kudo, 2019; Zhang, Bielory, & Georgopoulos, 2014). For example, trees' pollen seasons have been researched both in Japan and North America. Global interest in the effects of climate change is high especially for these days. It is complex and too many variables to measure the indicators of climate change and its effect. Arctic Council explained that human stewardship by people without borders is necessary to the health of our environment, for successful attainment of resilience and adaptation. The Arctic Council says that "successful collaboration requires innovation and meaningful engagement of the full range of Arctic stakeholders. (Council, 2016) " For these reasons, I emphasize the importance of community involvement, stimulation of citizen science, and life-long-learning, which are also central tenets of the OneTree Alaska program.

1.2. OneTree Alaska

1.2.1. Broader Impacts Activity

OneTree Alaska strives to model the Broader Impacts (BI) Guiding Principles of the National Alliance for Broader Impacts (NABI) in all its activities of "planned experience, engagement, action, function, etc. that is conducted over a finite period of time for a specific purpose and with a target audience." NABI, as a community of practitioners organized to help guide the National Science Foundation's consideration of its BI criterion, values evidence-based practices, which "refers to any concept, model, or strategy that is based on or informed by evidence- such as some type of research, metrics, performance, educational research." NABI's Broader Impacts Working Group defined a wide range of educational broader impacts to "improve STEM education and educator development at any level, increase public scientific literacy and public engagement with science and technology, development of diverse, globally competitive STEM workforce, and full participation of women, person with disabilities, and underrepresented minorities in STEM. (Adetunji et al., 2015; Moskal et al., 2007; Nadkarni & Stasch, 2013)" All types of BI enhance partnerships between academia, industry, and others to increase economic competitiveness of the United States in the 21st century.

1.2.2. STEM to STEAM

STEM stands for Science, Technology, Engineering, and Mathematics. The acronym was created by Judith Ramaley, who worked for the National Science Foundation in 2001. Rodger W. Byveem, a retired director of the Biological Sciences Curriculum Study, mentioned that the United States needs "a broader, more coordinated strategy for pre-college education in

STEM" in a 2010 article for the journal, Science (Association for the Advancement of Science, 2010). He emphasized that STEM develops the personal skills and best prepared citizens for the "grand challenges of the 21st century." According to him, a true STEM education increases a "pupil's understanding of how things work and improves their use of technologies" while letting students practice "problem solving and innovation" for every "nation's agenda (Stohlmann, Moore, Roehrig, Stohlmann, & Moore, 2012)." In other words, schools educate both for the public good and private citizen's good. Byveem's article and other studies supported the idea that STEM education is an important new feature of education for global economic competition in the 21st century.

STEM education is evolving into STEAM. One of the greatest scientists in the history of *Homo sapiens*, Albert Einstein said,

> *After a certain high level of technical skill is achieved, science and art tend to coalesce in esthetics, plasticity, and form. The greatest scientists are always artists as well.*

Watson (2013) suggested five key activities of STEAM; creating, inventing, innovating, engineering, controlling (Watson et al., 2013). The holistic process from thinking to outputting cannot be separated; they are connected to each other, so interdisciplinarity is required in education as well.

1.2.3. Concept and History

The OneTree Alaska project began in Fairbanks, Alaska through a small Wood Utilization Research grant in 2009 (Helfferich, Dawe, Meyers, Tarnai, & Parker-Webster, 2014). It was inspired by the 1998 United Kingdom project, OneTree, in which local artisans crafted objects from the wood of a single large oak ("onetree.org.uk - One Tree," n.d.). The research assistant professor of the School of Natural Resources and Extension, also my graduate committee co-chair, Dr. Janice Dawe, said in 2013 that introducing studensts to science

> *... through art is a natural offshoot of OneTree. Art serves as the invitation to explore STEAM skills in a natural way.*

OneTree Alaska teaches "an appreciation of the boreal forest and its potential products while using a nontraditional approach." The program has four main objectives. It engages teachers, students, scientists, artists and community members in the processes of 1) observing, documenting, and writing about their observations using the Grinnell System of Nature Journaling (Herman, 1986), 2) participating in community service and 3) citizen science projects, and 4) building community and exploring potential new forest products through enterprises such as the Fairbanks Birch Sap Cooperative (Dawe, 2015).

OneTree provides place-based professional development courses for teachers. Producing and consuming local food, using local trees for art projects, and learning the culture of the place are all parts of a place-based approach to education. All knowledge has a place of origin, whether indigenous or brought from outside a region, and the knowledge becomes a tradition when it is passed along to the next generation. Therefore, producing and consuming NTFPs and creating art out of local materials provide a holistic approach for STEAM place-based education; recognized as such through programs like 'Golden Heart Grown ("Agriculture – FEDC," n.d.).' The Golden Heart Grown brand/logo was established in 2016 to encourage interior Alaska grown products to be consumed.

Throughout the years of the OneTree programs, scientists and artists have collaborated with teachers and communities throughout the Fairbanks North Star Borough and other parts in Alaska, including Bethel and Juneau. Climate change scientists have given classes and presentations regarding birch sap production. Scientists and artists teach and have created exhibitions of birch in the community and in the OneTree Alaska STEM to STEAM Studio in the Lola Tilly Commons Building on the UAF campus. The first Fairbanks STEAM Institute, for example, produced an artist book called *Trailwalk*, that drew from the scientific literature, the students' observational Grinnell Journals and their drawings of wild plants growing along the trails in the arboretum on the UAF campus.

1.3. Justification

This M.S. thesis is one part of the overall OneTree Alaska life-long-learning STEAM education program. As a graduate student and staff member of OneTree Alaska, I report on the growth and quality of seeds, and how these matters can enhance STEAM education concerning Interior Alaska white birch (*Betula neoalaskana* Sarg.) progenies in the T-field. As a science educator, I value logical thinking. To impart this skill to students, I provide fact-based and interdisciplinary lectures. Since society is always changing and science technology is developing day by day, both I and the students have to be open-minded. I also care about children's safety and give their well-being the highest priority. Without these, children are not ready to learn subjects. My motivation for this thesis, my research, and all my work is contributing to a better society and STEAM education to all ages without limitation of borders, and sexes.

Chapter 2. T-field Vegetative and Reproductive growth

2.1. Introduction

2.1.1. Problem statements

Birch saplings planted in a research plot in the "T-field" on the University of Alaska Fairbanks campus represent eight half sibling families grown from the seed of eight maternal trees harvested on the Nenana Ridge in October 2009. In fall 2010, the seeds were germinated and grown for three different length growing seasons as an inquiry investigation by three K-12 classrooms at Watershed Charter School (Fairbanks North Star Borough School District). The experiment was replicated in a biological growth chamber on the University of Fairbanks Alaska campus. The saplings growing in the T-field are those produced in the university growth chamber, where daily maximum and minimum temperature and daylength were manipulated on a weekly basis to simulate May through September growing conditions in Fairbanks, as recorded by the National Oceanic and Atmospheric Administration (NOAA) ("National Oceanic and Atmospheric Administration | U.S. Department of Commerce," n.d.).

The students' and university researchers' original question was: "How do birch seedlings respond to the lengthening growing season that has been experienced in Interior Alaska since the mid-1970's?" Students tracked seedling growth for three different length periods: 3, 4, and 5 months. Both the start and the end of the growing seasons were shortened for 3month cohort whereas 5month cohort seedling being growth chamber the longest. Following this initial growing period, seedlings were placed into dormancy conditions in a cold room on the University of Alaska Fairbanks campus for at least three months. The seedlings grown at Watershed School were taken out of dormancy and placed back to the classrooms in spring, 2011 and allowed to leaf out. The students were surprised by how much the initial growing season length affected seedling height and number of leaves. They shared their findings with the Fairbanks community during a public science-art exhibit at the Morris Thompson Cultural and Visitors Center in April 2011, where the university's growth chamber-produced seedlings were removed from dormancy and put on display. Community members were so interested in the students' work and the seedlings that the university decided to dedicate a space on campus lands where the seedlings could continue to be grown and observed. On June 2, 2011 the seedlings were transplanted into the T-field by members of Boy Scout Troop 92 and allowed to establish themselves for later study.

The community's interest in the project had another important outcome: It led the state legislature to dedicate funding in 2012 to expand the work through Project Boreal Alaska – Learning, Adaptation, Production (BAKLAP). This funding has led to many further investigations. For example, in September 2012, a University of Alaska Fairbanks undergraduate ecology class conducted a lab in the T-field, during which the students took height and diameter measurements, and looked at the branching characteristics of two different seedling classes, i.e. those grown for three months vs. those grown for five months. The students found that seedlings grown initially for three months were significantly shorter, had a smaller diameter at 10 cm above ground level, and were significantly branchier near their base than seedlings grown for five months.

The saplings have now grown nine years in the T-field: my thesis considers whether the effects of the different length of their first growing season have eased since fall 2012. Did saplings from a specific maternal tree respond to nine growing seasons differently compared to others? Or did environmental conditions in the T-field exceed the inherited characteristics of the sibling families? Did vegetative growth and the initiation of sexual reproduction differ among progenies?

All these questions may now be explored and discussed. 101 of the 128 surviving trees (of 144 originally planted) reproduced in 2018, an increase since 2016, when sexual reproduction was observed in 10 trees. Both vegetative and reproductive growth of birch trees in the T-field have been observed and archived since transplanting, but no results have been published to date.

2.1.2. Hypothesis

Is there an effect of climate change to the birch saplings in the T-field? The T-field Next Generation OneTree research plot was established as a long-term monitoring site because of the community's interest in the project. The T-field plot was designed to evaluate the contributions of sibling family and initial growing season length (3, 4, 5 months) subsequent growth and reproduction.

The vegetative and sexual reproductive growth of birch trees in T-field differ by sibling family, inherent to the maternal trees on the Nenana Ridge. Birch trees also had differences in the length of their first growing season. Growing conditions in the T-field are more or less uniform across the whole area: the environment such as the elevation and the distance from the open space (the edge of sub-canopy) does not affect vegetative and reproductive growth of birch trees over the inheritance. The tree which produced female infructescence in 2017 would have a higher number of female infructescence in 2018 compared to the trees reproducing for the first time in 2018.

2.2. Material, Methods and Timeline of T-field

2.2.1. Original experiment from 2009 to 2011

Eight trees were harvested from N64 40. W148 33., approximately 3 miles south from Skinny Dick's Halfway Inn on Parks Highway in 2009 (Figure 2 Study Site in the Range of *Betula neoalaskana* Sarg. (Google, n.d.) Figure 3. Close Look of the Study Site Locations (Google, n.d.)). Trees were given numbers from closer to the highway. NR8 was the oldest among the eight trees; the first tree ring of NR8 was counted to 1841. NR17 had a much larger diameter at breast height (DBH) compared to NR8, however, the core of its stem had already decayed so we do not have a way to know its age. The youngest tree was from 1938.

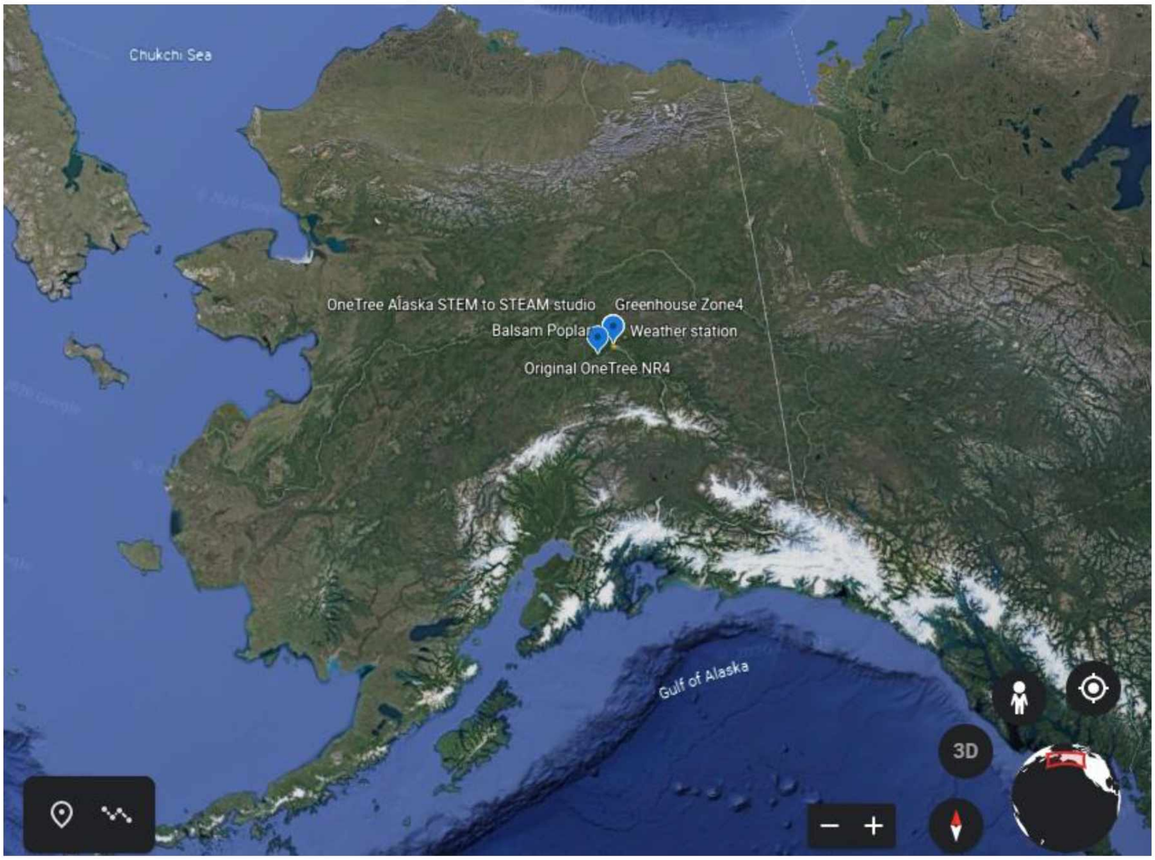

Figure 2 Study Site in the Range of *Betula neoalaskana* Sarg. (Google, n.d.)

The yellow point shows the place in the Nenana Ridge where original OneTrees were harvested in 2009. The blue point is the location of University of Alaska Fairbanks, home to the T-field, the greenhouse, and STEM to STEAM studio.

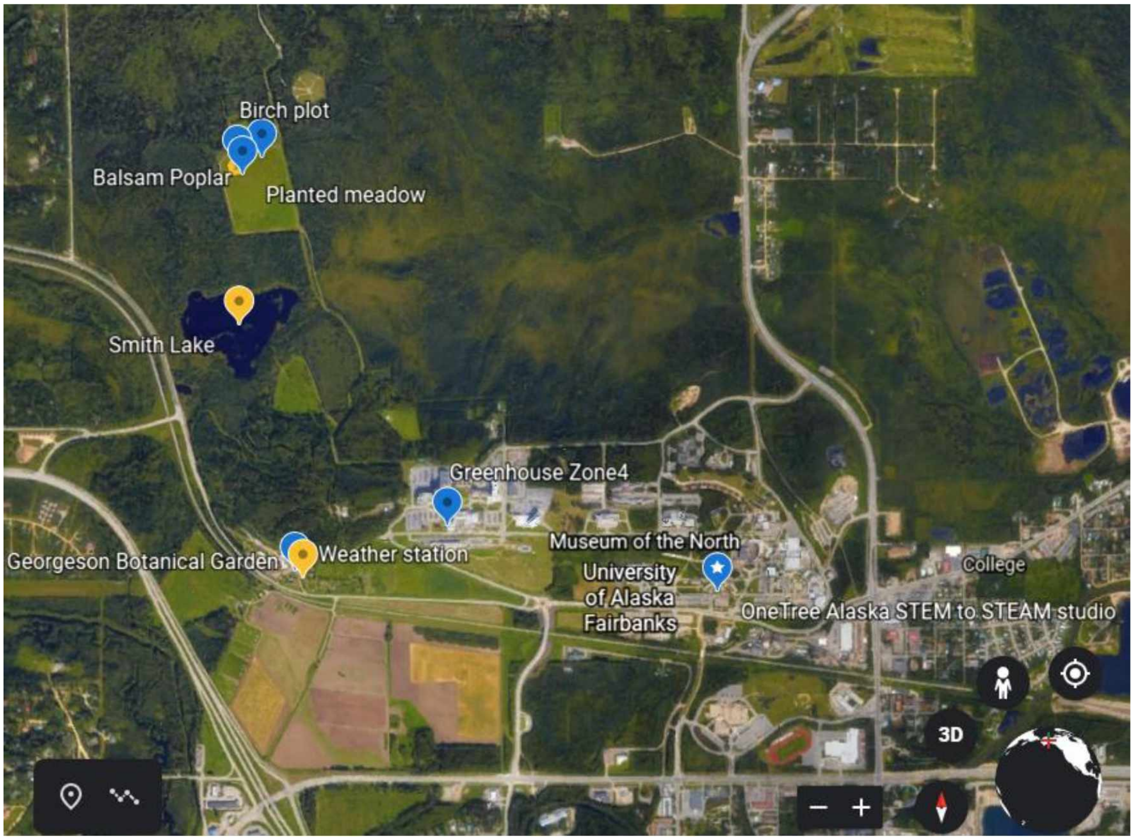

Figure 3. Close Look of the Study Site Locations (Google, n.d.)

This is the Tanana basin watershed. The trees were harvested from the point Original OneTree Nenana Ridge, a city on the Parks Highway.

The seeds from eight trees were planted in conetainers by the students of Watershed Charter School of Fairbanks North Star Borough School District. Their interest was "how do birch seedlings respond to the lengthening growing season that has been experienced in Interior Alaska since the mid-1970's?" To answer this question, seedlings were grown for three different simulated growing seasons in a growth chamber in the; 3, 4, or 5 months. The longest growing season for a group was 5 months, which is the predicted longest growing season over climate change. The shortest growing season was 3 months in this experiment, which was the average length of the growing season until the mid-1970's. The temperature and day length for the growing season were calculated by Dr. Janice Dawe and Mr. Zac Meyers based on the data of this century from the historic climate database of NOAA.

Eighteen seedlings derived from each of the 8 maternal trees for six each of different growing seasons, for a total of 144 seedlings, were transplanted into the T-field on June 2nd, 2011 by members of Boy Scout Troop 92. 18 replicate set of 8 trees (NR4, NR5, NR8, NR13, NR14, NR15, NR16, NR17) include replicates 4, 7, 8, 14, 15, and 18 had 3 months of first growing season, replicate 1, 3, 5, 10, 13, and 17 had 4 months, and replicate 2, 6, 9, 11, 12, and 16 had 5 age cohort. 60 boundary trees were also planted around the perimeter of the research plot to ensure equal shadowing of all research trees. These 60 trees derive from the Arboretum of UAF campus, originally corrected by Ms. Kyoko Okano. They were not measured in any way during this experiment. Trees were planted on a 2.5m grid. 16 trees did not root to the T-field, 128 trees are still growing in T-field today (Figure 4. The T-field (Google)). The positions of trees in replicates is shown in Figure 5. The Plan View of the T-field Birch Plot since 2011. The staircase shape of the plot is due to the distance from the fence; all trees are more than 5 meters away while using the space efficiently.

Figure 4. The T-field (Google)

A closer look at the plots in the T-field which is enclosed by a fence and encircled by a trail. The highlighted area is the stair-case shape of birch plot.

								B	B	B	B	B	B		
		N						B	5	13		8	B		3month
								B	14	4	16	15	B		4month
								B	17	14	8	16	B		5month
				B	B	B	B	B	15	4	13	5	B		
				B	14	8	4	16	8	16	14	4	B	B= Boundary trees	
				B	5	13	17	15	15	13	17		B		
				B	4	13	17	16	5	14		8	B		
B	B	B	B	B	15	8	5	14	13		15	4	B		
B	8	15	17	14	5	14	15	4	16	17	13	8	B		
B	4	13	5	16	8	17	16		4	14	5	15	B		
B	14	8	16	4	16	17	5			17	8	14	B		
B	17	5	15	13	4	15	13	8		5	4	13	B		
B	14	16		4		15	16	5	5	8	13	4	B		
B	15	8	5	13	8	14	4	13		15	14	17	B		
B	14	17		13	8	15			16	5	13	17	B		
B	16	15		4	4	5		14	14	8	4	15	B		
B	B	B	B	B	B	B	B	B	B	B	B	B	B		

Figure 5. The Plan View of the T-field Birch Plot since 2011

Number represent each Birch tree's maternal trees in Nenana Ridge. Boundary trees (b) were transplanted to provide shade. Colors represent the length of the first growing season. Blank spots are open spaces where trees died before 2018. Top of the figure is the north. See detailed information about the plot in Chapter 2 of Materials and Methods.

Before the establishment of the birch plot in June of 2011, Balsam poplar (*Populus tremuloides*) had been planted on the east side. The south side of the birch plot had been a planted meadow before the birch were transplanted and until now. The aspen plot and grassland are located more than 5 meters away from the boundary trees of birch plot, and they do not effect the light condition of birch plot. All aspen plot, grassland, and the birch plot are separated from public access by a 10 ft. tall fence; exclusion of any possible anthropogenic effects except for research and educational purposes.

T-field is located approximately 650 meters inside forest from vehicle accessible roads (Farmers loop, Yankovich road, Miller Hill road, and Sheep Creek road). There is Smith Lake 200 meters to the south (Figure 6. Location of Research Sites on the University of Alaska Fairbanks Campus (Google, n.d.)) The weather station which I cited in the section below as the growing condition is located at the Agricultural and Forestry Experiment Station (AFES). The weather station which I cited in the section below as the north side of the building in the fenced area. T-field faces south with a 5% of grade, the top of the slope is the Yankovich road and the bottom is the Smith Lake. It is in the periglacial environment of the Goldstream watershed, which is inside the Tanana river watershed.

Figure 6. Location of Research Sites on the University of Alaska Fairbanks Campus (Google, n.d.)

The T-field, weather station, STEM to STEAM studio, and Greenhouse are in Fairbanks. The data from the weather station was kindly supplied by Dr. Rick Thomann. The greenhouse zone 4 is managed by Dr. Meriam Karlsson.

2.2.2. LiDAR data and GIS Analysis for T-field in 2018

The elevation and vegetation data and the aerial picture of Fairbanks North Star Borough were downloaded from the FNSB website, and analyzed through a software ArcMap10.4 (ESRI, Redlands, CA, U.S.A.). The geological positions of the individual birch trees in T-field were sampled in a year after the transplant, which were combined with the LiDAR data of FNSB through this research. For the convenience of this research work, the contour lines were created over the data (Figure 7. Sub-canopy Created by GIS 10.4).

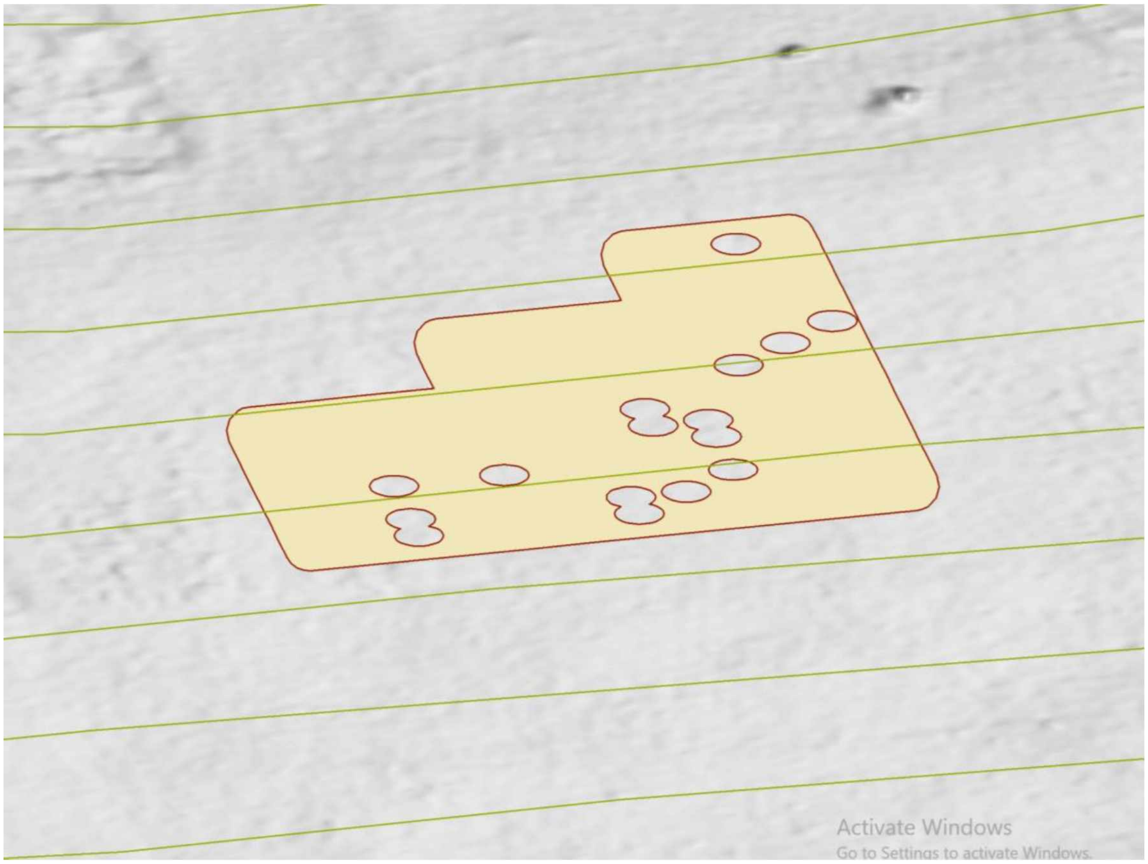

Figure 7. Sub-canopy Created by GIS 10.4

This image is based on the observation from the T-field in 2013. 16 blank spots represent the open space created by dead trees. The green lines are contour lines.

The polygon of the sub-canopy was also created: since 16 out of 144 trees died before the year of 2016, the distance from the edge of sub-canopy (0 ~ 9.15 m) differ among trees. In other words, some of the trees have advantages over others because of the 16 blank spots, by the competition of the resources, such as over and below soil space, sunlight, soil, and nutrition. There had not been any data taken on soil nutrition and sunlight so far, therefore, to substitute this disadvantage, I calculated the distance from the edge of the sub-canopy with ArcMap GIS. I assume the position of trees in the plot would give a correlated consideration of growing condition differences, such as soil nutrition, sunlight, water, and wind.

2.2.3. Growing condition: precipitation and temperature data

The temperature and precipitation data of Fairbanks Agricultural Farm Climate Station from 2011 to 2018 were provided by the climatologist Rick Thoman of the International Arctic Research Center. During this period, birch growing seasons of Fairbanks were the shortest in 2013 for 3.1 months, the longest in 2011 for 4.4 months, and the T-field had an average of 3.7 months growing season from 2011 to 2018 (Table 1. A Comparison of Average Temperature and Precipitation from 2011 to 2019 to the Normal Years of 1981-2010). It was drier in 2011, the year of transplanting, but it has been wet from 2014 to 2018, as highest 143% as the precipitation compare to the average year of last decades. This time period has seen as high as 140% of precipitation from the average of 1981 to 2010. 2014 - 2018 has also been 1.1 to 2.7°C warmer than the average of 1981 to 2010. Therefore, T-field had wet and warm years compared to previous decades.

Table 1. A Comparison of Average Temperature and Precipitation from 2011 to 2019 to the Normal Years of 1981-2010

This data was taken from the weather station at the Fairbanks Experimental Farm. The School of Natural Resources and Extension has managed the weather station since 1902. Two columns on the right were added for clarification. The T-field has had hot and wet growing seasons the past 6 years.

Year	Temperature (°C) Departure to 1981-2010 Normal	Precipitation Percent to 1981-2010 Normal	Growing season in month	Hot or Cold	Wet or Dry
2011	-0.11	0.85	4.40	ave	dry
2012	-1.83	1.02	3.73	cold	ave
2013	-0.22	0.94	3.13	ave	ave
2014	1.11	1.39	3.33	hot	wet
2015	1.11	1.33	3.87	hot	wet
2016	2.72	1.37	4.17	hottest	wet
2017	1.28	1.43	3.27	hot	wet
2018	1.28	1.36	3.53	hot	wet
2019	2.61	1.40	4.30	hottest	wet

2.2.4. Stem numbers, Height, and DBH measurement in 2018 by a class

The number of stems, height of the stems, and diameter at breast height (DBH) were measured by the class of Dr. Nancy Fresco, NRM240 Natural Resources Management and Inventory, in September, 2018. Eight undergraduate students of the University of Alaska Fairbanks, Dr. Fresco, and Dr. Janice Dawe measured the 128 birch trees in T-field in two days. I deeply appreciate their contributions to OneTree especially for one of our goals, life-long education.

2.2.5. Reproduction assessment

The female infructescences were counted before being collected from the shoots and put into envelopes. The number of infructescences by tree was written on the envelopes. I sampled seeds from August to October. Although the seeds were sampled as soon as becoming mature before the wind distributed them on the ground, it is inevitable and natural to assume that some percentage of seeds were on the ground and not in the seed envelopes. We have no way to estimate the amount of seed loss but hereafter I assumed that the amount of loss was equally likely for all trees. Besides counting the number of infructescence during sampling, I counted how many infructescences still remained on September 28th, 2018, since some infructescence were too high to reach safely or could not be sampled before being covered by snow. The number of infructescences remaining on trees were added to the number of sampled infructescences.

I counted male catkins on September 17th, 2018, on every tree, assisted by my faculty committee members, Dr. Janice Dawe and Mr. Scott Yeats. There were no leaves remaining on shoots, which decreased the chance of missing any catkins. To make the counting process easier and more precise, they were counted if there was a single catkin at the end of shoot, a twin, or more. Tips of shoots have a pair or a trio of male catkin, as maximum they can have 4 or 5 on a tip. After the catkins were counted by one observer, another observer double checked if he missed any catkins. The total number of catkins were calculated by summing all single and multiple catkin sets; i.e. 10 of single and 24 pairs of twin catkins equal to 58 of total catkins on a tree.

2.2.6. Statistic analysis

Data and statistical analysis were conducted using MS Excel 2016 (Microsoft) and SPSS Statistics (IBM) softwares. Number of stems (N = 128), height (N = 128), diameter at breast height (also known as DBH) (N = 128), number of catkins (n = 79), and number of infructescences (n = 100) were analyzed with One-way ANOVA and post-hoc Bonferroni test.

The tests were conducted and compared among Genotypes (NR 4, 5, 8, 13, 14, 15, 16, 17), Month Cohorts (3, 4, 5 months), and Replicates (1~18).

Regression analysis was conducted between all dependents and the position on the slope which defined with elevation (172.4 m ~ 175.2 m) and distance from the edge of sub-canopy (0 ~ 9.15 m). Additionally, Student's T-test was performed between trees over (n = 66) and below (n = 61) elevation of 173.5 m. Student's T-test was also conducted to the number of catkins and the number of infructescences in 2018 between two tree groups: a group of trees which produced infructescences in both growing seasons of 2017 and 2018 (n = 27) and another group of trees which produced infructescences only in 2018 (n = 72).

2.3. Results

2.3.1. Vegetative data of T-field in 2018

According to the one-way ANOVA analysis and post-hoc Bonferroni analysis, vegetative growth data only had significant differences on the number of stems between the 3month and 5month cohorts and on the DBH of Replicate 2 and 15 (Table 2. Growth Data as of 2018 Organized by Maternal Trees). Replicate 2 is a 5 month cohort and Replicate 15 is a 3 month cohort. Hence, the differences between DBH of the replicate derived from the difference of month cohort, the length of first growing season. The trend was also seen before the trees were transplanted to the T-field according to the citizen scientists from the FNSB school district. The difference in tree shape (the number of stems) has not changed in 8 years of growing seasons after the establishment of the seedling (Table 3. Growth Data as of 2018 Organized by Month Cohorts).

There was no statistical significance ($p=0.05$, ANOVA) of height of trees by Progenies, Replicates, nor Month cohorts. The regression analysis between elevations and the distance from the edge of sub-canopy were also not significance on height, DBH, nor the number of stems.

Table 2. Growth Data as of 2018 Organized by Maternal Trees

NR stands for Nenana Ridge, the place maternal trees were harvested. The numbers along the furthest left-hand column are the names of the maternal trees. Height, number of stems, Diameter at the Breast Height were measured in September 2018. The number of catkins and infructescence were counted in September 2018 and the germination rate was observed in January 2019. N is the number of the progenies that had survived until 2018. There were no statistically significant differences among the progenies of the different maternal trees.

Table 2 continued

NR		Height (cm)	Number of Stems	DBH (mm)	Number of Catkins	Number of Infructescences	Germination Rate on 21 day	N	n reproduced Catkins	n reproduced Infructescen
4	Average	468.9	1.3	43.1	27.2	58.0	0.128	18	9	14
	Standard Deviation	133.4	0.4	9.5	45.1	112.9	0.090			
	Maximum	688	2	57.0	154	395	0.283			
	Minimum	254	1	14.0	0	0	0.017			
5	Average	514.6	1.5	47.9	38.1	44.7	0.173	16	11	11
	Standard Deviation	76.1	0.6	12.7	61.8	99.4	0.190			
	Maximum	623	3	67.7	203	395	0.475			
	Minimum	394	1	33.1	0	0	0.017			
8	Average	520.5	1.5	49.8	133.9	44.4	0.187	17	15	14
	Standard Deviation	90.6	0.8	9.3	169.5	56.6	0.120			
	Maximum	690	3	71.5	554	158	0.475			
	Minimum	352	1	30.3	0	0	0.017			
13	Average	522.9	1.5	43.3	20.8	97.7	0.096	16	7	15
	Standard Deviation	112.3	0.7	13.6	33.2	137.4	0.110			
	Maximum	707	3	68.5	91	463	0.464			
	Minimum	304	1	8.3	0	0	0.000			
14	Average	489.6	1.5	40.2	11.9	21.2	0.220	17	9	15
	Standard Deviation	109.5	0.6	12.7	24.3	26.8	0.200			
	Maximum	698	3	57.6	95	95	0.642			
	Minimum	290	1	8.5	0	0	0.017			
15	Average	467.1	1.6	43.8	47.2	29.9	0.242	17	12	12
	Standard Deviation	122.1	1.0	15.3	84.5	58.3	0.120			
	Maximum	680	5	82.8	338	223	0.433			
	Minimum	157	1	9.2	0	0	0.042			
16	Average	544.3	1.6	47.0	30.6	59.3	0.192	14	8	12
	Standard Deviation	79.3	0.9	11.8	79.8	103.4	0.150			
	Maximum	677	4	58.5	208	444	0.542			
	Minimum	340	1	32.8	0	0	0.017			
17	Average	546.5	1.5	45.1	48.5	22.5	0.201	13	8	8
	Standard Deviation	73.3	0.8	14.5	90.7	56.8	0.160			
	Maximum	653	4	59.0	316	216	0.533			
	Minimum	425	1	8.3	0	0	0.042			

Month Cohort		Height (cm)	Number of Stems	DBH (mm)	Number of Catkins	Number of Infructescences	Germination Rate on 21st day	N
3	Average	497.3	1.8	41.4	36.6	54.2	0.143	43
	Standard Deviation	112.6	0.96	13.8	91.8	115.7	0.119	
	Maximum	690	5	68.5	542	463	0.464	
	Minimum	157	1	8.3	0	0	0.000	
4	Average	500.1	1.6	41.4	50	41.2	0.208	38
	Standard Deviation	97.7	0.64	11.3	105.4	80.4	0.168	
	Maximum	688	3	71.5	554	395	0.642	
	Minimum	254	1	8.3	0	0	0.017	
5	Average	520.8	1.2	51.1	47.7	45.4	0.179	47
	Standard Deviation	109.6	0.44	9.7	75.1	79.6	0.159	
	Maximum	707	3	82.8	338	395	0.567	
	Minimum	261	1	33.1	0	0	0.000	

Table 3. Growth Data as of 2018 Organized by Month Cohorts

Month cohorts stand for the length of the first growing season. The numbers along the furthest left-hand column are the number of months that trees grew. Height, number of stems, Diameter at the Breast Height were measured in September 2018. The number of catkins and infructescence were counted in September 2018 and the germination rate was observed in January 2019. N is the number of the trees within the cohort that had survived until 2018. The underlined numbers have significant differences of $p<0.05$.

2.3.2. Reproductive growth data of T-field in 2018

The elevation had an effect only on the number of infructescences but not male catkins. The Student's T-test of the number of catkins on the trees over the elevation of 173.5 had less infructescences than the trees below the elevation of 173.5 (Table 4. The Number of Catkins and Infructescences by Slope Position). However, the distance from the edge of sub-canopy did not affect either the number of infructescence or catkins. The Student's T-test on the trees that had produced infructescences in both 2017 and 2018 revealed that these trees reproduced significantly more infructescences than the trees which produced infructescences for the first time in 2018 which is shown as Table 5. A Comparison of the Infructescences Produced by Trees that Reproduced in both 2017 and 2018 and Trees that Reproduced only in 2018.

Table 4. The Number of Catkins and Infructescences by Slope Position

All the trees in the T-field were divided into two groups based on elevation. Almost half of the trees have an elevation over 173.5m and the other half have an elevation below 173.5m. Note that N=127 in this analysis because NR17-7 Replicate4 3month cohort was excluded from the analysis of reproductive growth. Accidental girdling caused this tree to produce an abnormally high amount of seeds in 2016, the effects of the girdling might continue to alter the seed production.

Elevation		Number of Catkins	Number of Infructescences	N
Up Slope	Average	39.9	**35.2**	66
	Standard Deviation	85.7	72.2	
	Maximum	554	395	
	Minimum	0	0	
Down Slope	Average	50.0	**60.7**	61
	Standard Deviation	95.5	111.3	
	Maximum	542	463	
	Minimum	0	0	

Table 5. A Comparison of the Infructescences Produced by Trees that Reproduced in both 2017 and 2018 and Trees that Reproduced only in 2018

98 trees produced seeds in 2018 for the first time while 29 reproduced seeds both in 2017 and 2018. The number of infurctescences reproduced by those two groups of trees were significantly different; the continuous reproduction increased the number of infurctescences on a tree in 2018. The averages are based on the number of infructescences on trees in 2018.

Note that N=99 (number of trees reproduced seeds in 2018) in this analysis because NR17-7 Replicate4 3month cohort was excluded from the analysis of reproductive growth. Accidental girdling caused this tree to produce an abnormally high amount of seeds in 2016, the effects of the girdling might continue to alter the seed production.

Continuous Infructescences Reproduction		Number of Infructescences in 2018	N
Only 2018	Average	**<u>36.0</u>**	72
	Standard Deviation	84.7	
	Maximum	463	
	Minimum	1	
Both 2017 and 2018	Average	**<u>150.7</u>**	27
	Standard Deviation	240.7	
	Maximum	395	
	Minimum	4	

2.4. Discussion

2.4.1. The effect of the first growing seasons

The effects of the length of the first growing season (3, 4, 5 month age cohorts) still can be seen in the difference between the number of stems and the DBH of the main stems of the 3 vs. 5 month cohort. It is possible to understand that the shape of crown and the distribution of non-photosynthetic cost in the space differed by the length of the first growing season. The trees in the 3 month cohort had more stems (average 1.8, maximum 5 stems) than the 5 month (average 1.2, maximum 3 stems): the 3 month cohort trees grew in width dimension from the winter buds after second growing seasons, whereas the 5 month cohort grew taller in shoot extension during the first growing season (Table 3. Growth Data as of 2018 Organized by Month Cohorts).

In natural condition under the resources competition and the theory of patch dynamics, it is understandable that the change in the first growing season gives the diversity of their life strategies to the stands (Pickett & White, 1985). The first research question of the original experiments since 2009 was the elongation of growing seasons due to climate change; this result agrees with other studies about climate change and its effect on the forest landscape dynamics, the meta scale experiments (Hiura, Sato, & Iijima, 2019).

2.4.2. The effect of elevation and the distance from the edge of the sub-canopy

The elevation difference among trees impacted on the number of infructescences but not male catkins. Prior works and review papers mentioned that "overwintering materials evoke male inflorescence but current metabolic process elicit female flowers' since the catkins are induced before budburst, whereas infructescences are induced during the growing season. It is also known for silver and hairy birch that "the frequency of parthenocarpy and apomixis can be high" when "low spring temperature" rather than rain suppress the catkin developments (Bark, Zasada, & Service, n.d.).

I assume that the difference of elevation gave the different growing conditions; underground water. The water underground would flow from the top to the bottom of the hill by gravity. It will be more wet at the bottom of the hill. However, the distance from the edge of the sub-canopy did not have an effect on either the number of male catkins or infructescences. The canopy is not completely closed yet, but lower branches just started touching each other in 2018.

The competition over space both above ground and underground did not significantly affect the data but it could possibly affect data in the future.

2.4.3. Resemblance from the former studies on birch and critiques

Research by Stern (1963) in birch reported that "the number of male and female flowers is governed by different sets of genes and environmental factors, and year-to year differences are greater for female than for male flowers. (translated through Perala & Alm, 1990) " The birch trees used in this research are from 8 maternal trees that harvested from Nenana Ridge; the trees in the T-field are half siblings but there is no way to know the pollen sources for both the original trees in Nenana Ridge, the trees in T-field, and the seedlings germinated in part of this experiment mentioned in Chapter 3 below.

Birch trees in nature are also known that the seed set from a flower on the opposite side of the crown is better: it is their life strategy to keep the DNA concentration low for organizing different flowering times for male catkins and infructescences in an individual tree. The prevention of self-pollination is their strategy and it actually gives advantage to offspring. Trees both in Nenana Ridge and T-field presumably would have not self-pollinated and have different paternal trees. It is possible to underestimate the effects of inheritance in this research as I do not know the pollen sources.

Chapter 3. Germination Experiment

3.1 Introduction

3.1.1. Problem statement

Seedlings of birch (scientific name, origin etc) were transplanted in the T-field on the UAF campus in 2011. A large number of the planted seedlings (128 of the 144) successfully grew into trees. Ten trees (one due to unintentional girdling) produced female infructescences in 2016. Thirty-four trees produced female infructescences in 2017. Seeds from the growing season of 2017 were collected and stored at room temperature until January of 2018. In January, five K-12 classrooms and the OneTree staff in the STEAM Studio on campus undertook a germination trial of all 2016 and 2017 seeds, to determine whether there were differences in seed germination between seed years and between sibling families. The results of the first germination trial showed that seeds from 2016 germinated much more successfully than those from 2017, and three sibling families, NR8, NR13, and NR17, had higher germination rates than the remaining five sibling groups. Accordingly, seeds from the 12 best seed production trees (nine came fromNR8, NR13, and NR17) were germinated during a second germination trial in the STEAM Studio and the 5 participating K-12 classrooms. Classroom teachers came to the STEAM Studio to set up their germination trays together, to ensure that the same protocol was followed and results could be compared across the six replicates. At the time of germination, the seeds from 2016 had been stored an additional year compared to those from 2017, but germinated at a higher rate than the 2017 seed, suggesting, at least anecdotally, that seed quality was higher in 2016 than in 2017.

In 2018, 101 out of 128 trees produced female infructescences, when the trees were only 8 calendar years old. The birch trees reproduced earlier than expected based on the information in the classical literature (U.S. Forest Services, n.d.). Seed quality remained an unanswered question in the literature (Finch-Savage & Bassel, 2016). As reported in Chapter 2, the number of female infructescences and male catkins of birch in T-field in 2018 did not differ by inheritance; progenies, replicates, or month-cohort. Elevation on the other hand affected the number of female infructescences but not the number of male catkins.

3.1.2. Hypothesis

Hypotheses, to account for differences in germination rate among the 101 seed-bearing trees, I tested during a 21-day germination trial include the following: Germination rate differs by 1) progenies, inherit to the maternal trees on the Nenana Ridge, 2) age cohort (the length of the first growing season) also affects the seed germination ability, 3) growing conditions are similar throughout the T-field: so that environment factors, such as elevation and distance from the edge of the study site, does not affect the germination of seeds over the inherited reasons, and 4) seeds produced in 2018 by trees that also produced seeds in 2017 can be expected to have a higher germination rate than seeds from the trees producing seeds for the first time. These are the hypothesis stated before the germination experiment of 2018.

3.2 Material, Methods, and Timeline

3.2.1. Seed sampling from T-field in 2018

Seeds were sampled from the 101 birch trees producing seeds in the T-field from August to October. Seeds were sampled every week by hand once they had dried to a brown color. A clean Dyson V6 Cordless Vacuum Cleaner (Dyson, Wiltshire, England) was used when seeds could not be reached from a 10-foot ladder. A long extension tool was attached to the head of the Dyson vacuum cleaner. It precisely vacuumed the infructescences without undue seed damage because of its "cyclone technology" ("Dyson | Dyson V6™ vacuum," n.d.). The seeds were easily removed from the core of infructescences. It could be inferred that the seeds were sufficiently mature to be distributed by wind (Rudolf, 1974).

Seeds were stored in paper envelopes (8.89*16.5cm) and dried at room temperature before being stored in tote containers at room temperature in January 2019. The number of infructescence were counted and recorded before being collected from the shoots. The total number of infructescences was determined at the end of the growing season for each tree. Almost all seeds were sampled by the first snowfall, however, infructescence out of reach at the top of the trees were observed and counted without being sampled and added to the calculation of the total number of infructescences. Seeds beyond reach were not used in the germination experiments. Although seeds were sampled before wind distribution, it is inevitable and to be expected that some percentage of seeds were not collected into the seed envelopes. There is no way to accurately estimate seed loss but hereafter it is assumed seed loss was equal across the site.

Seed sampling was carried out every week by advisory chair Dr. Janice Dawe and OneTree staff members, Chelsea Brown, Tiffany Lane, and Pearson Brodie, plus volunteers from the community of Fairbanks North Star Borough and OneTree K-12 teachers of the School District. I want to deeply acknowledge them for all their contributions and kind support.

3.2.2. Cupcake method

Plastic trays with 12 compartments to hold cupcakes were purchased and used for the germination experiment in this study. The lid was detached and used as a tray underneath the "cups". The tray was 32.85 * 26 * 8.6cm, and each tray had 12 compartments which were connected to each other at the point of ¾ in. from the bottom of the cups ("Inline Plastics - Innovative Food Packaging Inline Plastics," n.d.) (InLine Plastics, Shelton, CT, U.S.A.) (Figure

8. Plastic Cupcake Tray). Five small holes were made in the bottom of each cup to allow drainage. 180 g of PRO-MIX BX growing medium (PRO-MIX, Quakertown, PA, U.S.A.) were placed into each tray, so that each individual cup contained 15g of soil ("PRO-MIX BX MYCORRHIZAE," n.d.). Once prepared, the trays were brought to the Agricultural and Forestry Experiment Station (AFES) greenhouse in the Arctic Health Research Building. The cost of the plastic trays and growing medium can be found in the results section below to emphasize the low-cost of the experiment. Citizen scientists, students and community members are able to carry out this project on their own.

Figure 8. Plastic Cupcake Tray

The cupcake tray used for the gemination experiment in Zone 4 of the greenhouse in the Arctic Health Research Building. The size, price, and other details are given in Chapter 3. of Materials and Methods. Photo was taken from the website of "company".

Hundred twenty healthy seeds were selected from each tree. When we collected seeds into envelopes from the trees over several days, the seed envelope which had the highest number of infructescences was chosen. For one tree, there was a shortage of seeds as it only produced 110 seeds. Seed health was judged by color. Damaged, diseased or insect injured seeds were discarded. Ten seeds were sown in each cup. The seeds were placed and softly pushed into the medium but were not covered. The medium was saturated following sowing through sub irrigation with tap water through the bottom holes. Each cup with its medium was separated from the other in the tray. During the first and second week when most seeds germinated, the cups were watered from the top as well as from the bottom by soaking the cup in a half inch of water. Germination was counted when the pericarp of cotyledons was visible over the media surface. The number of seeds germinated was counted every day for the first and second week and then every two days when germination decreased in the third week.

3.2.3. Growing conditions in the greenhouse

One section of the AFES greenhouse in the Arctic Health Research Building at the University of Alaska Fairbanks was used throughout this experiment. This was thanks to the support of Dr. Meriam Karlsson. The greenhouse section was automatically controlled for humidity, temperature, and light conditions. The seeds were grown and germinated at 20.4 ± 2.5 °C for 31 days in January, 2019. The daily light level from HPS (high pressure sodium) lamps was 6 to 7 mol/day m^2 from 6:00 to 22:00, for a 16-hour day length. The only difference from the natural germination condition would be the lack of pre-chilling before germination. In nature, seeds are distributed to land and overwinter in snow before germinating the following spring.

Peak germination of yellow birch (*Betula alleghaniensis* Britt.) was observed "at 20C under continuous light" by Valanne (1973). "Fluctuating temperatures within the range of 20-30C may be more favorable for germination than a constant temperature for all birch" (translated through Perala & Alm, 1990). The growing condition in the AFES greenhouse appears to have been favorable to birch seed germination (Figure 9. Greenhouse Zone 4 in January 2019).

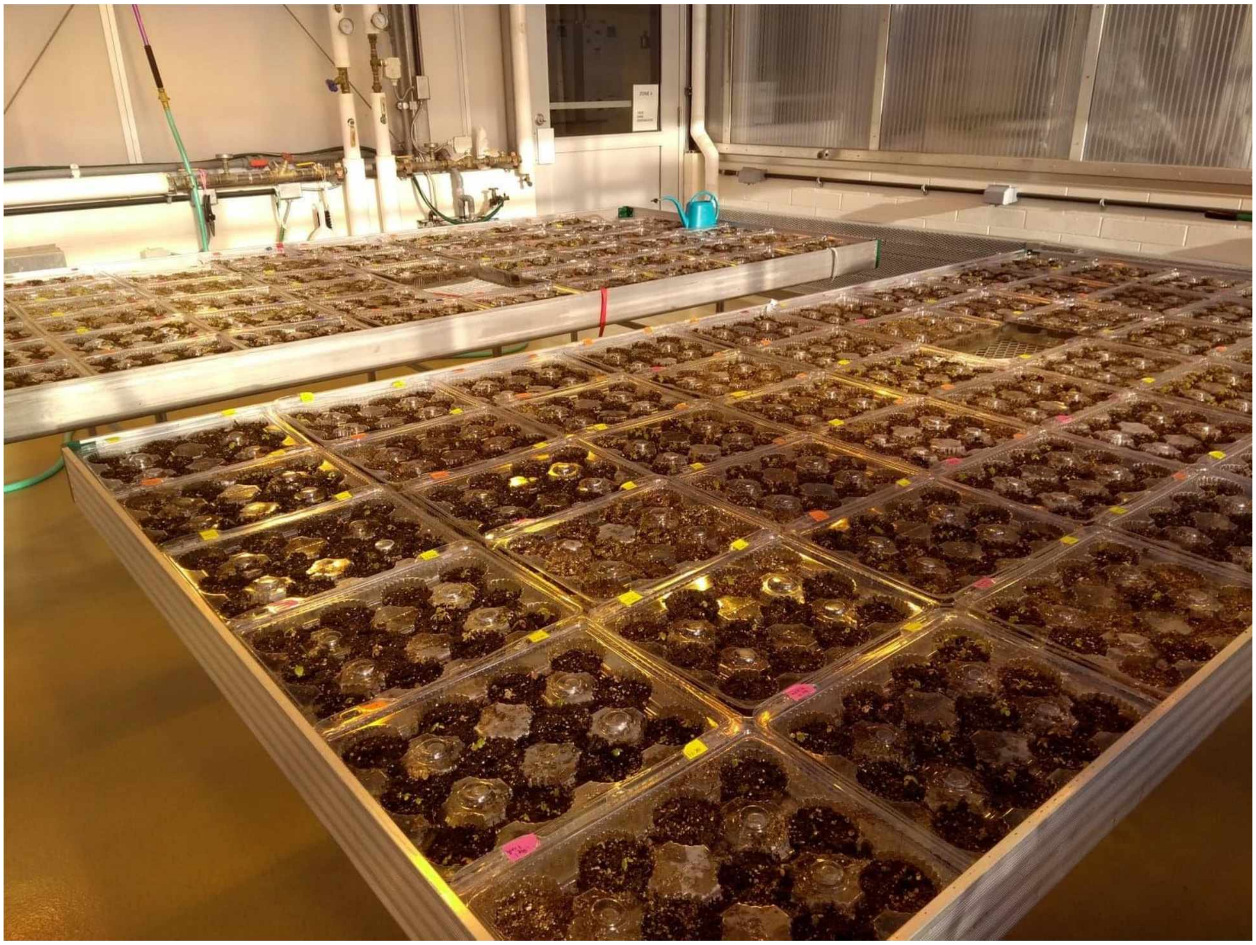

Figure 9. Greenhouse Zone 4 in January 2019

Seeds were sowed in the laboratory next to Zone 4. They had never been exposed to freezing temperature. All trays get sunshine through windows, facing the west and south. The data of temperature and light were described in Chapter3.

3.2.4. Statistic analysis

Data and statistical analysis were conducted using MS Excel 2016 (Microsoft, Redmond, WA, U.S.A.) and SPSS Statistics (IBM, Armonk, NY, U.S.A.) softwares. To verify the lack of bias of the cupcake germination method, one-way ANOVA and post-hoc Bonferroni tests were conducted to determine whether any of the 12 cup positions produced significantly different results the 12 positions of cups in a plastic cupcake tray (N=1211). If there were significant differences among the 12 positions, the cupcake germination method should not be used as an inexpensive alternative to germination trays used more often alternative for citizen scientists. On the other hand, if I did not find significant differences among the 12 positions, the germination method would be considered reliable and the results could be further analyzed. Hereafter, additional statistical analyses are explained, based on the assumption that there are no significant differences among positions.

Regression analysis considering the number of germinations at Day 21 versus the elevation and distance from the edge of canopy of each sapling were performed. Additionally, a Student's T-test was performed between trees above and below an elevation of 173.5 m. A Student's T-test was also conducted to compare the number of germinations on the 21st day between two tree groups; the group of trees which produced infructescences in both 2017 and 2018 (n = 27) and the group of trees which produced infructescence only in 2018 (n = 72).

3.3. Qualification of the cupcake method

3.3.1. Result of the statistic analysis

There were no significant differences in germination rate on the day 21 among the 12 positions of cups according to one-way ANOVA. The position of cups in a tray did not affect the germination. The environment was similar throughout the trays even though this product was not designed for this type of experiment.

3.3.2. Price of the cupcake method

The cost of the tray was $1 through a kitchen supply store and the medium was $60 for 107 liters. I used only half (53.5 liter) of the medium for the 101 trays. The temperature and light growing environments were similar to room conditions except for a higher relative humidity. These growing conditions can be maintained in classrooms or individual households citizen scientists hydrate the trays daily.

Containers for growing tree seedlings are commercially available. For example, Ray Leach “Cone-tainer”™ was used in earlier OneTree Alaska projects. The Con-tainers require a support frame and trays to capture drainage water (“Stuewe & Sons - Ray Leach Cone-tainers,” n.d.) (Figure 10. Cone-tainer, the Professional Seedling Pots). The cost for Cone-tainers would have been close to $700 with an additional $558 for the trays. The commercially designed containers are cone shaped with slits for drainage to allow the seedlings to grow until they are ready for field planting. Using cupcake trays, the seedlings need to be transplanted to larger containers after about a month for continued growth. The cost using the cupcake holders was less than 10% of the cost of the commercially designed containers while generating statistically reliable data.

Figure 10. Cone-tainer, the Professional Seedling Pots

Professionally made seedling pots by the company, Stuewe. This kit was not used for the thesis but it is typically used for growing tree seedlings. Refer to Chapter 3. for the pros and cons of using these professional kits instead of using the cupcake method. The picture was taken from the official catalog of the company.

3.3.3. Recommendation

I can therefore endorse and recommend the use of cupcake holders to citizen scientists and low-cost projects. This low-cost experiment would be a nice example for children to learn about plants, math and statistics, scientific journaling system, and more depending on their ages, levels, and more modifications; STEAM education. Additional and more detailed instructions and advice for conducting this experiment will be mentioned in Chapter 4.

3.4. Germination results

3.4.1. The increment of germination over 21 days

Germination was first observed on the third day after seeds were sown, peak germination occurred on days seven through ten, and all germination occurred before the 21st day (Figure 11. The Increment of Germination Rate of All Seedtrees from the First Day of Sowing). Successful germination and seedling establishment was considered and recorded when the pericarp of cotyledons were visible. Most seedlings produced the first true leaf before the end of the experiment, (the 31st day) which means that apical shoot elongation had started for further growing with the products of photosynthesis.

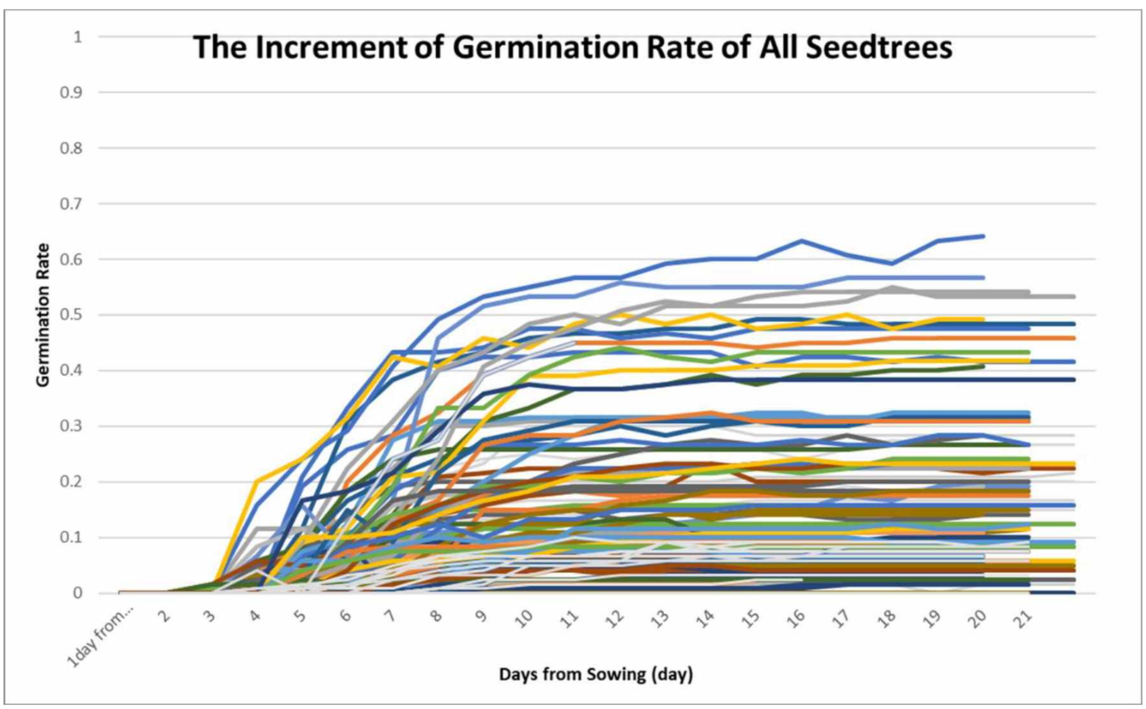

Figure 11. The Increment of Germination Rate of All Seedtrees from the First Day of Sowing

Most germination for all seedtrees happened between the 3rd to 7th day and the increment gradually slowed down after 7th day. The fluctuations of increments after the 7th day were caused by counting errors by multiple observers and by alien plants inside trays.

3.4.2. The numbers of germination on 21st day

The numbers of germination on 21st day were not affected by progenies, replicates, nor age (month) cohort. The regression analysis for germination as a function of elevation was a significant cause of germination (Figure 12. Germination Rate vs Elevation). Seeds from trees planted in higher elevation in the T-field resulted in higher germination rates. The germination rates were slightly lower in lower elevation than higher up the slope. The position on the slope (elevation) effected on both the germination rates and the number of infuctescences but the number of infructescences got more impact than the germination rates.

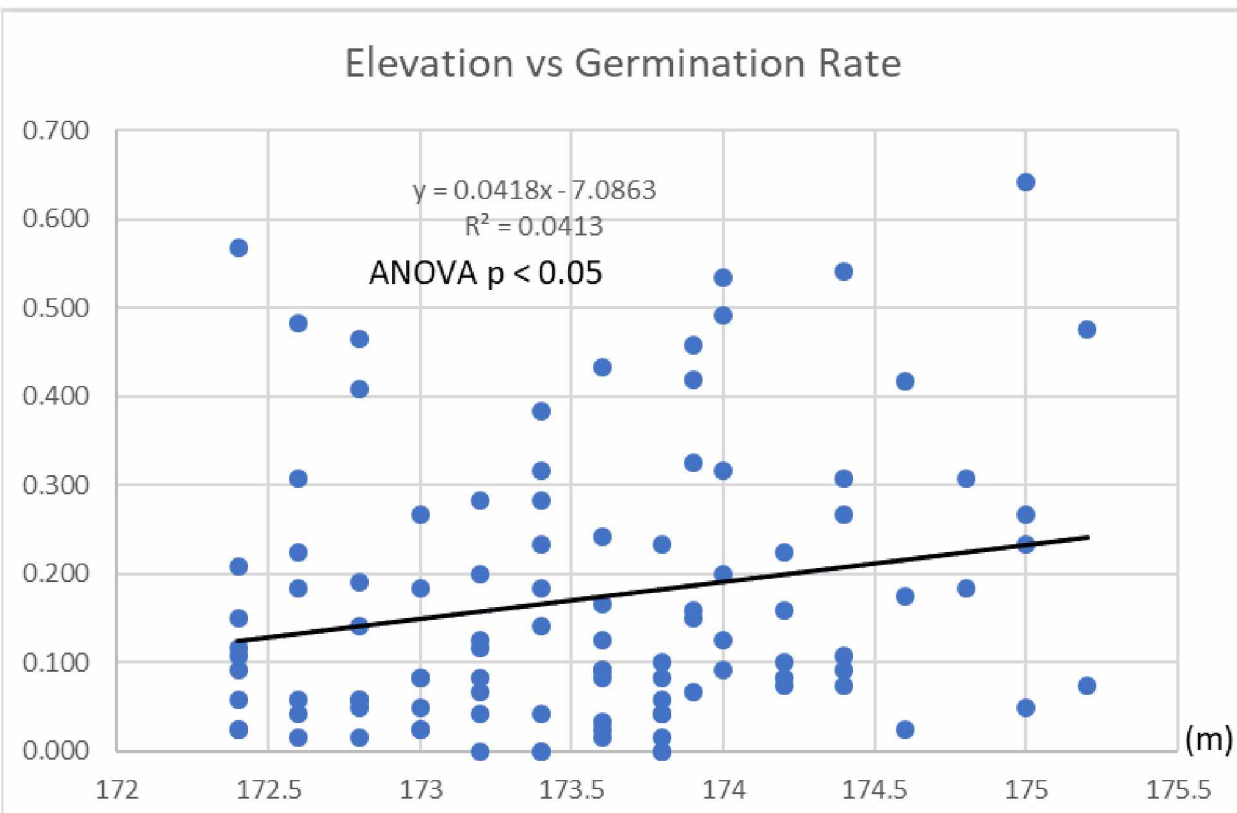

Figure 12. Germination Rate vs Elevation

The x-axis is elevation of trees in T-field, and y-axis is the germination rate of the seeds . Each points are equal to 120 seeds taken from one tree and germinated in the greenhouse. 1.0 at the y-axis means all 120 seeds germinated. The regression analysis shows the significant correlation between elevation and the germination rate. Higher elevation results in higher germination rates whereas the R-squared is low; the reliability of the impact elevation made has to be examined through continuous observation every year.

3.5. Discussion

3.5.1. Reproductive ecology in life strategy and seed vigor

The wind typically blows from Yankovich Road to Smith Lake (Haiden & Whiteman, 2005). As the wind moves through the sub-canopy of the birch plot, it slows toward the bottom of the hill. These wind patterns might enhance pollination efficiency and/or stomatal gas exchange to decrease pollination, while increasing photosynthesis. The percent germinable seeds is directly related to the size of pollen shed and years of abundant flowering (translated through Perala & Alm, 1990, Hyde 1951, 1963; Sarvas 1952). Further discussion of these results with those presented in Chapter 2 and 3 are available in Chapter 4.

Seed vigor has various definitions but is usually based on germination performance and seedling establishment such as rate and uniformity of germination and seedling growth, germination in stressful environments, germination after storage and more (Finch-Savage & Bassel, 2016). In this experiment, germination was counted when the pericarp of cotyledons was visible over the media surface. The establishment was determined to be the same as the germination in this study because of the shallowness of the container. Roots appeared through the bottom holes on the last day of the study. It was not constructive to keep the seedlings growing beyond the 31st day to determine establishment beyond the two true leaves that had been produced: root volume was limited in the cupcake cells.

Seed vigor in terms of germination uniformity has different implications for natural settings versus agriculture. Uniform germination where all seeds in a lot germinate immediately at the same time after seeding is a desirable agronomic trait because of crop management and optimal yield potential. However, Cohen (2006) and Segar and Brockmann (1987) mentioned that, in their natural condition, "seeds are likely to germinate across years to spread the risk of failure": it is called "bet-hedging strategies" against unpredictable environmental conditions (Cohen et al., 2007; Finch-Savage & Bassel, 2016; Zasada, 1978). From the viewpoint of my research question, seed vigor in terms of uniformity is less important. Birch seeds disperse and seedlings get established based on climatic and ecological events rather than managed crop systems. For natural ecosystems, non-uniform plant establishments are preferred to take advantage of favorable conditions and overcome extreme weather events under climate change. Zasada et al. in 1978 found "poor survival of June germinants" under a "hot and dry" environment: extreme weather would definitely decrease the survival rate of seedlings.

3.5.2. Resemblance from the former studies and questions for the future

Growing season temperature seldom limits viable seed production, but "the rate of ripening depends on temperature sums", Mork (1944) and Sarvas (1956) reported (translated through Perala & Alm, 1990). It required me more workforce and time than I had to refer this former study: it is recommended to count the number of infructescences in summer. It is harder than counting and collecting in autumn because leaves hide infructescences in summer. Taller ladders or heavy duty ladder with oil pump will be needed to observe green infructescences. Good planning and quick observation are strongly recommended not to give pressure stress on soil and root systems. At least more than three years of continuous observation is needed to find the correlation among growing season temperature, viable seed production, and ripening.

The size of birch-seed crops differs greatly from year to year (Sarvas 1948). The discussion over years of masting will be constructive when seed production of the majority of the

Birch trees in T-field is observed over the years. 2018 was the first year that approximately 80% of the Birch produced; they are ready for further research on masting in coming years. Not only in the T-field but other birch trees in the FNSB area produced massive amount of seeds in 2018. Masting is a whole complex variety of synchrony and periodicity which could be explained by many theories, such as resource matching hypothesis, predator satiation hypothesis, wind pollination hypothesis, animal pollination hypothesis, and animal dispersal.

The studies of Mork (1944) and Sarvas (1956) seem to support the resources matching hypothesis. Sarvas (1952) also proved that low temperatures in spring induce poor pollen production, which supports both resource matching hypothesis and the wind pollination hypothesis. The highest germination rate of silver- and paper-birch stands coincides with years having the highest seed production, Sarvas (1952) and Bjorkbom (1965) reported (translated through Perala & Alm, 1990). These reports also support the resource matching hypothesis. The news from Anchorage Daily News "Ideal growing conditions lead to Fairbanks birch seed boom" reported in 2016 that "the trend has provided abundant food for chickadees, grouse, and most significantly, redpolls." One biologist in the Alaska Department of Fish and Game estimated that Fairbanks had seen the largest influx of redpolls in seven to 10 years in 2016. The predator satiation hypothesis cannot be dismissed to the masting system of birch as well. ("Ideal growing conditions lead to Fairbanks birch seed boom - Anchorage Daily News," n.d.)

Chapter 4. General Discussion and Conclusion

4.1. General discussion

The length of the first growing season has affected one aspect of tree structure for sapling growing in the T-field plot: i.e. canopy shape. Seedlings from the 3month cohort had more stems than those in the 5month cohort prior to transplanting into the T-field plot and the resulting difference in canopy shape has persisted through the subsequent nine years of growth in the plot. An environmental factor--elevation--has had significant effects on female reproduction, in terms of the number of infructescences per tree and the rate of seed germination. Being positioned higher on the slope led to slightly higher germination rate, albeit through much reduced infructescence production. Neither sibling family nor distance from the plot perimeter affected vegetative or reproductive growth. These results could not be anticipated when the seedlings were transplanted into the research plot in 2011, and they are reported here for the first time. The open spots created by dead trees did not have an effect on other trees' growth until 2018. If we keep the Birch plot without artificial thinning, which will likely be our management strategy, we will likely see effects on resource competition. On the other hand, the effect of elevation was greater than expected: only 5% of the grade. The overall result underscores the necessity of measuring environmental data at the T-field.

In terms of reproductive vigor, 5 of the 128 birch trees in the T-field produced seed in 2016, 2017, and 2018 and 29 trees reproduced seeds in both 2017 and 2018. 101 trees in total reproduced seeds in 2018, and 110 trees reproduced in 2019 (data from 2019 has not included in this thesis). The number of trees that have reproduced seeds has continued to increase for 4 years. Birch trees in T-field first began producing seed when they were 5 years old and, as already noted, 5 trees have produced seeds continuously from 2016 to 2018. Another 5 trees produced seeds in 2016 and 2018 but not in 2017. The germination rate of 2018 seeds did not decrease due to the continuity of seed reproduction. It suggests that the scheme of initiating reproductive growth is sensitively controlled and managed: the saplings do not waste the cost of reproduction.

4.2. General conclusion

In this study, sibling family was found not to have an effect on either vegetative or reproductive growth. Length of the initial growing season did have an effect, ea. By providing canopy shape diversity, which is, itself, a feature of patch dynamics. Position in the plot, using the criterion of elevation, has so far provided the most significant effect on female reproductive growth: further research in the plot is needed. Continuous observations of phenology are expected especially to untangle the mystery of reproductive growth mechanism of *Betula neoalaskana* Sargent.

4.3. Further research suggestions

Having completed this study, I suggest both under- and over-ground analysis (roots, stems, leaves, and soil) and comparisons: measuring soil pH, carbon/nitrogen ratio, and water content to find the correlation with leaf mass per area, C/N ratio, photosynthetic traits, and chlorophyll concentration. It is already known that paper birch seedlings grow “faster on humus over mineral soil than on sandy loam, silty mineral soil, or decayed wood” (Winget & Kozlowski, 1965). Seedlings grow faster if “coarse woody debris [is] incorporated into mineral soil,” which gives “nutrients, water, and source of mycorrhizal inoculum” (Perala & Alm, 1990). I suggest further research on the relationship between above ground and underground birch here, although some of the data collecting procedures would be invasive and should only be done, if at all, at times during the year that will have the lowest impact to the saplings.

Soil moisture in growing season should be measured with Time Domain Reflectometer (TDR): three points at the top of the plot, three points at the inside middle of the plot, and three points at the bottom of the plot. Wind speed/direction sensors and solar radiation data loggers are additional options to attach on the TDR spots. I hypothesize that wind is stronger on the top of the slope with wind speed decreasing further down the plot. I also predict that the soil at the bottom of the plot contains more moisture than soil on the top. Soil core sampling should be carried out after every growing season to analyze pH (H_2O), Carbon/nitrogen ratio, and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for micronutrients. Those two chemical analysis should be carried out on leaf samples as well. Carbon/Nitrogen ratio of seeds will also provide a fair assessment of the thickness and size of pericarp. Yamanaka-style compaction meter would be a simple addition to the soil measurement: the compaction of the soil is an important factor for seedling establishment, and may provide useful information about the failure of seedlings to become established in the dead zones.

Seedbed (soil) chemistry and physics are themes we can further research in the T-field. For example Rudnicki reported in 1953, that at a pH less than 5.0 no paper-birch survived. pH condition of soil affects seedlings in various ways (translated through Perala & Alm, 1990). Leaching of metal ions from the soil and transport into seedlings is one of the most significant effects on seedlings. The tolerance of extreme soil conditions, such as volcanic ash and serpentine, of three *Betula* species in Hokkaido were compared and were known that they have two different defense mechanisms against extreme conditions. One protection against heavy metal was the mechanism with symbiothesis with Ectomycorrizae (Kayama & Koike, 2015), by defending the rentrance of toxic material into the roots. Another protection mechanism against heavy metal was to create compartments with modifying chemicals inside the vacuole, by separating toxic materials from metabolism in leaves. *Betula ermanii* had stronger tolerance against high alkaloid soil such as serpentine (Järvinen et al., 2004; Kanie, 2018; Kayama et al., 2006). Therefore, I suggest the analysis of soil pH throughout the T-field which will describe micro nutritional dynamics and its availability on the slope. It will reveal the mystery of the trees which did not survive until 2018, if the soil condition were unfavorable for their growing.

A non-fluorescent water-soluble substance in the seed coat of silver and hairy birch has germination-inhibiting properties (Longman & Wareing, 1959). Seeds germinate by breaking the hard cell wall, the pericarp. There has been no reports yet of germination-inhibiting compounds in *Betula neoalaskana* seeds. Separation of scales and seeds after sampling (which has been done in some years for the T-field) is also recommended, and can still be carried out in the seed archives. The number of scales and seeds as well as their weight, can be recorded general data of infructescence and seed quality. 100-seed weight quantitative traits is a typical seed quality descriptor. Former studies proved that the pre-chilling process after sowing on soil and/or inside envelopes to the germination experiments was not necessarily effective on birch seeds : imitate the overwintering effects to seeds. Pre-chilling process was also carried out to the seeds originally collected from the Nenana Ridge in 2009, but not to the seeds collected from the T-field in 2018. They found the result that the pre-chilling experiment did not change the germination rate of birch in 2009. The literature from 1961 also explained that pre-chilling before planting was effective in limited environmental conditions (Yelenosky, 1961).

4.4. Germination experiment protocol for citizen scientists

4.4.1. Introductory remarks

Note to reader: This chapter is written for K-12 citizen scientists, who are interested in plants and wish to work with seeds and saplings. Since it's written for children, the writing style differs from all other parts of my thesis. My objective is to write it clearly, simply and with enough explanation that K-12 students who want to serve as citizen scientists can do so. My belief, shared by OneTree Alaska, is that K-12 students can do low-level, but legitimate, useful research (such as determining germination rates of seeds in a long-term monitoring site such as the T-field birch plot) if supervised sufficiently and with other checks and balances in place (such as replicating an experiment or germination trial, at the university, as a check on the classroom work.

Note to K-12 citizen scientist: In this paper, you will learn everything you have to do in order to conduct this experiment with Betula neoalaskana safely and successfully. You'll also see that you have to buy stuff such as cupcake trays and soil, so check your piggy bank first because this experiment was designed in an economically friendly way! If you need financial support to start this experiment, talk with your parents, teachers, or guardians so they know you are interested in plants. I bet they'll help you find a way to do this experiment!

4.4.2. Find Birch

Betula neoalaskana has a white trunk and triangle shaped leaves. Leaves occur on two types of branches. Early spring leaves are ton short branches, which are the first to n spring, whereas late summer leaves flush throughout the summer on long branches. Birch usually grow in clearings with abundant sunshine and abundant water. So you've found birch, now let's find seeds.

Oops, wait a moment. Please make sure the birch tree stands in the place you can access. Is it on private property? Do you know who takes care of the Birch tree? Talk with the homeowner or land manager and ask if it is okay to sample seeds. Is it sunny outside? It is better not to work outside when it is rainy, safety is the top priority all the time.

4.4.3. Find and get birch seeds

How tall is the tree? Do you need a ladder or a shoulder ride? Be careful if you are working on a slope! Was it rainy yesterday? If so, the slope will be slippery. If the birch tree is old enough to make seeds, you will find the group of seeds next to the early spring leaves. The group of seeds is called infructescence, and looks like a tail. It is green in summer, and turns into brown toasted color when the seeds are ready to be dispersed (Figure 13. Infructescence in Summer, Figure 14. Mature Infructescence in Fall). If the infructescence you find is green, remember where it is and come back later! If you find tails on the tips of branches in late summer, you've found the male flowers, or male catkins.

When the infructescence turns into a brown toasted color, bring paper envelopes to collect seeds. Hold the envelope open beneath the infructescence with your left hand, and gently rub the infructescence with your right fingers. If you're gentle, the core of infructescence will remain on the branch. If the seeds do not separate from the core (the central axis of the infructescence) easily, the seeds are not ready to be sampled. They need a little bit more time to mature. If a part of the infructescence has turned dark black, you'll know that part was eaten by insects. Leave these alone, and find other infructescences. After you get seeds in envelopes, lay them on a table inside to dry. If you collect them in the morning, it will take longer to dry because of the morning dew.

Figure 13. Infructescence in Summer

Infructescence of Birch emerges between pairs of early spring leaves. The one on the left is healthy, the right is eaten by the red aphis. Each scale is green, soft, and attached to the scales beneath it. The seeds are hidden beneath the scales.

Figure 14. Mature Infructescence in Fall

The color turns brown and the scales open to distribute seeds. The seeds and scales will easily come off when you touch the infructescences. Leaves are deciduous and fall by the time the seeds start flying.

4.4.4. Prepare tray and soil

Do you like cupcakes? Well, you want the tray of cupcakes for this experiment. You can buy just the plastic tray or with cupcakes in the plastic tray. You can also ask your friends and family to keep the trays after they eat cupcakes. The cupcake tray is the pot for growing birch now! Next, you will need a push pin. You will punch 5 holes on the bottom of each cup to make water drain. Be careful with your fingers, just poke the bottom gently.

Let's get soil. If you want to compare how germination differs between trees, you want to get the same soil for all trays. If it was not used for other plants before, leftover soil from last summer you bought to grow vegetables is fine. You will need about 180g for a tray. Find a kitchen scale, please wipe when you finish using it to keep your mom happy! After putting soil in the cups, you can add tap water. It is easy and makes no mess if you cut off the cover of the tray and put it under the cups upside down. You can put water in the cover and soak the whole tray too. Let's saturate the soil because birch is a really thirsty tree.

4.4.5. Sow seeds

Now we can open the envelopes of seeds to sow, but before that, we have to close the windows and stop the fans. Seeds are pretty small and use wind to travel to new places! You will need a flat plate and toothpicks from the kitchen. Put the seeds on a plate and count them with toothpicks. There are two things in your envelope, seeds and scales. You want the seed which has two wings on both sides. Scale looks like a flying bird, you do not need to germinate seeds.

Put 10 seeds on the soil of each cup. If you plant more than 10, it will be hard to observe when they grow! After putting 10 seeds on the soil, gently push them down into soil with the toothpick. The seeds will stay there but be careful not to wash them out when you water (hydrate in scientific term) the soil.

4.4.6. Take care of seeds

Hydrate the soil everyday with tap water from the top. It is important not to move seeds on the soil; do not use strong stream of water or hydrate directly from the tap. It is a good idea to use tablespoons, eye droppers, or straws. Start with hydrating 12ml of tap water per cup. You will also add water into the upside-down cover to keep soil moist, it will act as a water reservoir. The water line should touch the bottom of the cups. Keep tray on a table inside a warm and bright room where you also feel comfortable. You will turn off the light at night to let them sleep as well. This experiment is expected to continue for a month; it would be good to ask your family and friends if the trays are not in their way. You should also ask your pets to not eat soil and seeds, if it is needed, build a barricade before the trays.

4.4.7. Find germination

In 4 to 7 days from the day you planted, you may start seeing small germinations (Figure 15. Germination of a Tree January 2019). The germinant first looks like a loop (hypocotyl) and then a pair of leaves (cotyledons) appears in seed shell. The seed shell (pericarp) will come off by itself. When you see the seed shell on the tip of loop, you count it as a seedling. Keep hydrating the soil until 31st day to make sure all germinable seeds have germinated. You may also see the third leaf (first true leaf) later if you take good care of the seedlings.

If you want to grow them into taller and bigger seedlings, you can transplant germinations into bigger pots. Cut off the cup and dank into a bucket of water. Use fingers to gently separate germinations. Their roots will be tangled together like bad bed hair in the morning, it is not a good idea to pull a germinant out of the soil without soaking it in water.

Figure 15. Germination of a Tree January 2019

A pair of cotyledons emerge from the soil first, and the germination extends the true leaves in between the cotyledons.

4.5. Afterthoughts

This chapter describes how the separated educational/professional training programs and works are connected to each other. In other words, this chapter supports the statement of justification and motivation on Chapter 1 again after completion of this research work.

My motivation for this thesis is contributing to a better society and STEAM education to everyone without gender, language, age and ethnic borders. As a science educator, I value logical thinking. To give the skill of logical thinking to students, I provide fact-based and interdisciplinary lectures. Since society is always changing and science technology is developing day by day, both I and the students have to be open-minded. My own personal philosophy of education is progressivism, however, I will not give up teaching children who are not in favor of science, rather will motivate them and stimulate their curiosity by allowing them to feel closer to their life. I believe that some basic scientific ideas we learn in school are essential to social life (essentialism), but I also believe if students do not feel personally connected, they will not be interested.

To inspire children's curiosity and keep the context of lectures fresh, I will fully utilize the technology. However, I do not support the idea that technology can replace all roles humans do for others: loving, caring for children, and listening to them with patience and an open mind are essential for better behavior and psychological well-being.

In addition to providing the skills of logical thinking, I consider self-advocacy and behaviorism important pieces of children's personal development. Self-advocacy is essential for all students, including non-English native speakers and students from foreign cultures (English as a Second Language Learner). I want my classroom to be a place where students feel respected and can embrace their own uniqueness. I believe this atmosphere would be the most comfortable place to learn for everyone. When logical thinking, and self-advocacy meet, individual children will learn how to create their own identity and also respect others' identities: it is the ethics of a multicultural inclusive society. All logical thinking, motivation, and self-advocacy will create a foundation inside everyone to survive in a rapidly changing society of the 21st century.

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