Summer 2020

Dendrochronological Assessment of the Easton Glacier's Terminus Position Over the Last 150 Years

Monica A. Villegas
Western Washington University, monica.ann.villegas@gmail.com

Recommended Citation

Villegas, Monica A., "Dendrochronological Assessment of the Easton Glacier's Terminus Position Over the Last 150 Years" (2020). *WWU Graduate School Collection*. 984.
https://cedar.wwu.edu/wwuet/984

Dendrochronological Assessment of the Easton Glacier's Terminus Position Over the Last 150 Years

By

Monica Villegas

Accepted in Partial Completion
of the Requirements for the Degree
Master of Arts

ADVISORY COMMITTEE

Dr. Andy Bach

Dr. Aquila Flower

Dr. Doug Clark

GRADUATE SCHOOL

David L. Patrick, Interim Dean

Master's Thesis

Monica Villegas

08/05/20

Dendrochronological Assessment of the Easton Glacier's Terminus Position

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Arts

by
Monica Villegas
August 2020

Abstract

The Easton glacier on Mt. Baker, Washington has been the focus of several studies looking at ecological succession, (Heikkinen 1984, Rosa 2016, Whelan and Bach 2017) glacier recession, (Harper 1993, Long 1953, Long 1955, Osborn et al 2012, Pelto and Hedlund 2001) and glacier mass balance (Pelto 2006, 2010). Several of these studies have noted a gap in the literature regarding the Easton glaciers terminus position in the early twentieth century. This study has refined the glacier's terminus position by using dendrochronological methods and identified the latest Little Ice Age end moraines. A chronology of the Easton glaciers terminus position overtime was created showing its recession and advancement since 1879. The rates of recession and advancement were calculated during this time highlighting the unpredictable behavior of glacial systems. By 1956, the Easton glacier had retreated a total of 2,708 meters since 1879. Between 1879 and 1910 the glacier retreated slowly, followed by a 25 year period of rapid retreat where the glacier retreated 1.87 kilometers. The retreat slowed until 1956, when the glacier began a period of advancement. Since 1990 the glacier has been in retreat, which has accelerated over the last few years. This study has also determined ecesis, the interval between deglaciation to vegetation establishment. Ecesis is about 9 years at the bottom of the foreland and 27-28 years at the top of the foreland. This trend of longer ecesis intervals at higher elevations reflects the colder conditions, poorer soil conditions and larger distance from seed sources compared to lower elevations. The findings from this study are only estimates but can still be used to inform on the Easton glaciers response to climate change and other environmental factors.

Acknowledgements

I would like to specially thank Dr. Andy Bach, Dr. Aquila Flower, and Dr. Doug Clark whose guidance, assistance and knowledge helped me complete this research. Many thanks to my field crew who put in countless hours in the Easton foreland through rough conditions to obtain my samples (Kelly Fitzpatrick, Keaton Martin, Marissa Wall, Brady Schwartz, Colter Lemons, Duncan Mullen, Ryes Logan, and Ashley Meyers). Sincere thanks to the Huxley Small Grant for funding my research expenses. Lastly, thanks to my friends and family for their continuous support throughout my master's thesis.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

Alpine and glacial environments play a crucial role for the regions in which they reside. In the Pacific Northwest (defined here as Oregon, Washington and southern British Columbia, abbreviated hereafter as PNW), glacier behavior has implications for recreation, hydropower, fisheries, and other commercial uses as well as providing ecosystem services. As climate change effects continue to increase in severity, the future health of these areas is at risk.

Glaciers are sensitive to variations in climate and are an important proxy that document past climate conditions in mountain environments (IPCC 2013, Osborn et al 2012, Pelto and Brown 2012). With rising annual temperatures projected to increase, IPCC studies suggest changing precipitation patterns from snow to rain at higher elevations, reduced snowpack accumulation, and reduced spring snowmelt runoff into streams in mountain ecosystems (Stewart 2009). PNW streams fed by glaciers have experienced a decline in late summer flow which can result in lower water quality, higher stream sedimentation, and higher temperatures all of which negatively impact aquatic ecosystems (Marcinkowski and Peterson 2015).

Since about the 1980s, a majority of alpine glaciers in the Pacific Northwest have been receding rapidly (Hodge et al. 1998, Koch et al. 2009, Marcinkowski and Peterson 2015, Pelto 2006, Whelan and Bach 2017) with several glaciers in the North Cascade Range entirely disappearing (Pelto 2006). The glaciers on Mount Baker have had significantly negative mass balance records since 1990. Mount Baker glaciers from 1990 to 2010 cumulatively lost 12–20% of their entire volume leading to significant retreat of all of the glaciers (Pelto and Brown 2012). Since 1990, the Easton Glacier has retreated about 520 meters to its current position (Harper 1993, Pelto 2010, Pelto and Brown 2012). Specifically, in the year of 2015, the Easton glacier retreated approximately 34 meters up slope and lost 6 times more ice than the 1984-2014 average for North Cascades glaciers (Pelto, 2018). A study done by Pelto and Hartzell 2004, showed glaciers in the North Cascades experienced extreme thinning that resulted in 35-50% reduction in their total volume since the turn of the century. These glaciers are expected to continue to retreat in the foreseeable future with some projected to disappear.

As glaciers continue to recede in the future, new land surfaces will emerge and become colonized by vegetation, transforming ice and rocky surfaces to meadows or forests (Whelan and Bach 2017). Understanding the relationship between glacier recession, soil development, vegetation succession and climate change will provide information for predicting future conditions in alpine environments that are important for forest management and conservation practices.

Mount Baker, Washington (48°46’38” N, 121 °48’ 48” W) is an active stratovolcano that resides in a west coast maritime climatic environment about 50 kilometers southeast of Bellingham, Washington (Figure 1.1). Rising approximately 3,286 meters above sea level, Mount Baker is the largest peak in the North Cascades with 10 major valley glaciers flowing from a 38.6 km^2 ice-cap (Pelto and Brown, 2012) with the Easton glacier on the south flank (Figure 1.2). The Easton foreland is defined in this study as the most recent deglaciated trough from the 1912 terminus position to the present-day terminus position (Figure 1.3).

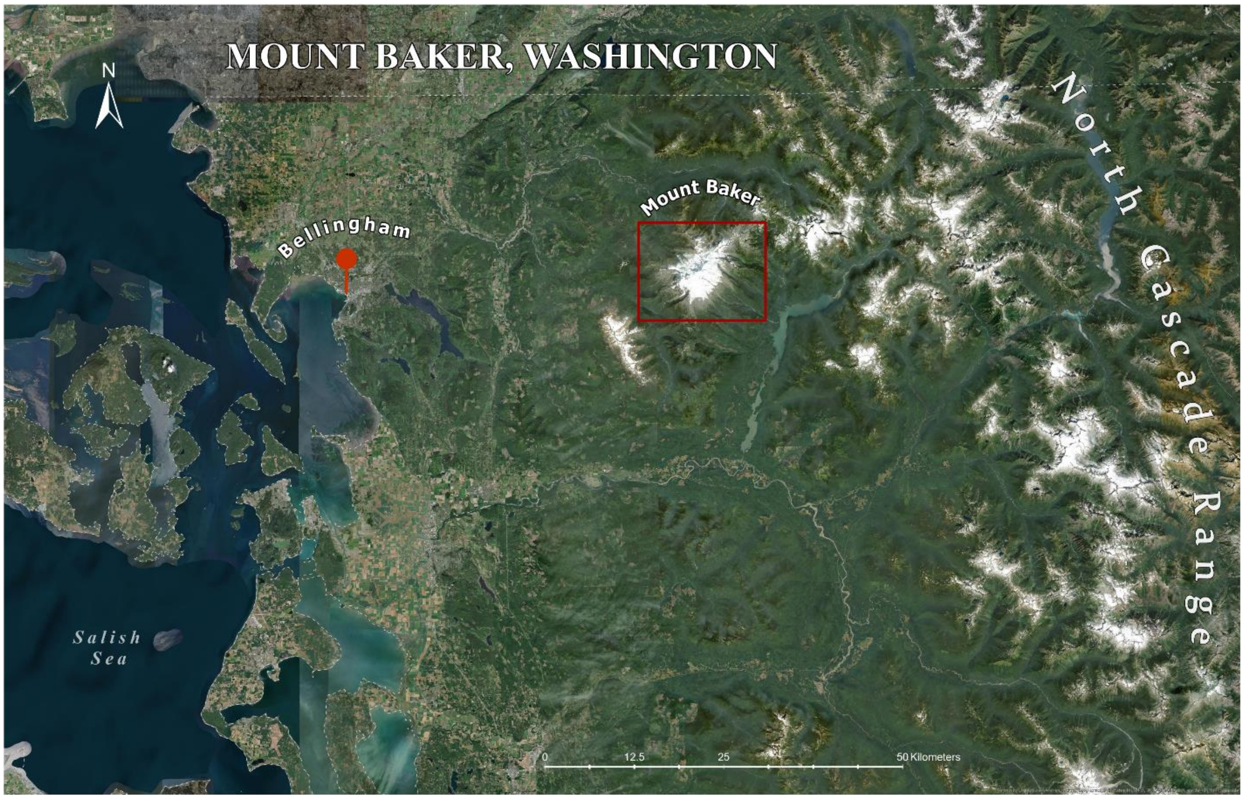


Figure 1.1: Location of Mount Baker

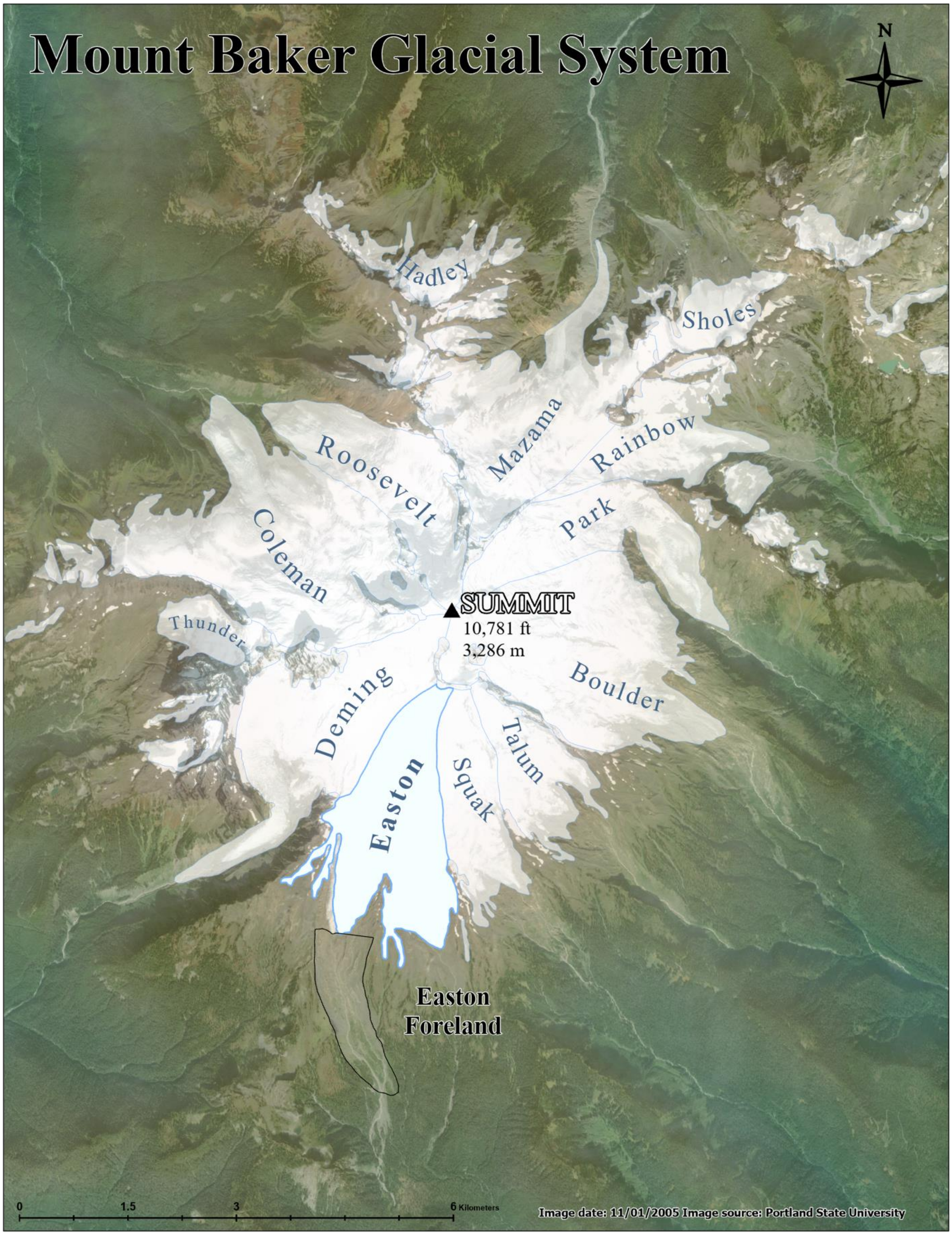

Mount Baker Glacial System

Image date: 11/01/2005 Image source: Portland State University

Figure 1.2: Easton Foreland's Location on Mount Baker

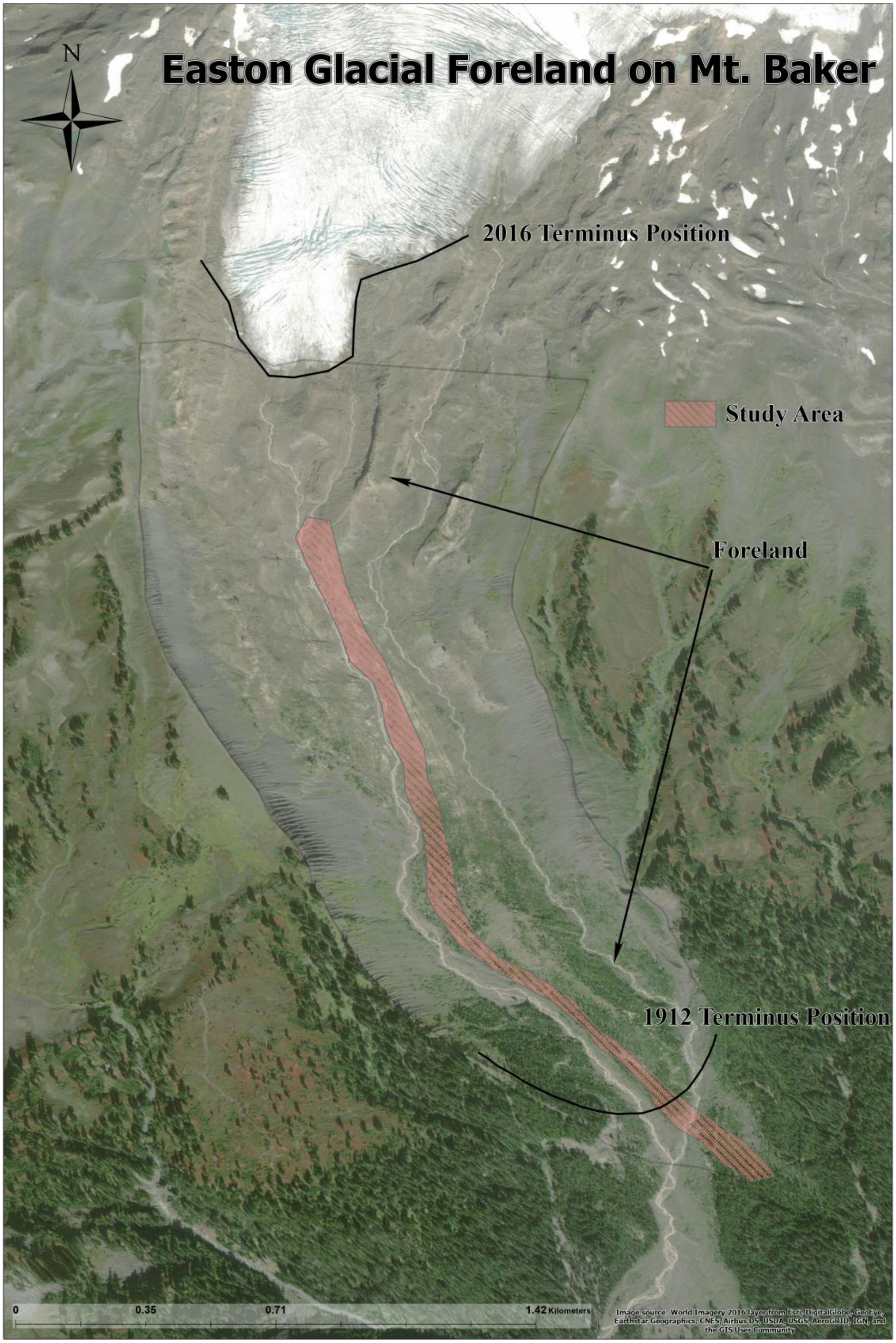


Image source: World Imagery 2016 layer from Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1.3: Study Area in the Easton Foreland

1.1 Purpose of Research

This research assesses the historic glacial terminus position of the Easton glacier in the first half of the twentieth century. As climatic conditions continue to change, it is important to document and analyze how glaciers are responding to the changes for future predictions of climate in the PNW. The Easton foreland is a prime location to study glacier recession and vegetation succession in response to climatic changes. The results from this study will provide information on glacier recession rates, glacier response time to climate variations, soil development, and vegetation succession rates. This will contribute to the knowledge of glacier behavior and resilience in an ever-changing environment.

Air photos, ground photos and satellite images have been used to reconstruct the glacier's terminus from 1912 to the present (Harper, 1993, Whelan and Bach 2017). Before 1940, a ground photo from Loomis Mountain shows the glacier much larger than present, however, the terminus position was obscured by a ridge in the foreground making its location undetermined (Figure 2.1). Photographic evidence of the terminus position during this period is scarce and the images that are present are variable in their reliability (e.g. low resolution and indeterminate location). By refining the Easton glacier terminus position during the early twentieth century, a chronology can be created to compare with historical annual temperature, average precipitation and other environmental conditions. This information can then be used to describe glacier behavior overtime in response to climate change in the PNW.

This research also aims to improve our understanding on spatial and temporal patterns of both soil and vegetation succession on glacial forelands as a response to changes in climate that have already occurred (Whelan and Bach 2017). With a more refined terminus position chronology, finer estimates of soil age and vegetation succession rates are possible. This information can add to the conversation of glacial foreland ecology and dynamics.

1.2 Research Questions and Framework

This research's objectives are to refine the historical glacier terminus positions of the Easton glacier from 1940 back into the late 1800s. With past studies using information involving photographic evidence (Heikkinen 1984, Harper 1993, Long, 1953), soil and geological evidence (Osborn et al 2012, Whelan and Bach 2017), mass balance (Pelto and Brown 2012, Pelto 2010; 2018) and historical climate data (Kovanen 2003), this research will add to the vegetation succession component of glacial foreland characteristics using dendrochronological data. Two main research questions are investigated:

- What are the historical terminus positions during the early twentieth century?
- What is ecesis for the Easton foreland?

These questions will be answered by determining the ages of trees established on glacier deposits and then by adding the ecesis time to the tree establishment age, thus determining the timing of deglaciation. In order to estimate a glacier's past terminus position at a given location, a minimum age of the underlying surface must be determined. Once a glacier's terminus recedes and exposes the underlying substrate, the surface is subjected to vegetation colonization and soil development. Over time, these processes advance the successional stage and eventually allows for forest establishment. The time between glacier retreat and seedling establishment is known as ecesis (Sigafoos and Hendricks 1969, Speer 2013). This time factor is added to the establishment age of a tree, thus providing a minimum age of substrate and a date of the glacier terminus position at that location (McCarthy and Luckman 1993). None of the glacial forelands on Mt. Baker have had ecesis determined yet, so this study will work towards identifying the length of time needed for vegetation establishment. This will not only inform on the glacier terminus behavior over time but also on the spatial and temporal patterns of soil and vegetation succession. This information can then be used to describe and predict glacial foreland response to changing climatic conditions now and into the future.

Chapter 2. Background

Glaciers have formed many of the landscapes we see today in the PNW. Over time, glaciers worldwide have cycled through phases of large glacial advancement to periods of glacial recession. Glacial dynamics are driven by both long-term gradual climatic changes and shorter climatic variations; as well as geological changes underneath the glacier (Akasofu 2010, Harper 1993). However, the current period of recession has been linked to anthropogenic climate change and glaciers have been receding and disappearing at an alarming rate (IPCC 2007, Pelto and Brown 2012, Pelto 2016). In this chapter, I will discuss the common practices used to measure and monitor glacier behavior and how previous studies have used numerous strategies to refine the Easton glaciers position overtime. I will then explain my alternative approach in measuring the terminus position that connects glacial recession, soil development and vegetation succession theories. Then, I will describe the climatic conditions, geologic history, vegetative characteristics, glacial history and land use practices in the Easton foreland.

2.1 Practices Measuring Glacier Terminus Positions

Glacier terminus positions are generally measured using aerial photographs, satellite images (Coulthard and Smith 2013), or in some cases where attainable, with in field measurements. Measuring a glaciers terminus position over time can inform researchers about the glacier's behavior and glacial foreland succession in relation to changing climatic conditions that have already occurred. When historic photographs are missing or unavailable (i.e. generally prior to the 1850s, and prior to 1912 at the Easton foreland), other methods can be used to measure the past glacial behavior. Dendrochronological analysis in the context of counting and measuring the rings in trees on the glacial foreland can provide information regarding the glacier's terminus position over time (Koch et al 2004). This can be achieved by recording the number of rings within each tree to acquire the tree's age. This age provides a minimum date of the glacier's terminus position at that location (Koch et al 2004) given that the tree established on a formally glaciated location after glacial retreat. With enough trees sampled throughout the foreland, a chronology may be created for the study site.

Dendrochronology has frequently been used as a method for describing past glacial behavior (Coulthard and Smith 2013, Lewis and Smith 2004, Malcomb and Wiles 2013, Osborn et al 2012, Wood et al. 2011). Analyzing tree rings can be used to reconstruct glacier mass balance (Laroque and Smith 2005, Marcinkowski and Peterson 2015), date moraine formation and stabilization (Koch et al 2004) and estimate glacier terminus positions (Heikkinen 1984). However, due to geographic uniqueness of each glacial environment, consistency among studies' methods and results varies to fit the conditions of that study area. Like any method, dendrochronology analysis has its limitations, specifically in this study the main source of error will come from the determined ecesis interval (Burbank 1981, Coulthard and Smith 2013, Heikkinen 1984, Koch 2009, McCarthy and Luckman 1993, Sigafoos and Hendricks 1969). Ecesis can be described as the time interval from de-glacierized exposed substrate to the establishment of tree seedlings (Coulthard and Smith 2013). The ecesis interval can be determined in several different ways (McCarthy and Luckman 1993) but the most common method is accomplished by using the location of a known terminus position and measuring the oldest tree's age at that position (Luckman 1986, McCarthy and Luckman 1993, Sigafoos and Hendricks 1969). This method will be using a known terminus position from aerial and ground photographs (Harper 1993, Whalen and Bach 2017) and field observations (Long 1953; 1955), providing the opportunity to measure ecesis in three locations.

Ecesis is site specific due to variations in ecosystem characteristics like geology, seed source, nutrient availability, climate, microclimate, moisture, nutrient availability, and topography among glacial forelands (Koch and Kilian 2005, Koch 2009, Sigafoos and Hendricks 1969). Since these factors are all different in every glaciated valley, mountain range, and along elevational gradients within a single valley, ecesis needs to be determined for each dendrochronological study. Several factors can affect the ecesis interval on a glacial foreland specifically being type of substrate, climatic conditions, and plant life history traits (Sigafoos and Hendricks 1969). The type of substrate can also dictate the rate of soil succession and affect plant succession (Burga et al 2010, Whelan and Bach 2017). Microclimate can affect ecesis depending on the current climatic conditions during which the substrate is exposed and affecting soil development but also when the seedling is beginning to establish. Notably, in alpine glaciated valleys temperature and precipitation vary with elevation, with lower elevations warmer and less snowpack than higher elevations, leading to longer growing seasons and shorter ecesis intervals (Bach and Price 2013). The plant life history traits (seed growth rate, seed size, longevity, and first reproduction) associated with dispersibility can affect the ecesis interval if any of these traits do not have the adequate conditions (Chapin et al 1994). The proximity of a seed source also can affect the ecesis interval depending on how far the seed has to travel and if climatic conditions or other factors prohibit its movement. Specifically, in the Easton Valley, ecesis is hypothesized to be short, because the valley lies down wind and down slope from a vegetated ridgeline, which provides windblown organic matter (i.e. nutrients) and seeds, both encourage soil development and plant establishment (Whelan and Bach, 2017). At the same time the growing season is short due to deep snowpack and summer conditions are hot and dry due to a southern aspect. Both lead to a high mortality rate of seedlings, and thus a potentially longer ecesis interval.

2.2 Historical Easton Glacier Terminus Positions

The Easton glacier has been monitored sporadically over the past century by numerous parties, collecting images and field measurements. The oldest known photographic documentation of the Easton glacier was taken in 1912, where the terminus position was determined from a ground photograph taken by E.D. Welsh and obtained from the Mount Baker Volcano Research Center [MBVRC] 2012 (Figure 2.1). The photograph was later recreated in 2012 to show a 1.95 kilometer recession over 100 years (Figure 2.2) (Whelan and Bach 2017). A study done by Harper (1993) used aerial photographs that were taken at 2 to 7-year intervals to map the change in Mt. Baker glaciers' terminus positions from 1940-1990 (Figure. 2.3). Decade scale intervals of retreat-advance-retreat were experienced from during this period (Figure 2.4). Prior to 1940 the glaciers are believed to have been in a rapid retreat for several decades (Long 1956). Following the retreat of ~2 km, the Easton glacier began to advance sometime between 1956 and 1960; the last glacier on Mt. Baker to begin advancing, 8-12 years after the Coleman glacier (Harper 1993). The Easton glacier was also the last glacier to begin its current state of retreat sometime between 1987 and 1989 and accelerating during the 2010s (Pelto, 2018).

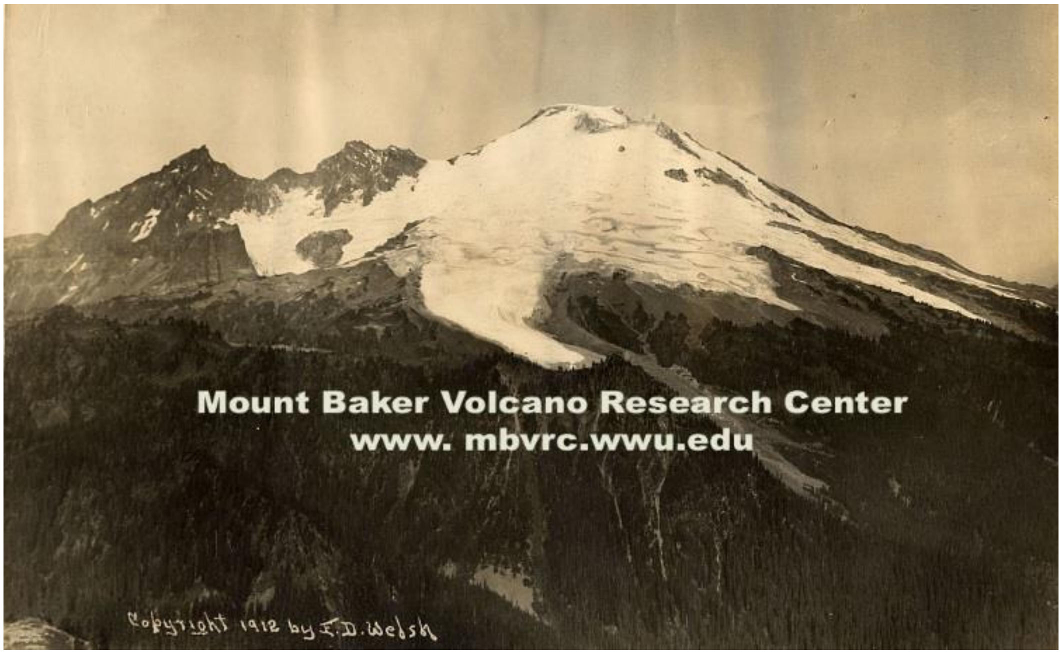


Figure 2.1: Easton Glacier Terminus Position in 1912

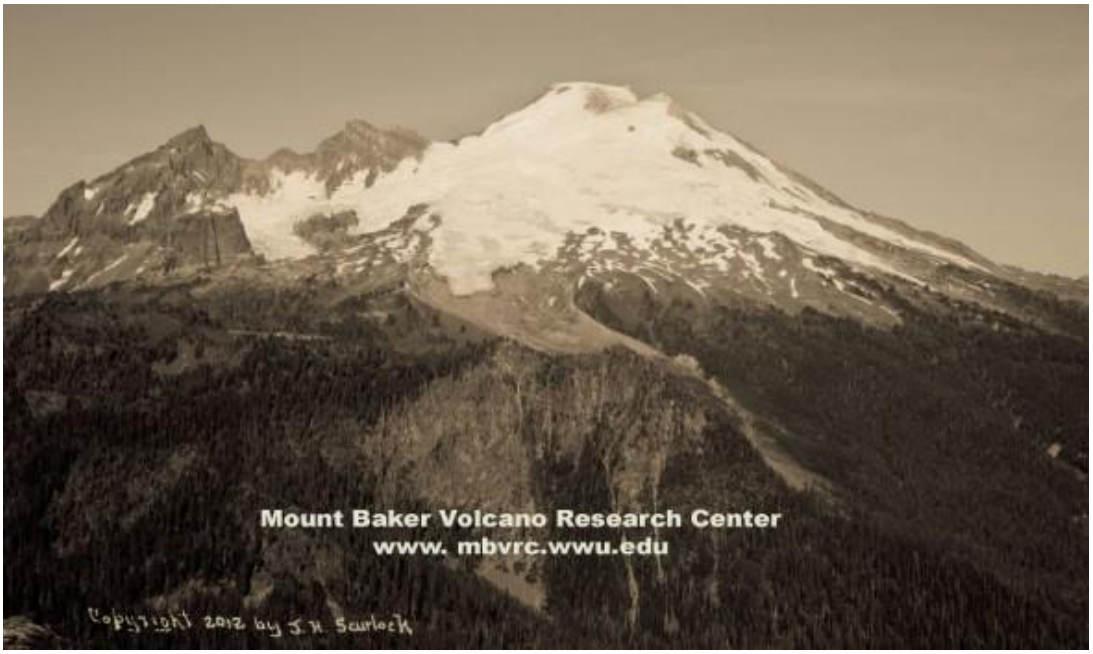


Figure 2.2: Easton Glacier Terminus Position in 2012

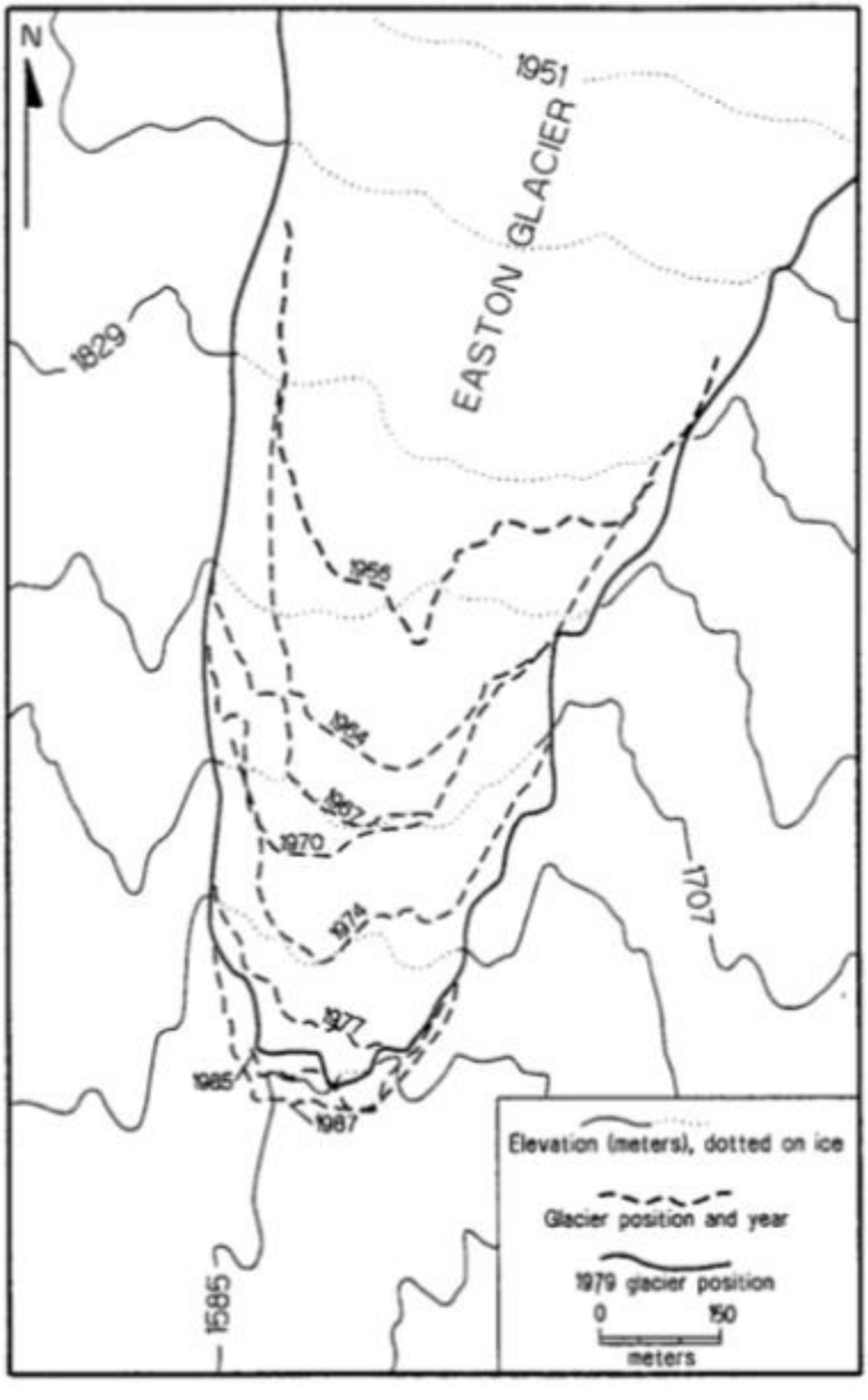


Figure 2.3: Record of the Easton Glacier's Terminus Position from 1940-1990 (Harper 1993)

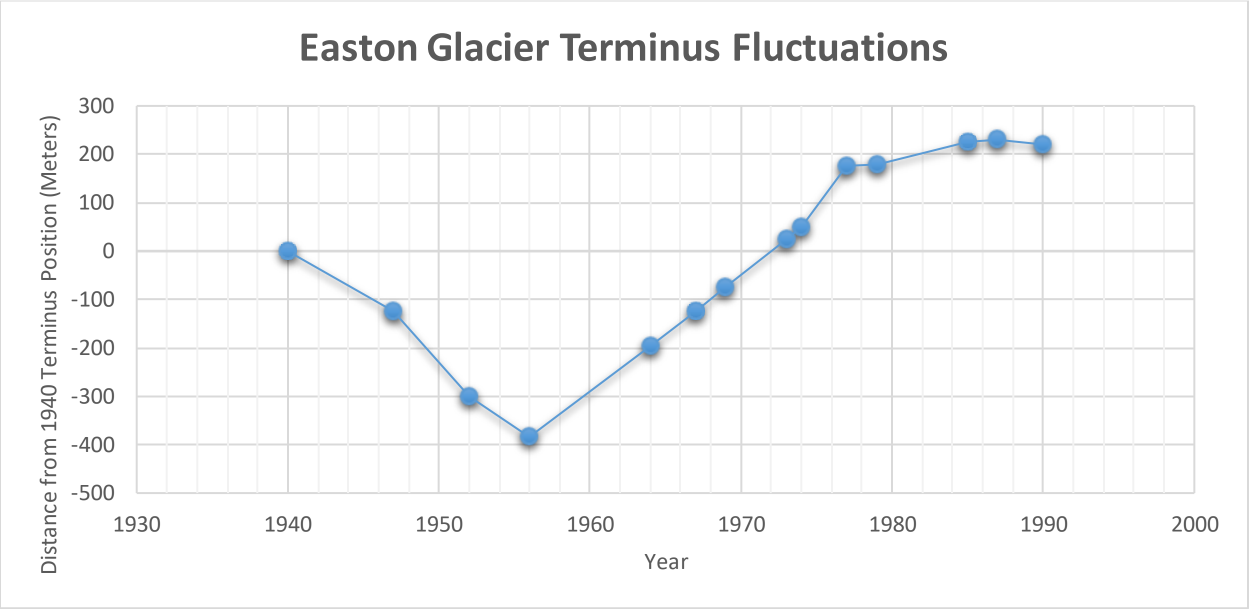
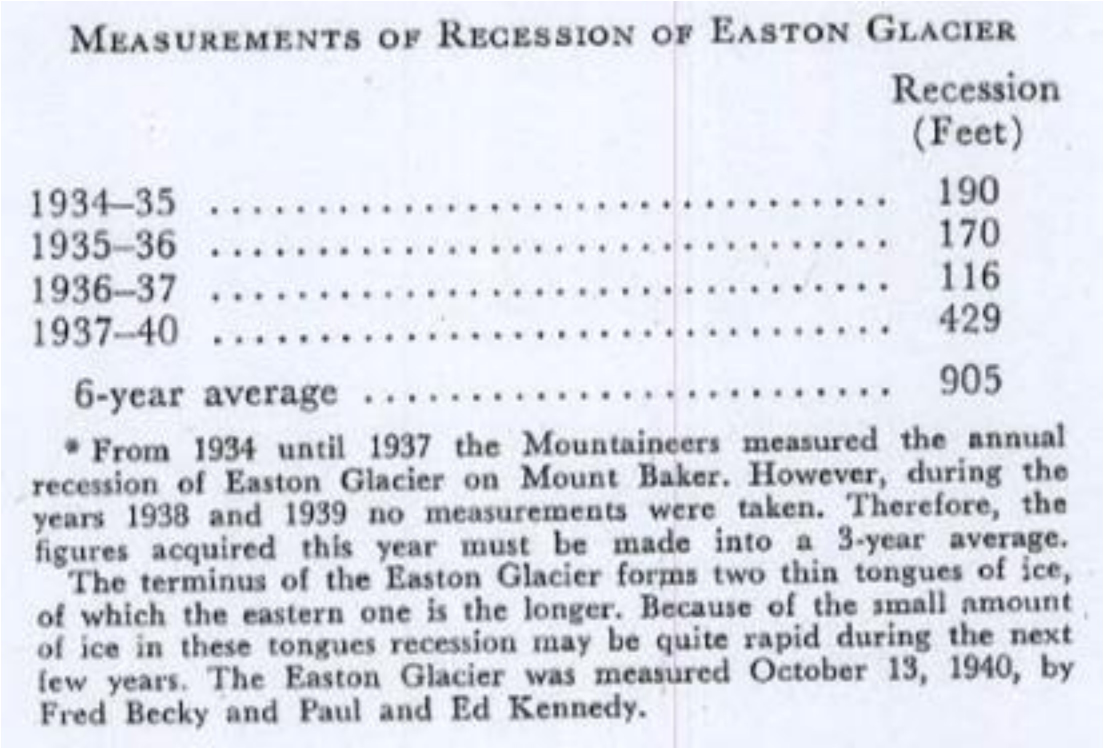


Figure 2.4: Record of Easton Glacier Terminus Positions relative to its 1940 Position. Data from Harper (1993).

A study from Long (1953), tracked the recession of Easton glacier from 1907 to 1952. The study used aerial and ground photographs, elevation and distance measurements, as well as records kept by the Mountaineers Club of Seattle, Washington from 1934 to 1940. Information from the mountaineers tracked the Easton glaciers recession and was measured annually except the years 1938 and 1939 by marking the terminus with monuments and measuring the annual retreat in feet (Figure 2.5). Ground photographs were taken in 1917 (Figure 2.6), 1925 (Figure 2.7), 1931 (Figure 2.8), 1947 and 1952 of the Easton glacier with some showing the position of the terminus and others only giving a glimpse of the glacier’s position (Long 1953, 1956).



MEASUREMENTS OF RECESSION OF EASTON GLACIER

	Recession (Feet)
1934–35	190
1935–36	170
1936–37	116
1937–40	429
6-year average	905

* From 1934 until 1937 the Mountaineers measured the annual recession of Easton Glacier on Mount Baker. However, during the years 1938 and 1939 no measurements were taken. Therefore, the figures acquired this year must be made into a 3-year average.

The terminus of the Easton Glacier forms two thin tongues of ice, of which the eastern one is the longer. Because of the small amount of ice in these tongues recession may be quite rapid during the next few years. The Easton Glacier was measured October 13, 1940, by Fred Becky and Paul and Ed Kennedy.

Figure 2.5: Easton Glaciers Terminus Position Measurements from the Mountaineers Club. Data from Long (1953).

Figure 2.6: Photograph of the Easton Glacier in 1917 by George Ely (Long 1953)

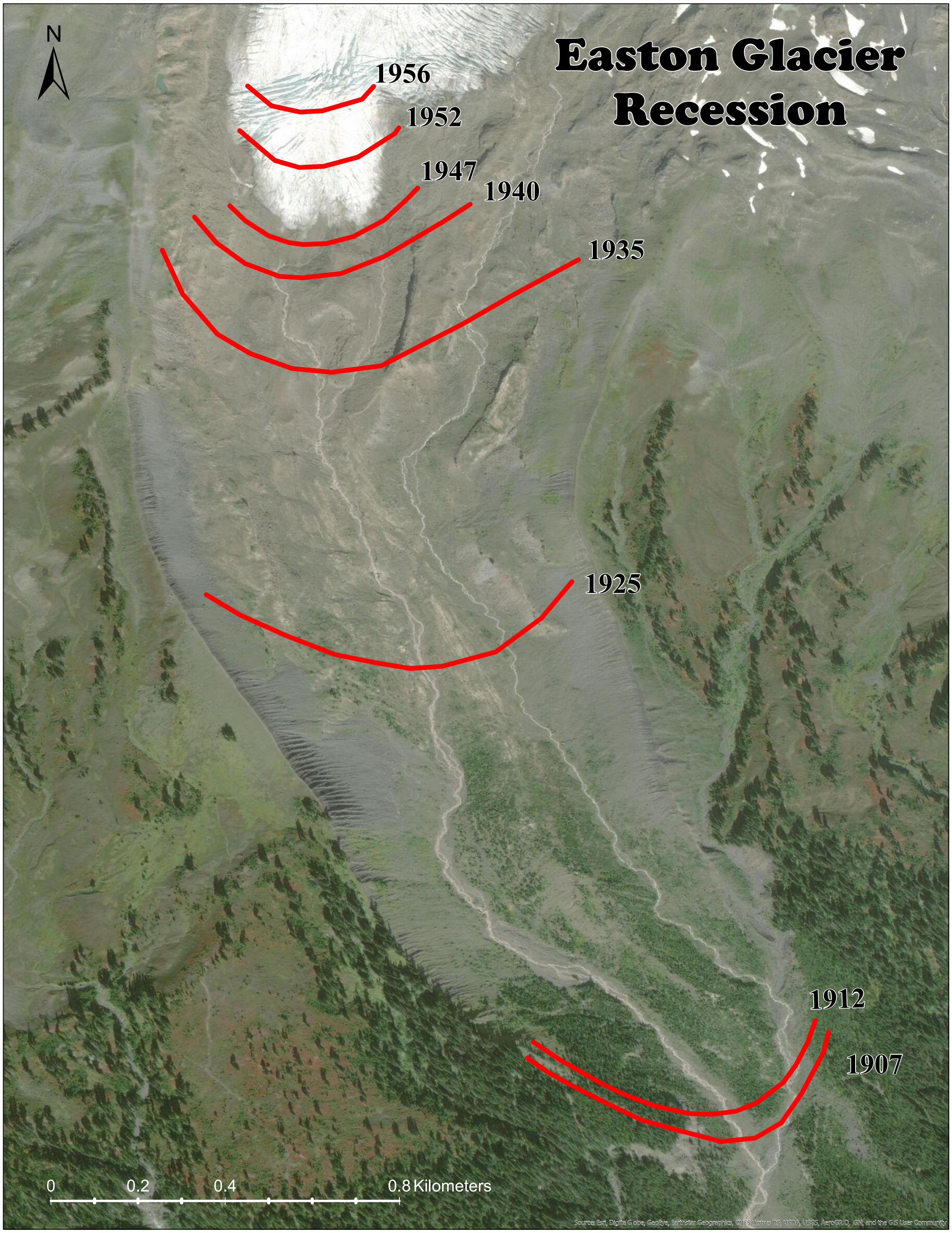
Figure 2.7: Photograph of the Easton Glacier (right) in 1925 by George Ely. (Long 1953)

Figure 2.8: Easton Glacier (center) in 1931. Positions of ice in 1907, 1917, and 1925 are shown on map. Photograph by U.S. Forest Service (Long 1953)

The information from Long (1953), was compiled into Table 2.1 and used to recreate historical terminus positions for 1907, 1925, 1934, 1947, and 1952. These positions were estimated in ArcGIS Pro using current geographic data (Figure 2.9). This extensive recession of the glacier's terminus position follows the general trend that was estimated from other sources (Harper 1993, Pelto 2016). This recession lasted until the mid 1950s, when the Easton glacier began its advancement sometime between 1956-1960 (Harper 1993, Pelto 2016). This estimate is based on nearby glaciers that were monitored yearly during this time period, so an exact date of Easton glacier's advancement is still undetermined (Pelto 2016). The Easton glacier continued to advance until around 1987-1989, when it began its current state of recession (Harper 1993). This advance deposited a 2 meter high end moraine known to researchers as the 1990 moraine that was later destroyed by a debris flow in the late 2010's (Bach, personal communication).

Year	Elevation (ft)	Distance from other locations (ft)
1907	4100	n/a
1917	n/a	Less than 400-600 feet difference from 1907 position
1925	4800	Almost half the distance (7,464 feet) from 1907 to 1952 position
1931	n/a	Receded more than 3960 feet from 1907 position
1934	n/a	About 2210 feet difference down valley from 1952 position
1935	5200	n/a
1947	5450	About 6864 feet difference up valley from 1907 position
1952	n/a	About 600 feet difference up valley from 1947 position

Table 2.1: Easton Glacier Terminus Measurements from Various Sources/Methods. (Information from Long, 1953)



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2.9: Easton Glacier Terminus Positions Estimated from Long (1953)

Since 1990, the North Cascade Glacier Climate Project has taken mass balance measurements every summer on the Easton glacier. From 1990 to about 2014 Easton glacier had lost about 20% of its total glacier volume (Harper 1993, Pelto 2010, Pelto and Brown 2012, Pelto 2016). Since 1990, the Easton glacier terminus position has receded about 430 meters. In 2015, Washington state experienced the warmest winter season on record (Bond et al 2015), ultimately affecting freezing levels, accumulation season snowpack and glacier mass balance (Abatzoglou 2011, Pelto 2018). The Easton glacier terminus position receded the most in the twenty-first century at about 34 meters in 2015 (Figure 2.10).

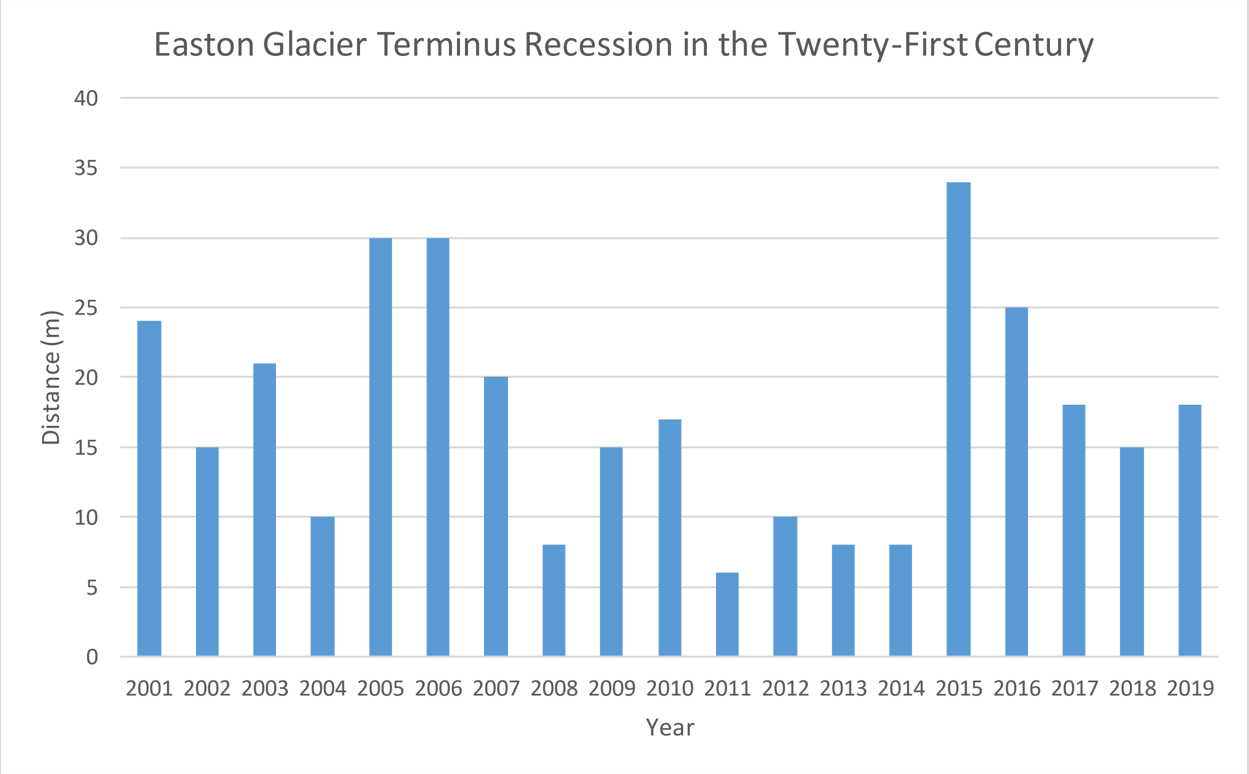


Figure 2.10: Easton glacier yearly terminus recession in the Twenty First Century. Data form Mauri Pelto 2020.

Cumulatively, the Easton glacier receded 2,510 meters between 1907-1956 (Long 1953, Long 1956, Harper 1993). It then advanced 584 meters until the late 1980s where it has since receded 529 meters almost reaching its 1956 position (Harper 1993, Pelto and Brown 2012, Pelto and Hedlund 2001, Pelto 2018). The Easton glacier's behavior in the past 100+ years relative from its earliest known position (1907) can be seen in Figure 2.11.

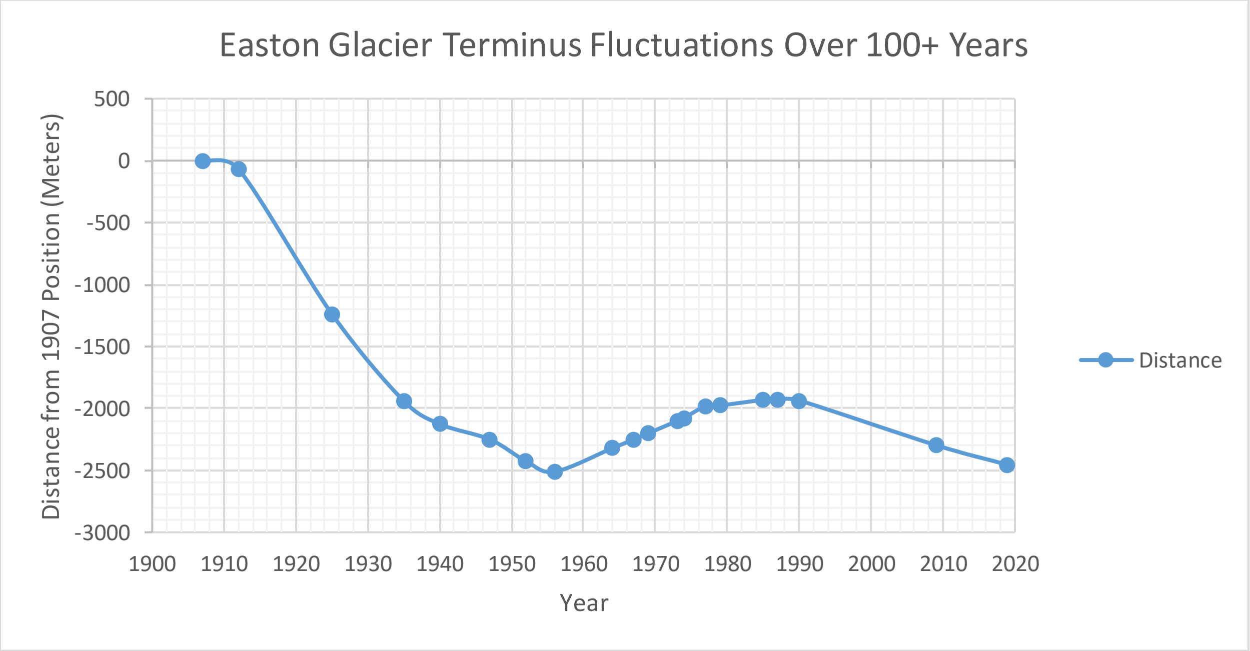


Figure 2.11.: Easton Glacier Recession from 1907 Terminus Position. Data from Long 1953; 1956, Harper 1993, Pelto and Brown 2012, Mauri Pelto.

The historical photograph from 1912 (MBVRC 2012) was used as a reference point for a soil toposequence study that examined soil succession properties against terrain surface age by creating zones based on vegetation type and elevation (Whelan and Bach 2017). The study's main objective was to determine if there was a relationship between terrain age and stage of soil succession to eventually calculate how much carbon was being sequestered by the soil over time. The surface age for each zone was estimated by historic aerial photographs (Figure 2.12) and observed/reconstructed glacier mass balance (Harper 1993, MBVRC 2012). Their results showed that terrain age was not always the main indicator of soil development but instead the stage of succession was the best determinate.

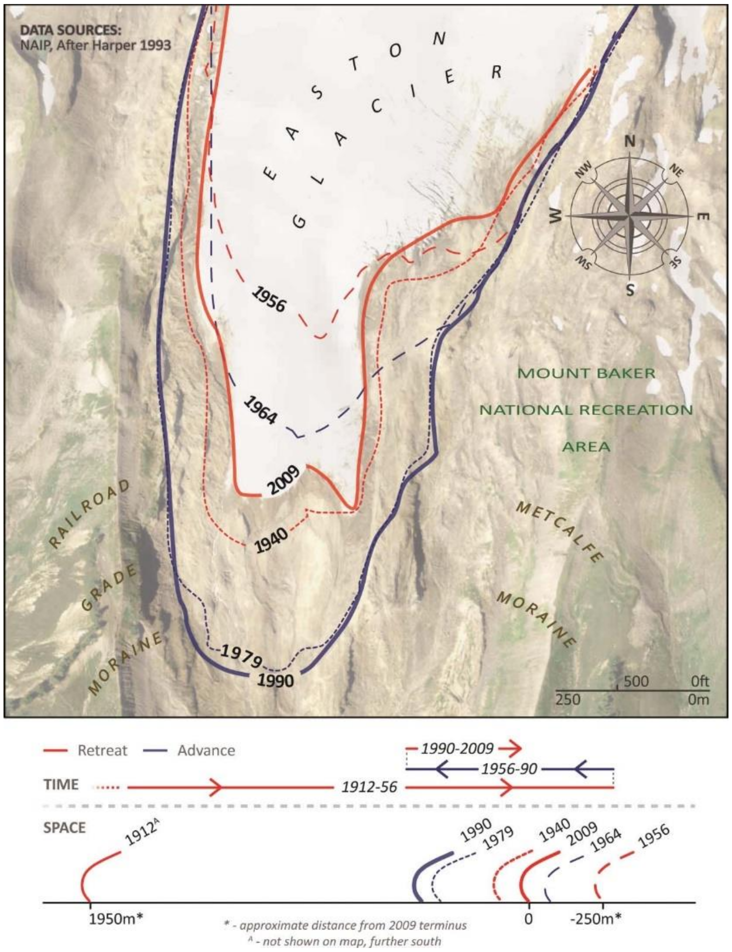


Figure 2.12: Map of Easton Glacial History from 1940-1990. From Whelan and Bach 2017; after Harper 1993.

A vegetation succession study (Rosa 2016) used similar photos and techniques to estimate the terminus position of the Easton glacier from 1912 to 2015. Rosa (2016), used information (Whelan and Bach’s 2017) to determine the terminus position but refined the approximate 1940 terminus position from literature (Figure 2.13). The study found that the terrain age was the most significant variable influencing vegetative succession on the glacial foreland. However, the ages of each zone for both (Whelan and Bach 2017) and (Rosa 2016) studies was never fully determined, instead a rough time period was noted. Soil succession and vegetation succession are linked between the concepts that the soil must first develop enough to allow for vegetation succession to begin, making them connected in spatial and temporal patterns. A possible explanation for the differences in findings between these two studies may be due to the differences in terrain estimates that may cause a relationship to be over exaggerated or underestimated. There are also large differences in the estimates of the Easton glacier's terminus positions over time. Information from Long (1953) suggests a rapid recession in the early twentieth century ending in the late 1950s. However, information from Rosa (2016) suggests a slower recession in the first half of the century only covering half the distance of Long (1953) estimates (Figure 2.14). The differences in estimated terminus positions in these studies and others (Harper 1993, Heikkinen 1984, Long 1953, Pelto and Hedlund 2001) leads to the issue of needing to better refine the historical Easton glacier's terminus position to validate previous studies work and conclusions.

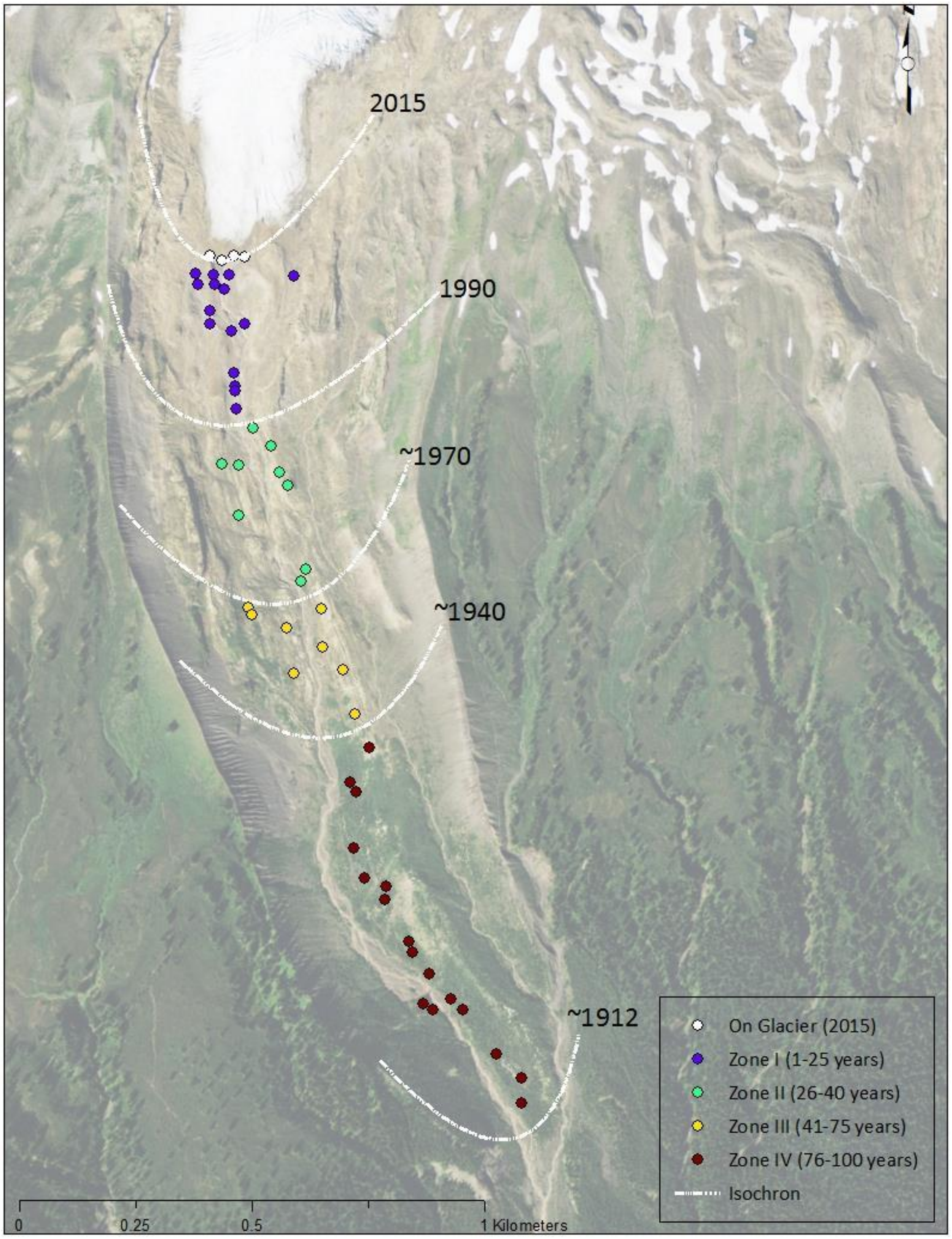


Figure 2.13: Map of Easton Glacial History from 1912-2015 (Rosa 2016)

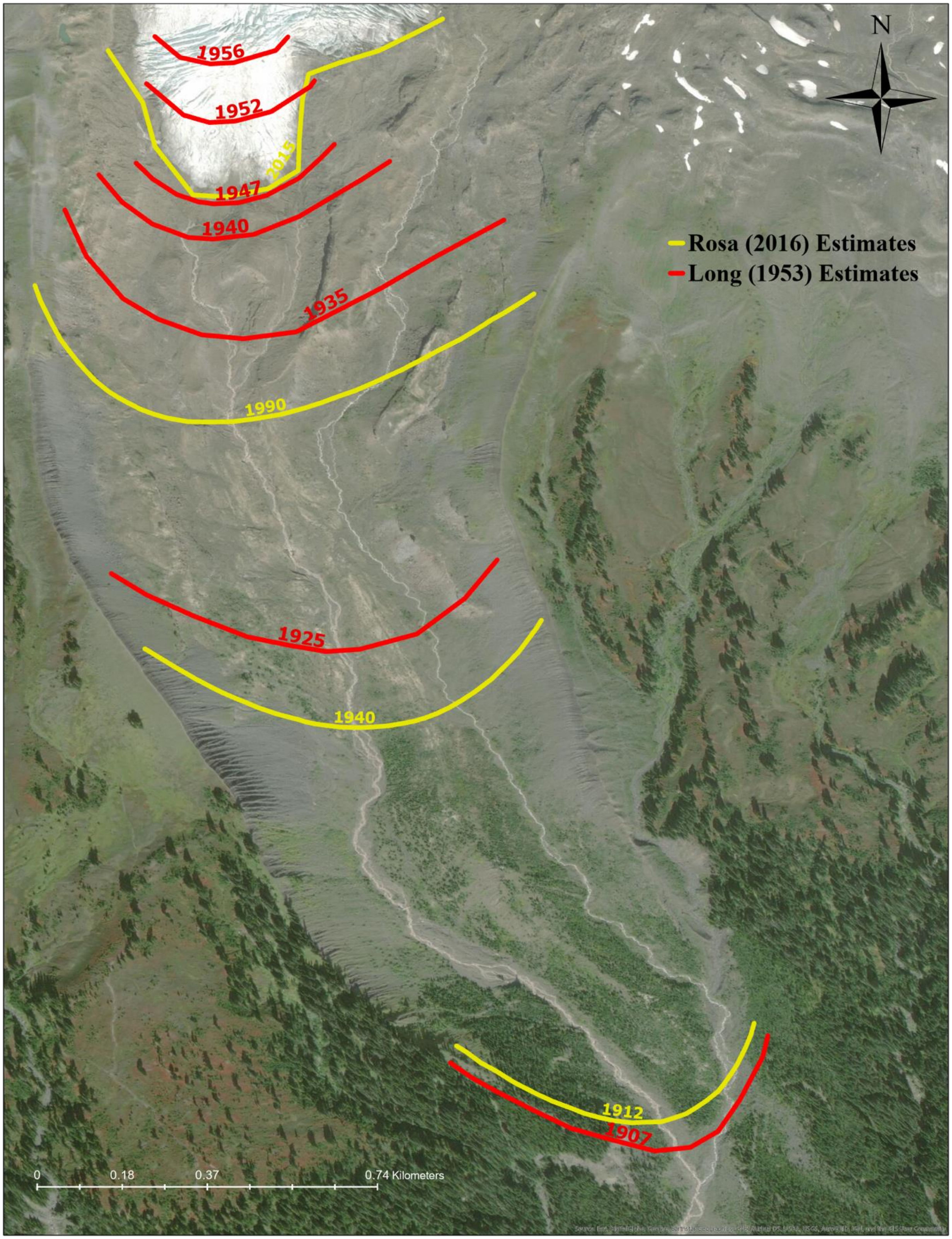


Figure 2.14: Comparison of Easton Glacier's Terminus positions from previous studies. (Long 1953 and Rosa 2016).

2.3 Characteristics of the Easton Foreland

Mount Baker is a large stratovolcano that rises 3,285 meters above sea level and is a part of the Cascade Mountain range in the northwest corner of Washington state (Figure 1.1). The Easton glacier flows due south from Mt. Baker's ice cap, one of ten major glaciers (Figure 1.2). The Easton glacier flows down a long steep valley bounded by two mid-Holocene lateral moraines (Figure 2.15) (Osborn et al. 2012). The Easton foreland is approximately 2 km in length and 0.6 km wide (Figure 1.3). The elevation of the valley ranges from 1200 meters to 1640 meters. The Easton valley has a southern aspect allowing for more sun exposure and higher daytime temperatures. In the following section, I will describe characteristics of the Easton foreland including climate, geology, vegetation, glacial history, and land use practices.

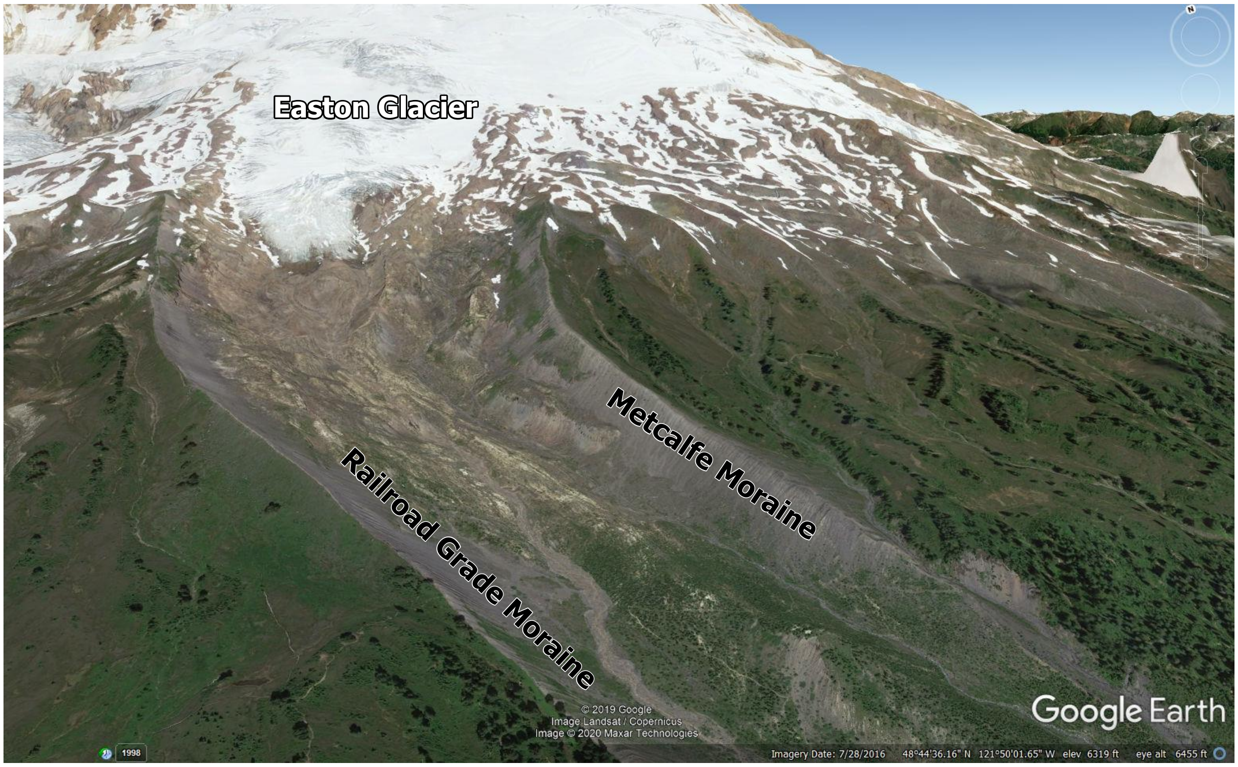


Figure 2.15: Easton foreland in 2016 bounded by two mid-Holocene moraines

2.3.1 Climate

Mount Baker resides in a west coast maritime climate that is heavily influenced by the Pacific Ocean (Mass 2008). The Easton glacier is located on the south side of Mount Baker, and temperatures in the area generally range from 14.5 degrees Celsius in the summer and 0.5 degrees Celsius in the winter (Bach 2003, Minder et al. 2010). Due to its high elevation, it experiences heavy snowpack in the winter, (Mass 2008) and relatively mild and dry summers.

Due to its proximity to the Pacific Ocean, Mount Baker is heavily influenced by large scale atmospheric and ocean circulations including the Pacific Decal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO) (Bitz and Batisti 1999, Harper 1993, Hodge et al 1998). PDO can be thought of as a long-lived ENSO like pattern, characterized by alternations lower and higher sea surface temperatures in the north Pacific Ocean (Lewis and Smith 2004). The variability of maritime glaciers' high sensitivity to changes in climatic conditions produces the significant relationship between PDO and winter mass balance of PNW glaciers (Lewis and Smith 2004).

The Pacific Oceans climate forcing mechanisms have extensive effects on glaciers in the PNW, which can be shown through long term mass balance oscillations (Laroque and Smith 2005). Maritime glaciers in the PNW are highly sensitive to variations in winter precipitation, with some glacier's mass balance dependent on summer temperatures (Lewis and Smith 2004). The maritime environment is described as having warmer and wetter conditions in the winter and cooler conditions in the summer as compared to other continental glacier environments (Harper 1993) with some numerical modeling suggesting that maritime glaciers experience greater changes in mass balance for a given change in climate compared to continental glaciers (Oerlemans 1992).

Wind conditions in the Easton foreland are affected by several factors. On a large scale, wind is influenced by prevailing Westerly winds off the Pacific Ocean that wrap around the Olympic mountains and then move through the Puget Lowlands before eventually reaching Mount Baker with a strong southernly component (Mass 2008). In the winter months, the polar jet stream brings cold fronts to the mountain with winds flowing into the Easton valley from the south and west. As winds blow over Railroad Grade moraine, they carry fine grain material, seeds and detritus into the foreland (Whelan and Bach 2017). Within the foreland, northerly katabatic winds flow off the Easton glacier bringing chilling gusts down the valley, contributing to harsh environments for seedlings and saplings (Bach and Price 2013). In contrast, southernly winds flow up valley bringing fine grain material, seeds and detritus from older growth forest in the lower valley to younger surfaces in the upper valley.

Historically, the climate conditions have been warming over the past century, specifically in the North Cascades by 0.8 degrees Celsius from 1900 to 2012 (Abatzoglou et al 2014). A warmer and drier period in the beginning of the twentieth century caused many glaciers around the world to rapidly retreat (Burbank 1981, Long 1955). From 1944 to 1976, the region experienced cooler temperatures and more precipitation leading to advancements of many glaciers (Kovanen 2003, Pelto 1993). After this period, a warmer and drier climate from 1978-1998 caused many glaciers to begin their current state of retreat (Pelto 2009). Precipitation and temperature trends from the mid 1930’s to 1990 for the Mount Baker region were compiled into a time series chart (Figure 2.16) and show annual variations as well as smoothed trends over time (Harper 1993).

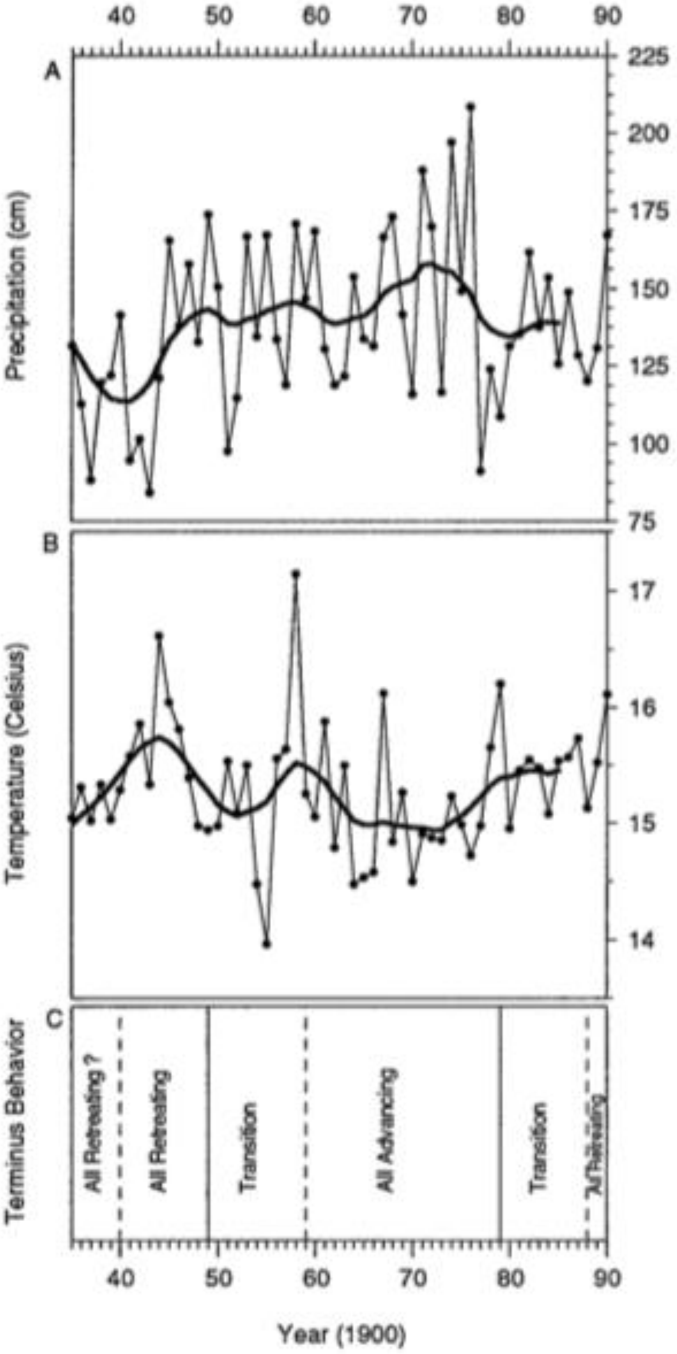


FIGURE 6. Climate and glacier time-series: (A) measured (points) and smoothed (thick line) accumulation-season precipitation at Concrete, WA; (B) measured (points) and smoothed (thick line) ablation-season mean temperature at Sedro Woolley, WA; (C) glacier terminus phases, where dashed lines represent approximate time boundaries.

Figure 2.16: Precipitation and Temperature Time Series for Mount Baker Area. From (Harper 1993)

In 2015, conditions strayed far from normal. The 2015 winter season was the warmest winter season on record for Washington state (Bond et al. 2015). The average freezing level for the Mount Baker region in November-March is about 1077 meters (Abatzoglou 2011) but in 2015, the freezing level raised to about 1645 meters (Pelto 2018). The snowpack storage efficiency was at its lowest, resulting in the lowest accumulation season snowpack in the last 30 years (Pelto 2018). The combination of exceptional warmth in sea surface temperatures and air temperatures, higher freezing levels, and reduced winter snowpack lead to substantial retreat and thinning (approximately 30% of total glacier volume) of North Cascade glaciers (Pelto 2018).

2.3.2 Geology and Soils

The Easton valley's substrate material is largely influenced by Mount Bakers geologic composition, volcanic history including lava flows and ash falls, and wind-blown aeolian inputs. Pleistocene-age pyroxene andesites make up most of bedrock for the glacier forelands of Mount Baker (Bockheim and Ballard 1975). The remaining materials of composition includes plagioclase, hypersthene, and augite (Coombs, 1939).

Ash deposits and lahars from the mid-Holocene have been mapped on the south flank of Mount Baker (Osborn et al. 2012). Over time, these ash eruptions help lead to unique soil properties including rapidly forming fertility diagnostic of andisols (Dahlgen et al. 1998). For example, when ash deposits become buried, deep rooting vegetation can access the ash deposits during late-successional development (Frenot et al. 1998). However, since there has not been an eruption for 1000s of years, these ash deposits have little influence on the younger surfaces (<100 years old) examined in this study (Whelan and Bach 2017).

A soil study conducted on the Easton foreland found that surfaces exposed for about sixty years will become fully covered with vegetation and organic matter (Whelan and Bach 2017). Glacial till on the glacier was found to have trace amounts of organic matter delivered by wind deposition. As surfaces increase in age, organic matter increases, especially as vegetation becomes established. After 100 years of development, the organic matter had increased 2800% to 12.6% of the surface horizons (Whelan and Bach 2017). Having extreme environmental conditions combined with a short growing season, this categorizes the foreland as having a rapid rate of soil development. This has been hypothesized to be related to edaphic factors including aspect, andesitic parent material, and topographic setting relative to established vegetation.

2.3.3 Vegetation

The vegetation in the Easton Foreland can be described as continuous vegetation in the lower valley becoming discontinuous vegetation in the mid valley, and too little too no vegetation in the upper valley. Mountain Hemlock (*Tsuga mertensiana*) can be found throughout the Easton valley and is notably the most dominant tree species. Other tree species include Yellow Cedar (*Cupressus nootkatensis*) and Pacific Silver Fir (*Abies amabilis*) which compete with Mountain Hemlock. Although Alders (*Alnus tenuifolia*) are common in recently disturbed locations in PNW and alpine environments, the Easton foreland has little to none making its presence very rare. Conditions in the foreland allow for many shrub species including heather (*Phyllodoce empetriformis*), bird's beak lousewort (*Pedicularis ornithorhyncha*), partridge foot (*Luetkea pectinata*) and lupine (*Lupinus articus ssp. subalpinus*).

2.3.4 Prehistoric Glacial History

Over the past millennium, Mount Baker glaciers have advanced and retreated many times (Grove 1988, Luckman 2000). During the early Holocene, the glaciers on Mount Baker were of minimal extent compared to their Pleistocene extents (Osborn et al 2012). The Easton glacier's early Holocene position is believed to be the same or smaller than its current glacial extent (Osborn et al 2012). About 6,000 years ago, the glaciers began to advance and continued to advance into the late Holocene with periods of retreat in between. The last advance began 400 years ago during the Little Ice Age (LIA), and glaciers reached their maximum Holocene extents in the coldest LIA period for Western North America in the 19th century (Mann 2002). The LIA ended in the mid to late 1800's, and global temperatures began to rise (Luckman 2000). Currently, glaciers in the Pacific Northwest are in a state of disequilibrium as summarized in section 2.2 (Pelto 2006).

Observed in the Pacific Northwest, a period of glacier recession occurred beginning in the early-mid 1800's and was interrupted by a period of advance from the 1950's to the 1980's. Since then most glaciers have been receding rapidly. The glaciers on Mount Baker have had significantly negative mass balance records from 1990 to 2010 (Figure 2.17) with the Easton glacier having -12.07 meters water equivalent annual mass balance during this time (Figure 2.18) (Pelto 2018). Mount Baker glaciers from 1990 to 2010 have cumulatively lost 12–20% of their entire volume. This has led to significant retreat of all of the glaciers and will lead to continued retreat (Pelto and Brown 2012). Specifically, the Easton Glacier, on Mount Baker, has retreated 290 meters since 1990 (Pelto 2010). A study done by Pelto and Hartzell 2004, showed glaciers in the North Cascades experienced extreme thinning that resulted in 35-50% reduction in their total volume since the turn of the century. The LIA maximum position (Figure 2.19) formed the moraines that surround the Easton foreland and the lower most extent of the Easton glaciers LIA maximum position has yet been identified. This extreme reduction can show how much Mount Baker's ice cap has lost in the twentieth century. These glaciers are expected to continue to retreat in the foreseeable future with some projected to disappear.

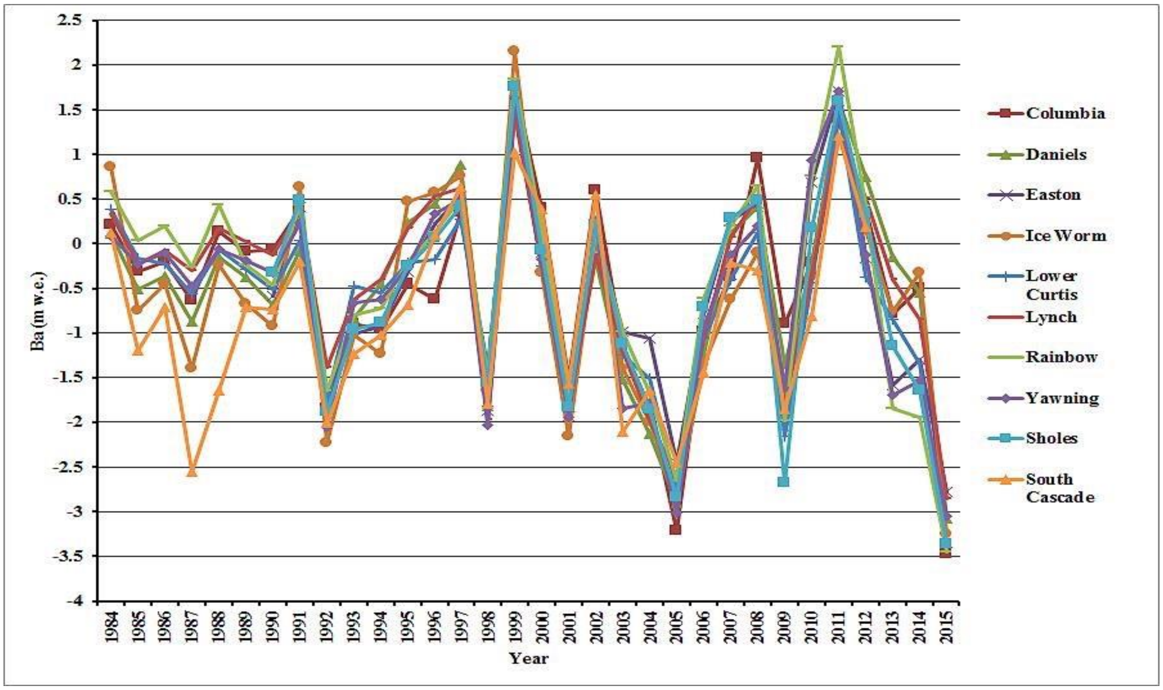


Figure 2.17: Individual Mass Balance of North Cascades Glaciers (Pelto 2018)

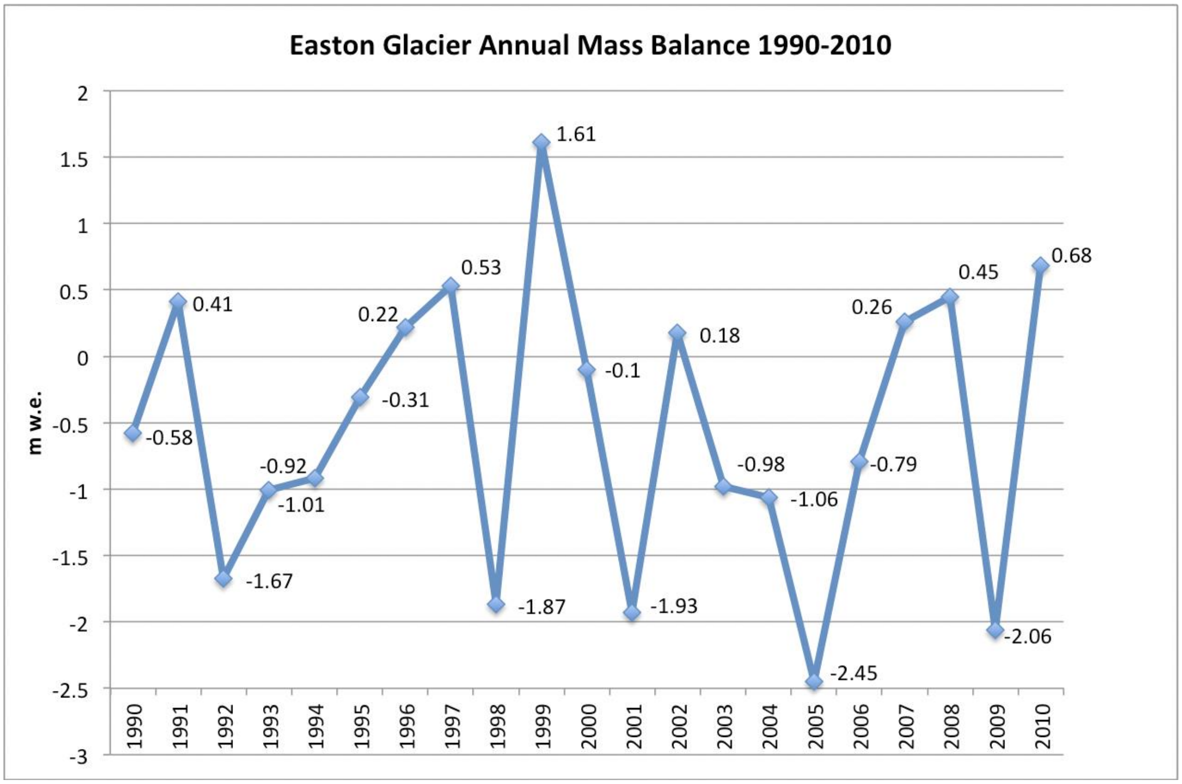


Figure 2.18: Easton Glacier Mass Balance from 1990-2010 (Pelto 2013)

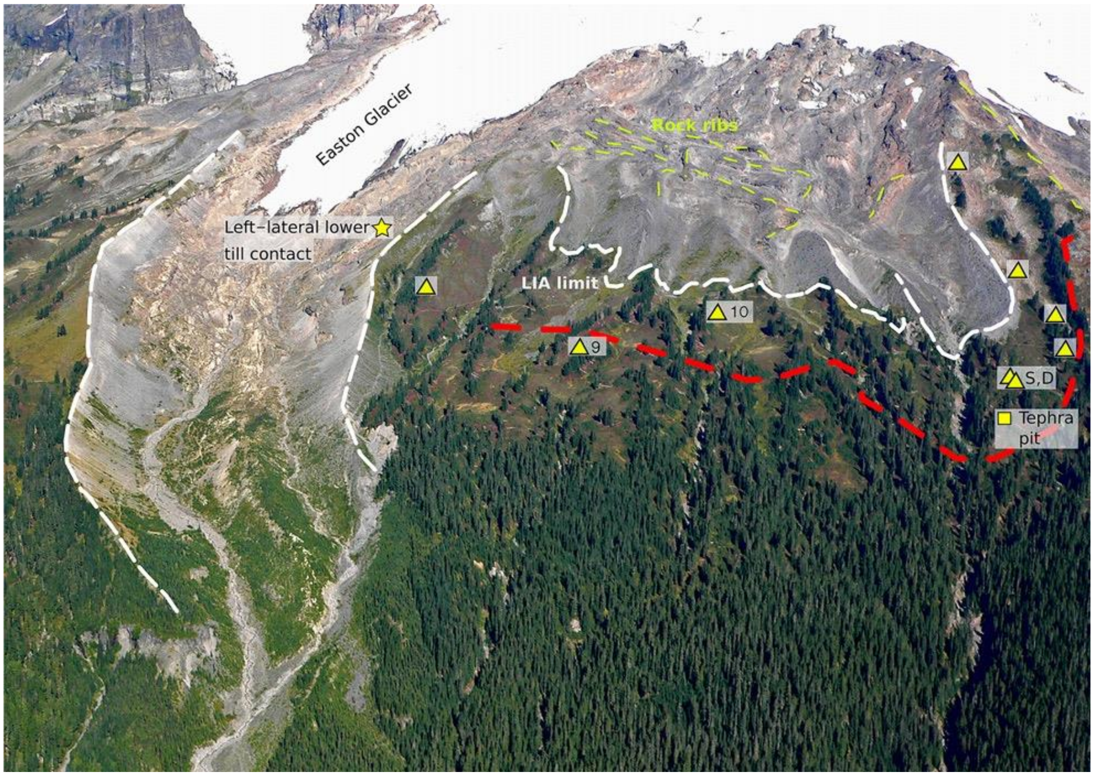


Figure 2.19: LIA Glacial Extent (Osborn et al. 2012)

2.3.5 Land-use Practices

The Easton foreland is located within the Mount Baker National Recreation Area which is a part of the Mount Baker Snoqualmie National Forest. The recreation area was created in 1984 and has been used for hiking, camping, horseback riding, and mountaineering in the summer months. Snowmobiling is permitted in the winter months when snow accumulation exceeds two feet. The Easton foreland can easily be accessed by several different trails including Schreiber’s meadow, Scott Paul, Railroad Grade and Park Butte.

Recreational uses on glacial forelands and alpine environments can have negative impacts. Snowmobiling in particular can lead to increased fragmentation of highly sparse vegetation which can alter the development of vegetation within the foreland (Simpson and

Terry 2000). Snowmobiling can contribute to increased soil erosion, pollution, and damaging vegetation. Recreational activities, especially snowmobiling have an impact on the vegetation development in the Easton foreland, but there was no way to control this factor for this study.

Chapter 3. Methods

The methods and techniques used for this research were supported by previous literature and input from my thesis committee. The ideas and methods used in this research help answer my research questions: What are the historical terminus positions in the early twentieth century? What is ecesis for the Easton foreland?

This chapter is divided into three sections. First, I will explain the process of my sampling strategy including site selection and locating the sites. Then, I will describe the data collection process including how each variable was measured. Lastly, I will discuss the statistical methods used to analyze the collected data and how this leads to my results in Chapter 4.

3.1 Sampling Strategy

This research aimed to capture the full glacial history and tree establishment in the Easton Glacier foreland over the past century using dendrochronology. To accomplish this, trees must be sampled throughout the valley preferably in places where the glacier is known to have once been present. My sampling area, the Easton foreland, is approximately 1,950 meters long (measured in Google Earth Pro) ranging from the current glacier terminus down valley, 360 meters past the location of the glacier terminus shown in the 1912 photograph (Figure 2.1), and down valley to a group of moraines that might have been deposited during the Little Ice Age. The sampling method used for this study was the variable radius sampling strategy (Scott 1990) in one transect running the full length of the foreland (Figure 3.1). The transect lies east of the major stream that runs down the middle of the foreland. The distance between each plot was roughly 100 meters. The radius for each plot was 10 meters for dense vegetation plots and larger for plots with more dispersed trees (higher up the foreland). The 10 closest trees in each radius plot were sampled. The trees' ages should progressively become younger as you move from the bottom to top of the foreland, mirroring the glacial recession overtime.

3.1.1 Site Selection and Locating Sites

ArcGIS Pro (ESRI 2011) was used to create the transect running the length of the foreland from the 1990 terminus position extending to an old growth forest which is believed to be the Little Ice Age Maximum position (Figure 3.1). This transect avoids the stream that runs down the center of the foreland and mass-movement deposits along the margins of the foreland, which are generated off the steep, Holocene age moraines. From this, twenty-four plots were created approximately one hundred meters apart on the transect and GPS coordinates were obtained (Figure 3.2). The transect and plots were cross referenced with images from Google EarthPro to ensure tree cover was present for each plot.

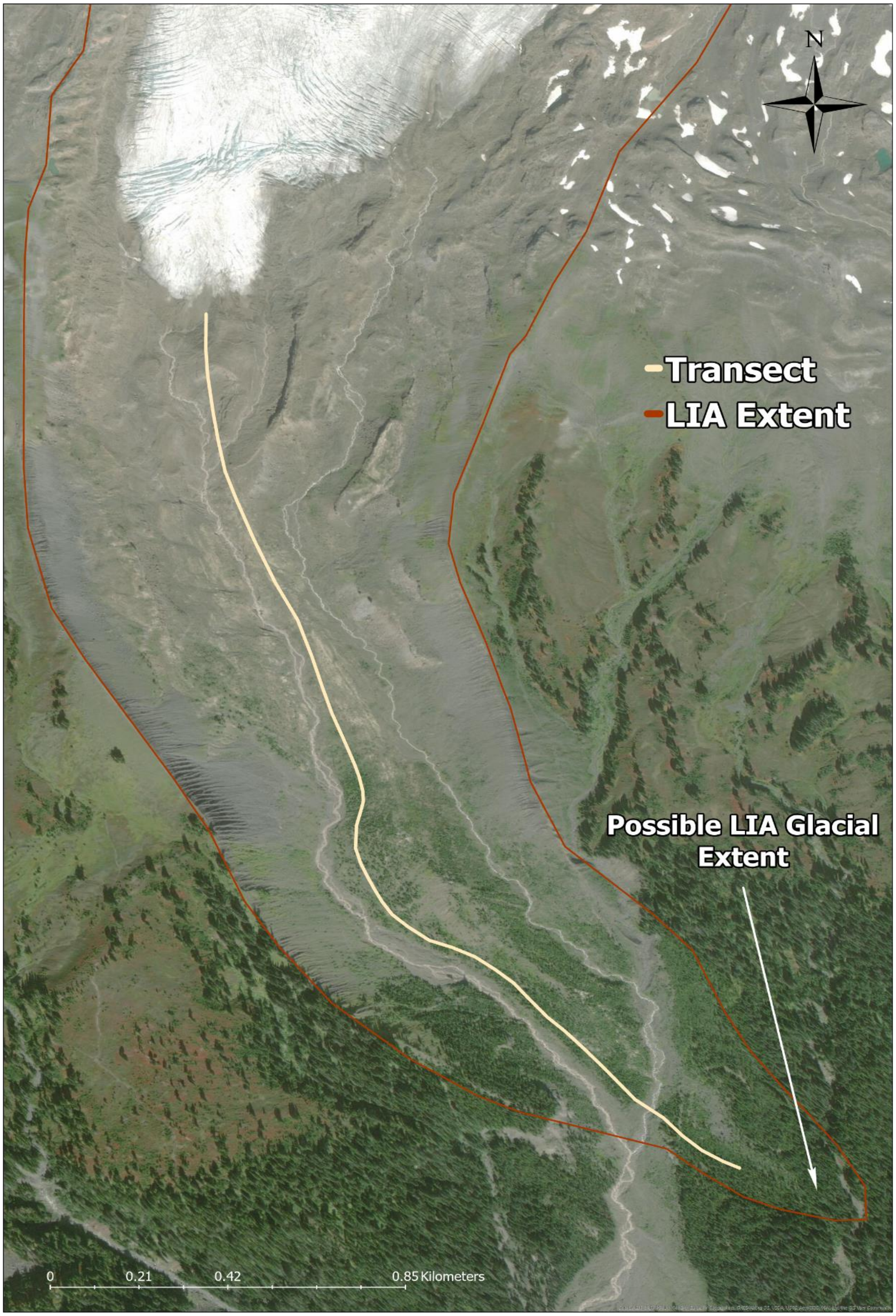


Figure 3.1: Transect located within possible LIA glacial extent

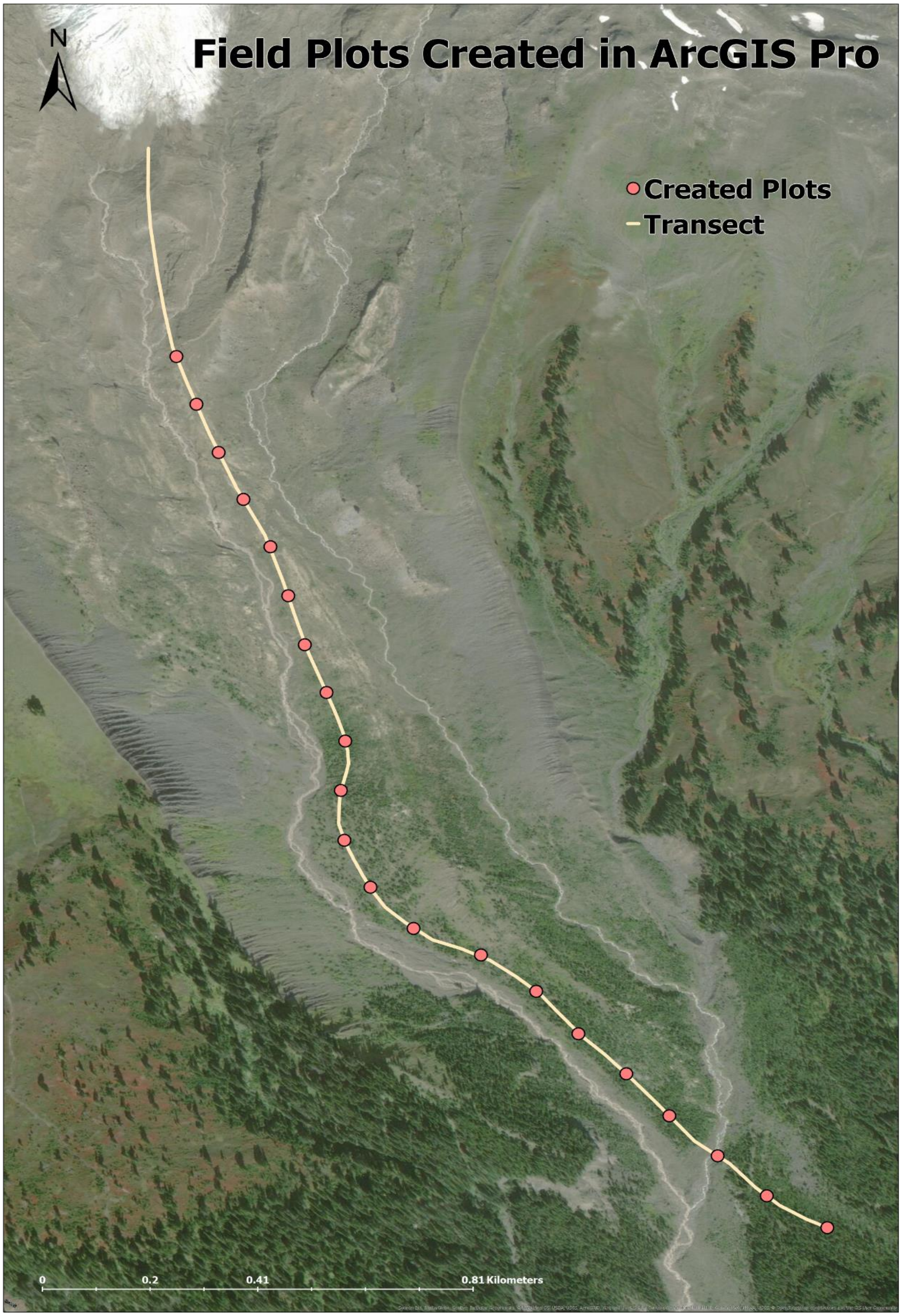


Figure 3.2: Location of GIS created plots in the Easton Foreland

While in the field, troubles occurred with the Garmin GPSMAP 60CSx unit making it difficult to locate the positions of each plot. Plots were then determined by roughly estimating one hundred meters apart and randomly designated the plots center by throwing a large rock backwards in the location estimated to be the plot location. The location of the real plots compared to the Arc PRO generated plots is presented in Figure 3.3.

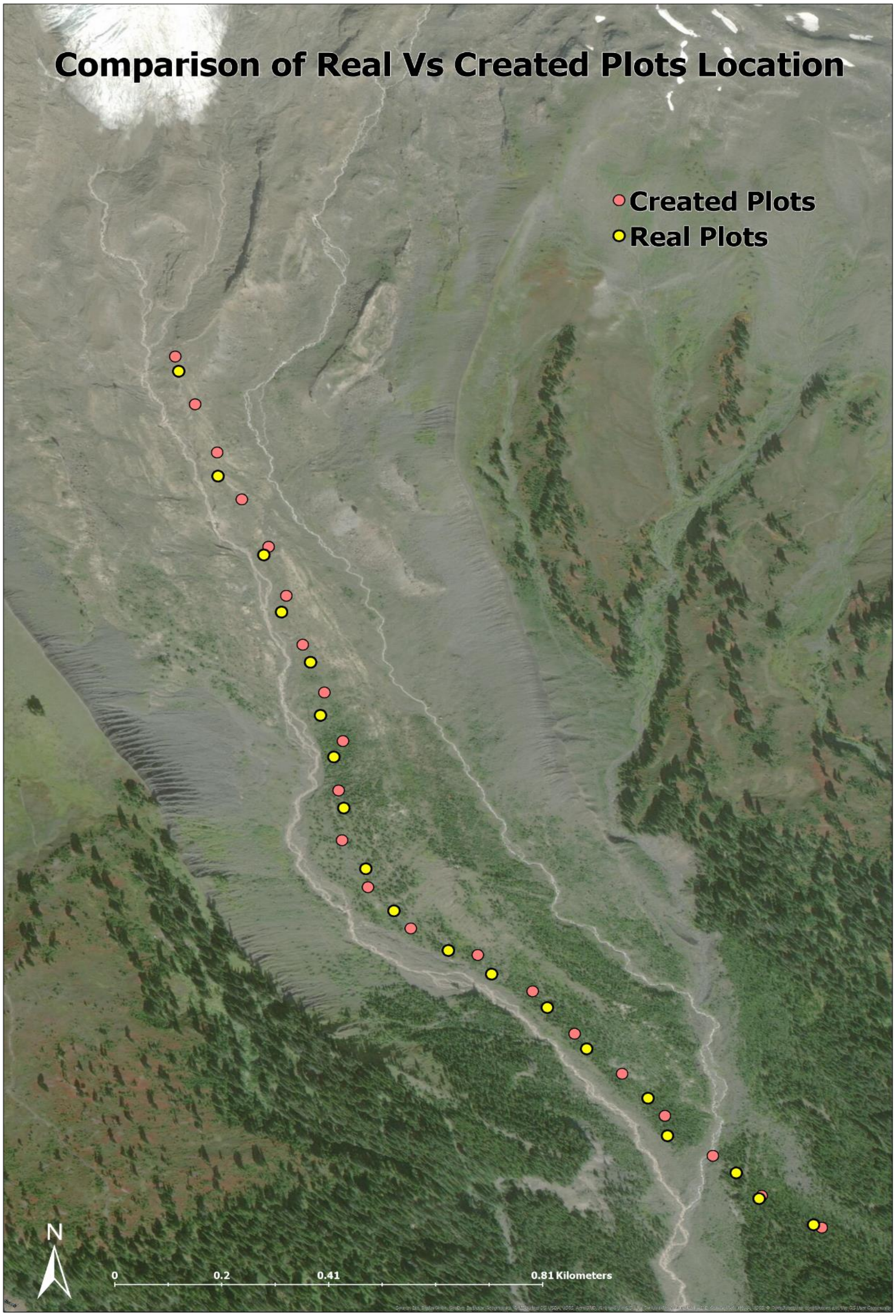


Figure 3.3: Real plot locations relative to GIS created plots

3.1.2 Determining Ecesis

Before the historical terminus position can be refined and the terrain age can be estimated, the ecesis value for the foreland must be determined. Ecesis may be a single value or an interval depending on the foreland characteristics and dendrochronology data. In this study, the minimum and maximum ecesis values will be noted and the average ecesis interval will be calculated. There is no single standardized method for measuring ecesis but McCarthy and Luckman (1993) offer various methods used by previous studies that have shown to be effective. For this study, ecesis will be determined by measuring the tree's age at a known terminus position and subtracting the age of the tree from the current year and then subtracting that by the date of the terminus position. The equation can be explained below:

Ecesis = A – B – C
A = Current Calendar year
B = Age of tree at known terminus location
C = Year of known terminus position

An approximate location of the 1912 terminus position was determined using a historic photograph (MBVRC 2012) and geographic information system (GIS) techniques (Whelan and Bach 2017). This location and the 1990 terminus position estimated from satellite images (Rosa 2016) will be used to estimate ecesis for the foreland (Figure 3.4). The minimum age of the substrate at these locations can then be estimated by adding the age of the tree and the ecesis value (Sigafoos and Hendricks 1969). Once the age of the substrate is determined, the minimum time since deglaciation can then be estimated.

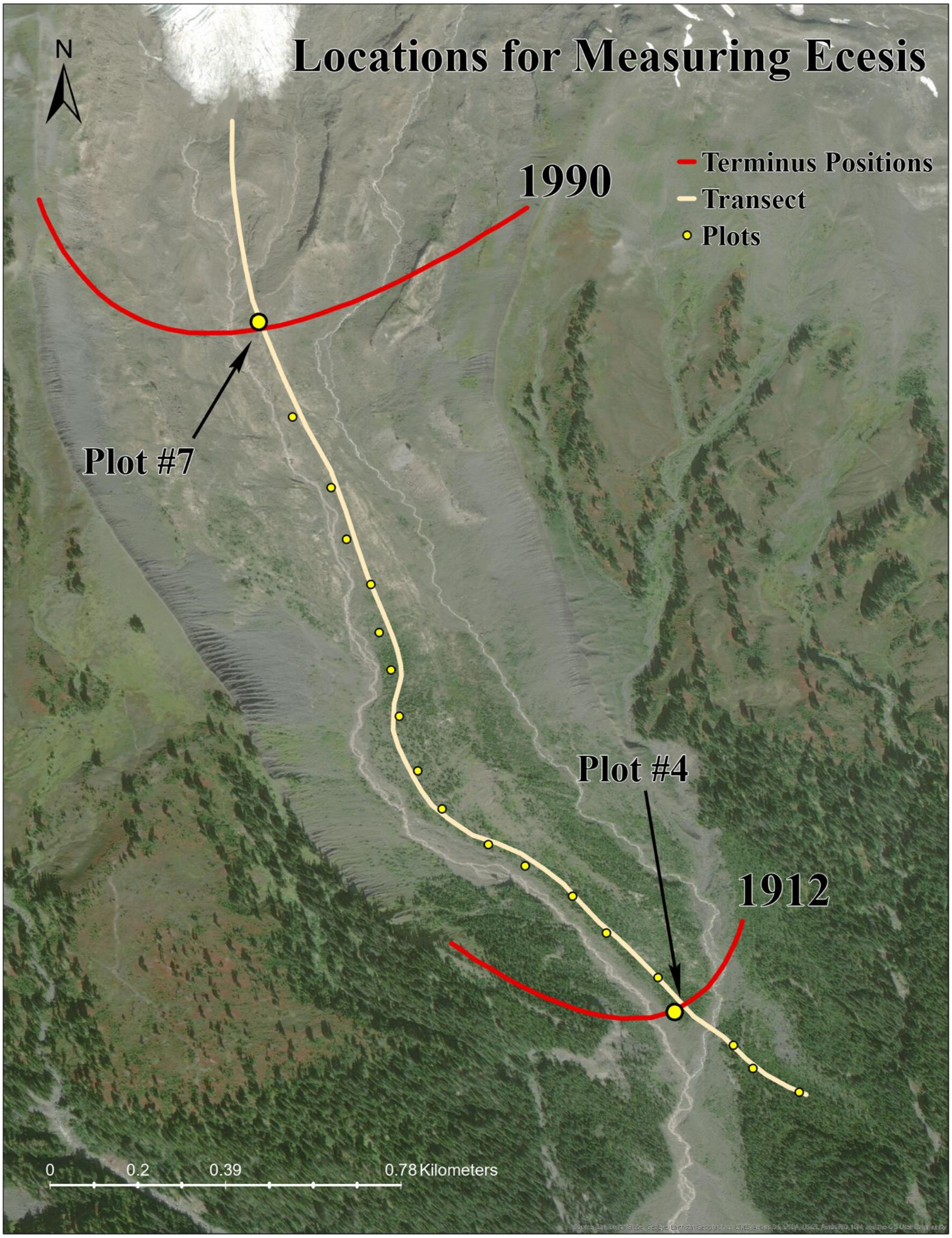


Figure 3.4: Locations for Measuring Ecesis in the Easton Foreland

3.2 Data Collection

In this section, I will describe the methods used to identify, and sample plots and their variables within the Easton foreland. The fieldwork was conducted August 4-9, August 18-20, and September 28, 2019 with the help of several volunteers.

Determining Plot Center and Radius

Once the plot was located, the center of the plot was determined by randomly throwing a large rock. From this center position, a radius was constructed for sampling. Most plots stuck to the original 10-meter radius, however, plots in the north foreland were less dense in vegetation so the radius was increased to as much as 17 meters to ensure 10 samples per plot. The geographic coordinates of each plots center were recorded using a Garmin GPSMAP 60CSx unit.

Plant Identification

Only trees that were of the species Mountain Hemlock or Pacific Silver Fir were sampled for this study. Tree species were identified based on their bark and needles. Tree height was visually estimated for every sample in meters. Basal diameter at the base were recorded with measuring tape. The data are presented in Appendix 1.

Slope and Aspect

Slope and aspect were measured using iPhone® applications. The iPhone® inclinometer application was used to measure slope for each plot. Aspect for each sample relative to the plots center was measured using the iPhone® Compass application. The iPhone inclinometer application has been shown to be as reliable as a traditional gravity bubble inclinometer (Kolber et al. 2013).

Elevation

Elevation was measured in meters above sea level using a Garmin GPSMAP 60CSx unit.

Tree Coring

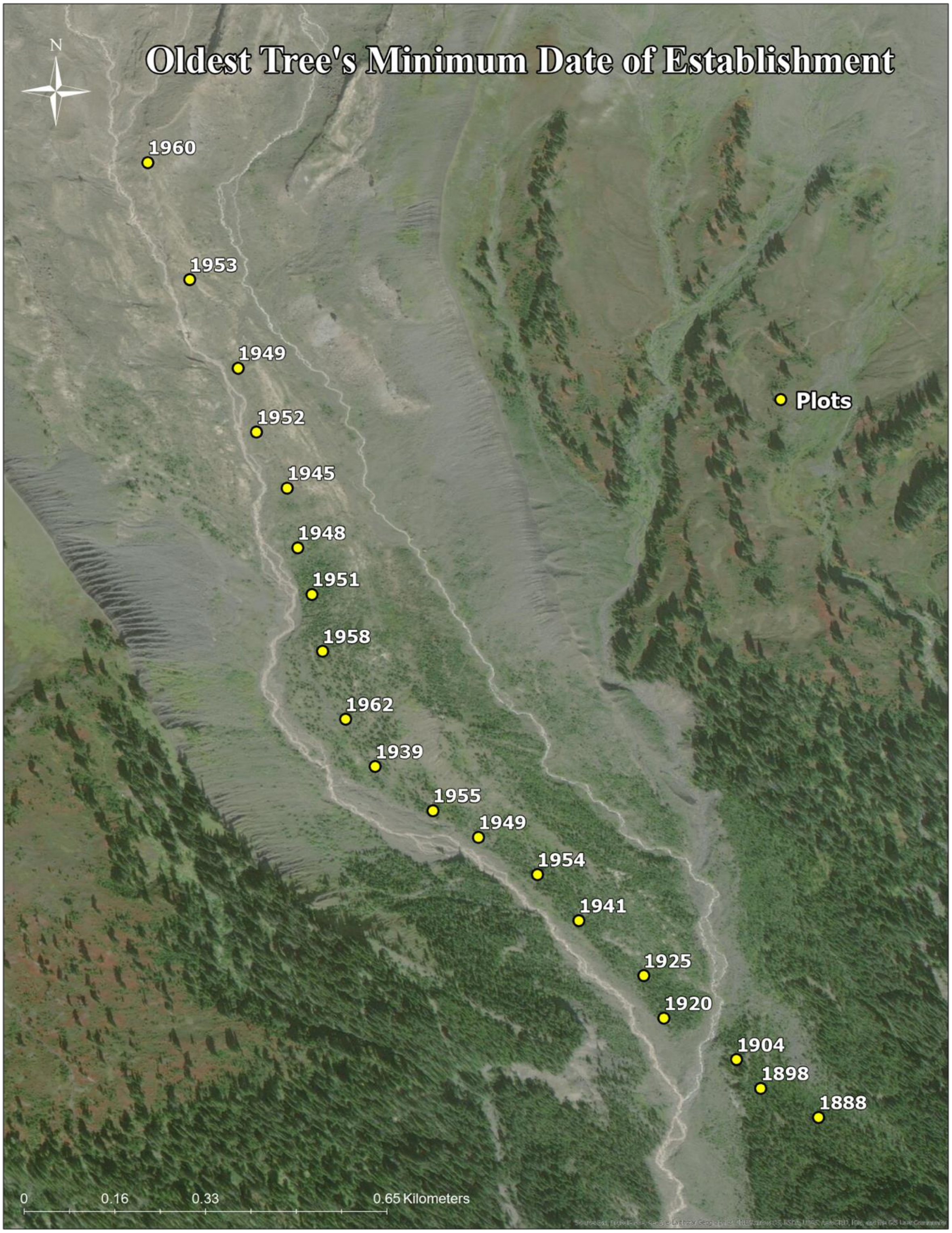
Each tree was sampled once and its distance relative from the plots center was recorded with measuring tape. Depending on the size and position of the tree, samples were either cut into disks using a hand saw or cored using an increment borer. In some cases, to reach the base and root collar of the tree, surrounding soil and substrate were removed. With 19 plots and 10 trees sampled from each plot, a total of 190 samples were collected. All the core samples were stored in straws or plastic bags to keep them from drying out when transferred from the field to the laboratory.

3.3Laboratory Analysis

Lab methods followed basic dendrochronological methods (Flower et al. 2017, Matthews, Birks, and Wiens, 1992, Speer 2013). All core samples were mounted on a pre-fabricated backing with wood glue and sanded on a belt sander. Each core was sanded using coarse to fine sandpaper (100-600 grit). The annual rings for each sample were counted three times, once by myself, and once each by my two assistants using a dissecting microscope. If there were miscounts on a sample greater than 2 years, the sample was recounted for a fourth time to correct for error. No cross dating was preformed to verify ages/dates. Samples may have false or missing rings that could over or underestimate the ages.

3.4 Statistical Analysis

The coordinates for each plot along with basic characteristics (tree height, diameter, elevation, etc.) collected on each sample were uploaded from excel to ArcGIS Pro. For the analysis the coordinate system used was GCS NAD 1983. From here, the oldest trees from each plot were plotted spatially on the Easton foreland (Figure 3.5). When looking at the data, the ages do not all follow a continuous trend up the foreland. This is mostly due to the fact that the oldest tree in the area was not sampled in every plot, so some plots were removed for visual interpretation purposes (Figure 3.6). Plot 1 was the only plot from these that did not have an exact date as the pith was not accounted for in this sample. This means that although its establishment date is set at 1904, its true establishment date is older. It is unclear whether it is off by 1 or 20 years so this estimate should be noted when viewing the data. A chronology of the Easton glaciers terminus position was created using previous terminus position data, tree establishment dates and ecesis values. Recession rates were calculated for each area in between terminus locations. Substrate age was estimated at each terminus position and age zones were created to reflect the time since deglaciation (Figure 3.7).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3.5: Oldest trees from each plot showing minimum date of establishment

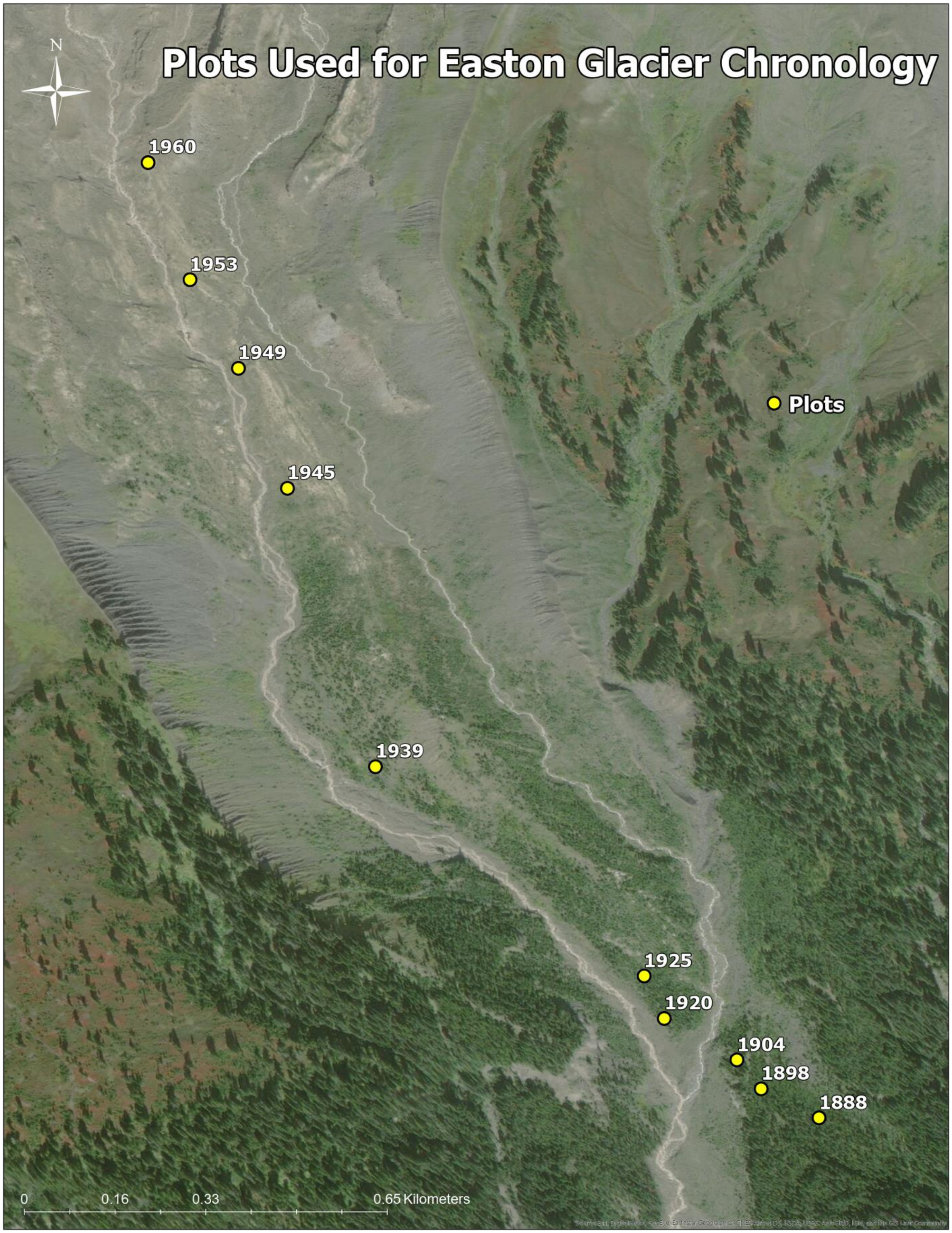


Figure 3.6: Plots in Chronological order by Establishment Date

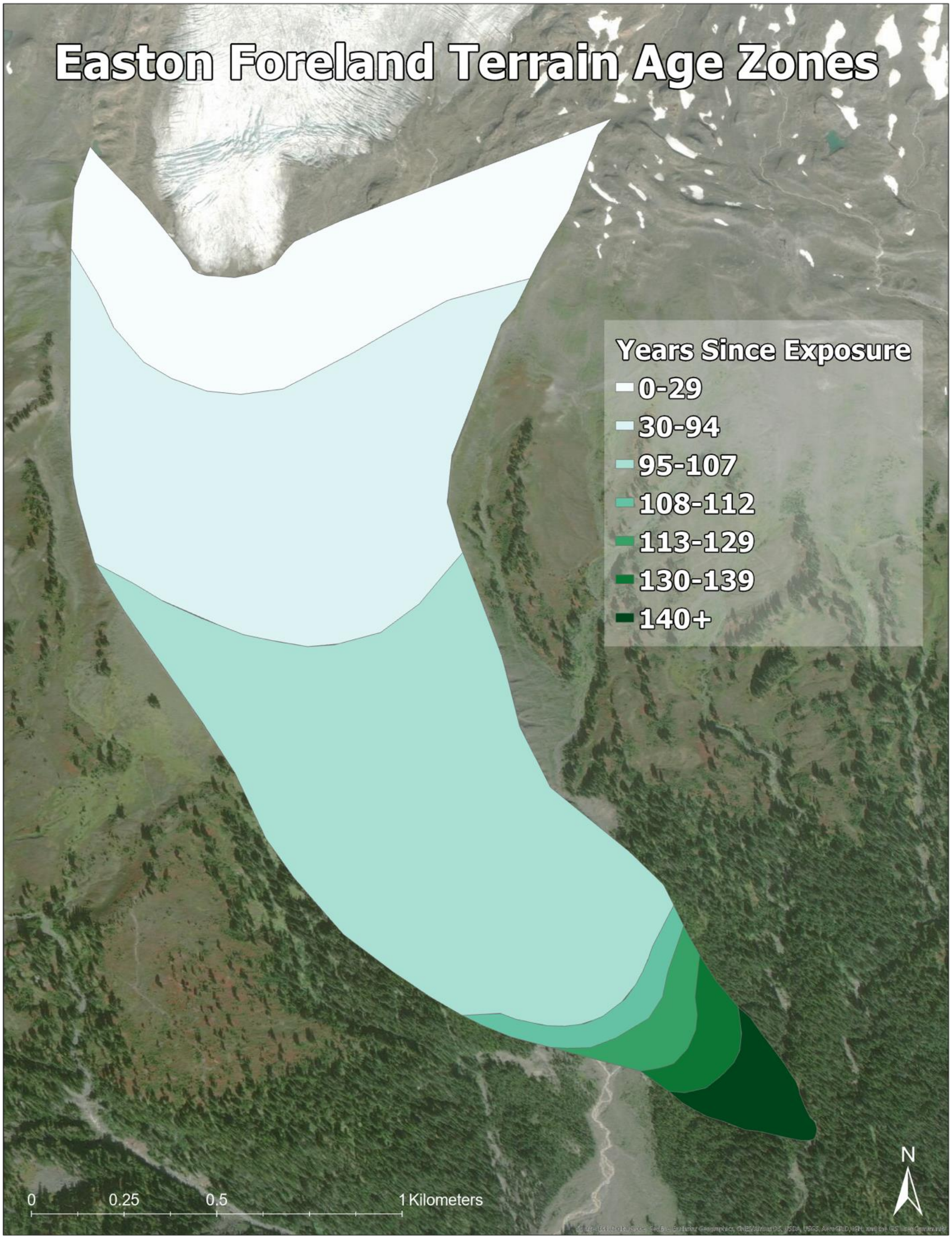


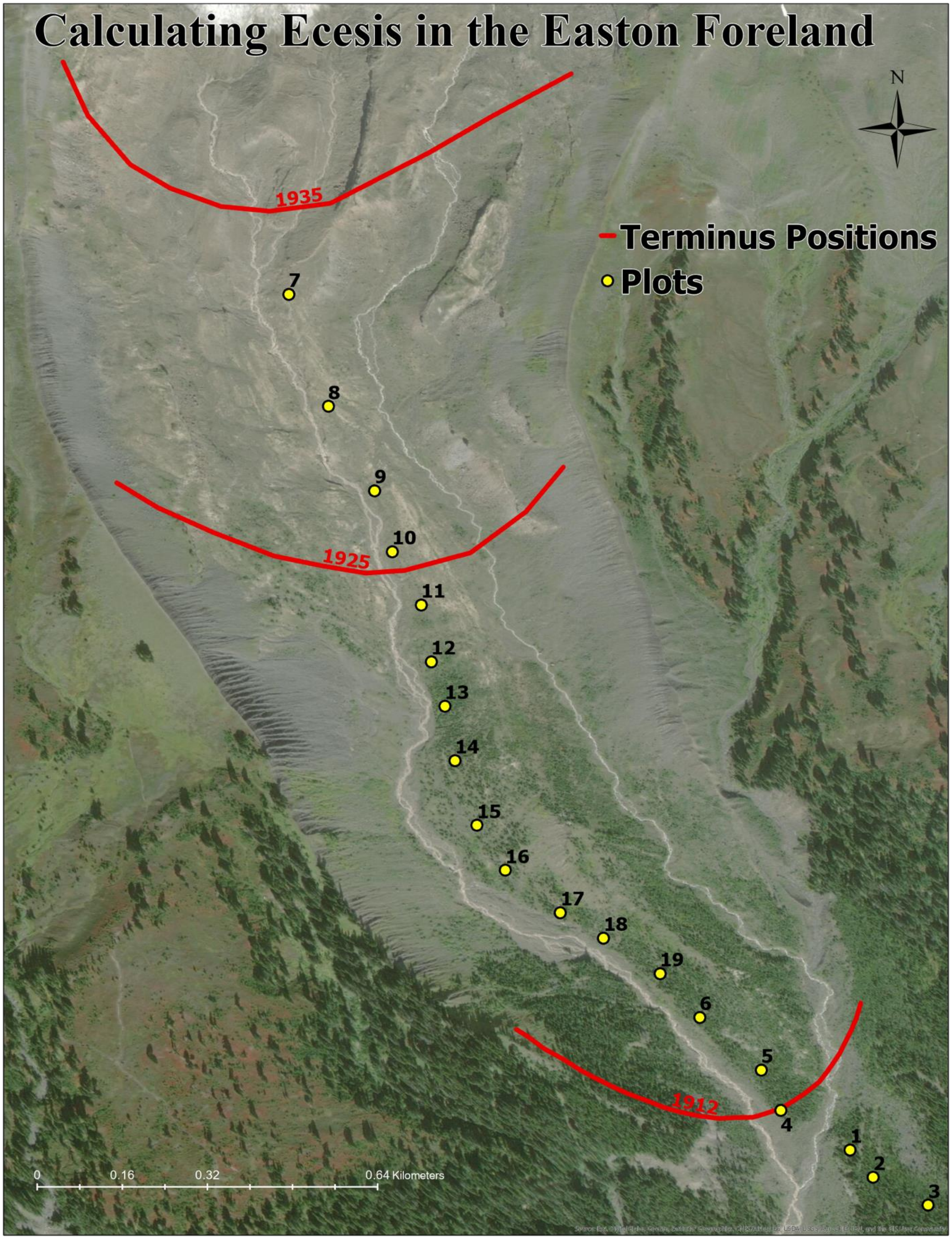
Figure 3.7: Substrate age zones based on tree establishment and ecesis. (Note: the sides of these areas were not surveyed, only the down valley location)

Chapter 4. Results and Discussion

Approximately six glaciers on Mount Baker experienced a similar fluctuation sequences during the twentieth century (Harper 1993, Long 1956). Decade scale intervals of retreat-advance-retreat were experienced from 1940-1990 and prior to 1940 the glaciers are believed to have been in a rapid retreat since the mid-late 1800's (Long 1956). The Easton glacier specifically, is known to have a slower response time than other glaciers on Mount Baker (Harper 1993, Pelto and Hedlund 2001). The reasons for this slower response time are still unclear yet obtaining a detailed glacial chronology and comparing it with numerous environmental factors, may shed light on influential stimuli affecting the Easton glaciers behavior during this period. The following chapter will discuss the findings of this research in its entirety and discuss possible explanations for these outcomes.

4.1 Ecesis

Ecesis was estimated from two locations (plot 4 and 7) in the foreland as shown in Figure 3.4. A third location at the 1925 terminus position was used in Arc GIS Pro to estimate ecesis in the middle of the valley. Using the information of terminus positions from Long (1953), Harper (1993) Rosa (2016) and Whelan and Bach (2017), ecesis can be calculated from the 1912, 1925 and 1935 locations. The 1990 terminus position that was estimated from previous studies, was determined inaccurate by the tree data of this study. At the estimated 1912 terminus position, the oldest sample from plot 4 is 99 years old setting a minimum date of 1920. At this position, ecesis is at most, about 8 years. At the 1925 terminus location, no plot falls directly on the terminus position. Plot 10 is north of this location by about 26 meters and plot 11 is south of this point by about 80 meters (Figure 4.1). The age gap between these samples is small (7 years) with plot 10 having a minimum date of 1952 and plot 11 having a minimum date of 1945. By taking the recession rates during this time (69-70m per year) and assuming a constant rate, then the terminus position at each plots location can be estimated. This is done by taking the distance between the plot and the known terminus position and dividing it by the recession rate to obtain the amount of years. This amount of years is then added or subtracted by the terminus position year depending if the plot it north or south of the terminus. This new date then is the year in which the terminus is estimated to be on or near that plot. Ecesis in the middle of the valley can be estimated to about 22-26 years with a mean of 24 years. At the top of the valley, the oldest sample from plot 7 is 59 years old setting its establishment date as 1960. The 1935 terminus position is approximately 165 meters north from plot 7 (Figure 4.1). If you consider the recession rate of 70 meters per year for the decade of 1925-1935, then you can estimate the 1932-1933 terminus would be on or near plot 7's location. This sets ecesis at about 27-28 years for the top of the foreland.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4.1: Location of plots relative to the Easton glaciers terminus positions

Ecesis is not one single value nor one particular range for the Easton foreland. Instead, ecesis is site specific depending on the position within the valley. Ecesis is longer at higher elevations in the valley where conditions are more extreme and harsher for seedlings. The elevation difference from the top to the bottom of the foreland is 1005 meters (measured in Google Earth Pro). Ecesis's variation with elevation is due to a combination of differences in nutrient availabilities and microclimate. The nutrient availability of recently deposited till at the bottom of the foreland would not be too much higher than the till deposited at higher elevations. The difference then in establishment rates is due to proximity of seed source and longer growing seasons.

On average, the bottom of the foreland is 1.43 degrees Celsius warmer than the top of the foreland, making seedling establishment and survival more favorable down valley (Wang et al 2016). Snow accumulation stays longer throughout the year in the top of the valley shortening the growing season and ultimately impacting seedling establishment and mortality. Besides having a longer growing season and warmer temperatures, the lower valley also has a close proximity to a continuous montane old growth forest providing more nutrients with detritus rich micro flora and fauna. This factor too may contribute to the faster ecesis intervals for the lower valley plots compared to higher elevations. At the top of the valley, vegetation is sparser and less mature making the nutrient availability very poor compared to the lower valley. Plant life history traits associated with seed dispersibility are critically important for successional species on newly exposed terrain (Chapin et al. 1994) making areas near more developed surfaces (lower valley) favorable for seedling establishment and sapling development.

4.2 Easton Glacier Chronology

The ages and dates from this study agree with most other findings regarding the Easton glaciers terminus position and movement over time. However, the data from this research has also modified and falsified some information from previous studies. The findings from this study have dated the Easton glaciers terminus position back to its believed Little Ice Age (LIA) position, extending the chronology back by 27 years. The Easton glacier now has a more refined glacial chronology for the past century than what was previously recorded.

The oldest trees sampled in this study from plots 1-3, are down valley past the 1907 terminus position, a part of an older growth forest assumed to be where the Easton glaciers LIA position was (Figure 4.2). During sampling, many overlapping end and lateral moraines were observed in this area (Figure 4.3). When looking at satellite images, a clear moraine can be spotted and differences in trees' height and composition can also be identified (Figure 4.4) suggesting the Easton glacier was positioned there at one point in time. The trees sampled in this area dated back into the late 1800s. Out of the three oldest ages, only two are exact ages (plots 2 and 3). The age for plot one is an estimate as the pith was not reached in this sample. If you consider the ecesis to be the same in this lower valley, approximately eight years, then at most you can consider that at plot three's location the Easton glaciers terminus position would have been there in 1880. At plot two's position, the glaciers terminus would have been there at the earliest of 1890 (Figure 4.5). The distance between these two plots is 86 meters over ten years, making its recession rate 8.6 meters per year.

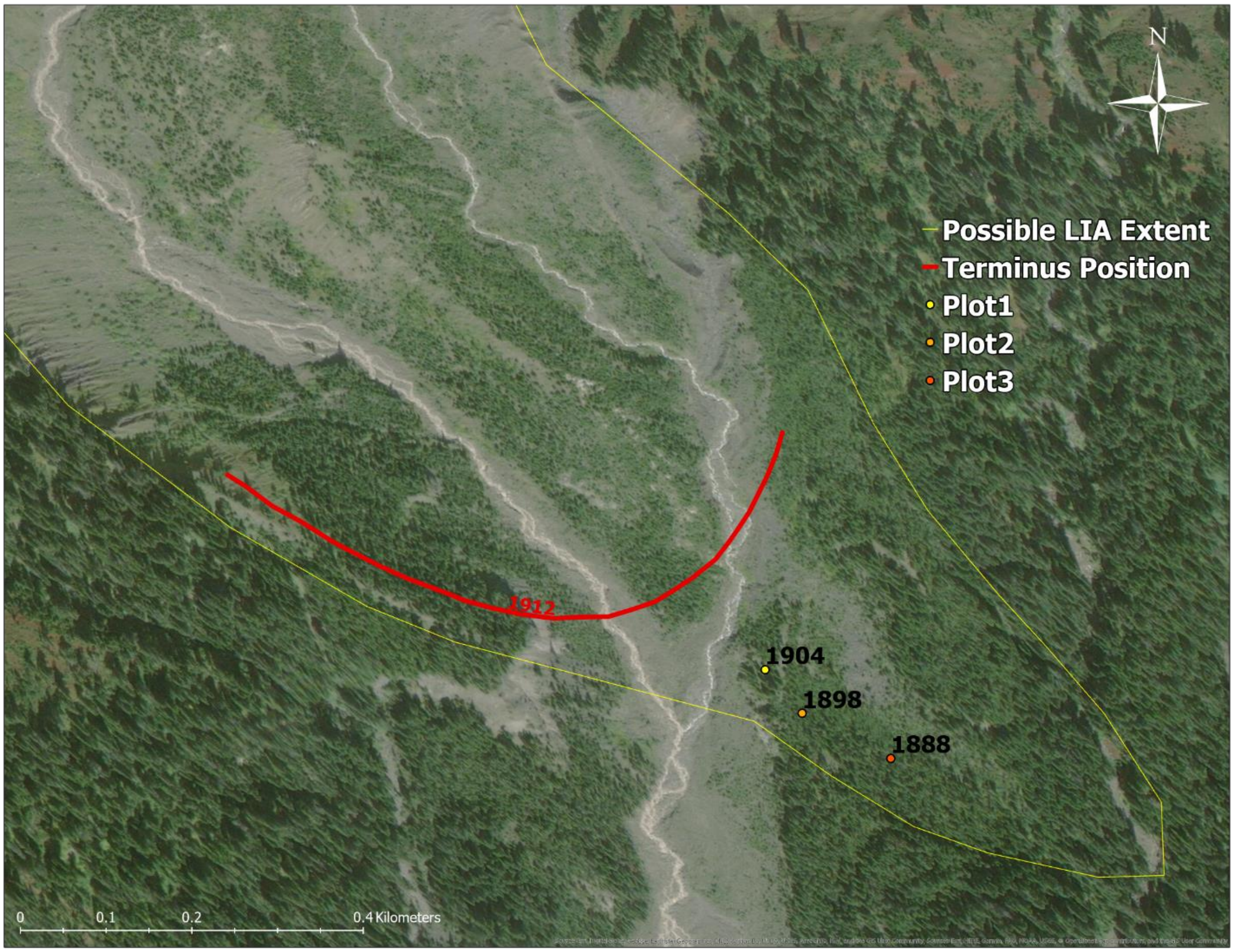


Figure 4.2: Plots sampled in LIA maximum position

Figure 4.3: Moraines spotted in lower foreland. (Monica is seen standing on one, and another lies behind Ryes Logan to the right)

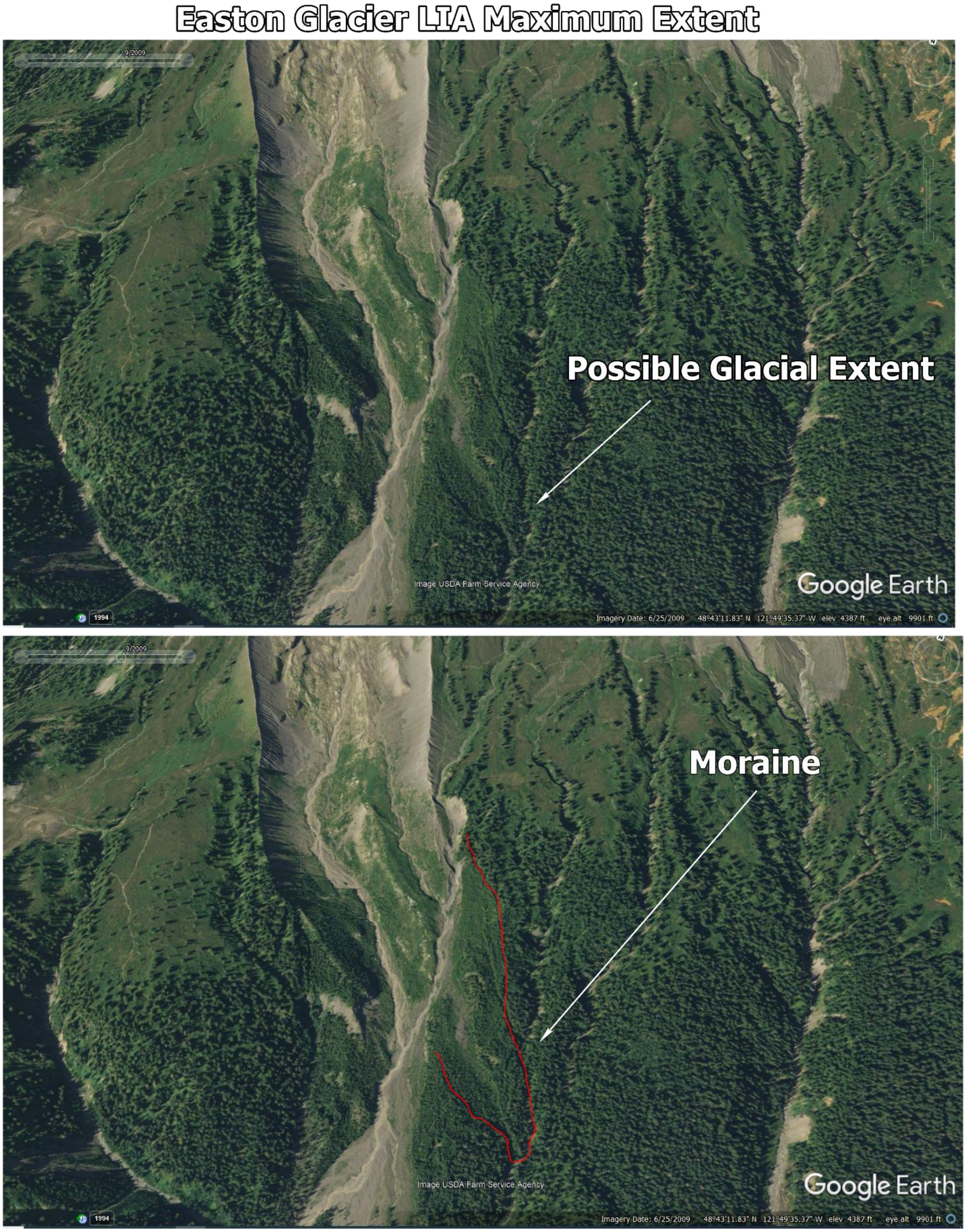


Figure 4.4: Estimated Location of Easton glacier's LIA Maximum Position (not surveyed in this study)

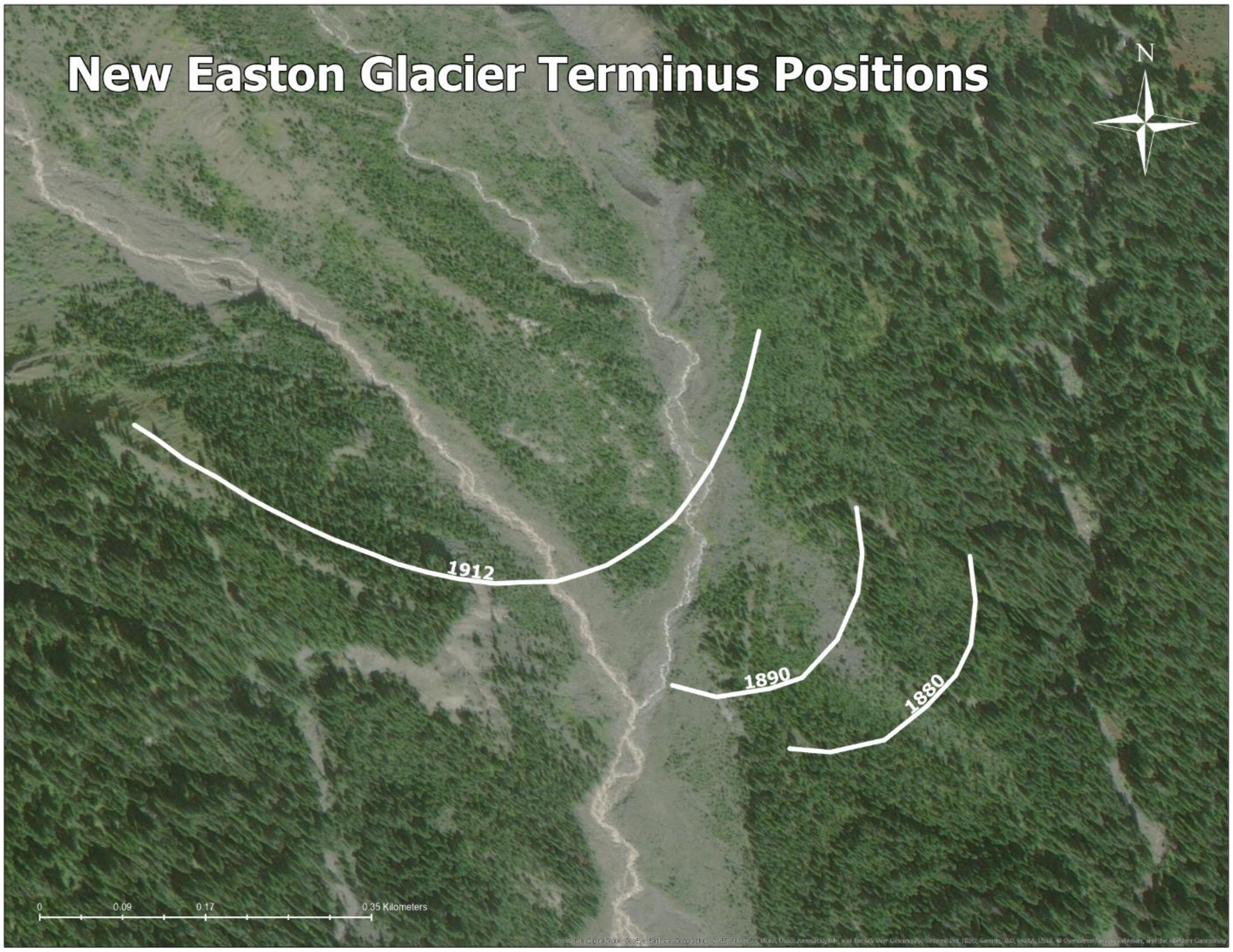


Figure 4.5: Location of Easton Glacier's newly discovered terminus positions. (Locations estimated from single trees, shape and extent of the termini not surveyed)

Plot 7 lies near the top of the foreland, the youngest surface sampled in this study. The trees in this area were very small in terms of height (0.25m) and diameter (1cm) compared to other plots lower in the foreland. The trees were sparse and showed signs of damage from being buried by snow. North of plot 7, there were no trees large enough to sample making this area the boundary between vegetation and bare soil. The oldest tree in this plot was 59 years old setting its establishment date at 1960. This age does not match the estimated 1990 terminus position from Rosa (2016) located on plot 7. Using data from (Harper 1993, Long 1953, Pelto 2018) and google Earth PRO (Figure 4.6), the 1990 terminus position was estimated 30 meters north Rosa's (2016) estimate and about 14 meters north of plots 7's location (Figure 4.7).

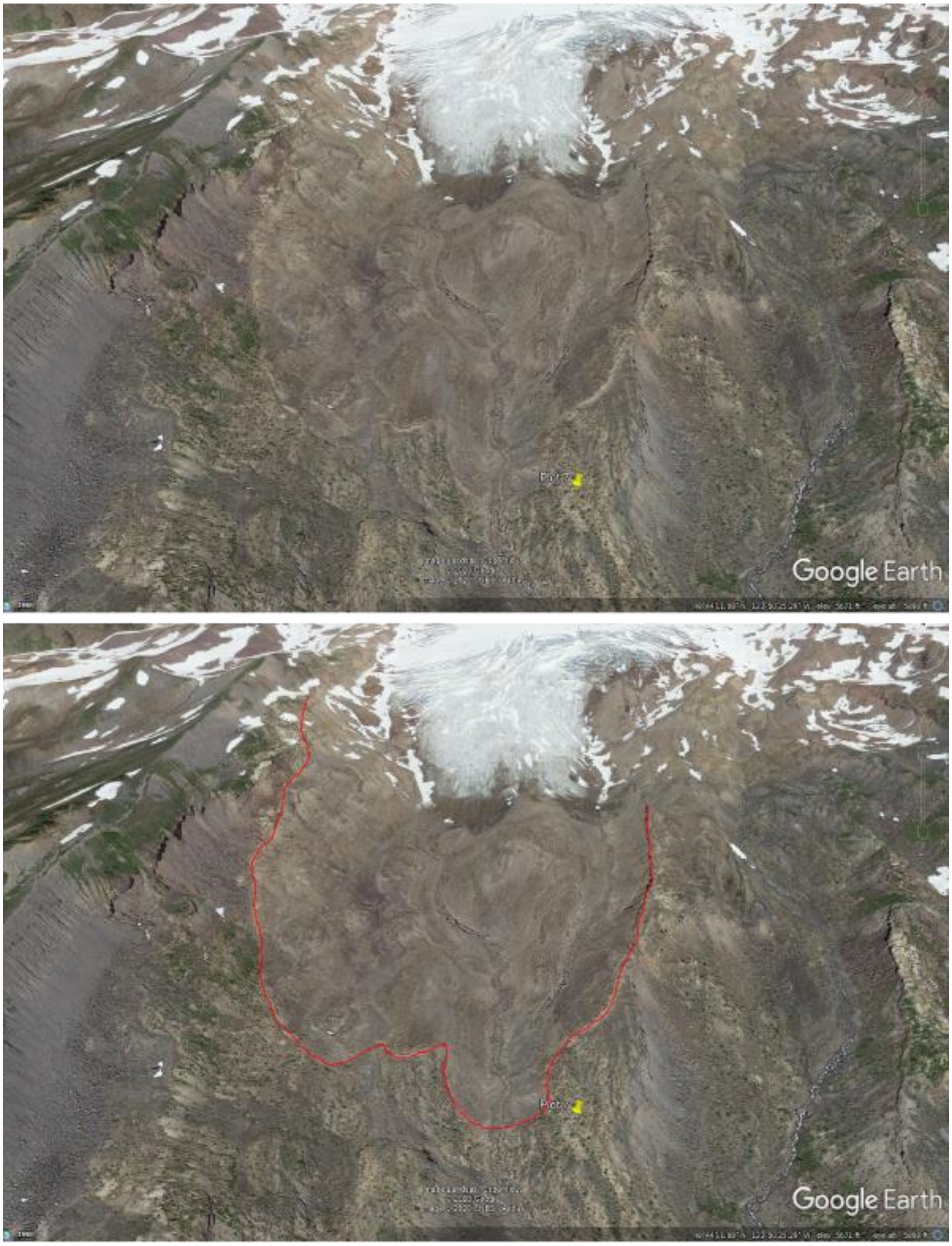


Figure 4.6: Easton Glacier 1990 Moraine seen in Google Earth PRO

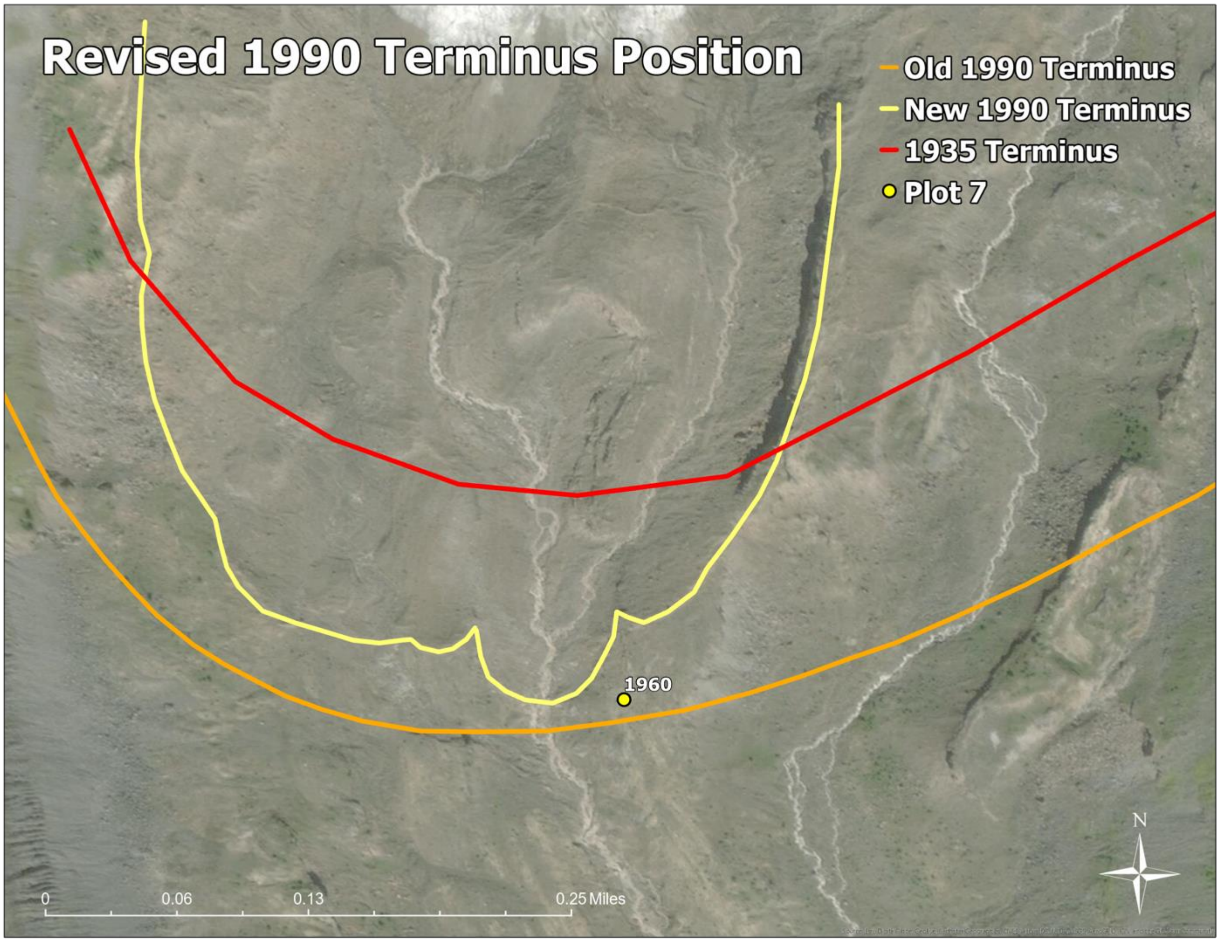
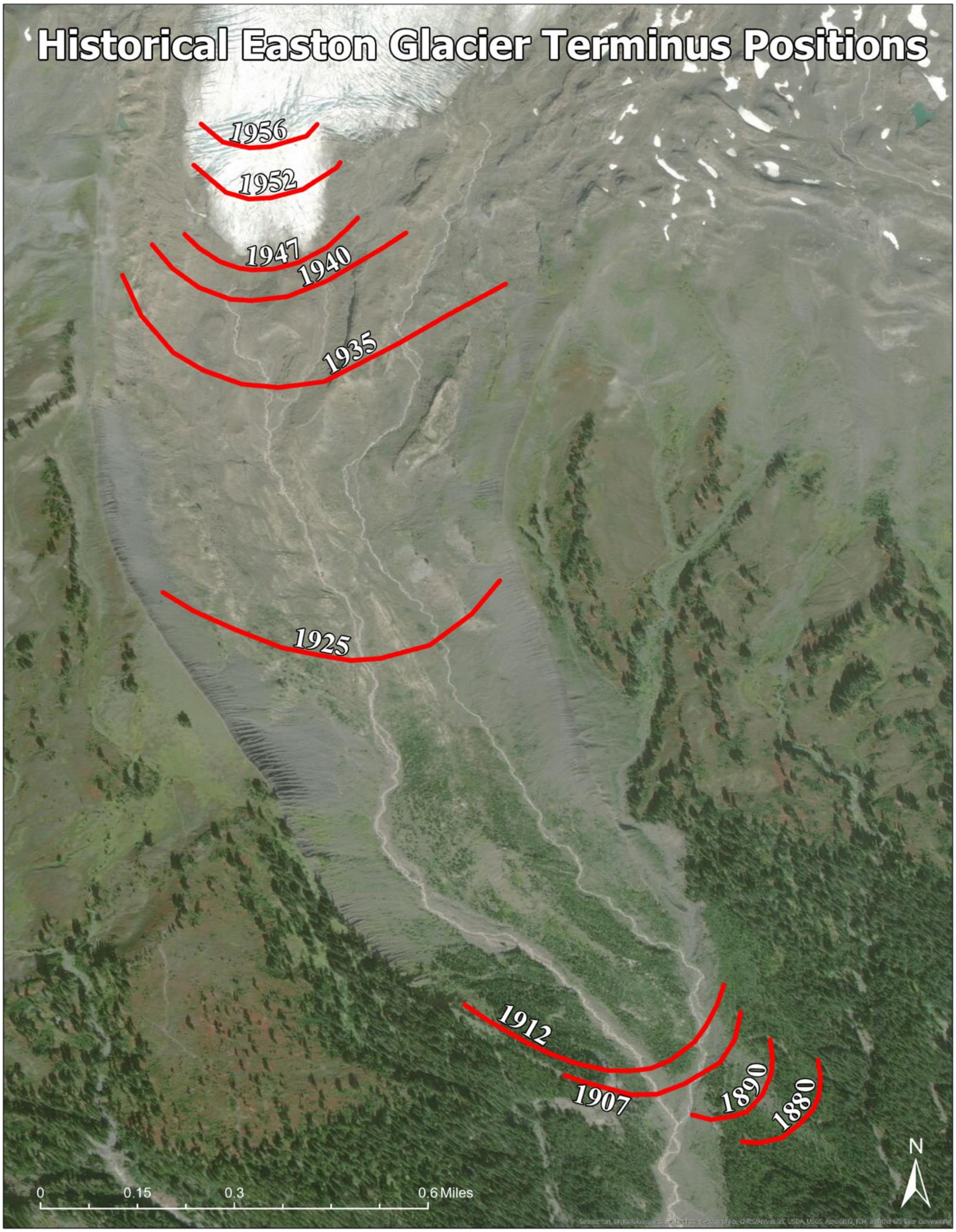


Figure 4.7: Location of new 1990 terminus position

Surfaces north of plot 7's location are believed to have been exposed during the first recession ending in the late 1950s and then recovered by the glacier in its advancement from 1957-1988. The difference in size between the saplings north of plot seven and the trees sampled in plot seven was quite large. The size range was not as continuous as the rest of the foreland by going from large to increasingly small trees from the bottom to top of the foreland. It almost appears that a stage or two is missing between the trees in plot seven and the saplings north of it. This could very much be due to the fact that any trees established north of plot seven were destroyed during the Easton glaciers readvancement. This area is also the steepest part of the valley sampled, so the trees may have had difficulty establishing due to erosion. The surfaces at this point are no longer continuous with the rest of the foreland in terms of time since deglaciation due to the Easton glaciers most recent readvancement.

After ecesis was calculated, and added to the tree establishments minimum dates, then a chronology of the Easton glaciers terminus position could be created (Figure 4.8). The chronology highlights the extreme retreat of the Easton glaciers terminus position in a relatively short period of time. The chronology also points out that the behavior of the recession was not always linear, but experienced periods of slower and quicker retreat.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4.8: Chronology of the Easton glaciers terminus position from 1880-1956. (Shape and lateral extend of termini positions was not surveyed. The lines represent the approximate extent of the termini)

4.3 Recession Rates

Recession rates were calculated using the information from previous studies (Harper 1993, Long 1953, Long 1955, Rosa 2016, Whelan and Bach 2017) and the results from this study in ArcGIS PRO. The recession rates were calculated by taking the linear distance between the two terminus years and dividing it by the difference in the terminus position. The following recession rates of the Easton glacier are presented below:

Recession rates:
1880-1907: 10.5m per year
1907-1925: 68.77m per year
1925-1935: 70m per year
1935-1947: 26m per year
1947-1952: 36m per year
1952-1956: 32.25m per year
1880-1956: 35.6m per year
1987-2019: 16.5m per year

Table 4.1: Easton Glacier Recession and Advancement Rates Overtime

By extending the Easton glaciers terminus position back to 1880, the opportunity to examine its behavior overtime and compare it to environmental stimuli greatly increases. During the late nineteenth century, the Easton glacier was receding at a slow rate compared to its future behavior. From 1880-1907 the recession rate was 10.5 meters per year. Then, during first part of the twentieth century, the Easton glaciers recession rate increased rapidly from 1907-1935 with and average recession rate of 69 meters per year. It then slowed its recession, experiencing a brief 11-year stage (1936-1947) where the recession rate dropped to 26 meters per year before increasing to 34 meters per year in the next 9-year stage (1947-1956). This retreat lasted until 1956 and resulted in the Easton glacier retreating a total of 2,708 meters (Figure 4.9). The Easton glacier then began to advance, but slowly compared to its recent recession. The advance lasted until 1987, only making up about 584 meters at about 18.8 meters a year, putting the glacier's terminus back near its 1935 position. The Easton glacier then entered its current state of retreat where it has almost reached its 1956 location, with a comparatively slower recession rate of 16.5 meters per year.

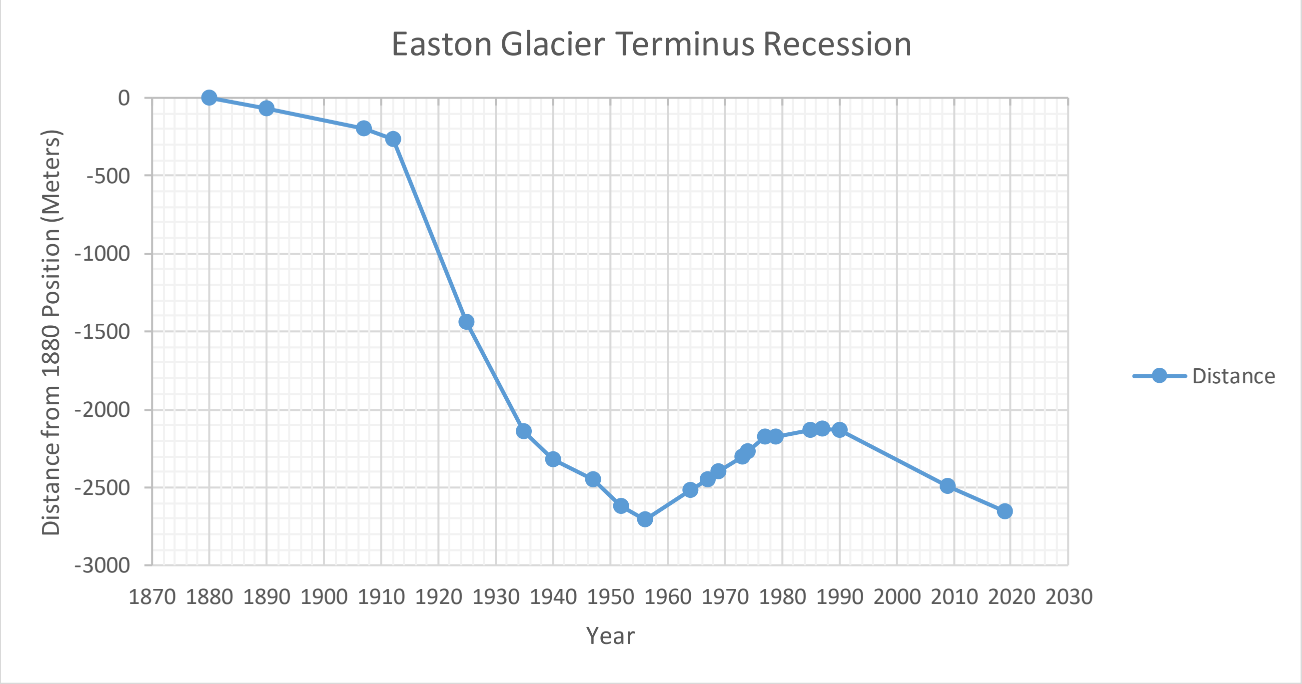


Figure 4.9: The recession of the Easton glaciers terminus position from 1880

4.4 Glacier Behavior Relation to Climate Data

It is known that the internally controlled dynamic processes of a glacier may cause advance or retreat for non-climatic reasons (Harper 1993). These geothermal processes, like basal sliding, can either retreat or advance a glacier depending on the extent of melting. However, the Easton Glacier does not lose significant mass by calving or avalanching, therefore changes observed are primarily a function of winter accumulation and summer ablation on the glacier’s surface (Pelto and Brown 2012). This highlights the importance of understanding glacier behavior response to changes in climatic conditions.

It is important to note the differences in the recession rates over different stages of the glacier’s retreat. The Easton glacier did not retreat linearly in response to changes in its environment (temperature, precipitation, PDO, etc.). When comparing climatic trends against the Easton’s recession rate and glacial history, many conclusions can be drawn. Glaciers respond to temperature changes more quickly than changes in precipitation, but usually the response time is lagged (Jóhannesson et al. 1989). The lag time between glacier response to temperature changes can be on the order of decades, mostly depending on the glacier and its environment (Jóhannesson et al. 1989, Marcinkowski and Peterson 2015).

The mean annual temperature (MAT) average for the Easton foreland is 4.7 degrees Celsius for the 1901-2018 period (Wang et al. 2016) (Figure 4.10). The climatic normal for the first part of the century, 1901-1931, had a MAT of 4.25 degrees Celsius. The most recent climatic normal, 1988-2018, had MAT of 5.18 degrees Celsius resulting in a 0.93 degree increase across the foreland over the past century.

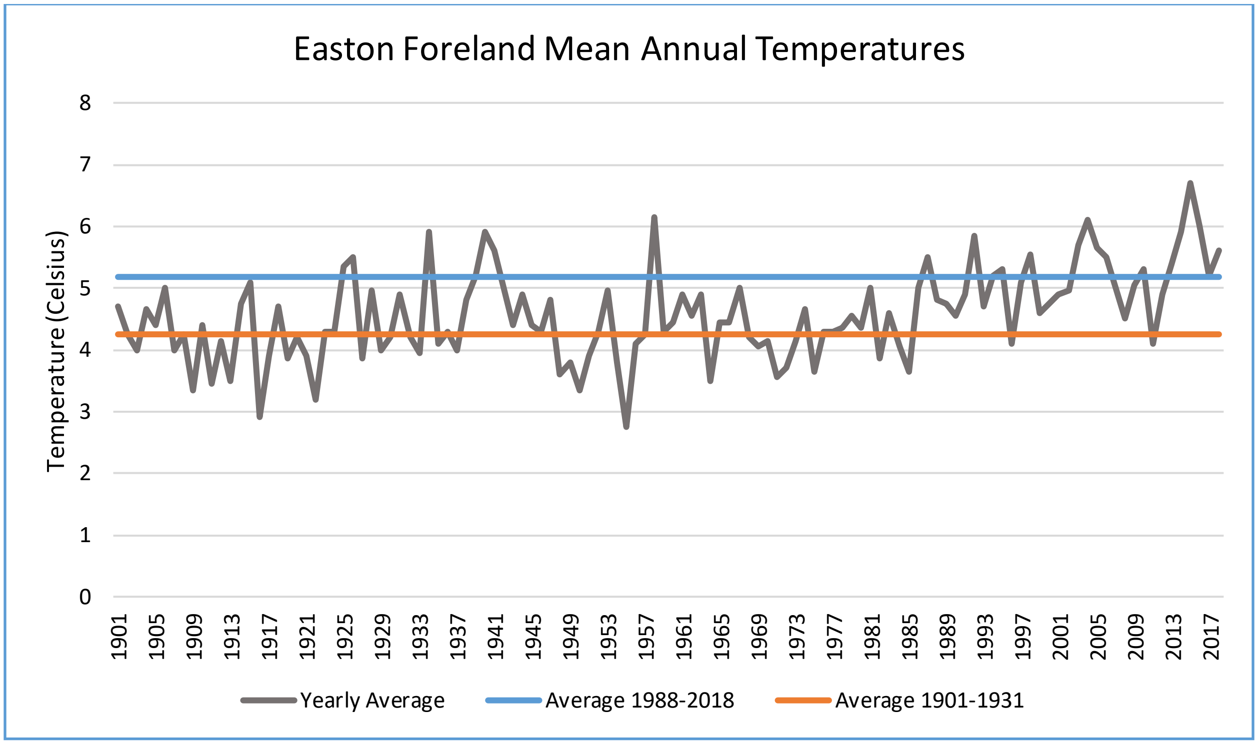


Figure 4.10: MAT for the Easton Foreland with climatic normal periods (Data from Wang et al. 2016)

The rise in global temperatures during this period are related to anthropogenic climate change but temperatures were increasing prior to the twentieth century. A possible explanation for the change in climate can be linked to the Little Ice Age (LIA) which began in the 12-13th century and lasted until the late 19th century. The LIA is defined as a period of more extensive glacial cover when global temperatures dropped relative the medieval warming period (Grove 2004, Luckman 2000, Matthes 1939) and then began to rise during the mid 19th century (Figure 4.11). A recent study (Trinies 2019) reconstructed western Washington temperatures from yellow cedar (*Callitropsis nootkatensis*) tree rings that dates back to the LIA (Figure 4.12). The study was conducted northwest from the Easton foreland at an elevation of about 1,350 meters. The close proximity of this study site to the Easton foreland allows this information to be very representative of the Easton forelands historical climate. The results from this reconstruction depict a relatively cooler period in the 1800s which are consistent with other reconstructions (Anchukaities et al. 2017, Luckman et al. 1997). This period is when many glaciers in the area reached their LIA maximum positions, specifically with glaciers on the south side of Mount Baker, believed to have reached their maximum extents in the mid – 1800s (Osborn et al. 2012).

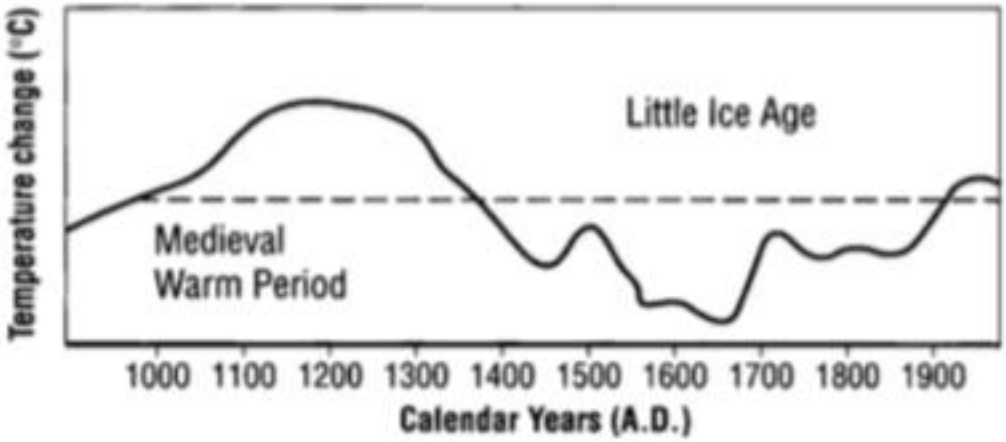


Figure 4.11: LIA Global Temperature Change Over Time (Luckman 2000)

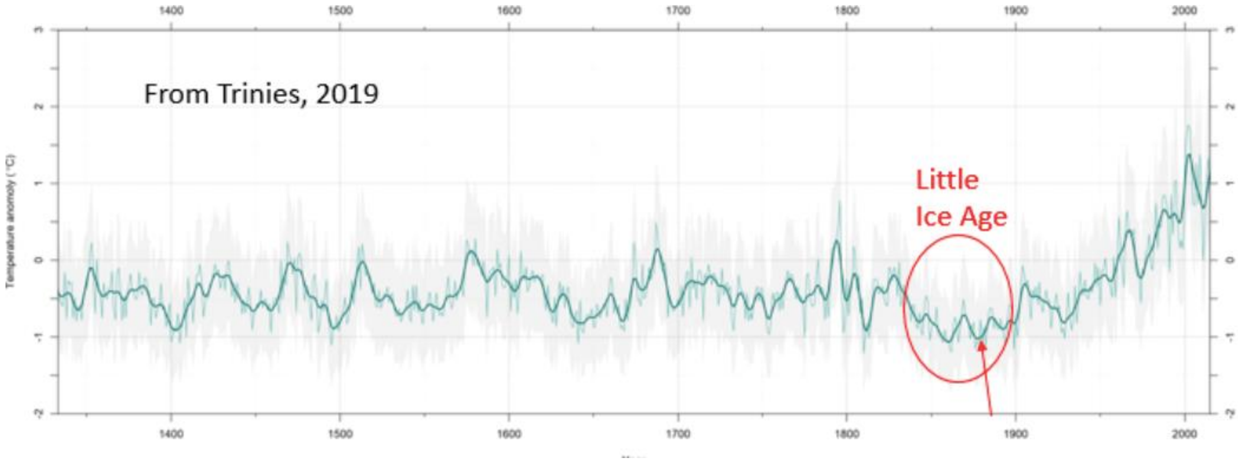


Figure 4.12: Reconstructed Western Washington Temperatures from Yellow Cedar (Trinies 2019)

After the end of this cooling period, temperatures began to drastically increase in a short period of time starting around the beginning of the twentieth century. This dramatic increase in temperature is the likely cause of the Easton glaciers dramatic retreat from 1912-1935. The lag-time between temperature change and glacier response is on the order of decades (Jóhannesson et al. 1989), making this visual comparison significant. On this inference alone, we can suggest the temperatures in the Easton foreland were rising prior to the twentieth century and the Easton glacier began its retreat sometime between 1870-1880.

The mean annual precipitation (MAP) average for the Easton foreland from 1901-1931 was 4292 mm while the MAP for 1988-2018 was 4334 mm (Figure 4.13) (Wang et al. 2016). This shows that precipitation has not changed as drastically over the century as MAT. However, even though the amount of precipitation has not changed, the type of precipitation (rain vs snow) is likely to have been altered. With one degree increase of climate warming in the Cascade Mountains, the snowline can rise about 200 meters in elevation ultimately reducing annual snowpack accumulation by 15-18% (Minder 2010). Eventually, this disequilibrium will lead to negative glacier mass balances and terminus recession which has been present and documented in the Easton foreland (Harper 1993, Heikkinen 1984, Long 1953, Long 1956, Pelto 2018, Pelto and Brown 2012). Less precipitation may be falling in the form of snow due to higher temperature in the foreland reducing snowpack accumulation and resulting in negative glacial mass balance and recession. Another possibility is the type of precipitation has remained unaltered but due to the higher annual temperatures, snow and ice are melting significantly more than normal summer seasons.

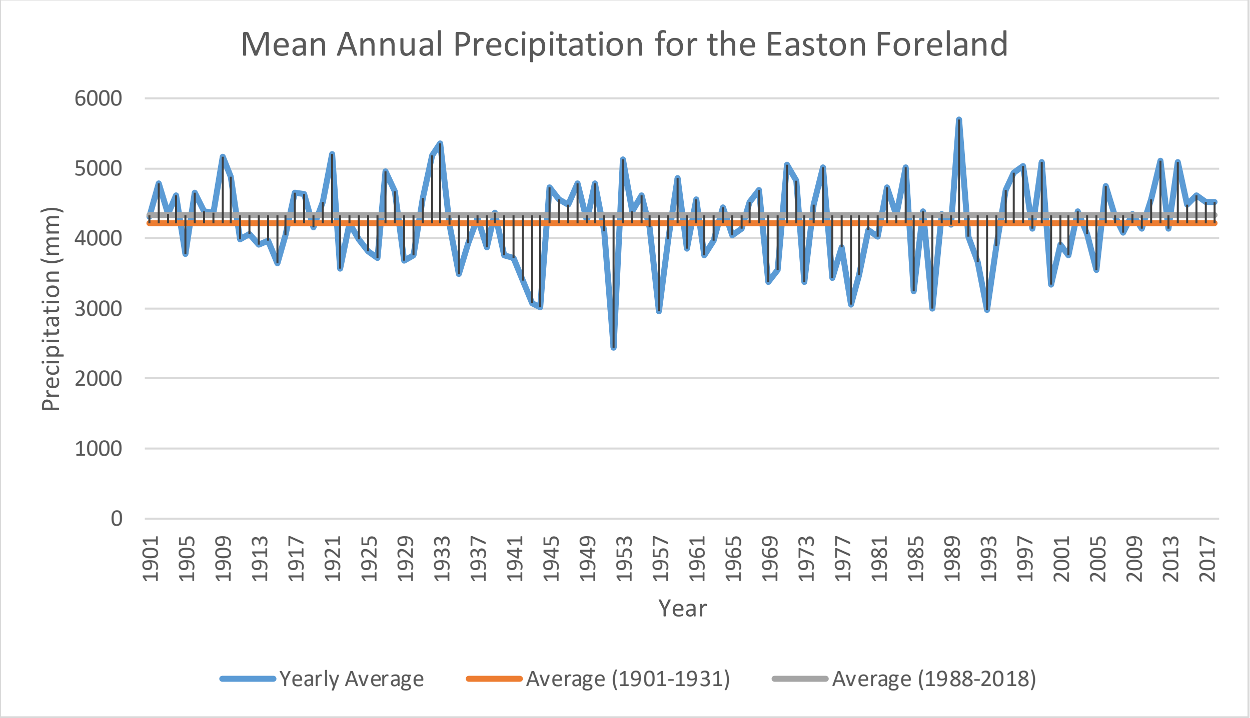


Figure 4.13: MAP for the Easton Foreland with climatic normal periods (Data from Wang et al. 2016)

4.5 Limitations

When trying to account for the oldest tree in a plot many limitations can arise. Choosing trees based solely on their height is not a good sampling strategy to account for the oldest tree. Trees can experience stunted growth in the beginning of life due to harsh conditions after deglaciation. Prolonged snow cover, low nutrient availability and extreme temperatures can result in slow growth and stunting in many young trees. However, overtime as conditions become more suitable, trees can experience rapid growth in the same location. Therefore, it is important to note that the tallest trees in a plot are not necessarily the oldest. Most of the time, a large diameter at the base can entail older age but this too can sometimes be inconsistent. It is important to note that the dates from each plot may not be the real age of the surface if the oldest tree in the area was not sampled. However, these ages do give an absolute minimum estimate date in which the surface was exposed.

There are many factors that may have influenced the first generation of colonizing trees in the Easton foreland. The harsh conditions within the valley can make it difficult for trees to get established and continue to survive. A trees success is dependent on many variables including a little bit of luck. Which summer growing season the tree began establishing could very well determine the trajectory of its survival. If a tree begins growing in a cold short growing season its likelihood of survival is slim compared to a long warm growing season. The soils in the valley are very well drained and the seedlings also face desiccation during warm summers with little rain. Landslides and erosion can also affect the survival of trees within the valley, wiping out an entire generation of trees. Conditions at the time of seedling establishment have to be just right to ensure the survival long term.

Although it was the objective to obtain exact ages for all trees sampled, in some cases the pith was not reached. This is mostly related to asymmetric diameters of the trees. Trees respond to external factors affecting their growth by experiencing eccentric growth (Figure 4.14), causing the pith to be off center (Richter 2014). Factors that can cause this in trees include growing on hillsides or sloped surfaces, prevailing wind pressure, prevailing snow load, snowmobiling damage, constant one-sided supply of sunlight, and crowding by adjacent tree crowns. This information is important to consider when reviewing the data because the exact age of these trees is underestimated. The ages provided give a least a minimum age and date to use in the study, but the actual age cannot be determined. Fortunately, none of these samples were used in calculation of ecesis or surface age estimates for the foreland.

Figure 4.14: Eccentric growth in Samples. Sample 85 (left) and sample 61 (right)

Another problem that occurred while sampling trees was difficulty in sampling the root collar. Many trees were in unusual positions (Figure 4.15), covered by rocks, on a sloped hillside, and located in dense brush making it hard to reach the root collar. If not sampled at the root collar, the core sample will underestimate the true age of the tree up to 30 years (Gutsell and Johnson 2002, Wong and Lertzman 2001). Trees may also have locally missing growth rings due to environmental stress, whether that is caused by climate, fires or insect outbreaks. In one study, all overtopped trees had either partial or missing rings making them inconclusive in the cross-dating results (Lorimer et al. 1999). In the Easton valley, trees are at risk of being topped over from snow loads, landslides, and recreational use of snowmobiles.

Figure 4.15: Sampling the Root Collar in Difficult Positions. (Assistant Keaton Martin cuts a tree growing horizontally out between 2 boulders in plot 12)

One further step of data evaluation in the form of cross dating was not performed in this study. The process of cross dating involves matching patterns of wide and narrow rings to accurately calibrate the tree's establishment dates (Matthews, Birks, & Wiens, 1992). This method would provide external validity by accounting for false or missing rings that may misdate the trees by one or more years (Speer 2013). Without this evaluation, the dates and ages recorded in this study must be viewed as estimates. Missing rings occur due to different environmental stresses, such as disease, natural disasters, or unfavorable climatic conditions. False rings usually occur due to a drought during the growing season followed by moister conditions later in the year, causing the tree to grow latewood cells resulting in false rings

(Copenheaver et al. 2006). In the Easton valley, the growing season is short, and conditions are not as favorable possibly resulting in missing or false rings. Without proper error adjustments or cross dating, ring count ages can only be viewed as estimates with inaccuracies up to several decades (Fraver et al. 2011).

Chapter 5. Conclusion

The overall purpose of this study was to refine and create a chronology of the Easton glaciers terminus positions over the past 150 years through dendrochronological analysis. The main research questions were: What are the historical terminus positions in the first half of the twentieth century? What is ecesis for the Easton foreland? The results from this study provide information that will help better understand glacial behavior, soil development and vegetative succession in response to a changing climate.

The relationship between soil development and vegetation succession has been studied in the Easton foreland (Rosa 2016, Whelan and Bach 2017) and major findings concluded that soil development was best described by the stage of succession and vegetation begins to establish 20-40 years after glacial retreat. With the information obtained from this study, ecesis was calculated for the Easton foreland and was found to be around 8 years at the bottom of the foreland and 27-28 years at the top of the foreland. The differences in these values can be explained by a number of factors relating to the foreland's characteristics (microclimate, nutrient availability, proximity to seed source, etc.). Although ecesis values typically are site specific, the ecesis values from the Easton foreland can be used for estimating vegetation succession and glacier behavior for other forelands on Mount Baker.

Prior to this study, the oldest documentation of the Easton glaciers position was a photograph in 1912 with an obscured view of the terminus position and a field ground measurement in 1907 (Long 1956). It was believed that at this point in time, the Easton glacier was in a state of retreat, but the exact timing and length of this retreat was unknown. The results from this study extended the knowledge of the Easton glaciers terminus position by 27 years dating back to 1880. This location is believed to be in or on the latest LIA maximum position where dozens of end and lateral moraines were identified in the field further down slope. Future research can determine if these are LIA or pre-LIA moraines.

It is unclear if the Easton glacier was retreating or just beginning its retreat in 1880 that lasted until 1956. This retreat however, mirrors climate reconstructions in the area that found mean annual temperatures began to increase in the mid-late 1800s and then drastically increased at the turn of the twentieth century (Trinies 2019). This can explain the Easton glaciers recession behavior going from a relatively slow recession rate to increasing its rate by 660% from 1912-1935. A lag time occurs between a change in climate and glacier response, usually on the order of decades (Jóhannesson et al. 1989), which would explain the timing of the Easton glaciers recession behavior.

Climate forcing mechanisms in the Pacific Ocean affect glacier responses in the western North American region similarly (Larocque and Smith 2003) and it has been shown that many glaciers around the world have been retreating since 1800-1850s (Akasofu 2010, Burga et al. 2010). Based on this relationship, it is predicted that the Easton glacier began its first retreat after the LIA, sometime between 1860-1880. Due to the Easton glaciers slower recession prior to 1912, the MAT for the area also may have been gradually increasing from previous LIA temperatures before skyrocketing. Without further information regarding the Easton glaciers position during this time, these dates are only estimates of when the glacier may have responded to the change in climate.

More information is needed regarding the position of the Easton glacier during the LIA to accurately determine its maximum extent during this time. The rate and extent of the Easton glaciers recession since the LIA can then be estimated to document glaciers response to anthropogenic climate change. Future research should focus on identifying the end and lateral moraines in the lower foreland near the 1880 terminus to date their formation and hopefully extend the knowledge of the Easton glaciers terminus positions. Future studies should also verify the establishment dates and ages by cross dating or other error adjustment methods. Without this extra step of validity, the date and age results from this study can only be viewed as estimates.

The impacts of anthropogenic climate change have already taken a toll on glaciers worldwide and specifically reducing the Easton glaciers terminus by 2,653 meters and losing 1,110 ft in elevation since 1880. Temperatures have increased by 1-2 degrees Celsius throughout the foreland and are expected to continue to warm throughout the century (IPPC 2013). It is expected that many glaciers will continue to retreat with some disappearing completely (Pelto 2015). If the Easton glacier retreats another 2,653 meters in the next 150 years, then its terminus would be at an elevation of 2,438 meters (Summit: 3,286m) making its chances of survival slim. It is important to understand the nature of glacier behavior and response to changes in their environment to ultimately predict the future health of alpine glaciers. Glaciers are an important element in all ecosystems providing freshwater and many other ecological services, it is crucial to document their health for the future of the environment.

References

Abatzoglou, J.T. (2011). Influence of the PNA on Declining Mountain Snowpack in the Western United States. *International Journal of Climatology*. **31**(8), 1135-1142.

Abatzoglou, J.T., Rupp, D.E., Mote, P.W. (2014). Seasonal Climate Variability and Change in the Pacific Northwest of the United States. *Journal of Climate*. **27**(5), 2125–2142.

Akasofu, S. (2010). On the recovery from the Little Ice Age. *Natural Science*, **2**(11), 1211-1224.

Anchukaitis, K. J., R. Wilson., K. R. Briffa., U. Büntgen., E. R. Cook., R. D. D’Arrigo., N. Davi., J. Esper., D. Frank., B. E. Gunnarson., G. Hegerl., S. Helama., S. Klesse., P. J. Krusic., H. W. Linderholm., V. Myglan., T. J. Osborn., P. Zhang., M. Rydval., L. Schneider., A. Schurer., G.Wiles., and E. Zorita. (2017). Last millennium Northern Hemisphere summer temperatures from tree rings: Part II, spatially resolved reconstructions. *Quaternary Science Reviews,* **163**, 1–22.

Andreis, C., Caccianiga, M., Cerabolini, B. (2001). Vegetation and environmental factors during primary succession on glacier forelands: Some outlines from the Italian Alps. *Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology,* **135**(3), 295-310.

Bach, A. J. (2003). Snowshed contributions to the Nooksack River watershed, North Cascade Range, Washington. *The Geographical Review,* **92**(2), 192-212.

Bach, A.J. and L.W. Price (2013). “Mountain Climate” chapter in *Mountain Geography: Physical and Human Dimensions,* edited by M. Price A.C. Byers, D.A. Friend, T. Kohler, and L.W. Price., Berkeley: University of California Press, 41-85.

Birks, H.J.B. (1980). The present flora and vegetation of the moraines of the Klutan Glacier, Yukon Territory, Canada a study in plant succession. *Quaternary Research,* **14**, 60–86.

Bockheim, J. G., & Ballard, T. M. (1975). Hydrothermal soils of the crater of Mt. Baker, Washington. *Soil Science Society of America*, **39**, 997-1001.

Bond, N.; Cronin, M.; Freeland, H.; Mantua, N. (2015). Causes and impacts of the 2014 warm anomaly in the NE Pacific. *Geophysical Research Letters,* **42**(9), 3414–3420.

Burbank, D.W. (1981). A chronology of late Holocene glacier fluctuations on Mt. Rainier. *Arctic and Alpine Research,* **13**(4), 369–386.

Burga, C. A., Kr€usi, B., Egli, M., Wernli, M., Elsener, S., Ziefle, M., Fischer, T., and Mavris. C. (2010). Plant succession and soil development on the foreland of the Morteratsch glacier (Pontresina, Switzerland): Straightforward or chaotic? *Flora,* **205**(9), 561–576.

Chapin, F., Walker, L.R., Fastie, C.L., and Sharman, L.C. (1994). Mechanisms of primary succession following deglaciation at Glacier Bay, Alaska. *Ecological Monographs,* **64**(2), 252–84.

Coombs, H. A. (1939). Mount Baker, a Cascade Volcano. *Geological Society of America Bulletin,* **50**(10), 1493-1509.

Copenheaver, C.A., Pokorski, E.A., Currie, J.E., and Abrams, M.D. (2006). Causation of false ring formation in Pinus banksiana: a comparison of age, canopy class, climate and growth rate. *Forest Ecology and Management,* **236**(2-3), 348–355.

Coulthard, B., and Smith, D.J. (2013). Dendroglaciology. In: Elias SA (ed.) *The Encyclopedia of Quaternary Science,* **2**(2), 104-111.

Erschbamer, B. (2007). Winners and Losers of Climate Change in a Central Alpine Glacier Foreland. *Arctic, Antarctic, and Alpine Research,* **39**(2), 237-244

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Flower, A., Bookout, B., Hagedorn, B., Hankin, L., Lovseth, J., Smith, L., Whelan, A. (2017). Muscling into meadows: A preliminary dendrochronological analysis of recent conifer encroachment in Mount Rainier's subalpine meadows. *Yearbook of the Association of Pacific Coast Geographers,* **79**,115-134.

Fraver, S., Bradford, J.B., and Palik, B.J. (2011). Improving tree age estimates derived from increment cores: a case study of Pinus resinosa. *Forest Science*, **57**(2), 164–170.

Frenot, Y., Gloaguen, J. C., and Bellido, A. (1998). Primary succession on glacial forelands in the subantarctic Kerguelen Islands. *Journal of Vegetation Science*, **9**(1), 75-84.

Grissino-Mayer, H.D. (2001). Evaluating crossdating accuracy: A manual and tutorial for the computer program COFECHA. *Tree-Ring Research,* **57**(2), 205-221

Grove, J.M. (1988). *The Little Ice Age*. London: Methuen.

Grove, J.M. (2004). *Little Ice Ages: Ancient and Modern*. (2 volumes). Routledge. London. 406-718.

Gutsell, S.L. and Johnson, E.A. (2002). Accurately ageing trees and examining their height-growth rates: implications for interpreting forest dynamics. *Journal of Ecology*, **90**, 153–166.

Harper, J. T. (1993). Glacier terminus fluctuations on Mt. Baker, Washington, U.S.A., 1940–1990, and climate variations. *Arctic and Alpine Research,* **25**(4), 332–40.

Heikkinen, O. (1984). Dendrochronological Evidence of Variations of Coleman Glacier, Mount Baker, Washington, U.S.A. *Arctic and Alpine Research,* **16**, 53-64

Heikkinen, O. (1984). Forest Expansion in the Subalpine Zone during the Past Hundred Years, Mount Baker, Washington, U.S.A. *Erdkunde*, **38**, 194-202.

Intergovernmental Panel on Climate Change (IPCC). (2013). *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Jones, C. C., and Del Moral, R. (2005). Patterns of primary succession on the foreland of Coleman Glacier, Washington, USA. *Plant Ecology*, **180**, 105–116.

Jóhannesson, T., Raymond, C., and Waddington, E. (1989). Time–Scale for Adjustment of Glaciers to Changes in Mass Balance. *Journal of Glaciology*, **35**(121), 355-369.

Koch, J., and Kilian, R. (2005). Little Ice Age glacier fluctuations at Gran Campo Nevado, southernmost Chile. *The Holocene*, **15**, 20–28.

Koch, J. (2009). Improving age estimates for late Holocene glacial landforms using dendrochronology – Some examples from Garibaldi Provincial Park, British Columbia. *Quaternary Geochronology,* **4**, 130-139.

Kolber, M.J., Pizzini, M., Robinson, A., Yanez, D., and Hanney, W.J. (2013). The Reliability and Concurrent Validity of Measurements used to Quantify Lumbar Spine Mobility: An Analysis of Iphone Application and Gravity Inclinometry. *The International Journal of Sports Physical Therapy,* **8**(2), 129-137.

Laroque, S.J., and Smith, D.J. (2003). Little Ice Age glacial activity in the Mt. Waddington area, British Columbia Coast Mountains, Canada. *Canadian Journal of Earth Sciences*, **40**, 1413-1436.

Laroque, S.J., and Smith, D.J. (2005). ‘Little Ice Age' proxy glacier mass balance records reconstructed from tree rings in the Mt. Waddington Area, British Columbia, Coast Mountains Canada. *The Holocene,* **15**, 748–757.

Lewis, D., and Smith, D. (2004). Dendrochronological mass balance reconstruction, Strathcona Provincial Park, Vancouver Island, British Columbia, Canada. *Arctic, Antarctic and Alpine*, **36**, 598–602.

Long, W.A. (1953). Recession of Easton and Deming Glaciers. *The Scientific Monthly*, **76**(4), 241-247.

Long, W.A. (1955). What's Happening to Our Glaciers! *The Scientific Monthly*, **81**, 57-64.

Lorimer, C.G., Dahir, S.E. and Singer, M.T. (1999). Frequency of partial and missing rings in Acer saccharum in relation to canopy position and growth rate. *Plant Ecology* **143,** 189–202.

Luckman, B. (1986). Reconstruction of Little Ice Age Events in the Canadian Rocky Mountains. *Géographie physique et Quaternaire*, **40(**1), 17–28.

Luckman, B. (2000). The Little Ice Age in the Canadian Rockies. *Geomorphology*, **32**, 357-384.

Luckman, B. H., Briffa, K.R., Jones, P.D., and Schweingruber, F.H. (1997). Tree-ring based reconstruction of summer temperatures at the Columbia Icefield, Alberta, Canada, AD 1073- 1983. *Holocene*, **7**(4), 375–389.

Malcomb, N. L., and Wiles, G.C. (2013). Tree-ring-based reconstructions of North American glacier mass balance through the Little Ice Age Contemporary warming transition. *Quaternary Research*, **79**, 123-137.

Mann, M. E. (2002). Little ice age. *Encyclopedia of global environmental change*, **1**, 504-509.

Marcinkowski, K., and Peterson, D.L., (2015). A 350-year Reconstruction of the Response of South Cascade Glacier to Interannual and Interdecadal Climatic Variability. *Northwest Science,* **89**(1), 14-33.

Mass, C. (2008). *The weather of the Pacific Northwest*. Seattle: University of Washington Press.

Matthes, F.E., (1939). Report of the Committee on Glaciers. *Transactions American Geophysical Union,* **20**, 518–523.

Matthews, J.A., Birks, H.J.B., and Wiens, J.A. (1992). *The Ecology of Recently deglaciated Terrain*: A Geoecological Approach to Glacier Forelands: Cambridge University Press.

McCarthy, D.P., and Luckman, B.H. (1993). Estimating Ecesis for Tree-Ring Dating of Moraines: A Comparative Study from the Canadian Cordillera. *Arctic and Alpine Research*, **25**(1), 63-68.

Minder, J.R. (2010). The Sensitivity of Mountain Snowpack Accumulation to Climate Warming. *Journal of Climate,* **23**, 2634-2650.

Minder, J. R., Mote, P. W., and Lundquist, J. D. (2010). Surface temperature lapse rates over complex terrain: Lessons from the Cascade Mountains. *Journal of Geophysical Research,* **115**(D14).

Osborn, G., Menounos, B., Ryane, C., Riedel, J., Clague, J.J., Koch, J., Clark, D., Scott, K., and Davis, T.P. (2012). Latest Pleistocene and Holocene glacier fluctuations on Mount Baker, *Washington Quaternary Science Reviews*, **49**, 33-51.

Pelto, M.S., and Brown, C. (2012). Mass balance loss of Mount baker, Washington glaciers 1990-2010. *Hydrological Processes,* **26**, 2601-2607.

Pelto, M.S., and Hedlund, C. (2001). Terminus behavior and response time of North Cascade glaciers, Washington, U.S.A. *Journal of Glaciology*, **47**(158), 497-506.

Pelto, M.S. (2009). Glacier annual balance measurement, forecasting and climate correlations, North Cascades, Washington 1984–2006. *The Cryosphere*, **2**, 13–21.

Pelto, M.S. (2010). Forecasting temperate alpine glacier survival from accumulation zone observations. *The Cryosphere,* **4**, 67-75.

Pelto, M.S. (2016). *Recent climate change impacts on mountain glaciers*. Chichester, UK; Hoboken, NJ: John Wiley & Sons.

Pelto, M.S. (2018). How Unusual Was 2015 in the 1984–2015 Period of the North Cascade Glacier Annual Mass Balance? *Water*, **10**, 543.

Pelto, M.S. Personal Communication. March, 2020.

Richter, C. (2014). *Wood Characteristics: Description, Causes, Prevention, Impact on Use and Technological Adaptation*. Springer International Publishing.

Rosa, Katherine A. (2016). "*One Hundred Years of Vegetation Succession in the Easton Glacial Foreland, Mount Baker, Washington*" WWU Graduate School Collection. 506.

Simpson, K., & Terry, E. (2000). Impacts of backcountry recreation activities on mountain caribou. Wildlife Working Report WR-99, Ministry of Environment, Lands and Parks, Victoria, B.C.

Scott, C.T. 1990. An overview of fixed versus variable-radius plots for successive inventories. *State-of-the-art methodology of forest inventory*. V. LaBau and T. Cunia. Randor, PA 19087. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report 263.

Sigafoos, R.S., and Hendricks, E.L. (1969). The time interval between stabilization of alpine glacial deposits and establishment of tree seedlings. *Geological Survey Research,* **650-B,** 89-93.

Speer, J. H. (2013). Fundamentals of tree-ring research. Tucson, AZ: The University of Arizona Press.

Trinies, C.A. (2019). "*Dendroclimatology of yellow cedar (Callitropsis nootkatensis) and late Holocene temperature variability on the western slopes of the North Cascades in Washington State*". WWU Graduate School Collection. 899.

Wang, T., Hamann, A., Spittlehouse, D., and Carroll, C. (2016). Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America. *PLoS ONE*, 11(6): e0156720.

Whelan, P. and Bach, A.J. (2012). Retreating Glaciers, Incipient Soils, Emerging Forests: 100 Years of Landscape Change on Mount Baker, Washington, USA. *Annals of the American Association of Geographers*, **107**(2), 336-349.

Wong, C., and K.P. Lertzman. (2001). Error estimates in tree age: Implications for studies of stand dynamics. *Canadian Journal of Forest Research*, **31**, 1262–1271.

Wood, L., Smith, D.J., and Demuth, M.N. (2011). Extending the Place Glacier mass balance record to AD 1585, using tree-rings and wood density. *Quaternary Research*, **76**, 305–313.

Appendices

Appendix A: Field Data

Field data collection was performed inconsecutively beginning August 5th, 2019 and ending on August 19th, 2019. The results from the data collection can be seen in Figure A. The XY coordinates for each plots center was recorded and can be seen on the first samples row. The samples distance from its plot center is recorded in centimeters and its angle from the plots center is recorded in degrees. From this information the samples may be plotted spatially in regards to their plots center. A column (pith) records whether the pith was reached in each sample, and another column (type) describes the sampling method used for each sample. Notes were taken of most samples regarding information relative to counting. For example, if the pith was reached in the sample but unreadable due to cracking a note was taken as “pith is destroyed”. Each sample was counted three times, once by myself and once each by my two research assistants (Keaton Martin and Marissa Walls). If a sample was miscounted by 2 or more years, I would review the sample for a fourth time. The “Age” column represents the estimated age of each sample after evaluation. The “Year” column represents the trees date of establishment.

Plot	Sample	Date	X-coordinates	Y-coordinates	Distance from Plots Center (cm)	Angle from Plots Center	Height (m)	Diameter (cm)	Species	Pith	Type	Notes	Age	Year
1	1	5-Aug	121.8274	48.71736	80	338	2.5	12	Silver	Yes	Disk		107	1912
1	2	5-Aug			464	130	8	17.5	Silver	Yes	Core	Pith is destroyed	93	1926
1	3	5-Aug			489	67	12	22	Hemlock	No	Core	Close to the pith but a little off	89	1930
1	4	5-Aug			505	79	2	12	Hemlock	Yes	Disk		100	1919
1	5	5-Aug			511	105	11.5	22	Silver	No	Core	Close to the pith but a little off	84	1935
1	6	5-Aug			525	27	19	54	Hemlock	No	Core	Did not reach pith	107	1912
1	7	5-Aug			610	94	19	33	Hemlock	No	Core	Close to the pith but a little off	85	1934
1	8	5-Aug			635	115	18	24	Hemlock	No	Core	Close to the pith but a little off	114	1905
1	9	5-Aug			521	169	21		Hemlock	No	Core	Close to the pith but a little off	115	1904
1	10	5-Aug			615	221	1.5	6.5	Silver	Yes	Disk		68	1951
2	11	5-Aug	121.82701	48.7169	215	165	15	28.5	Hemlock	No	Core	Did not reach pith	101	1918

2	12	5-Aug			181	83	2.5	7	Hemlock	Yes	Disk		104	1915
2	13	5-Aug			225	317	7	27	Hemlock	No	Core	Pith is not present but reached center	81	1938
2	14	5-Aug			278	289	8	18.5	Hemlock	Yes	Disk	Pith is destroyed	117	1902
2	15	5-Aug			210	24	7	23	Hemlock	Yes	Core	Pith counted in rings	121	1898
2	16	5-Aug			304	99	12	22.5	Hemlock	No	Core	Close to pith but a little off	97	1922
2	17	5-Aug			364	84	6	13	Hemlock	Yes	Disk	Pith is destroyed	119	1900
2	18	5-Aug			449	279	8.5	24	Hemlock	No	Core	Multiple piths not counted	100	1919
2	19	5-Aug			355	289	2	5	Hemlock	Yes	Disk		107	1912
2	20	5-Aug			365	232	1.5	6	Hemlock	Yes	Disk		99	1920
3	21	5-Aug	121.82608	48.71643	150	142	11	26.5	Silver	Yes	Core	Pith is destroyed	131	1888
3	22	5-Aug			139	288	16	28	Hemlock	No	Core	Pith not present but reached center	116	1903
3	23	5-Aug			207	220	6	14.5	Hemlock	No	Core	Multiple piths not counted	108	1911
3	24	5-Aug			144	331	7	11.5	Hemlock	Yes	Disk		100	1919
3	25	5-Aug			275	195	15	24	Hemlock	No	Core	Pith not present but reached center	91	1928
3	26	5-Aug			490	37	20	38	Silver	No	Core	Pith not present but reached center	110	1909
3	27	5-Aug			310	94	11	23	Hemlock	No	Core	Close to the pith but a little off	77	1942
3	28	5-Aug			215	121	4	13.5	Hemlock	Yes	Disk		102	1917
3	29	5-Aug			299	37	8	19	Hemlock	No	Core	Close to the pith but a little off	118	1901
3	30	5-Aug			236	185	2.5	6	Hemlock	Yes	Disk		60	1959
4	31	6-Aug	121.82857	48.71803	110	130	15	25	Silver	No	Core	Pith not present but reached center	55	1964
4	32	6-Aug			65	304	5	12	Silver	Yes	Disk		58	1961
4	33	6-Aug			100	214	3	7	Hemlock	Yes	Disk		83	1936
4	34	6-Aug			110	350	5.5	9	Silver	Yes	Disk		60	1959
4	35	6-Aug			235	22	2.5	8	Hemlock	Yes	Disk	Two piths present	91	1928
4	36	6-Aug			320	210	17	46.5	Hemlock	No	Core	Pith not present but reached center	67	1952
4	37	6-Aug			100	240	1.5	5	Hemlock	Yes	Disk		67	1952
4	38	6-Aug			250	221	5	17	Hemlock	Yes	Disk		83	1936
4	39	6-Aug			165	113	1.5	6	Hemlock	Yes	Disk		94	1925
4	40	6-Aug			205	78	2	10	Hemlock	Yes	Disk		99	1920
5	41	6-Aug	121.8289	48.71871	225	117	4.5	20.5	Hemlock	Yes	Core	Two piths present	62	1957
5	42	6-Aug			260	84	3	13	Hemlock	Yes	Core	Possible pith counted in rings	81	1938
5	43	6-Aug			210	49	6	19	Hemlock	No	Core	Close to the pith but a little off	48	1971
5	44	6-Aug			270	22	1.5	9	Hemlock	Yes	Disk		56	1963
5	45	6-Aug			339	358	4.5	16.5	Hemlock	No	Core	Close to the pith but a little off	53	1966
5	46	6-Aug			180	316	2	9.5	Silver	Yes	Disk		94	1925
5	47	6-Aug			220	263	6	24	Hemlock	Yes	Core	Pith counted in rings	70	1949
5	48	6-Aug			150	252	1	3	Hemlock	Yes	Disk		56	1963
5	49	6-Aug			300	173	5.5	16	Hemlock	No	Core	Close to pith but a little off	64	1955
5	50	6-Aug			1000	111	22	40	Silver	No	Core	Close to pith but a little off	65	1954
6	51	6-Aug	121.82994	48.7196	350	352	10	25	Silver	Yes	Core	Pith counted in rings	54	1965
6	52	6-Aug			445	325	10	23	Silver	No	Core	Multiple piths present but not counted	38	1981
6	53	6-Aug			256	247	4	15	Hemlock	No	Core	Pith is not present but reached center	49	1970
6	54	6-Aug			480	180	7	26	Hemlock	No	Core	Pith is not present but reached center	50	1969

6	55	6-Aug			580	147	7.6	19	Hemlock	No	Core	Pith is not present but reached center	49	1970
6	56	6-Aug			270	100	1.5	5	Hemlock	Yes	Disk		57	1962
6	57	6-Aug			305	128	5.5	14.5	Silver	Yes	Disk		56	1963
6	58	6-Aug			310	66	3	10	Hemlock	Yes	Disk		68	1951
6	59	6-Aug			380	58	7.5	20	Hemlock	No	Core	Pith is not present but reached center	49	1970
6	60	6-Aug			410	39	6	17	Hemlock	Yes	Disk		78	1941
7	61	7-Aug	121.83714	48.73180	775	246	1	5	Hemlock	Yes	Disk	Multiple piths present but not counted	52	1967
7	62	7-Aug			550	310	2.25	7	Hemlock	Yes	Disk		33	1986
7	63	7-Aug			520	340	2	8	Hemlock	Yes	Disk		59	1960
7	64	7-Aug			215	341	0.5	3.5	Hemlock	Yes	Disk		38	1981
7	65	7-Aug			730	0	0.25	2	Hemlock	Yes	Disk		45	1974
7	66	7-Aug			1235	1	0.25	4	Hemlock	Yes	Disk		33	1986
7	67	7-Aug			1700	15	3	10	Hemlock	Yes	Disk		57	1962
7	68	7-Aug			1150	33	1	7.5	Hemlock	Yes	Disk		56	1963
7	69	7-Aug			680	47	1.5	10	Hemlock	Yes	Disk		53	1966
7	70	7-Aug			810	204	0.5	4	Hemlock	Yes	Disk		43	1976
8	71	7-Aug	121.83621	48.72991	340	322	2	6	Hemlock	Yes	Disk		52	1967
8	72	7-Aug			115	313	0.25	1	Silver	Yes	Disk	Very small sample	21	1998
8	73	7-Aug			770	304	1.5	5	Hemlock	Yes	Disk		58	1961
8	74	7-Aug			593	276	0.4	2.5	Hemlock	Yes	Disk		53	1966
8	75	7-Aug			350	266	0.4	1	Hemlock	Yes	Disk	Very small sample	13	2006
8	76	7-Aug			310	197	1	6.5	Hemlock	Yes	Disk	Pith is destroyed	66	1953
8	77	7-Aug			770	131	1	8	Hemlock	Yes	Disk	Two piths present	61	1958
8	78	7-Aug			462	107	1	6	Hemlock	Yes	Disk		58	1961
8	79	7-Aug			490	94	0.75	6	Hemlock	Yes	Disk		31	1988
8	80	7-Aug			750	61	0.5	4	Hemlock	Yes	Disk		56	1963
9	81	7-Aug	121.83543	48.72849	200	74	1	5	Hemlock	Yes	Disk		35	1984
9	82	7-Aug			175	7	1.25	5	Hemlock	Yes	Disk		34	1985
9	83	7-Aug			575	341	3	12	Hemlock	Yes	Core	Pith counted in rings	59	1960
9	84	7-Aug			670	329	1.4	5	Hemlock	Yes	Disk		55	1964
9	85	7-Aug			720	290	2	13	Hemlock	Yes	Disk	Two piths present	62	1957
9	86	7-Aug			545	285	0.5	3.5	Hemlock	Yes	Disk		29	1990
9	87	7-Aug			345	270	1	4.5	Silver	Yes	Disk		45	1974
9	88	7-Aug			360	210	0.75	4.5	Hemlock	Yes	Disk	Two piths present	50	1969
9	89	7-Aug			480	195	1.5	10	Hemlock	Yes	Disk		70	1949
9	90	7-Aug			75	250	0.25	2.5	Hemlock	Yes	Disk		24	1995
10	91	7-Aug	121.83513	48.72746	350	9	1	6.5	Hemlock	Yes	Disk		62	1957
10	92	7-Aug			490	68	1	8	Hemlock	Yes	Disk		53	1966
10	93	7-Aug			302	101	2	13	Hemlock	Yes	Disk		63	1956
10	94	7-Aug			670	131	1.5	6	Hemlock	Yes	Disk		67	1952
10	95	7-Aug			620	133	1.5	5.5	Hemlock	Yes	Disk		63	1956
10	96	7-Aug			250	207	2	9	Hemlock	Yes	Disk		60	1959
10	97	7-Aug			325	289	2.25	15.5	Hemlock	Yes	Disk		65	1954

10	98	7-Aug			605	307	1.5	9	Hemlock	Yes	Disk		64	1955
10	99	7-Aug			380	305	0.25	2.5	Hemlock	Yes	Disk	Two piths present	29	1990
10	100	7-Aug			618	336	3	12.5	Hemlock	No	Core	Close to the pith but a little off	51	1968
11	101	8-Aug	121.83464	48.72656	105	160	0.3	2.5	Hemlock	Yes	Disk		49	1970
11	102	8-Aug			182	82	1	8	Silver	Yes	Disk		74	1945
11	103	8-Aug			175	35	1.5	7.5	Hemlock	Yes	Disk		54	1965
11	104	8-Aug			264	15	1.5	6.5	Hemlock	Yes	Disk		55	1964
11	105	8-Aug			420	13	3	9.5	Hemlock	Yes	Disk		67	1952
11	106	8-Aug			475	333	3	11.5	Hemlock	Yes	Disk		70	1949
11	107	8-Aug			246	290	2	9	Hemlock	Yes	Disk		71	1948
11	108	8-Aug			210	254	1	7	Hemlock	Yes	Disk		69	1950
11	109	8-Aug			293	220	1	8	Hemlock	Yes	Disk		70	1949
11	110	8-Aug			242	195	1	8	Hemlock	Yes	Disk		72	1947
12	111	8-Aug	121.83447	48.7256	644	354	1.5	8	Hemlock	Yes	Disk		51	1968
12	112	8-Aug			395	56	1	7	Hemlock	Yes	Disk		64	1955
12	113	8-Aug			455	125	0.75	4	Silver	Yes	Disk		28	1991
12	114	8-Aug			640	130	1	8	Hemlock	Yes	Disk		66	1953
12	115	8-Aug			553	162	3	13.5	Hemlock	Yes	Disk		68	1951
12	116	8-Aug			710	176	2	9.5	Silver	Yes	Disk		51	1968
12	117	8-Aug			436	205	0.25	1.5	Silver	Yes	Disk		30	1989
12	118	8-Aug			640	215	0.5	5.5	Silver	Yes	Disk		31	1988
12	119	8-Aug			800	265	5	14	Hemlock	Yes	Disk		71	1948
12	120	8-Aug			998	289	3	9.5	Hemlock	Yes	Disk		64	1955
13	121	8-Aug	121.83424	48.72485	368	359	1.5	7.5	Hemlock	Yes	Disk		41	1978
13	122	8-Aug			341	49	2	7	Hemlock	Yes	Disk		48	1971
13	123	8-Aug			376	83	5.5	22	Hemlock	No	Core	Close to pith but a little off	47	1972
13	124	8-Aug			627	138	7.5	23	Hemlock	Yes	Core	Possible pith not counted in #rings	63	1956
13	125	8-Aug			532	115	1.5	3.5	Hemlock	Yes	Disk		51	1968
13	126	8-Aug			150	193	2.5	9.5	Hemlock	Yes	Disk		51	1968
13	127	8-Aug			550	178	3	10	Hemlock	Yes	Disk		51	1968
13	128	8-Aug			889	176	8	20	Hemlock	No	Core	Possibly two trees growing together	21	1998
13	129	8-Aug			626	290	5.5	24	Silver	No	Core	Pith not visible	23	1996
13	130	8-Aug			576	313	8	20	Hemlock	No	Core	Did not reach pith	68	1951
14	131	18-Aug	121.83407	48.72393	965	294	9	41	Silver	Yes	Core	Possible pith counted	57	1962
14	132	18-Aug			259	285	3	10	Hemlock	Yes	Disk	Pith is destroyed	51	1968
14	133	18-Aug			311	265	2.5	9	Hemlock	Yes	Disk		61	1958
14	134	18-Aug			310	241	6.5	24	Hemlock	No	Core	Close to pith but a little off	54	1965
14	135	18-Aug			362	219	6	28.5	Silver	Yes	Core	Possible pith counted	53	1966
14	136	18-Aug			194	164	1.5	10	Silver	Yes	Disk	Multiple piths	34	1985
14	137	18-Aug			188	122	10	49	Silver			Sample lost		
14	138	18-Aug			1150	129	1	4.5	Silver	No	Core	Pith not visible	31	1988
14	139	18-Aug			556	104	3	13	Hemlock	Yes	Disk		25	1994
14	140	18-Aug			421	164	7	18.5	Hemlock	No	Core	Close to pith but a little off	43	1976

15	141	18-Aug	121.8337	48.72284	359	172	9	36	Silver			Sample lost		
15	142	18-Aug			492	192	2.5	13	Silver	Yes	Disk		52	1967
15	143	18-Aug			588	158	3	17.5	Hemlock	No	Core	Close to pith but a little off	53	1966
15	144	18-Aug			207	66	2.5	9.5	Hemlock	No	Core	Close to pith but a little off	33	1986
15	145	18-Aug			400	46	3	22	Hemlock	No	Core	Close to pith but a little off	44	1975
15	146	18-Aug			552	22	3.5	14	Hemlock	No	Core	Possible pith counted	49	1970
15	147	18-Aug			541	335	6	20	Hemlock	No	Core	Close to pith but a little off	53	1966
15	148	18-Aug			465	315	6	20	Silver	Yes	Core	Possible pith not counted in #rings	34	1985
15	149	18-Aug			620	267	5	22	Hemlock	No	Core	Close to pith but a little off	57	1962
15	150	18-Aug			360	236	3	15	Hemlock	Yes	Core	Possible pith counted	53	1966
16	151	18-Aug	121.83322	48.72208	170	205	6	19	Hemlock	No	Core	Stopped at possible pith change	53	1966
16	152	18-Aug			213	114	7	23	Hemlock	No	Core	Pith not visible	39	1980
16	153	18-Aug			169	60	9	28	Hemlock	No	Core	Close to pith but a little off	52	1967
16	154	18-Aug			335	55	10	31	Hemlock	No	Core	Close to pith but a little off	45	1974
16	155	18-Aug			290	357	7	14	Hemlock	No	Core	Close to pith but a little off	23	1996
16	156	18-Aug			533	350	5	30	Hemlock	Yes	Core	Possible pith counted	80	1939
16	157	18-Aug			558	331	3	14	Hemlock	Yes	Disk		70	1949
16	158	18-Aug			357	318	4.5	19	Hemlock	No	Core	Close to pith but a little off	55	1964
16	159	18-Aug			250	286	4	22	Hemlock	Yes	Core	Pith not visible	68	1951
16	160	18-Aug			356	111	9	30	Hemlock	No	Core	Pith not visible	49	1970
17	161	18-Aug	121.83229	48.72137	640	49	12	29	Hemlock	No	Core	Possible pith not counted in rings	49	1970
17	162	18-Aug			135	170	7.5	18	Silver	No	Core	Close to pith but a little off	39	1980
17	163	18-Aug			270	229	7	23	Hemlock	No	Core	Close to pith but a little off	57	1962
17	164	18-Aug			810	290	9	32	Silver	No	Core	Close to pith but a little off	57	1962
17	165	18-Aug			235	346	5	19	Hemlock	No	Core	Multiple piths	42	1977
17	166	18-Aug			475	48	5	24	Silver	No	Core	Close to pith but a little off	38	1981
17	167	18-Aug			435	73	7	15	Hemlock	No	Core	Close to pith but a little off	64	1955
17	168	18-Aug			255	119	2.5	18.5	Hemlock	No	Core	Close to pith but a little off	36	1983
17	169	18-Aug			380	207	10	19.5	Silver	Yes	Core	Possible pith counted	55	1964
17	170	18-Aug			425	314	8	22	Hemlock	No	Core	Close to pith but a little off	56	1963
18	171	19-Aug	121.83156	48.72094	429	190	8	26	Hemlock	No	Core	Close to pith but a little off	47	1972
18	172	19-Aug			554	143	9	25	Hemlock	No	Core	Close to pith but a little off	50	1969
18	173	19-Aug			482	96	4	33	Silver	No	Core	Close to pith but a little off	40	1979
18	174	19-Aug			290	34	8	32	Hemlock	No	Core	Close to pith but a little off	57	1962
18	175	19-Aug			491	253	8.5	25.5	Hemlock	No	Core	Close to pith but a little off	60	1959
18	176	19-Aug			490	233	5	19	Silver	Yes	Core	Possible pith not counted in rings	56	1963
18	177	19-Aug			443	213	5	19.5	Hemlock	No	Core	Close to pith but a little off	35	1984
18	178	19-Aug			610	331	5	20	Hemlock	No	Core	Close to pith but a little off	44	1975
18	179	19-Aug			962	313	6.5	26	Hemlock	Yes	Core	Possible pith not counted in rings	56	1963
18	180	19-Aug			1265	48	8.5	34	Hemlock	No	Core	Did not reach pith	70	1949
19	181	19-Aug	121.83061	48.72034	722	6	10	34	Silver	Yes	Core	Pith is present but unreadable	65	1954
19	182	19-Aug			299	123	8	31	Silver	No	Core	Almost reached possible pith	54	1965
19	183	19-Aug			640	104	5	24	Hemlock	No	Core	Possibly two trees growing together	38	1981

19	184	19-Aug	699	64	9	26	Silver	No	Core	Close to pith but a little off	42	1977
19	185	19-Aug	892	260	10	36	Silver	No	Core	Cloe to the pith but a little off	54	1965
19	186	19-Aug	617	264	10	24	Silver	No	Core	Close to pith but a little off	54	1965
19	187	19-Aug	745	269	11.5	29	Hemlock	No	Core	Close to pith but a little off	53	1966
19	188	19-Aug	1680	75	10	45	Silver	No	Core	Close to pith but a little off	54	1965
19	189	19-Aug	762	155	9	28	Silver	No	Core		39	1980
19	190	19-Aug	1010	211	7	27.5	Hemlock	No	Core	Close to pith but a little off	44	1975

Figure A: Field and Lab data for each sample.

Appendix B: Variable Analysis

With nineteen plots and ten trees sampled from each plot, a total of 190 samples were taken throughout the length of the Easton foreland. Tree composition changed throughout the valley, with more dense old growth forest in the lower valley, and small dispersed saplings in the upper valley. A graph (Figure B.1) was created to show the distribution of tree ages throughout the valley, specifically moving from the lower valley to the upper valley. It is important to note that the distribution of plots sampled within the valley do not follow standard chronological ordering. For example, the plots are numbered in the following order moving from the bottom of the valley to the top of the valley (3,2,1,4,5,6,19,18,17,16,15,14,13,12,11,10,9,8,7). Plots were renumbered to follow a chronological order (1-19) moving up the foreland (plot 3 was relabeled as plot 1 etc.) for Figure B.1. The samples ages/dates or position within the foreland did not change. Noticeably the oldest samples were taken in the lower old growth forest of the Easton foreland. The ages gradually decrease as you move up the valley until you reach the middle of the foreland where a small rise in ages can be seen. From this point the ages all begin to level off and stay in the same age range. This may be due to the fact that the oldest trees may have not been sampled in this area which would result in an underestimation in the trees ages. Another explanation could be due to the Easton glaciers recession behavior during this time period. The

Easton glacier receded very rapidly from its 1912 position in the lower foreland to its 1935 position in the upper foreland losing 1,872 meters. This would result in a large area of land all being exposed around the same time period making the soil development process and tree establishment times very similar. The recession following 1935, was slower and more gradual for the next 20 years. This could have caused a less dramatic change in tree ages in the upper portion of the Easton valley.

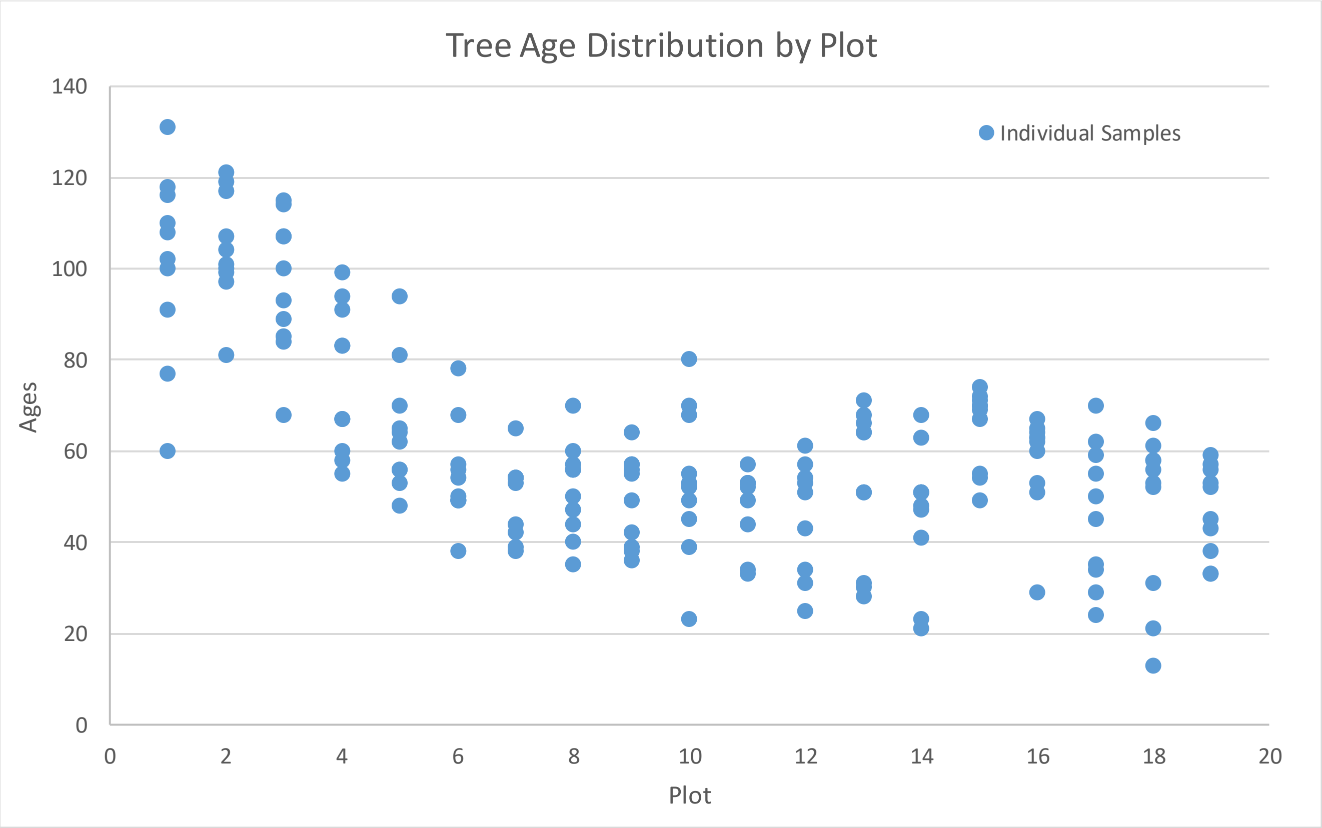


Figure B.1: Tree age distribution by plot (Plots were rearranged 1-19 going from the bottom of the foreland to the top of the foreland)

A series of linear regression graphs were created to compare variables among our tree sample data. The graphs included tree age vs tree diameter (Figure B.2), tree age vs tree height (Figure B.3), and tree diameter vs tree height (Figure B.3). Tree's ages were not significantly correlated with the tree's diameter having and R^2 value of 0.0358. While one might predict that the tree's diameter would be larger in an older tree, this was not the case in trees within the Easton foreland. Tree's ages were not significantly correlated with tree's height having and R^2 value of 0.1357. So, in the Easton foreland, tree's ages are not correlated to the tree's height. Tree's height was significantly correlated to the tree's diameter having a R^2 value of 0.7093. This means that in the Easton foreland, the tree's height is related to its diameter.

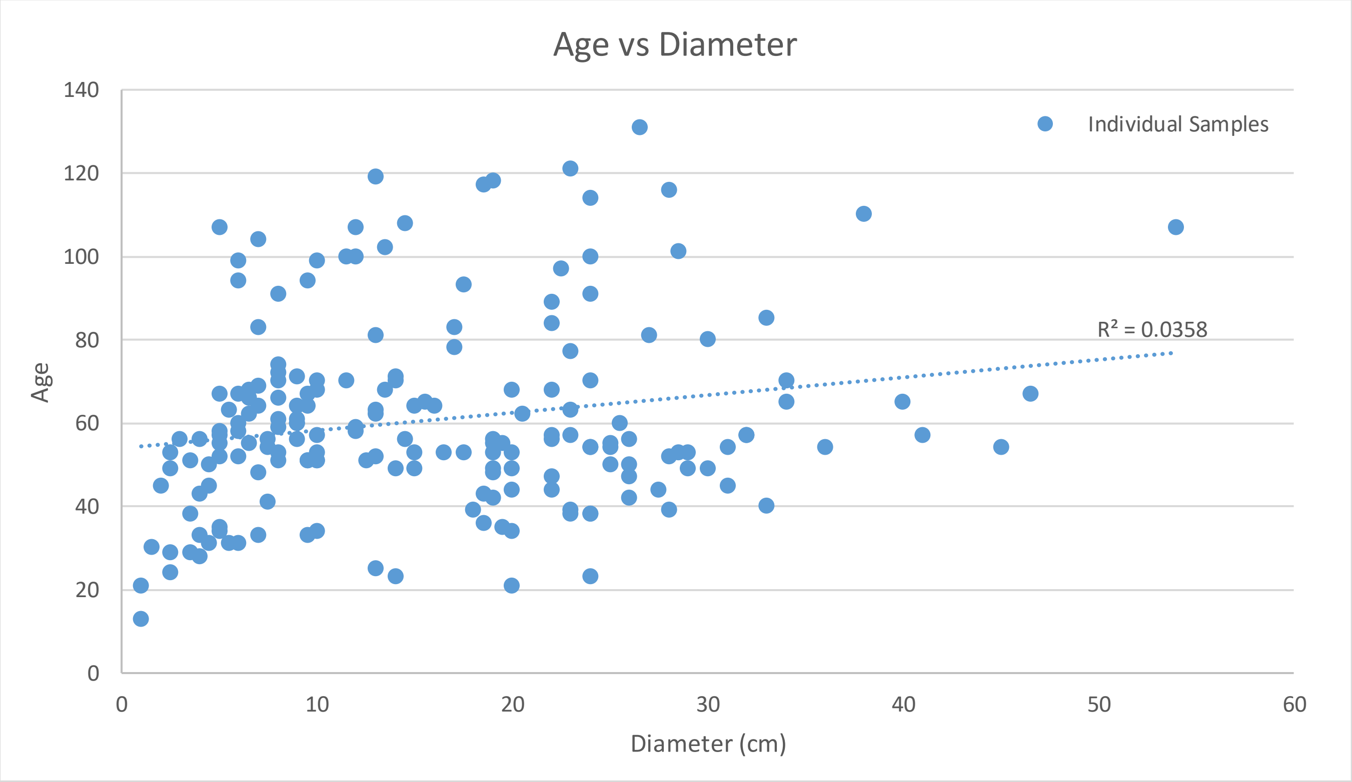


Figure B.2: Tree age compared to tree diameter

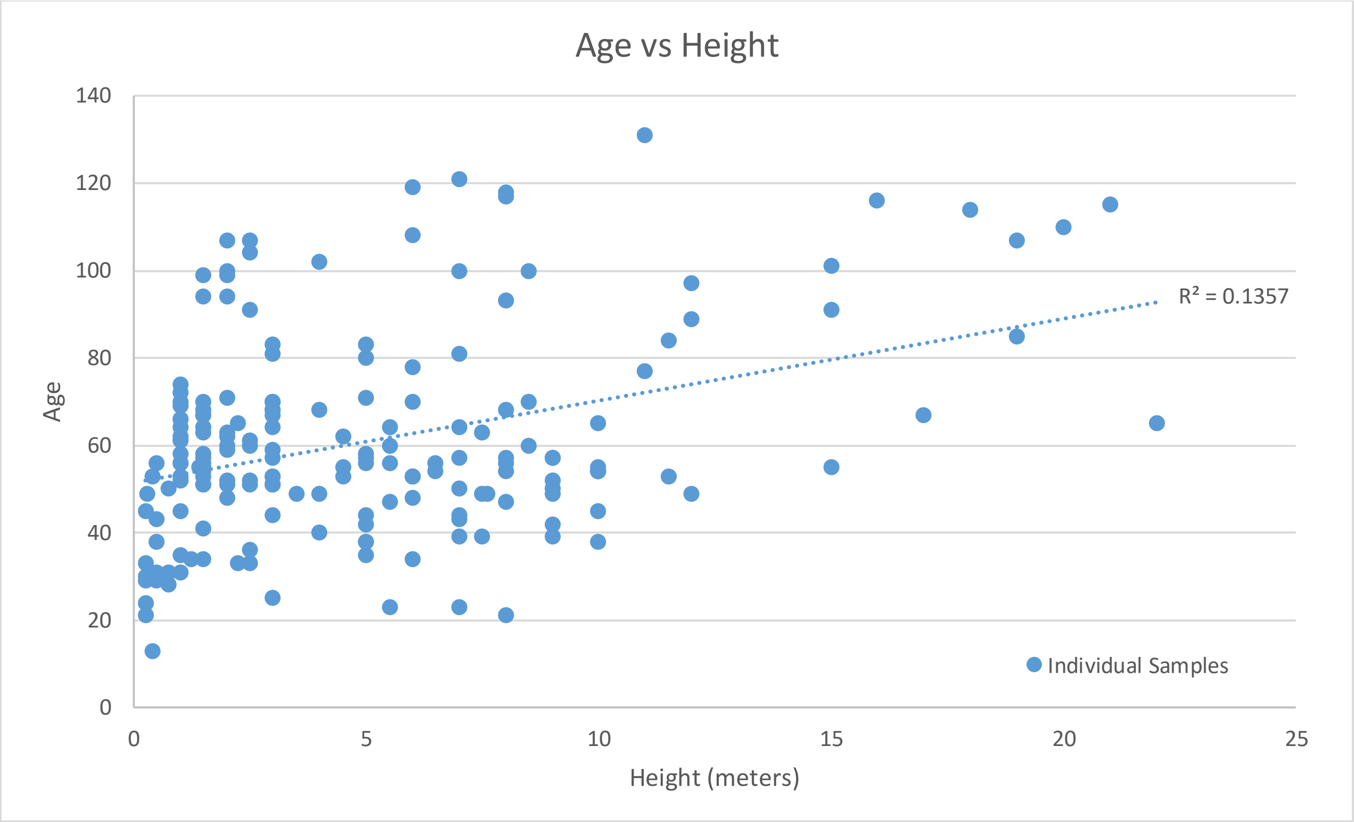


Figure B.3: Tree Age compared to tree height

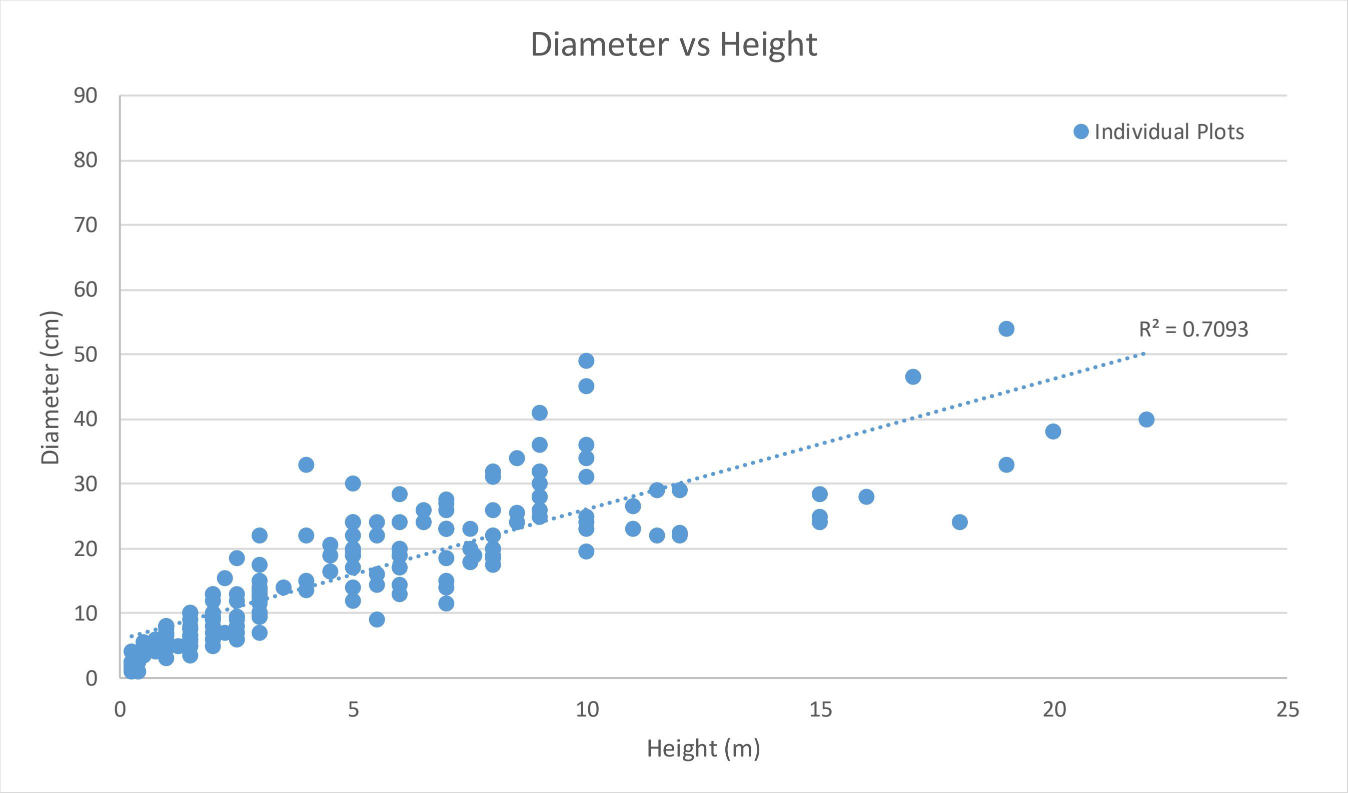


Figure B.4: Tree diameter compared to tree height