A comparative Study of Tree-ring Chronologies of Downy Birch (*Betula pubescens*) and Rowan (*Sorbus aucuparia*) in Ranaskógur, East Iceland, with focus on the Response of Tree-ring Growth to Climate

A Study of tree-ring growth of Icelandic Downy Birch and Rowan and the relationship between growth and climate in Ranaskógur, an old natural Birch Forest in East Iceland

Nandini Hannak

born 02.03.1998 in Chennai, India

(Matr.Nr.: 16210711)

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Supervisor (Betreuer): Dr Ólafur Eggertsson, Prof. Dr. Martin Guericke

First Examiner (1. Gutachter): Prof. Dr. Martin Guericke

Second Examiner (2. Gutachter): Prof. Dr. Jens Schröder

HNE Eberswalde
Hochschule für nachhaltige Entwicklung

University of Sustainable Development Eberswalde (HNE)

Abstract

Iceland is located near the Arctic Circle, close to the tree line. At this latitude, near the edge of the range in which tree growth is possible, abiotic factors such as climate have a greater effect on the growth of trees. The effect of climate on the tree is recorded in the tree-ring widths of the stem, as a "climate signal". The aim of this study is to investigate the tree-ring growth of the tree species Rowan (*Sorbus aucuparia*) and Icelandic Downy Birch (*Betula pubescens*) in the forest Ranaskógur, in East Iceland, and to determine the response of tree growth to climate over the last century.

Core-samples were taken from trees in Ranaskógur in September 2018, as part of a student internship at the Icelandic Forest Research Service (Skógræktin). From the cores, a tree-ring width (TRW) chronology and a standardized tree-ring index (TRI) chronology were produced for Downy Birch and Rowan. A statistical analysis of the chronologies and the monthly mean temperature and monthly precipitation was conducted using COFECHA, Microsoft Office Excel, and R Studio, to determine the response of growth to climate.

The study found that Downy Birch and Rowan had similar tree-ring growth in the last century. The growth of Downy Birch responds most to temperature in June and July, and precipitation in May. Rowan responds most to temperature in July and August, and precipitation in June. The tree-ring growth of Rowan has a stronger response to the temperature during the vegetation period than Downy Birch.

Keywords: Tree-rings, Dendrochronology, East Iceland, Ranaskógur, Downy Birch, Rowan

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I would like to thank Prof. Dr Guericke for help and feedback during the writing and formatting of the thesis.

Declaration of Authorship

I, Nandini Hannak (Matr.Nr.: 16210711), hereby declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own research.

A comparative Study of Tree-ring Chronologies of Downy Birch (Betula pubescens) and Rowan (Sorbus aucuparia) in Ranaskógur, East Iceland, with focus on the Response of Tree-ring Growth to Climate

This thesis was written by me independently. It was written as part of and in accordance with the requirements and regulations of the Bachelor of Science (B.Sc.) International Forest Ecosystem Management (IFEM) of the University of Sustainable Development of Eberswalde (HNE). All external sources are cited in the style MLA. All sources of help in the research and work are acknowledged.

Place/Date **Signature**

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Table of Contents

Table of Figures

1. Introduction

1.1 Aim and Purpose

Iceland is a country with few forests or woodlands. The forest cover of the country is predominantly composed of natural forests of Icelandic Downy Birch. The few other tree species native to Iceland are far less common than Downy Birch and are not capable of forming forests. Rowan is one such tree species native to Iceland, which is uncommon in the wild. Individual Rowan trees can be found growing in Birch forests and woodlands across the country. However, there are few forests in which Rowan trees occur in larger number, as a secondary species.

The aim of this study is ***to produce tree-ring width chronologies of Rowan (Sorbus aucuparia) and Icelandic Downy Birch (Betula pubescens) from trees in Ranaskógur, an old natural Birch forest in East Iceland, in order to investigate the past growth of the forest and to analyse and compare the annual tree-ring growth of the two species and their response to climate***.

Ranaskógur is an old natural Birch forest in East Iceland. It is one of the few forests where many, and especially older, Rowan trees are found. By producing tree-ring chronologies from trees of Rowan and Downy Birch in Ranaskógur, the study aims to gain insight into the past tree growth and the history of the forest. The purpose of this, is to determine how similar or different the annual radial growth of the two tree species is. Further, the purpose is to determine how the tree species respond to climate, and how this response has changed over time.

The climate factors focused on in this study are air temperature and precipitation. The climate variables used are monthly mean temperature, summer temperature, and total monthly precipitation

The research questions formulated to guide the study are:

- ***How does the annual tree-ring growth of the tree species Icelandic Downy Birch and Rowan compare?***
- ***To what extent does the tree-ring growth of Icelandic Downy Birch and Rowan respond to temperature and precipitation?*** And how does the response to temperature and precipitation of the two species compare?

Hypothesis:

Iceland is located at the Arctic Circle, and close to the tree line, the edge of the zone in which trees are capable of growing. At the edge of the ecological amplitude or natural range of a tree species, external abiotic growth-limiting factors have a greater effect on tree growth (Fritts p. 16, 2001). At high latitudes, climate, particularly temperature, are strong growth limiting factors (Fritts p. 16, 18, 2001). As the vegetation period at high latitudes is typically shorter, the climate during the vegetation period has great impact on the growth of the tree in that year (Fritts p. 84, 166, 2001). At high latitudes, low temperatures during the vegetation period have a particularly limiting effect on growth (Fritts p. 16, 2001). Other tree-ring studies conducted on chronologies from Rowan and Downy Birch in Iceland, found that the temperature in the vegetation period had a significant impact on growth (Eggertsson p. 52, 2014) (Þórarinsson and Eggertsson p. 26, 2012).

While there is a stronger correlation between tree growth and temperature at high latitudes, the correlation between growth and precipitation at high latitudes is typically very low or non-existent. An exception is, that during periods of very warm temperature at high altitude or elevations, water stress through too low precipitation can have a negative impact on growth (Fritts p. 18, 2001).

The hypothesis formulated in response to the second research question is, ***that a strong correlation between the tree-ring growth of Rowan and Downy Birch and air temperature, particularly the temperature during the summer months, exists***. Further predicted is, ***that no significant correlation between precipitation and the growth of either tree species exists***.

1.2 Background

1.2.1 Internship in Iceland

The study was conducted as part of an internship at the Icelandic Forest Research, in line with the requirements of the course (B.Sc.), International Forest Ecosystem Management. The semester abroad took place in Iceland, from September 2018 to January 2019. The host organization was the Icelandic Forest Research Service, part of the Icelandic Forest Service (Skógræktin). The internship was at the office of the Icelandic Forest Research service in Mógilsá, near Reykjavík, in Southwest Iceland.

In September 2018, fieldwork was carried out under the supervision of Dr Ólafur Eggertsson in East Iceland (Austurland). Core samples were taken from Icelandic Downy Birch and Rowan, from the Birch forest Ranaskógur. The measurement and analysis of the core samples was carried out by the thesis author, Nandini Hannak. The preliminary results of the analysis are described in the report "Study of the Ring-Width Chronologies of Icelandic Downy Birch and Rowan in Ranaskógur, Eastern Iceland" (unpublished). The report was written on the request of and for the use of Dr Eggertsson. Permission to use the research results for the bachelor thesis was given. Results from the report were presented by Dr Eggertsson as part of the presentation "Ranaskógur in Héraði - The History of the Forest as read from Tree-rings"[1], in Hallormsstaður in April 2019.

1.2.2 Dendrochronology

Dendrochronology is the study or dating of tree rings. Through the study of tree rings, past tree growth can be determined. This can be applied to identify abiotic or biotic growth-limiting factors or reconstruct events which affect tree growth over the course of the tree's life (Speer p. 4, 2010).

In climatic zones with seasonal variation, with vegetation periods and dormancy periods (e.x. winter and summer), trees form tree-rings (Speer p. 7, 2010). Tree rings are formed through secondary or radial growth of the stem and branches of a tree. The rings are formed by the cambium layer, below the bark, with the oldest rings closest to the core and newest rings by the bark. Each ring is generally composed of lighter earlywood, formed earlier in the vegetation period, and darker latewood, formed at the end of or after the vegetation period (Fritts p. 57-63, 2001).

The growth of tree-rings is determined by the tree physiology as well as by growth limiting factors (Fritts p. 15, 2001) (Speer p. 10, 2010). Physiological growth limiting factors are, for instance, the age or resilience of a tree. External factors can be abiotic, biotic and/or anthropogenic factors. Some such factors are the location (ex. latitude), climate conditions, natural disasters, pests or forest stand dynamics (ex. competition). Limiting factors that occur constantly or repeatedly during the tree's life, such as climate, result in a "signal" or pattern that can be identified in the tree-ring width (Speer p. 10, 2010). These signals can be used to better understand the past relationship and even future developments in the relationship between these factors and the tree growth.

[1] "Ranaskógur á Héraði – saga skógarins lesin úr árhringjum trjánna"

1. 3 Forestry in Iceland: Downy Birch and Rowan

1.3.1 Overview of Icelandic Forests

Iceland has few forests; the total forest cover, as of 2017, is 2%. Plantations and planted forests cover about 0.6%, while natural Birch forests and woodlands cover 1.5% of the whole country (Eysteinsson, Forestry in a Treeless Land p. 19, 2017). The present area of natural forests is shown in Figure 1, a map by the Icelandic Forest Service (Skógræktin 2017). Before the settlement of Iceland by Norse settlers, in the 9th and 10th century, forests covered about one third of the country. Following the settlement, factors such as logging, livestock grazing, and erosion resulted in deforestation and forest degradation (Eysteinsson, Forestry in a Treeless Land p. 4-5, 2017).

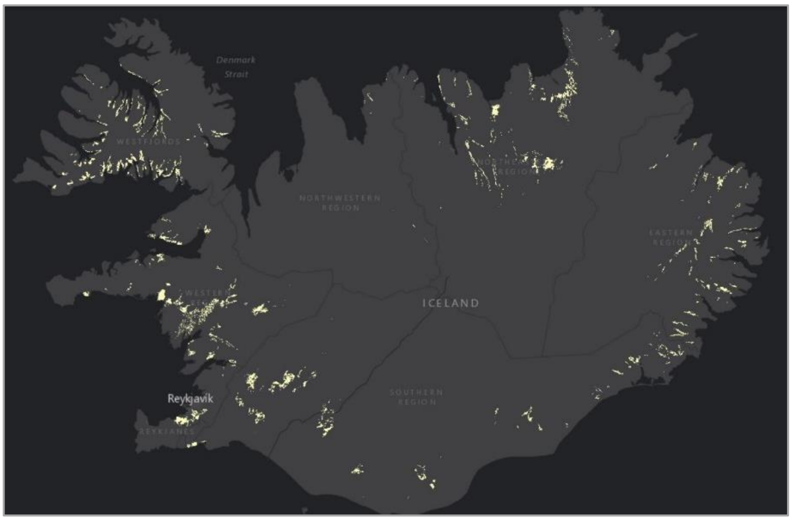


Figure 1 Map of Natural Birch Forests in Iceland, by the Icelandic Forest Service (Skógræktin). The Extent and Location of the Forest is denoted by the light-yellow areas on the Map.

The tree species native to Iceland are Icelandic Downy Birch (*Betula pubescens*), Rowan (*Sorbus aucuparia*) and Aspen (*Populus tremula*). Of these three species, Birch is the most common and widespread in Iceland, and is the only one that forms forests and woodlands (Eysteinsson, Forestry in a Treeless Land p. 4, 2017).

1.3.2 Downy Birch

Downy Birch is a deciduous broad-leaved tree species. It is light-demanding to semi-shade tolerant and is a pioneer tree species. The species reproduces both through seeds and through basal shoots (Kristinsson 2007).

The distribution of Downy Birch in Iceland is shown in the map above (Figure 1). It occurs across Iceland, except at higher elevations, such as in the Highlands in the centre of the country (Kristinsson 2007). In lower regions, the species occurs both inland and by the sea, growing individually or in closed forests and woodlands. Overall Birch is relatively tolerant of different site and climate conditions. While the species is capable of acting as a pioneer species and is frost and wind resistant, it does not grow on all sites in Iceland. Sites with poor and/or shallow soils or sites with greater erosion do not support the growth of Birch, or only with great difficulty (Kristinsson 2007). A further factor limiting the spread and distribution of Birch is grazing by sheep (Eysteinsson, Forestry in a Treeless Land p. 6, 2017).

The growth of Birch trees varies depending on the climate and site conditions, and between regions of the country. The trees can reach a height of up to 15 meters, but more often than not, the trees are shorter, less than 5 meters, and shrub-like in growth (Kristinsson 2007) (Eysteinsson, Forestry in a Treeless Land p. 4, 2017). The rate of growth varies by climate and site conditions, with trees growing particularly slowly in the undergrowth of dense forests.

Significant pests on Birch in Iceland are the moth species *Epinotia solandriana* (ISL. Tigulvefari), *Operophtera brumata* (ISL. Haustfeti,), *Erranis defoliaria* (ISL. Skogfeti,), and the aphid *Betulaphis quadrituberculata* (Halldórsson und Sverrisson 1997). These species feed on Birch leaves and can cause widespread defoliation.

1.3.3 Rowan

Rowan is uncommon in Iceland (Eysteinsson, Noble Hardwoods in Icelandic Forestry p. 19, 2006). The species does not form forests like Birch, and instead occurs in native forests and woodlands as a secondary tree species or as individuals (Blöndal, Reyniviður (Sorbus aucuparia L.) á Ísland p. 22-23, 2000). Rowan is otherwise also found in gardens and in and around urban areas, as well as in isolated gorges and valleys, where it was safe from grazing sheep (Eysteinsson, Noble Hardwoods in Icelandic Forestry p. 19, 2006) (Blöndal, Reyniviður (Sorbus aucuparia L.) á Ísland p. 26, 2000). At present, Rowan is found across Iceland, particularly in the Westfjords, central North Iceland, and East Iceland (Blöndal, Reyniviður (Sorbus aucuparia L.) á Ísland p. 26-27, 2000) (Eysteinsson, Noble Hardwoods in Icelandic Forestry p. 19, 2006).

Rowan is a deciduous hardwood species. It is semi-shade tolerant and young Rowan trees are capable of growing underneath open to light forest canopies. Further, Rowan is tolerant of different site and climate conditions. However, the age and size reached by Rowan varies depending on the site and climate conditions. The growth of the tree is greater on deeper, nutrient-rich soils and sites where the trees have more light (Blöndal, Reyniviður (Sorbus aucuparia L.) á Ísland p. 20, 2000). The maximum life span of Rowan in Iceland is unknown; trees aged 150 years or older have been documented (Blöndal, Reyniviður (Sorbus aucuparia L.) á Ísland p. 20, 2000) (Sigurðsson p. 36, 1979). In the wild, Rowan spreads through its seeds, which are distributed by birds (Eysteinsson, Noble Hardwoods in Icelandic Forestry p. 19, 2006). The species is also capable of producing new stems from basal shoots and root sprouts (Blöndal, Reyniviður (Sorbus aucuparia L.) á Ísland p. 18, 2000).

In Iceland, there are relatively few pests on Rowan. One major pest is the fungi *Cytospora rubescens* (ISL. Reyniáta) (Halldórsson und Sverrisson 1997).

1.4 Ranaskógur

1.4.1 Introduction

Ranaskógur is a private forest in East Iceland, in the municipality Fljótsdalshreppur. It is located at the lake Lagarfljót, adjacent to and South-West of the Hallormsstaður National Forest. The national forest, (Hallormsstaðaskógur), is one of the oldest, continuous Birch forests in Iceland, possibly dating back to before the settlement of Iceland (Hallgrímsson p. 20, 1989). Ranaskógur itself is famous for its old, tall Birch trees as well as its high number of mature Rowan, a species that is uncommon in Iceland.

The location of Ranaskógur and the forested area is shown below, in Figure 2 (Skógræktin 2017). At present, Ranaskógur covers an overall area of about 75 hectare (ha). Of this, 35.5 ha are old, mature Birch forest, about 3-5 meters tall. The other 37.5 ha are Birch forest that is younger, in the development stage, and 2-3 meters tall (Skógræktin 2017). Rowan trees were mainly found in the old, mature Birch forest (the red area in Figure 2).

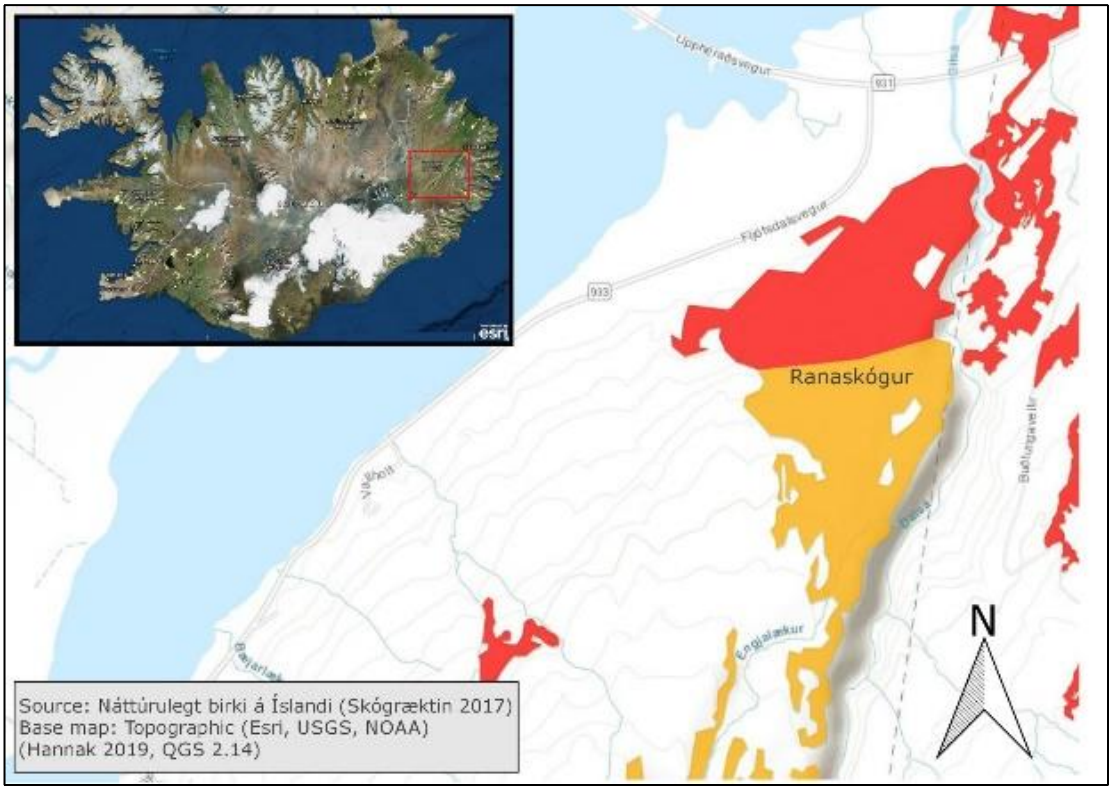


Figure 2 Map of Ranaskógur, a natural Birch Forest in East Iceland. The red area represents mature Birch forest, 60-100 years old, and the orange area represents Birch forest in the development stage, aged 30-60 years. The map was created by the author using the "Map of Natural Birch in Iceland" from the Icelandic Forest Service (Skógræktin 2017).

1.4.2 History & Development

The area around Hallormsstaðaskógur, where Ranaskógur is located, was described as being covered by forest in records dating as far back as the 13th century (Hallgrímsson p. 20, 1989). In the early 19th century, the Birch forest at Ranaskógur was a popular destination for visitors, due its tall Birch and Rowan trees (Hallgrímsson p. 26, 1989). After 1866, the new owner of Ranaskógur felled large parts of the forest for firewood and charcoal. Some sections of the older forest remained untouched; the rest was reduced to short, shrub-like Birch trees (Hallgrímsson p. 28, 1989). At the start of the 20th century, the forest was on average only 1-3 meters tall and was so dense that no light would reach the ground. At the same time, other parts of the forest, particularly the upper slopes along the Gilsá River Gorge, (where the old Rowan and Birch trees are found today), were bare, with little to no tree cover (Hallgrímsson p. 29, 1989).

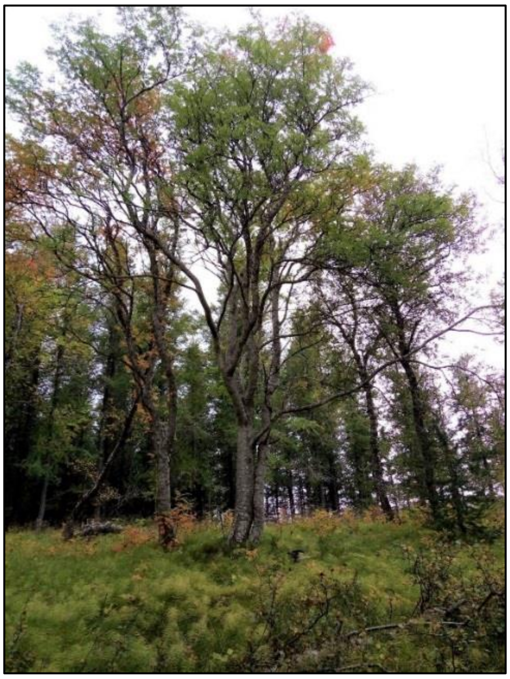


Figure 3 A Rowan tree growing in the Mature Birch Forest, Ranaskógur (Hannak 2018)

In 1910, after years of mismanagement, the forest was thinned and trees were harvested. By the 1950s, the trees had reached a height of 3-4 meters, with the tallest trees being 8-9 meters tall. The upper slopes of the forest were covered with young trees as well as some patches of old, continuous forest. At the time, the owner of the forest planted a stand of conifers, spruce and larch, on the upper slope, in the Southeast of the forest. The conifer stand was fenced off in the 1960s, and in the 1970s to 1980s, fences were built around the rest of the forest as well. This was done, to prevent grazing by sheep in the forest (Hallgrímsson p. 30, 1989). Helgi Hallgrímsson visited the area in 1989 and noted that, while little rejuvenation existed, fencing the area appeared to have brought about some improvement, with more rejuvenation found than before (Hallgrímsson p. 31, 1989).

In 2000, the former head forester of Hallormsstaðaskógur, Sigurður Blöndal, visited the area and found that the forest had one of the highest number of wild-growing, mature Rowan trees in East Iceland. The trees were 8-10 meters high at the time, with a mean diameter of about 25 centimetres (Blöndal, Reyniviður (Sorbus aucuparia L.) á Ísland p. 21, 2000).

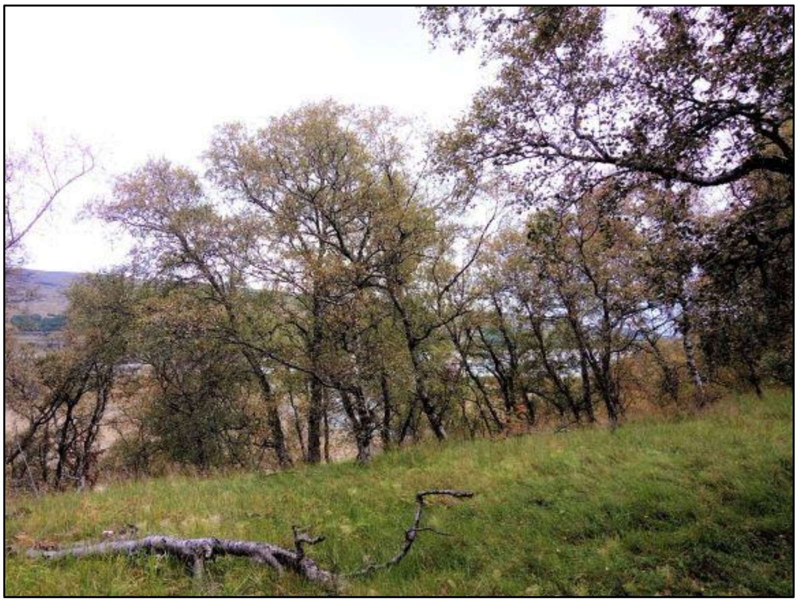


Figure 4 Mature Birch Forest halfway up the Hill, Ranaskógur (Hannak 2018)

1.4.3 Site and Climate

According to the "Soil Map of Iceland", the soil type of the overall region is a complex of Brown-Andosol and Gleyic-Andosol (BA/GA), and is volcanic in origin (Arnalds and Grétarsson 2001). Helgi Hallgrimsson, upon visiting Ranaskógur, describes the site as being fertile and having light, sandy soil with deposits of glacial clay (Hallgrímsson p. 20, 1989).

In East Iceland, the warmest month is typically August and the coldest is February (Einarsson p. 681, 1984). The area around lake Lagarfljót has a low annual precipitation, 400-600 millimeters (mm) (Einarsson p. 685, 1984). The highest precipitation occurs in autumn and early winter and the lowest in May and June (Einarsson p. 684, 1984). The vegetation period in Hallormsstaður and surrounding area lasts from June to September, with the leaves of Birch typically developing in early June, as noted by the head foresters (Þorfinnson) (Pálsson) (Loftsson) (Blöndal, Annual Reports of Forestry Officer in East Iceland).

Over the last century, Iceland has had multiple cold and warm periods. The period 1853-1920 was colder, followed by a warmer period in 1921-1965, with the warmest temperatures recorded in 1934-1945. In 1966-1971 the country, and particularly East Iceland, experienced another cold period (Einarsson p. 679, 1984). Since then the temperature has been gradually getting warmer.

1.4.4 Stand Description

A more comprehensive tabular stand description of the forest on the sample area is given in Appendix A. The old mature Birch forest was chosen for sampling, with sampling primarily in the Northeast of the forest. The area in which samples were taken is shown in Figure 7, in the following chapter.

The forest is located on a slope with a North by North-West exposition, rising from an elevation of about 60 to 100 meters above sea level (a.s.l.). The slope rises towards the South and East. The land evens out near the crest of the hill, before it then drops off steeply into the Gilsá River gorge. The forest grows up to the very edge of the gorge, with some trees even clinging to the steep sides of the gorge (Figure 5).

Figure 5 The Gorge through which the Gilsá River flows, borders the mature Birch Forest and seperates Ranaskógur from Hallormsstaðaskógur (Hannak 2018)

The Birch forest was formed through natural rejuvenation, from seeds or from basal shoots (coppice) (Hallgrímsson 1989). On the lower slope, the forest is denser, and the trees are shrub-like and short, with a height of about 2-5 m. The trees are crooked and frequently have multiple stems. The crown cover is medium to dense at the very base of the hill and grows less dense higher along the slope. On the upper slope, the trees are widely spaced and are taller, (5-10 m), with large crowns. Here, the forest is single-layered, with low to sparse crown cover. Rowan trees were only found in this part of the forest, on the upper slope and along the gorge.

Rowan trees grow across the upper slope and occur in a single stem mixture, occasionally with two or three separate stems growing from the same root system. The trees have well developed, round crowns and straight stems.

Figure 6 Mature Birch Forest on the lower to middle Slope, Ranaskógur (Hannak 2018)

Little to no Birch regeneration was found on the upper slope. Some young Rowan plants, 0.5-1 m tall, occur on the upper slope, mainly close to or in the understory of the neighbouring conifer stand. At the time of sampling, in September 2018, few plants other than mosses were observed in the understory on the lower slope. The undergrowth of the upper slope was primarily composed of grasses and herbaceous plants.

2. Materials and Methods

2.1 Methods used

The fieldwork and the measurement and analysis of the core samples was conducted, largely following the methods recommended by Dr Ólafur Eggertsson. The methods for measurement and analysis used in this study are based on those used by Eggertsson in “Growth of Birch in Hallormsstaður 1950-2011 and the relation to Climate and Larvae Outbreaks”[2] (Eggertsson 2014), and the method in “Ecology of Rowan (Sorbus aucuparia L.) in Trostansfjörður”[3] (Þórarinsson and Eggertsson 2012). Methods described in “Fundamentals of Tree-Ring Research” by James H. Speer were used as an additional aid during the crossdating and analysis with COFECHA (Speer 2010).

2.2 Fieldwork: Taking Core Samples in Ranaskógur

Core samples were taken from Downy Birch and Rowan during two days of fieldwork in early September 2018. The work was conducted with the help of and under the instruction of Dr Ólafur Eggertsson. The permission to sample trees was given by the owner of Ranaskógur, Sigurður Kjerulf. Ranaskógur and the sample area are described in detail in the section, 1.4 Ranaskógur. The area in which trees were selected and sampled is shown below, in Figure 7. This area covers about 7 ha in total.

[2] “Vöxtur Birkis á Hallormsstad árin 1950-2011 og tengsl vid Vedurfar og Madkaá“

[3] “Vistfræði reyniviðar (Sorbus aucuparia L.) í Trostansfirði“

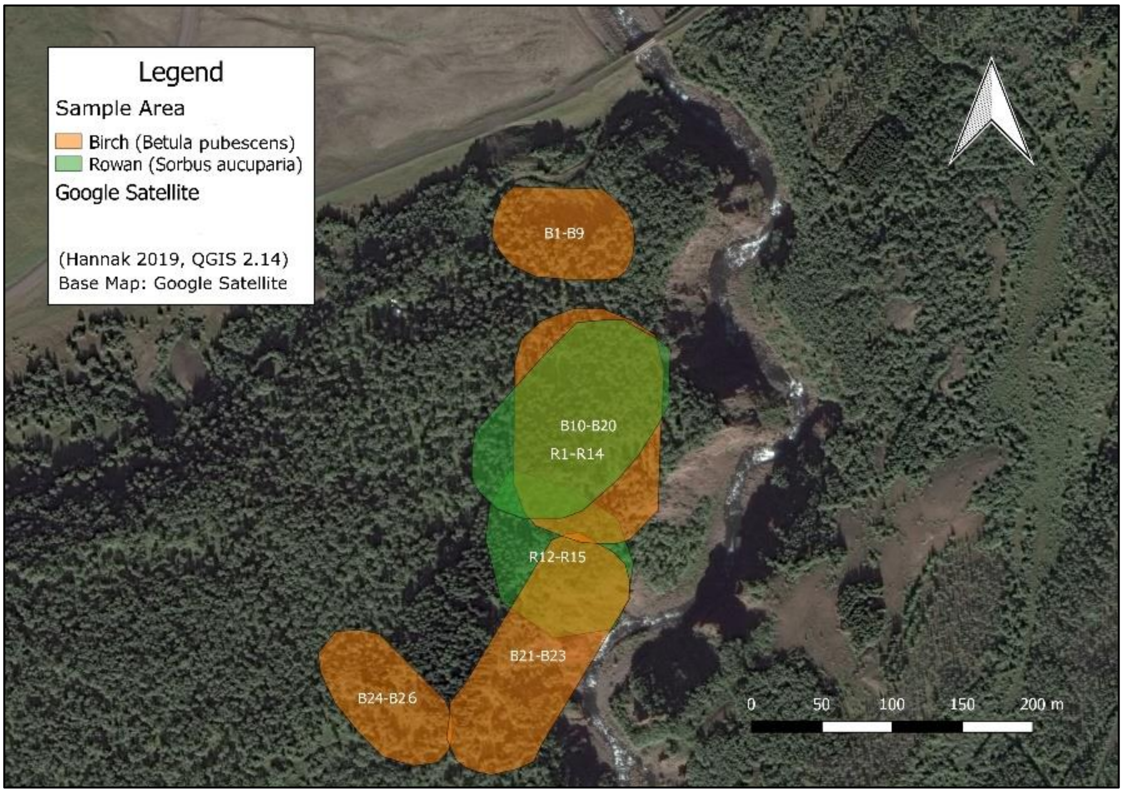


Figure 7 Map of Sample Area and approximate Location of sampled Birch and Rowan, Ranaskógur (Hannak 2019)

Sample trees were not selected based on a set sampling method. In studies of tree-ring growth and climate, it is recommended to take samples from older, dominant trees (Fritts p. 28-31, 2001) (Schweingruber, Kairiukstis and Shiyatov, 2.1 Sample Selection p. 26, 1992). Older trees provide a longer data series, while the tree-ring growth of dominant trees shows a stronger response to climate as the growth is limited less by non-climatic factors such as competition (Fritts p. 23, 30-32, 2001). A systematic sampling approach is not appropriate for this study, as it does not ensure a large enough sample of old, dominant or codominant trees (Schweingruber, Kairiukstis and Shiyatov, 2.1 Sample Selection p. 26, 1992). Instead the sample trees of Birch and Rowan were chosen through a simple estimation of tree age based on external characteristics of the tree (i.e. crown form, bark, height, diameter). The oldest or largest dominant or codominant trees, with tall, broad stems and wide crowns, were selected. Only living trees were sampled.

Two core samples were taken from each tree. For trees with more than one stem, the stem with the largest diameter was cored. The cores were taken at a height of 0.50 meters, using a Haglöf Increment Borer. The cores were taken perpendicular to each other, at an angle of about 90°. Once removed, the cores were placed in plastic holders (drinking straws) which were then sealed and labelled with the location, species, tree number, and height of the tree and the date of sampling.

Figure 8 Core sample being taken at 0.5 m height from a Downy Birch in Ranaskógur (Hannak 2018)

For some trees it was not possible to take the core samples at 0.50 meters or at a perpendicular angle to each other, due to branches or irregularities of the stem. In other trees, rot or decay in the stem at 0.50 meters height was suspected. In such cases, core samples were taken at 1.0 meters height.

A total of 15 Rowan trees and 26 Birch trees were sampled. Nine Birch trees were sampled on the lower to middle slope, 15 trees were sampled on the upper slope and hilltop, and two trees to the South of the conifer stand. A sample size of 20 trees is the typical minimum recommended sample size for dendrochronological studies, though Fritts and Speer recommend a sample size of up to 30 trees for studies of tree-ring growth and climate (Schweingruber, Kairiukstis and Shiyatov, 2.1 Sample Selection p. 27, 1992) (Speer p. 176, 2010) (Fritts p. 31, 2001). A smaller number of Rowans was sampled since few mature Rowan trees were found on the upper slope and on the crest of the hill, along the gorge.

The height of each tree was measured with a Haglöf EC-II Electronic Clinometer. At the time of measurement, the light and weather conditions were unfavourable. Due to this, the accuracy of the measured heights is taken to be approximately ±1 meter.

Due to the canopy and the overcast weather at the time of sampling, the coordinates of each individual tree could not be measured. Instead, the coordinates of certain trees and landmarks in the area were measured using the mobile phone applications Google Maps and MAP IS. A simple sketch of the sample area was produced after sampling. Using the sketch and the coordinates, a map was created (Figure 7).

2.3 Preparation and Measurement of the Core Samples

The collected core samples were measured and analysed in the laboratory of the Icelandic Forest Research station in Mógilsá.

The core holders were unsealed, and the cores were left to dry at room temperature, (approximately 20-25 degrees Celsius), for two days. After drying, the cores were glued onto wooden core mounts, with the transverse section, the cross-section of the stem with visible tree-rings, facing upward. The top of the cores was cut off, and soap water and talcum powder were applied to make the tree-rings more visible.

Figure 9 Rinntech LINTAB measuring apparatus and Rowan Core Sample viewed underneath a Microscope (Hannak 2018)

Prior to the measurement, the core samples were viewed under the microscope. The number of tree-rings was counted. Segments with narrow rings, potential false rings, or unclear ring boundaries, were marked with pencil. The core samples were then measured using a Rinntech LINTAB measuring system in conjuncture with the software program TSAPWin (4.67b, RINNTECH). The tree-ring widths were measured at a scale of hundredths (1/100) of a millimetre (mm). The measurement was started at the pith, if it was visible in the sample, or otherwise at the inner most ring. The measurement was stopped at the outer most ring at the bark, or at the last clear ring.

A core-series was produced from each core sample in TSAPWin. A few core samples could not be measured due to cracks or irregularities in the wood. The core series were labelled with the tree species and number.

2.4 Crossdating of Core-Series and Producing Tree-ring Series

The crossdating of the core-series was conducted using the program TSAPWin and the statistical tree-ring crossdating program, COFECHA (Holmes 1983). The crossdating was conducted in two parts: a visual comparison of the series in the form of line graphs with TSAPWin, and a statistical comparison in COFECHA, to verify the accuracy of the visual crossdating (Speer p. 23, 264, 2010).

From either species, the core-series with the clearest rings or the least number of segments with narrow or unclear rings were chosen. These series were visually crossdated in TSAPWin. Pointer years were identified. These are individual rings or series of rings that are significantly wider or narrower than neighbouring rings or all other rings, and which occur in most to all of the sampled trees of a species (F. H. Schweingruber p. 277, 1992). Using pointer years as an aid, the selected core-series were compared. The core-series which best matched each other were selected and averaged, to create a half-master series. All core series of one species were then compared with the half-master. Core-series which greatly differed from the half-master series, due to errors in measurement or missing or false rings, were measured again.

The visual crossdating of the core-series of Birch was conducted with the additional aid of the master chronology, *3BirkMKVal*. The *3BirkMKVal* chronology had been produced by Dr Ólafur Eggertsson from core samples from Birch trees in the Hallormsstaður National Forest (Eggertsson 2014).

After the visual crossdating, the cores-series of either species were input into the statistical program, COFECHA. The program runs a correlation analysis to calculate the intercorrelation of all series and to identify or “flag” series which do not match or have a significantly lower correlation with all other series. Core-series flagged by the program due to apparent missing or false rings were re-measured. Core-series flagged due to low correlation were measured again if necessary.

In TSAPWin, the two core-series of each Birch tree were averaged, to produce a tree-series. Speer recommends working with tree-series rather than core-series since, firstly, this prevents overrepresentation of individual tree-signals and distortion of the stand-level signal of the master chronology, and secondly, tree-series allow a better insight into the growth of individual trees (Speer p. 228, 2010). The tree-series of Birch were again input into COFECHA, to identify any errors or low correlation. The core-series of Rowan were not averaged to produce tree-series, as fewer Rowan trees had been sampled, and a lower risk of distortion was assumed.

2.5 Producing Tree-Ring Width (TRW) and Tree-ring index (TRI) Chronologies

A tree-ring width (TRW) chronology and tree-ring index (TRI) chronology were produced for both Rowan and Birch. The year-to-year growth of a tree is affected by a variety of internal and external limiting-factors. Even on a small area the tree-ring growth of individual trees of a species differ from one another, due to differences in the type and intensity of factors affecting their growth (Fritts p. 15-16, 2001) (Speer p. 29, 2010). By averaging multiple tree-series from an area, to produce a chronology, the noise or signal of factors which affect the individual tree is removed or reduced, while the shared signal of factors that affect all trees on the area becomes clearer (Briffa and Jones p. 137, 1992). The TRW chronology is produced by calculating the yearly mean annual ring-width of trees of a species in a certain area. The TRI chronology presents the mean annual growth in the form of growth indices. The growth indices are calculated values which indicate how much the trees grew in one year in relation to the growth throughout all years of the full period (Speer p. 198, 2010).

The TRW chronology was produced with TSAPWin. A transformation function was applied to set the mean of all tree-series to centre around the value 100, or 1 millimetre. The tree-series, or in the case of Rowan, core-series, were then averaged to calculate the mean annual tree-ring growth, to produce the TRW chronology.

To ensure that the stand-level signal was not too greatly distorted by the growth of individual trees, a minimum of five tree-series was chosen as the significant sample size. Years with less than 5 tree-series were cut from the chronology. The Birch chronology was cropped to 1900 to 2003 and the Rowan chronology was cropped to 1907 to 2017. The tree-series of Birch and core-series of Rowan were also cropped to 1900 to 2003 and 1907 to 2017, respectively.

The cropped tree-series were input into COFECHA to conduct standardization and to produce the TRI chronologies. H.C. Fritts and Speer recommend using standardized series or chronologies when comparing growth and climate (Fritts p. 219, 2001) (Speer p. 20-21, 2010). In the unstandardized TRW chronology, there is a risk that the stand-level signal is distorted by the age-trend of individual trees (Speer p. 11, 2010). Through standardization the age-trend of individual trees and autocorrelation are removed from the tree-series, to produce a cleaner chronology with a clear stand-level signal (Speer p. 23, 34-36, 2010).

Standardization was conducted using the default settings of COFECHA. The autocorrelation of each series was removed and a 32-year cubic smoothing spline applied to generate an age-growth curve from the series (Speer p. 189-190, 209, 2010). Using the growth curve, the program automatically removes the age trend and calculates the growth indices. The program then produces a master dating series, the TRI chronology, by taking the average of the growth indices of all tree series (Speer p. 190, 2010). In the TRI chronology, years with narrower rings or low growth are given as negative values, while years with wider rings are given as positive values. The value of the indices describes the magnitude of the variation of the ring-width for a certain year from the expected mean ring width of the series, which is given as 0.0 (Grissino-Mayer p. 211-212, 2001). Basic statistics of the chronology, including the series intercorrelation and average mean sensitivity, were calculated by COFECHA. The mean sensitivity indicates the degree of variability or variation in the width of tree-rings, showing how responsive or sensitive to external factors the growth of the ring-width is (Speer p. 173, 2010).

The analysis of the produced chronologies was conducted in Microsoft Office Excel and with R, a statistical computing and graphing software (R Core Team), as explained in the following section.

2.6 Data Analysis

2.6.1 Determining Tree Age

The tree age was determined based on the dated tree series produced in TSAPWin. Through crossdating the year of the inner most tree-ring and thereby the minimum tree age was determined. It was assumed that at least two years are needed to reach a height of 50 centimeters. This was added to the tree age. Then the number of rings between the first ring measured and the pith of the tree was estimating. In only a few core-samples, the pith had been reached with the borer. For core samples were the pith is not visible, the number of rings between the inner most ring and the pith was estimated using the radius and curvature of the inner most ring. The number of rings to the pith were added to determine the approximate tree age. This method is not precise and certain deviation from the real age is to be expected. These are estimations, and not the true age of the trees.

2.6.2 Pointer Years and Outliers

Identifying Pointer Years with pointRes

Pointer years, years with significantly wider or narrower tree-rings occurring in multiple to all trees in an area, were identified using the R package pointRes (F. Schweingruber, Dendroecological Information in Pointer Years and Abrupt Growth Changes p. 277, 280, 1992) (van der Maaten-Theunissen, van der Maaten und Bouriaud 2015). The analysis with pointRes was conducted to verify whether the rings used as pointers during the visual crossdating qualify as pointer years. That is to say, if the ring-widths of the identified pointer years are statistically significantly different to those in other years. The TRW tree- and core-series of Birch and Rowan were input into R. The function *relative growth change* (*pointer.rgc*), of the R package pointRes, was applied to identify pointer years. The function compares years within a tree-series and between tree-series. Through this the program identifies rings that occur in all trees, in which the ring-width is significantly different to the ring-width of preceding years and/or all other years. As an output the program plots the mean growth deviation of the ring-width in all trees for each year.

Identifying outliers of the TRI Chronologies

The outliers of the TRI chronologies of Birch and Rowan were determined in Microsoft Office Excel. The upper and lower quartile and interquartile range (IQR) of the index values were calculated. From these the upper and lower bounds of the data set were determined. The logical function was then applied to see whether the index value of each year fell within the lower and upper bounds or if they qualified as outliers.

2.6.3 Comparison of Birch and Rowan Chronologies

The TRW and TRI chronologies of Birch and Rowan were compared graphically and statistically in Office Excel. the TRW chronologies and the TRI chronologies were plotted as line graphs and compared visually. Further, a simple linear regression analysis of the index values of the Birch and Rowan chronology was conducted to determine the correlation coefficient (r^2). The Pearson correlation coefficient was calculated for the correlation between the tree ring-widths as well as the tree-ring indices of the two tree species, for the period 1907 to 2003. Further, the correlation coefficient was determined in 40-, 30-, and 20-year windows in order to identify periods in which the correlation between the growth of Rowan and Birch was significantly higher or lower. An independent or unpaired two-sample t-test was conducted, with 95% significance level, to determine if the calculated correlations were significant.

2.6.4 Correlation Analysis of Tree Growth and Climate

Source of Climate Data

The climate data used in this study was taken from the "Annual Forestry Report for East Iceland" and from recordings from weather stations of the Icelandic Meteorological Office (IMO, Veðurstofa Ìslands). Temperature and precipitation data given in the forestry reports was recorded by a measuring station of the forestry department in Hallormsstaðaskógur, (Hallormsstaður National Forest). Temperature and precipitation as well as other climate variables were measured by the nearby IMO weather stations, Egilsstaðir and Hallormsstaður. The location of the IMO weather stations and the forestry station and their distance from Ranaskógur is given in Appendix D to Appendix I.

Temperature data from Hallormsstaðaskógur was primarily used in the study. The forestry station is located closer to Ranaskógur and covers a longer time period than the nearby IMO stations. Data is available for Hallormsstaðaskógur from 1942 onwards. Further, given that Hallormsstaðaskógur is closer to Ranaskógur, it can be assumed that the temperature there is most similar to and most representative of the temperature in Ranaskógur. Missing data in the temperature series of Hallormsstaðaskógur was replaced with data from the IMO stations Hallormsstaður and Egilsstaðir. The temperature data of the three stations is very similar; a strong correlation exists between the mean annual temperature (>0.98 correlation coefficient) as well as the mean summer temperature (>0.97 correlation coefficient) recorded by the stations (See Figure 10, Figure 11).

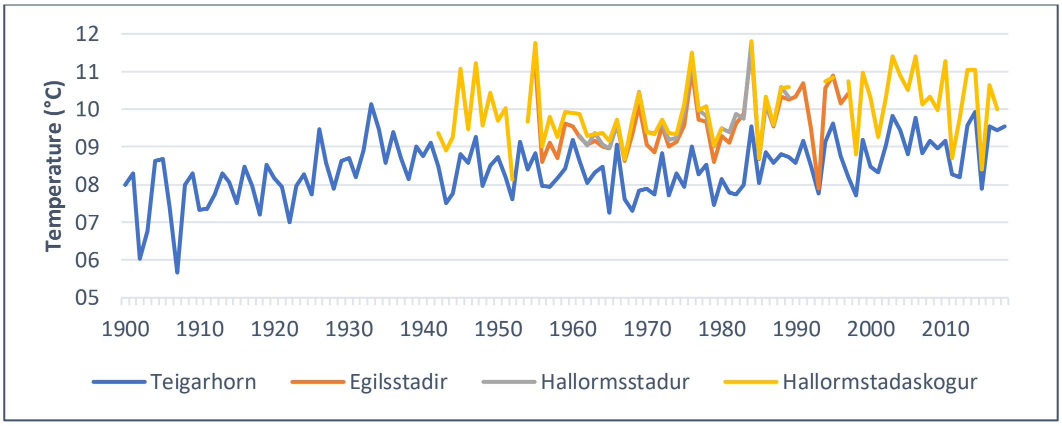


Figure 10 Line Graph comparing the Mean Summer Temperature (June-August) Data of the Forestry Station Hallormsstaðaskógur and the Icelandic Meteorological stations Hallormsstaður, Egilsstaðir and Teigarhorn, 1900-2018

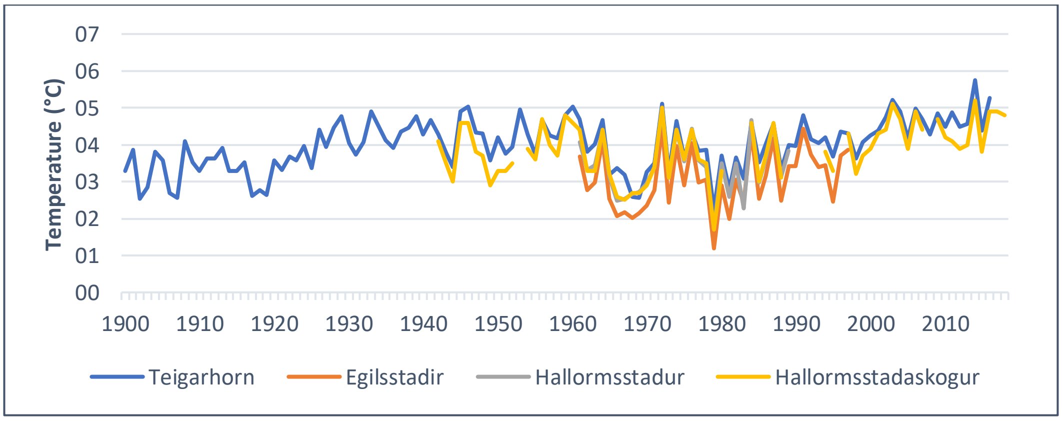


Figure 11 Line Graph comparing the Mean Annual Temperature Data of the Forestry Station Hallormsstaðaskógur and the Icelandic Meteorological stations Hallormsstaður, Egilsstaðir and Teigarhorn, 1900-2018

Tree-ring growth was also compared with temperature and precipitation data from the IMO station Teigarhorn. The station has one of the longest, continuous temperature series in Iceland, from 1873 onwards. Despite being longer, the Teigarhorn series was not used as the primary temperature series. The reason for this is that, the station is located furthest from Ranaskógur, and is located in a fjord by the sea while Ranaskógur is inland. Furthermore, while the correlation between the annual mean temperature of Teigarhorn and the other three data stations is very high (correlation coefficient >0.94), the correlation between summer mean temperature (June-August) of Teigarhorn and the other three stations is lower (0.62 to 0.76) (See Figure 10, Figure 11). As shown, the summer temperature at Teigarhorn is 0.5 to 2°C cooler. Therefore, it can be assumed that the temperature data from Teigarhorn is less representative of the climate at Ranaskógur.

Precipitation data was taken from the IMO weather station Hallormsstaður for 1950-1989. The precipitation series of Hallormsstaður was used, as it is longer than that of the IMO stations Egilsstaðir and Teigarhorn, and further, was more accessible than the precipitation data from the forestry reports.

Comparing Tree-Ring Growth and Climate Variables

Comparison of tree-ring growth and climate was conducted using the climate variables, mean monthly temperature and total monthly precipitation. These are the standard climate variables used in dendrochronological studies (Zang, Introduction to treeclim 2016).

The index series of Rowan and Birch were input into R, a statistical computing and graphing software (R Core Team). With the R package, treeclim, a calculation of the relationship between tree growth and the climate variables mean monthly temperature and total monthly precipitation was conducted. Treeclim is an R package created for dendroclimatology and dendroecology research, to study and analyse the relationship between climate variables and tree-rings (Zang, Introduction to treeclim 2016). With treeclim a response function analysis of the tree-ring indices and mean monthly temperature, and total monthly precipitation was conducted for both tree species. The response function analysis, formulated by H.C. Fritts, is a multiple regression analysis of a set climate variable and the tree-ring growth (Fritts p. 240-241, 2001) (Briffa und Cook p. 240-245, 1992) (Speer p. 177, 2010). The response function analysis compares the relationship between growth and temperature of one month of one year to the growth and temperature of previous years, to identify how strong of a relationship or response there is in the tree-ring growth to the climate of each month. Through this, the "effective climate window", the months with the greatest effect or relationship to tree-ring growth, is determined (Speer p. 177, 2010).

The response function analysis of temperature and tree indices was run with temperature data from Hallormsstaðaskógur, from the forestry reports, for the period 1907-2003. The period 1907-2003 is the period of overlap of the chronologies of Rowan and Birch. This period was used to allow for a better comparison of the climate response between the species. The precipitation analysis was run with precipitation data from the weather station Hallormsstaður for the period 1950-1989. Boxplots were generated from the results, showing the mean response coefficients and the range of response coefficients for the relationship between the tree indices and the temperature and precipitation of each month. Further, using the treeclim function “dcc”, a correlation analysis with moving windows was conducted for the variables. This run calculates the correlation between the tree indices and the temperature or precipitation data of each month for consecutive intervals or windows (Zang und Biondi, treeclim: an R package for the numerical calibration of proxy-climate relationships 2015). The correlation analysis with moving windows was conducted for both species with climate data from Hallormsstaðaskógur for 1907 to 2003.

The response function and moving windows correlation analysis was also conducted with temperature data from the weather station Teigarhorn, for the period 1900-2003 for Birch, and 1907-2016 for Rowan. The results of this are given in Appendix D to Appendix I. The correlation between precipitation at Teigarhorn and tree growth was not calculated as precipitation data from Teigarhorn is only available for 1950 to 1979.

In Excel, tree growth was compared with mean summer temperature, as done in the study “Growth of Birch in Hallormsstaður 1950-2011 and the relation to Climate and Larvae Outbreaks” (Eggertsson 2014). The mean summer temperature was calculated with the months June, July and August. The Pearson correlation coefficient of the correlation between tree-ring growth and mean monthly temperature of each month was calculated for the full period, 1907-2003. The Pearson coefficient was then calculated for the months June, July and August and the mean summer temperature (June-August) in 20-year intervals (1947-1967, 1967-1987, and 1987-2003). An unpaired two-sample t-test was conducted, with 95% significance level, to determine whether the calculated correlations were significant. The mean summer temperature and TRI chronology of Birch and Rowan were then plotted in a line graph, for 1900-2003 and 1907-2017 respectively.

3. Results

3.1 Height and Age

The method used to determine tree age is relatively basic. Therefore, the ages calculated may not be accurate. A certain deviation from the real age must be assumed. The tree heights are given at a degree of accuracy of ± 1 meter.

In Figure 12 the age of 18 of the 26 sampled Downy Birch and the height of all trees is given. The ages of the Birch trees range from 88 to 126 years, and the mean age is 113 years. The maximum height, as of September 2018, was found to be 12 m and the minimum height 5 m. The mean height is 9 m.

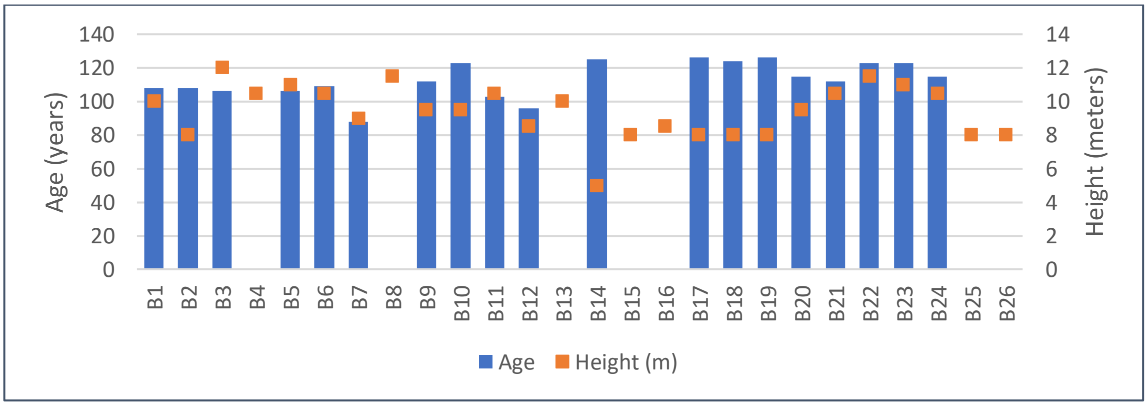


Figure 12 Height (meters) and age of the sampled Downy Birch trees, Ranaskógur.

In Figure 13 the age and height of each Rowan tree is given. The sampled Rowan trees are aged 83 to 141 years, and the mean age is 109 years. The mean height of the sampled Rowan trees was 10 m, with the heights ranging from 7 to 13 m. Aside from Rowan regeneration (≤ 1 m), no Rowan trees shorter than 7 m were found in the sample area.

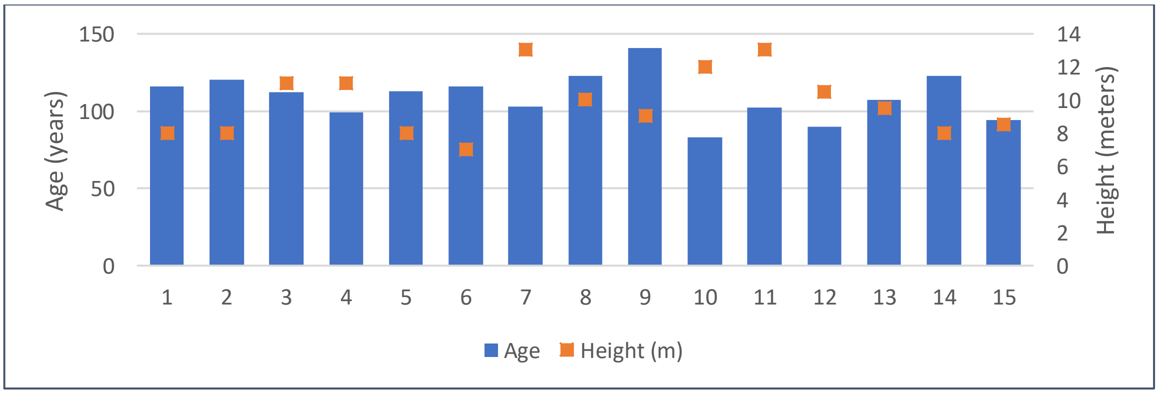


Figure 13 Height (meters) and age of the sampled Rowan trees, Ranaskógur

A simple linear regression analysis (xy) was conducted for tree age and height. No significant correlation between age and height was determined for either Birch (R^2 = 0.06) or Rowan (R^2 = -0.27).

3.2 TRW Chronologies of Rowan and Downy Birch

The Tree-ring width (TRW) series of all individual trees and the TRW chronology of Birch and Rowan are displayed in the line graphs in Figure 14 and Figure 15 respectively. The TRW chronologies represent the stand-level signal of the respective tree species. A basic overview and descriptive statistics of the TRW chronologies of Birch and Rowan are given in Table 1 and Table 2 respectively.

18 of the 26 core samples of Birch were dated. The earliest tree-series starts in 1894, though given that the tree-ring width measurement was not started at the pith, the tree may date back to before 1890. The TRW chronology covers a period of 104 years, from 1900 to 2003. Only three of the trees date back to before 1900. Though all Birch trees were alive at the time of sampling, few tree-series extend up to 2018. The reason for this is that there were difficulties in measuring the later tree-ring width due to unclear ring boundaries or otherwise cracks in the cores.

The chronology of Birch is represented by the bold, black line in Figure 14. The series intercorrelation of all tree-series, as determined with COFECHA, is 0.74. The average mean sensitivity is 0.44, indicating a greater sensitivity of annual growth to external environmental factors. The average of the autocorrelation of each tree-series is 0.45.

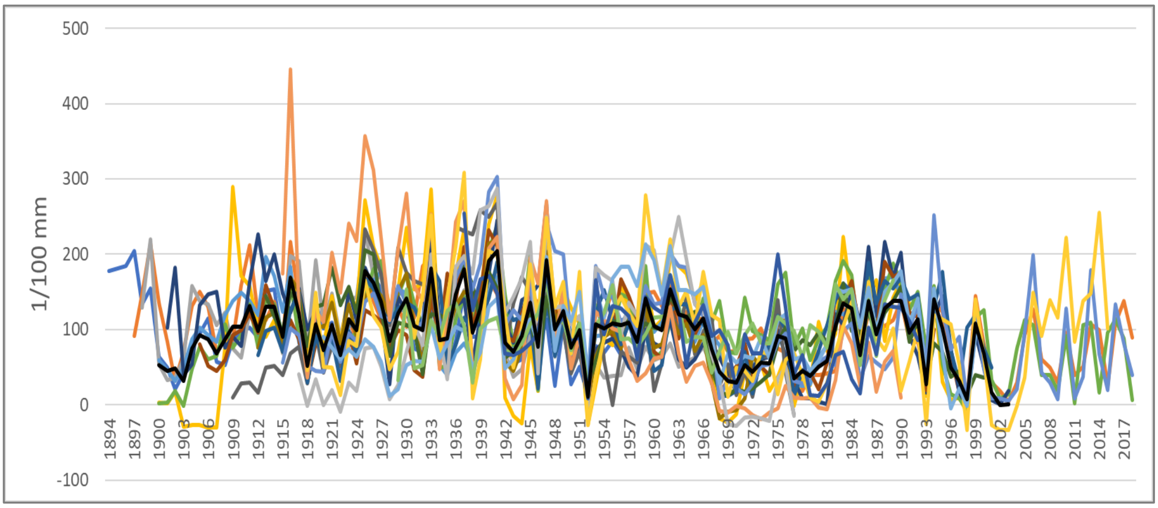


Figure 14 Line Graph showing the Tree-ring width (TRW) series of individual trees and the Master TRW Chronology, (represented by the bold black line), of Icelandic Downy Birch in Ranaskógur. The ring-width is given in 1/100th of a millimetre (mm).

Table 1 Basic Summary and Descriptive Statistics of Master Chronology of Downy Birch, Ranaskógur

Length of Master Index Chronology	104 years (1900-2003)
Number of dated Tree Series	18
Series Intercorrelation	0.743
Average Mean Sensitivity	0.442
Mean Autocorrelation	0.454
Mean Ring-width (1900-2003)	0.95 mm
Longest continuous Tree Series	122 years (1897-2018)

The Rowan chronology consists of 27 core-series. Two core-series were included for 11 trees. For four trees only one core-series per tree was included. The chronology covers 111 years, from 1907 to 2017. The oldest tree-series begins in 1880. The series intercorrelation is 0.75 and the average mean sensitivity is 0.32, lower than that of the Birch chronology. The average autocorrelation is 0.68, indicating that the annual ring-width growth is strongly influenced by the growth of the previous year.

Noteworthy, is the trend visible in Figure 15. The annual ring-widths of all trees increase from 1928 to 1949, followed by a gradual decrease until the 1980s. Following 1980, the ring-widths trend levels out. The trend is visible in the TRW Rowan chronology, the black line. It appears as if from 1920 onwards the chronology follows a standard age curve: first rapid growth (juvenile stage) then gradual decline (adult stage) (F. Schweingruber p. 24-25, 1996). This may be due to the similar age of the sampled trees.

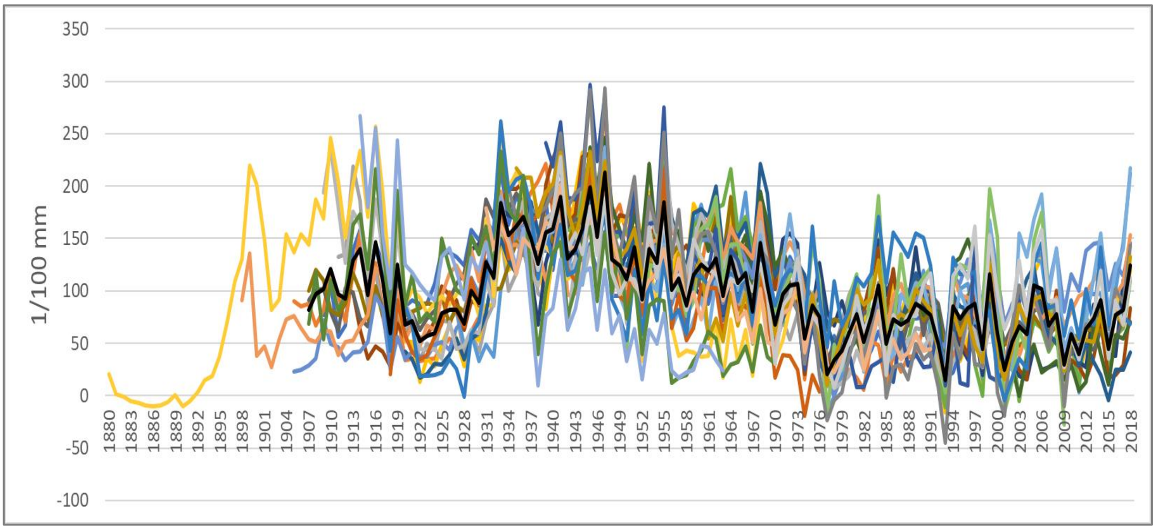


Figure 15 Line Graph showing the Tree-ring width (TRW) series of individual trees and the Master TRW Chronology, (represented by the bold black line), of Rowan in Ranaskógur. The ring-width is given in 1/100th of a millimetre (mm).

Table 2 Basic Summary and Descriptive Statistics of Master Chronology of Rowan, Ranaskógur

Length of Master Index Chronology	112 years (1907-2018)
Number of dated Core Series	27
Series Intercorrelation	0.749
Average Mean Sensitivity	0.321
Average Autocorrelation	0.679
Mean Ring width (1907-2018)	0.98 mm
Longest continuous tree series	121 years (1898-2018)

A strong series intercorrelation was determined with COFECHA for both tree species. The chronologies therefore give a reliable stand signal, despite including less than the recommended minimum sample size of 20 trees (Speer p. 4, 2010).

3.3 Pointer Years and Outliers

3.3.1 Pointer Years

During visual crossdating pointer years in the tree-series of Birch or Rowan were identified. To test for statistical significance of these pointer years and to identify further years with particularly high or low growth or with abrupt growth changes, the TRW series were analysed with the R package pointRes. In the bar graph in Figure 16 below, the pointer years of the Birch TRW tree-series are shown as dark grey columns. Pointer years, in the period 1900 to 2003, with significantly narrower years are 1901-1903, 1952, 1993, 1998 and 2002-2003. The mean percentage growth deviation of these years was greatest for 1952 and 1998. In 1983, the tree-rings were significantly wider.

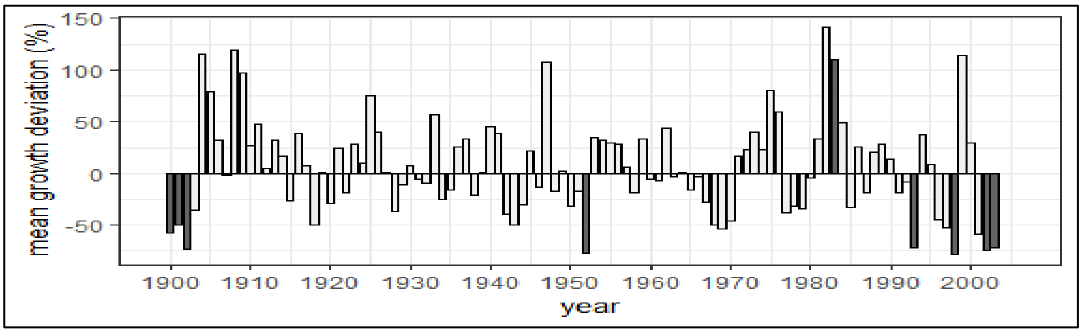


Figure 16 Bar Graph of Pointer years as identified in terms of Relative or Abrupt Growth Changes, and the respective mean growth deviation (%), in the TRW Series of Downy Birch in Ranaskógur, for the period 1900-2003.

The pointer years and abrupt growth changes in Rowan, in the period 1907 to 2017, as identified by pointRes from the TRW series, are given in Figure 17. The program determined that the tree-ring width was significantly narrower in the years 1977, 1993 and 2001. The greatest mean growth deviation was in 1977 and 1993, with a more than 50% decrease.

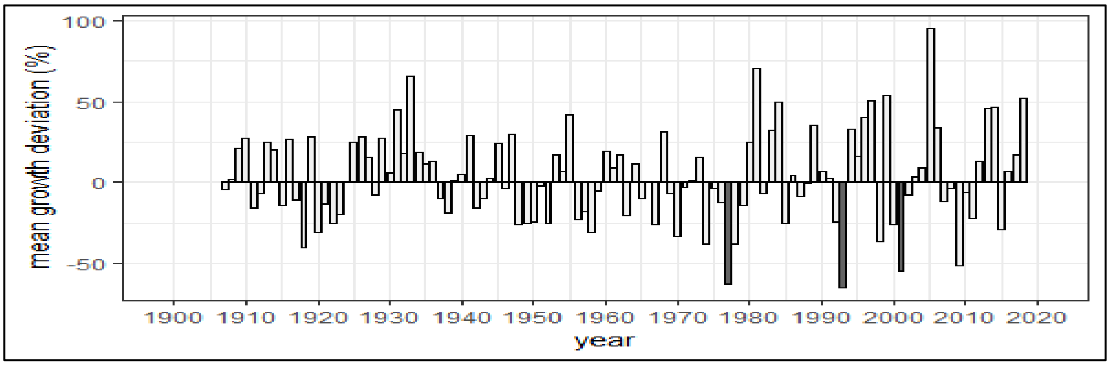


Figure 17 Bar Graph of Pointer years as identified in terms of Relative or Abrupt Growth Changes, and the respective mean growth deviation (%), in the TRW Series of Rowan in Ranaskógur, for the period 1907-2017.

3.3.2 Outliers

The Tree-ring index (TRI) chronology of Birch and Rowan were produced with COFECHA. The tree-ring index or growth index is a measure of the annual growth, relative to the mean annual growth for the full series. The Birch chronology starts 1900 and ends 2003. The Rowan chronology covers the period 1907 to 2017. Outliers in the TRI chronology of either tree species were determined. The outlier in the Birch chronology is 1952, in which the annual growth was significantly lower. Outliers in the Rowan chronology are 1977 and 1993; the growth in these years was significantly lower. The two tree species do not share any pointer years or outliers other than 1993.

3.4 Comparing the TRW and TRI Chronologies of Rowan and Downy Birch

The TRW chronologies of Rowan and Downy Birch were compared graphically for the periods 1880 to 2017 and 1894 to 2017 (Figure 18). A significant correlation was found between the yearly ring-widths for 1907 to 2003 (Pearson coefficient = 0.55). Looking at the line graphs of the two TRW chronologies (Figure 18), an overlap of the ring-widths of either species as well as a slight overlap in the long-term trend of the TRW can be seen. The tree-ring width peaks between 1930-1950, then showing a decrease in average ring-width after 1950, before the ring-widths level out again from 1980 onwards. The TRW chronologies show a relatively strong overlap in 1898 to 1907, despite the sample size of Rowan being less than five trees before 1907 and the sample size of Birch being less than five trees prior to 1900. Noteworthy years, in which there is a weaker or no visual correlation, are 1923-1928 and 1942-1943, 1952, 1967-1973, and 2002-2003. In all of these periods, with the exception of 1923-1928, the tree-ring width of Birch appears markedly narrower than that of Rowan.

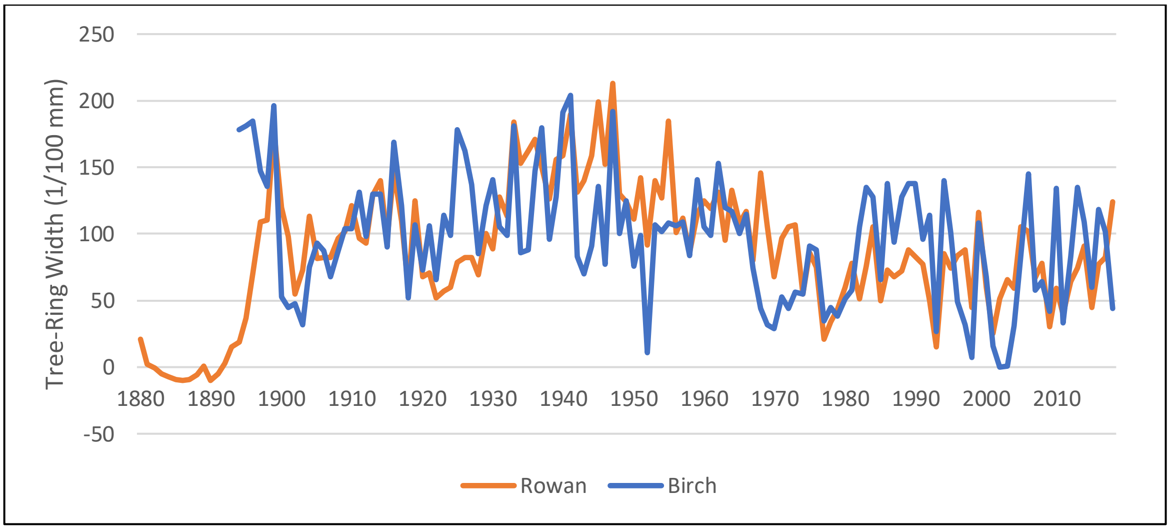


Figure 18 Tree-ring Width (TRW) chronologies of Downy Birch and Rowan in Ranaskógur for 1880 to 2017.

The TRI chronologies of Rowan and Downy Birch are compared graphically in the line graph in Figure 19. The line graph extends from 1880 to 2017, though the timeframe for which the two chronologies are compared is 1907 to 2003. In this period the chronologies of both Rowan and Birch were represented by the minimum significant sample size, five trees or more.

The tree-ring indices of both tree species show similarity. When comparing the chronologies graphically, a greater overlap or correlation can be seen in the periods 1907 to 1951 and 1983 to 2003. In 1952-1983, the growth indices of the two chronologies differ most, particularly from 1968 to 1971 and 1977-1979. Birch had noticeably lower growth than Rowan in 1952 and 1968 while Rowan had significantly lower growth in 1977. Further noteworthy is the difference in 1925 to 1927.

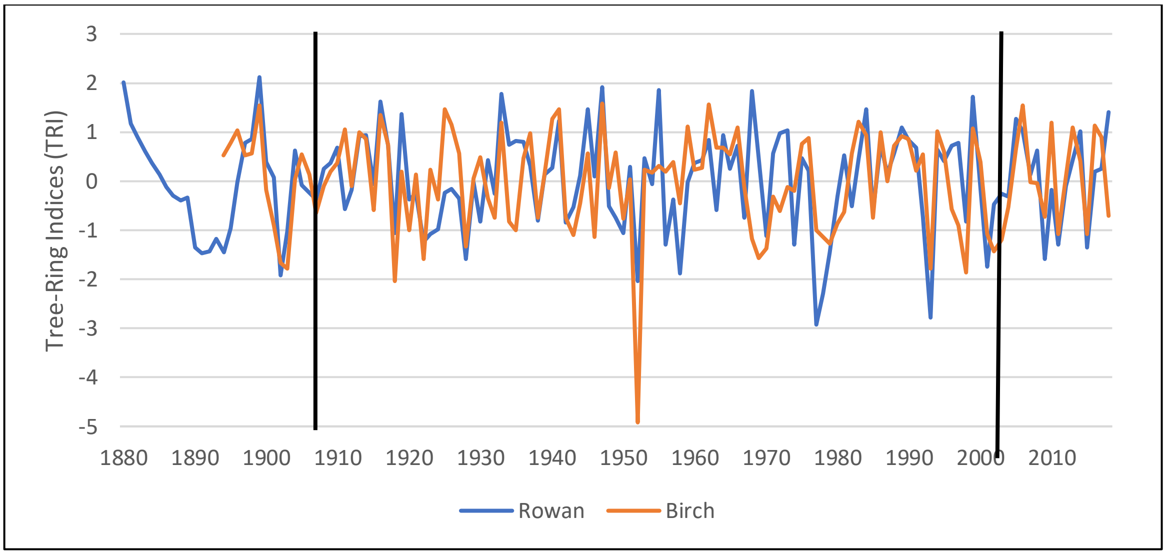


Figure 19 Tree-ring Index (TRI) chronologies of Downy Birch and Rowan in Ranaskógur for the period 1880 to 2017. The time frame in which both chronologies are represented by the minimum significant number of trees (≥5), 1907 to 2003, is indicated by the two black bars.

In Table 3 the Pearson correlation coefficient (R) of the correlation of the Rowan and Birch chronology are given. The correlation coefficient of the two series was calculated for the full period 1907-2003, as well as for 20-year intervals. A significant, positive correlation, with coefficient 0.55, exists between the tree-ring indices of Rowan and Birch from 1907 to 2003. A similar correlation, with correlation coefficient 0.56, exists between the indices for the period 1894 to 2017. For the 20-year intervals, the correlation between Rowan and Birch, as indicated by the correlation coefficient, was greatest in 1947-1967 and 1987-2003. The correlation was lowest in 1967-1987. The correlation for 1907 to 2003, without 1967 to 1987, has a correlation coefficient of 0.59.

A t-test had been conducted to test for the significance of the correlation for each 20-year interval. The correlation of each interval was is significant. Nevertheless, the values should be considered with caution, particularly the correlation coefficient for 1987 to 2003, given that it only considers the indices for 16 years. A high correlation is not necessarily an indicator of a strong relationship (Serre-Bachet and Tessier p. 249, 1992).

Table 3 Pearson Correlation Coefficient of the relationship of the TRI Chronologies of Rowan and Downy Birch in Ranaskógur for the entire time and in 20-year intervals. In the two columns on the far right the number of Birch tree-series and the number of Rowan trees part of the chronology in the respective time period is given.

Period	Correlation Coefficient	Number of Birch Trees	Number of Rowan Trees
1907-2003	**0.55**	**5-19**	**5-15**
1907-1927	0.57	6-17	5-12
1927-1947	0.61	17-19	12-15
1947-1967	0.64	18-19	15
1967-1987	0.39	14-18	14-15
1987-2003	0.70	5-14	11-14
1894-2017	**0.56**	**1-19**	**1-15**

3.5 Comparing Tree Growth and Climate

3.5.1 Mean Monthly Temperature

The response of the growth of Birch to the mean monthly temperature, is given in the box plot in Figure 20. The box plot displays the mean response coefficient as well as the minimum and maximum response coefficient for each month. The growth of Downy Birch in Ranaskógur shows a significant positive response to the mean monthly temperature in June (coefficient= 0.32), in Hallormsstaðaskógur, for the period 1942 to 2003. No significant response to temperature was determined for any of the other months.

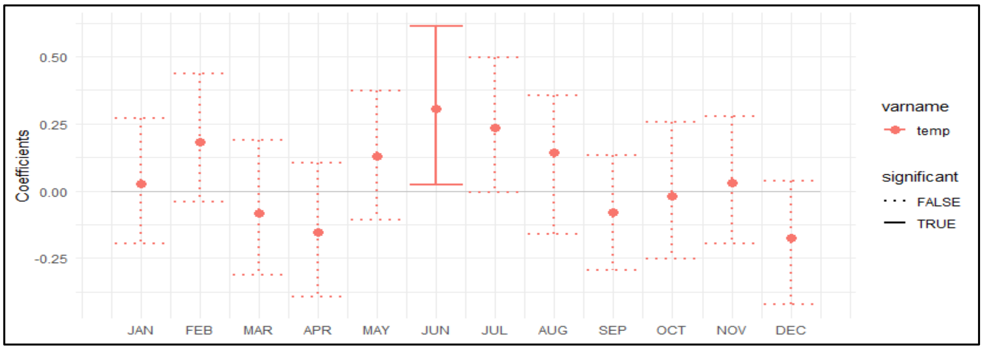


Figure 20 Boxplot of the Response Coefficient of the Relationship between the Tree-Ring Index (TRI) of Downy Birch in Ranaskógur and the Mean Monthly Temperature (°C) of Hallormsstaðaskógur, 1942-2003. A significant correlation (p < 0.05) is denoted by a solid line.

The growth of Birch does not have a continuous, significant correlation with the mean monthly temperature of any the months (Figure 21). The Figure below shows the plot of the development of the correlation between the growth of Birch and monthly temperature over time, as calculated through a correlation analysis with 30-year moving windows. A significant, positive correlation exists between the tree-ring indices and the temperature of February, June, and July. The correlation with temperature of July is significant for the windows 1961-1990 to 1974-2003 (coefficient ≈0.3-0.5). For February the correlation is significant for 1953-1982 to 1959-1988 (coefficient ≈0.4-0.5). For June, the correlation is significant for 1971-2000 to 1974-2003 (coefficient ≈0.4-0.5). In the early part of the series, little to no correlation exists between the indices and temperature, other than a low negative correlation with December temperature.

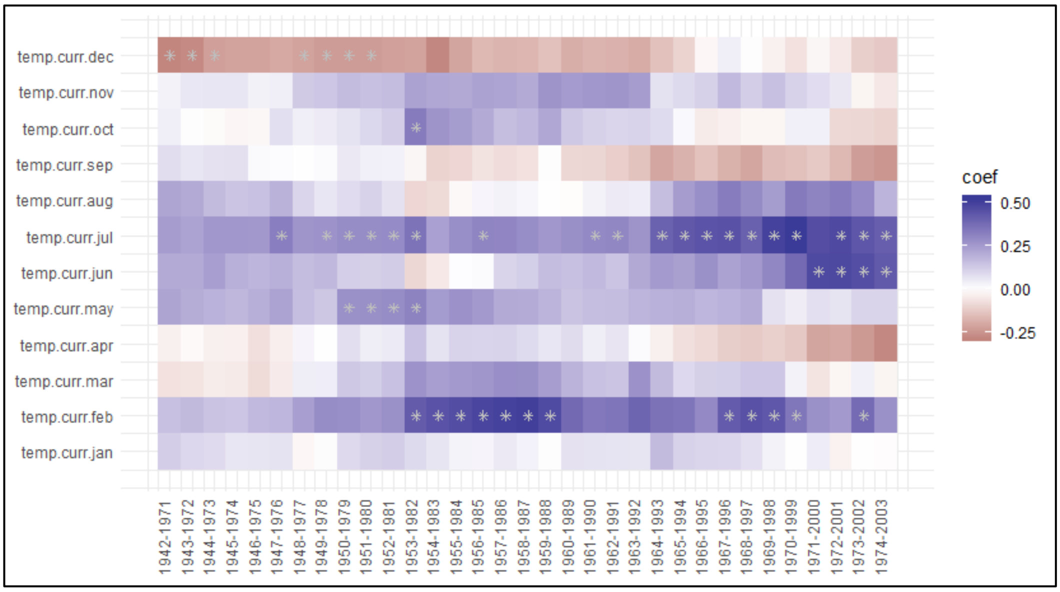


Figure 21 Graph of Correlation analysis with moving time windows (30-year windows) of the correlation between the Tree-Ring Index (TRI) of Downy Birch in Ranaskógur and the Mean Monthly Temperature (°C) at Hallormsstaðaskógur, 1942-2003. An asterisk (*) denotes a significant correlation ($p < 0.05$).

As determined through the response function analysis of the tree-ring indices of Rowan and the mean monthly temperature, the growth of Rowan had a significant positive response to the temperature of Hallormsstaðaskógur in July and August, in 1942 to 2003 (Figure 21). The greatest response was for July (coefficient = 0.40), followed by August (= 0.29).

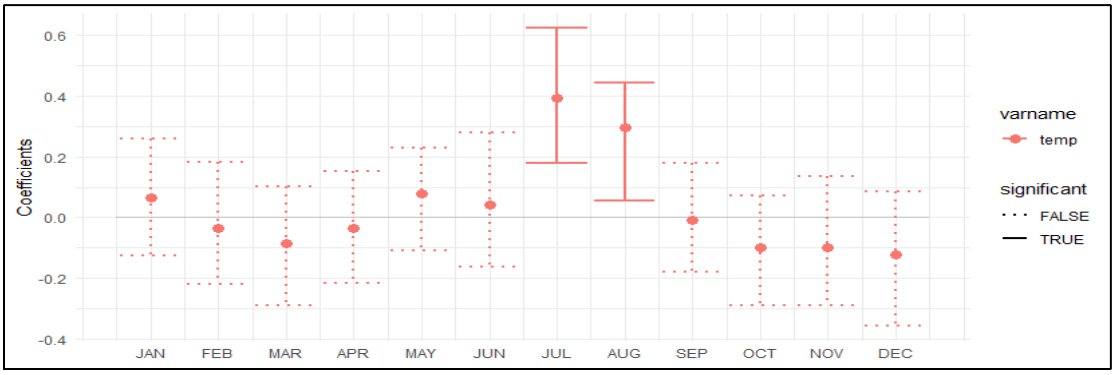


Figure 22 Boxplot of the Response Coefficient of the Relationship between the Tree-Ring Index (TRI) of Rowan in Ranaskógur and the Mean Monthly Temperature (°C) of Hallormsstaðaskógur, 1942-2003. A significant correlation ($p < 0.05$) is denoted by a solid line.

The plot of the moving windows correlation analysis (Figure 23), demonstrates that the indices of Rowan have a significant positive correlation with the temperature of July. The correlation is significant for all windows of July, for the full period 1942 to 2003 (coefficient ≈0.4-0.65). A significant positive correlation also exists between the tree-ring indices and mean temperature of August. However, the correlation between growth and temperature of August is not significant throughout the entire period. The correlation is lower and not significant for the period between the windows 1949-1978 to 1964-1993. In the windows preceding and following this period, the correlation is significant (coefficient ≈0.4-0.6).

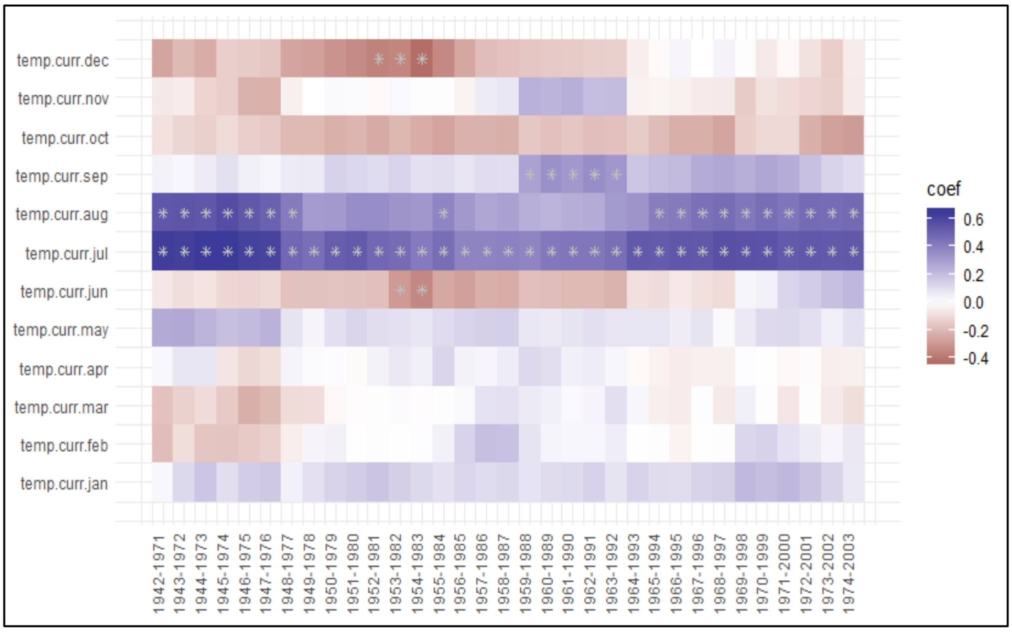
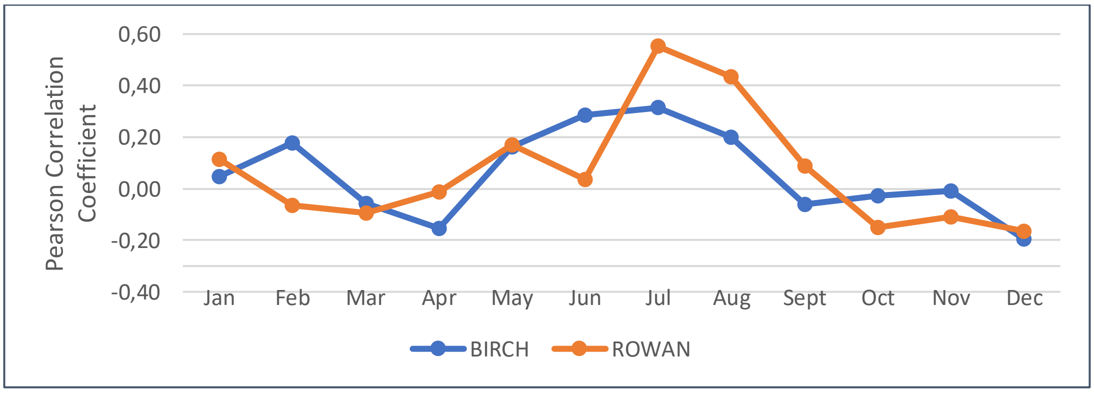


Figure 23 Graph of Correlation analysis with moving time windows (30-year windows) of the correlation between the Tree-Ring Index (TRI) of Rowan in Ranaskógur and the Mean Monthly Temperature (°C) at Hallormsstaðaskógur, 1942-2003. An asterisk (*) denotes a significant correlation ($p < 0.05$).

The Pearson correlation coefficient of the relationship between the tree-ring indices of either tree species and mean monthly temperature is given in the form of a table and graph in Figure 24. A significant positive correlation, (as determined through the correlation coefficient), exists between the tree-ring indices of Birch and the mean temperature of June (coefficient= 0.29) and July (=0.31). For Rowan, a significant positive correlation exists for July (= 0.55) and August (= 0.44). The correlation between growth and temperature is highest in July, for both tree species. Further, the trend of the correlation coefficient for each month, as shown in the graph in Figure 24, is similar for Rowan and Birch for all months other than February and June. For June the correlation coefficient for Rowan is noticeably lower than Birch and does not follow the trend curve.

Figure 24 Line Graph and Table of the Pearson Correlation Coefficient of the relationship between the Tree-Ring indices of Rowan and Downy Birch in Ranaskógur and the mean monthly Temperature (°C). Bold values in the table indicate significant correlation, as determined by the t-test.



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Birch	0.05	0.18	-0.06	-0.15	0.16	**0.29**	**0.31**	0.20	-0.06	-0.03	-0.01	-0.19
Rowan	0.12	-0.06	-0.09	-0.01	0.17	0.04	**0.55**	**0.44**	0.09	-0.15	-0.11	-0.16

Comparison of Summer Temperature and Tree-Ring Indices

The mean summer temperature at Hallormsstaðaskógur, as calculated from temperature data from 1942 to 2003, is 9.9 °C. The correlations between mean monthly temperature of June, July, August and the mean summer temperature at Hallormsstaðaskógur and the tree-ring indices of both Birch and Rowan is given in Table 4. The mean summer temperature and TRI chronologies are further visually compared in Figure 25 and Figure 26.

The tree-ring indices of Rowan have a significant correlation with the mean monthly temperature of July in 1947-1967 and 1987-2003, and with the temperature of

August in 1947-1967 (Table 4). Birch has a significant correlation with the temperature of June in 1987-2003 (Table 4). Rowan has a greater correlation than Downy Birch with the temperature of July and August in 1947-1967, 1967-1987 and 1987-2003. Of the summer months, Rowan correlates best with July and least with June while Birch correlates best with June and least with August. Both Birch and Rowan have a significant correlation with the mean summer temperature in 1947-1967 and 1987-2003. The correlation between the tree-ring indices of both species and summer temperature is not significant in 1967-1987.

Table 4 Pearson Correlation Coefficient of Relationship between Tree-Ring Indices of Rowan and Downy Birch in Ranaskógur and mean monthly temperature (°C) of June, July and August and Mean Summer Temperature (Jun-Aug). Values in italics are correlation coefficients that are not significant, as determined by t-test.

Month:	June		July		August		Summer Mean	
Period	**Downy Birch**	**Rowan**	**Downy Birch**	**Rowan**	**Downy Birch**	**Rowan**	**Downy Birch**	**Rowan**
1947-1967	*0.32*	*0.08*	*0.26*	0.56	*0.21*	0.55	0.43	0.55
1967-1987	*0.16*	*-0.27*	*-0.11*	*0.39*	*-0.07*	*0.35*	*-0.02*	*0.28*
1987-2003	0.49	*0.36*	*0.44*	0.73	*0.02*	*0.45*	0.52	0.79

The line graphs of the means summer temperature and TRI of Birch correlate poorly in 1953-1974 (Figure 25). The growth of Birch does not appear to respond to the warm summer in 1955 nor 1969. Further, the growth in 1962-1966 is higher than the temperature. In 1952 the summer was colder and the index of Birch index in this year is the lowest of the entire chronology.

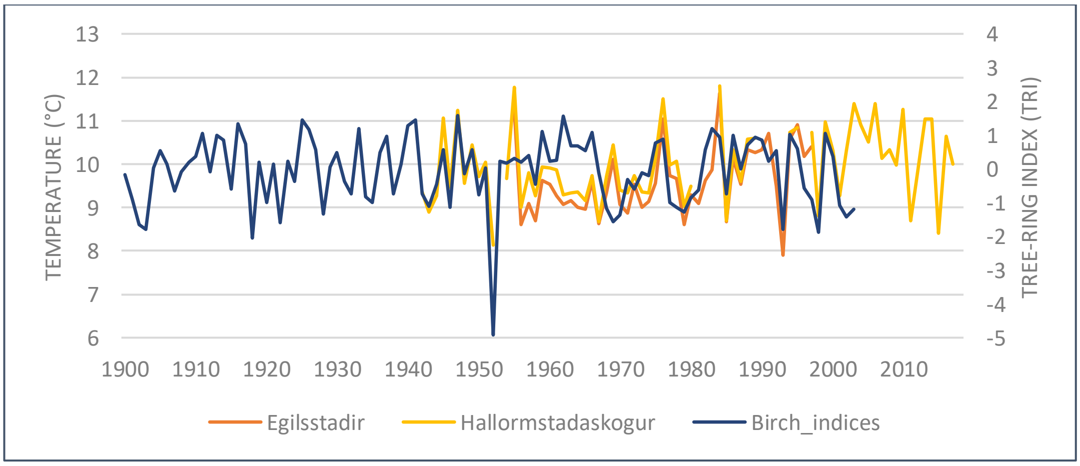


Figure 25 Line Graph of Tree-ring Index (TRI) Chronology of Downy Birch and the Mean Summer Temperature (June-August) at Hallormsstaðaskógur 1942-2003

The TRI chronology of Rowan and summer temperature were compared visually, (Figure 26). The plotted lines match most in 1942-1959 and match relatively well in 1982-2017. In 1959-1981 the overall overlap between low growth and low temperature and high growth and high temperature is lower. Years which are particularly noticeable as showing little to no correlation are 1972, 1976-1977, and 2003. Of these years, 1977 is most prominent.

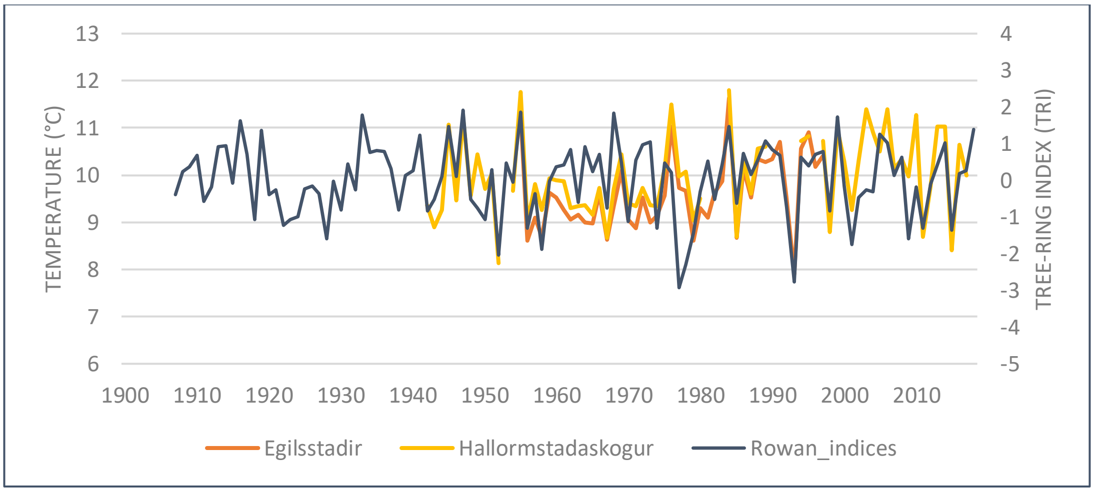


Figure 26 Line Graph of Tree-ring Index (TRI) Chronology of Rowan and the Mean Summer Temperature (June-August) at Hallormsstaðaskógur 1942-2017

The results of the response function analysis and correlation analysis with moving windows of tree growth of Rowan and Birch and the monthly temperature and mean summer temperature of the weather station Teigarhorn are given in Appendix D to Appendix I. Precipitation at Teigarhorn and tree growth were not compared as data was missing and continuous data was only available for 1950-1979.

3.5.2 Total Monthly Precipitation

A significant response was determined for the tree-ring indices of Downy Birch and precipitation of May at Hallormsstaður in 1950-1989 (Figure 27). The mean response coefficient is 0.25. There is no higher or significant response to the total precipitation of any of the other months.

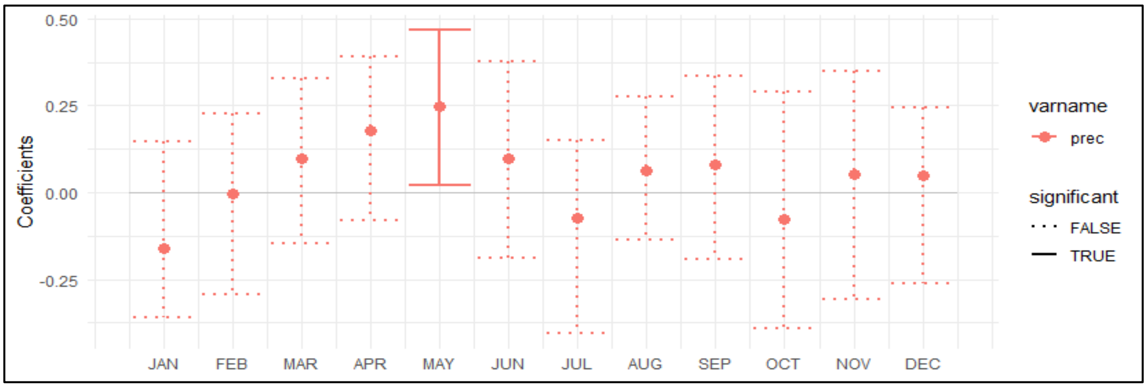


Figure 27 Boxplot of the Response Coefficient of the Relationship between the Tree-Ring Index (TRI) of Downy Birch in Ranaskógur and the Total Monthly Precipitation (mm) in Hallormsstaður, 1950-1989. A significant correlation is denoted by a solid line.

As determined by the moving windows correlation analysis (Figure 28), the month with the strongest correlation between Birch and precipitation is April. A significant correlation exists for 1950-1969 to 1955-1974, and 1959-1978 to 1963-1982. In between these periods, the correlation is high, though not significant. After 1963-1982, the correlation is weaker and not significant.

The correlation between precipitation of May and growth is higher and significant in later windows, from 1966 to 1989. Similarly, the correlation with March is significant from 1967 to 1989, while little to no correlation before 1967. Negative correlations exist for January, July, September, November and December. Of these, the only significant negative correlation, for multiple windows, is for December in 1960-1979 to 1962-1981.

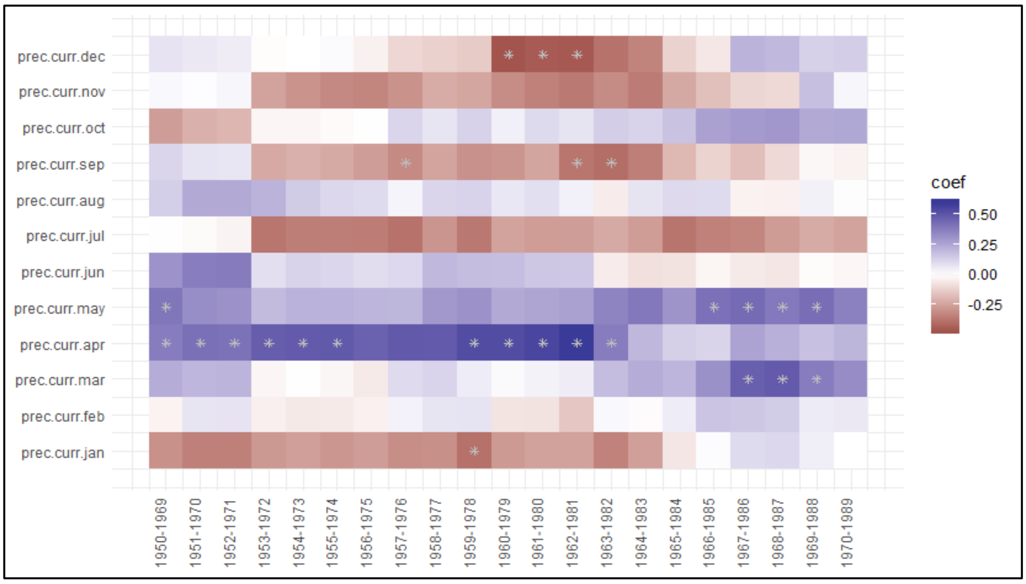


Figure 28 Graph of Correlation analysis with moving time windows (20-year windows) of the correlation between the Tree-Ring Index (TRI) of Downy Birch in Ranaskógur and the Total Monthly Precipitation (mm) in Hallormsstaður, 1907-2003. An asterisk (*) denotes a significant correlation.

A significant response was determined for the tree-ring indices of Rowan to the total monthly precipitation of June. The mean response coefficient for June is 0.29. There is no higher or significant response to the total precipitation of any of the other months.

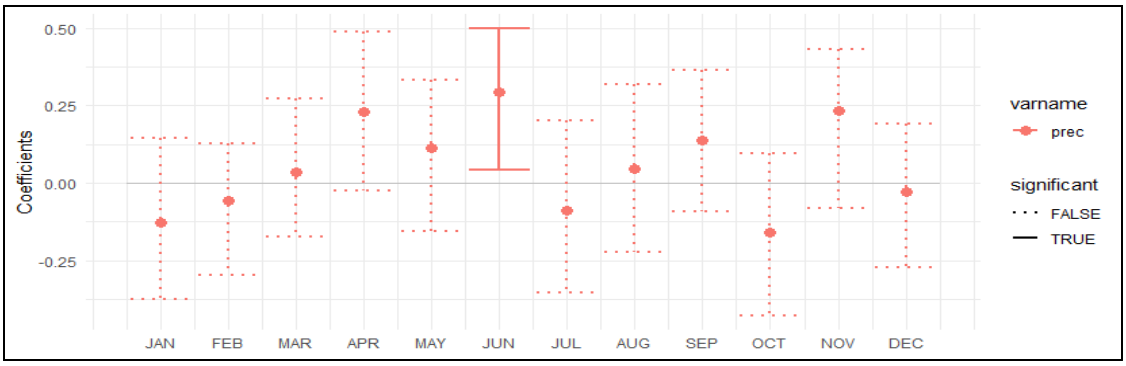


Figure 29 Boxplot of the Response Coefficient of the Relationship between the Tree-Ring Index (TRI) of Rowan in Ranaskógur and the Total Monthly Precipitation (mm) in Hallormsstaður, 1950-1989. A significant correlation is denoted by a solid line.

Little to no significant correlation was determined between tree-ring growth of Rowan and the total monthly precipitation for the windows of any of the months, other than June. A significant correlation exists for 1950-1969 to 1960-1979, after which the correlation is not significant and also decreases, as indicated by the colour scale.

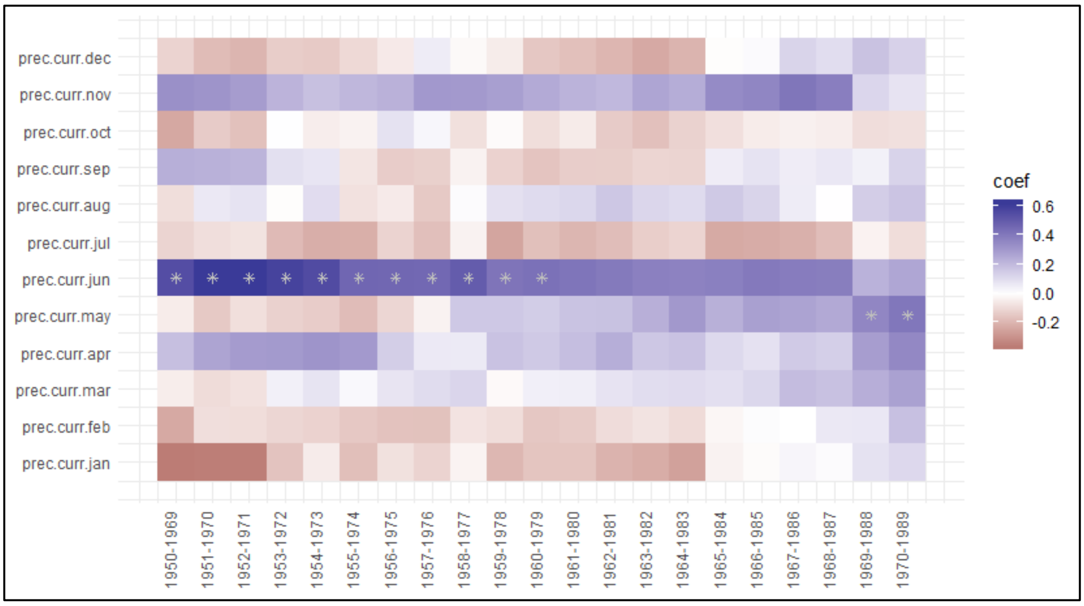


Figure 30 Graph of Correlation analysis with moving time windows (20-year windows) of the correlation between the Tree-Ring Index (TRI) of Rowan in Ranaskógur and the Total Monthly Precipitation (mm) in Hallormsstaður, 1907-2003. An asterisk (*) denotes a significant correlation.

4. Discussion

4.1 Comparison of Rowan and Downy Birch

A low to strong correlation was determined between the tree-ring growth of older trees of Downy Birch and Rowan in Ranaskógur. The TRW and TRI chronologies of Rowan and Birch show a significant visual and statistical correlation (coefficient = 0.55) from 1907 to 2003 as well as 1894 to 2017 (coefficient = 0.56), despite fewer tree series being included in the sample.

Overall the radial growth of Birch is more sensitive to external factors than Rowan, as indicated by the higher mean sensitivity and lower average autocorrelation. A lower autocorrelation indicates that the tree-ring growth of one year is less affected by the preceding year, and instead affected more by factors or conditions in the present year (International Tree Ring Database (ITRDB) 2005).

Birch has a lower correlation with both the Rowan chronology and the temperature of the months June, July, August and the mean summer temperature in 1967-1987 (Figure 24), or rather between 1952-1974 (Figure 25). It appears that some factor other than temperature affected Birch in this period, and further did not affect Rowan, or at least not affect it in a similar way. This is further discussed below.

4.2 Tree-Ring Growth and Climate

The two tree species have a similar response to climate, particularly temperature. The tree-ring growth of Birch has a significant positive response to the temperature in June, and correlates significantly with the temperature in June and July. The growth of Rowan has a significant positive response to the temperature in July and August, with little to no response to temperature in June. The greatest correlation (as determined by the Pearson correlation coefficient), was with the temperature in July, for both tree species. This demonstrates that **the vegetation period of Rowan and Downy Birch is July-August and June-July, respectively**.

Contrary to the hypothesis formulated in the Introduction, a significant positive relationship was determined between precipitation and the tree-ring growth of both Rowan and Birch. The growth of Birch showed a significant response to the precipitation in May, while Rowan responded significantly to the precipitation in June. May and June are driest Months in East Iceland (Einarsson p. 684, 1984).

The reliability and accuracy of the precipitation response analysis is somewhat questionable, given that precipitation data is only available for the period 1950-1989. In this period the correlation between the tree-ring growth of either species and between tree-ring growth and temperature was found to be particularly low (Figure 19, Table 3, Table 4). It would appear that some other factors aside from climate affected the growth in these years given how different the growth of Birch and Rowan is in this period. Putting these doubts aside, the results of the precipitation response analysis appear to indicate a connection between the month with the strongest response to precipitation and the months with the strongest response to temperature. The tree-ring growth of Birch has the most significant response to the precipitation in May and has the greatest response to the temperature in June and July. Similarly, Rowan has the greatest response to the precipitation in June and the greatest response to temperature in July and August. The conclusion drawn from this, is that **the tree-ring growth of both Rowan and Birch is significantly affected by the precipitation in the month preceding the start of the species' vegetation period**.

Long-term Trends and Development

The moving windows analysis was conducted to determine significant changes in or development of the relationship of temperature and tree-ring growth over time. The correlation between tree-ring growth of Birch and temperature in June and July, (and partially August), is greater in later years than earlier years, from 1960s or 1970s onwards (Figure 21). A significant positive correlation was determined between temperature in February and growth of Birch. This is unexpected, given that February is the coldest month (Einarsson p. 681, 1984). A negative correlation would instead be expected.

The correlation between tree-ring growth of Rowan and temperature in July and August is significant and relatively consistent for 1942 to 2003. No significant trend in the correlation of growth and temperature of any of the other months was determined.

A similar moving windows correlation analysis was conducted with temperature data from the weather station Teigarhorn, for the period 1907 to 2003 (Appendix E, Appendix H). The results for Birch and Teigarhorn were similar to those for temperature from Hallormsstaðaskógur, though with a stronger correlation in June and August. A strong correlation between the tree-ring indices of Rowan and temperature of August in Teigarhorn was found, similar to the correlation found for July in Hallormsstaðaskógur.

Overall, though, no significant development in the correlation of tree-ring growth of either species and temperature in Hallormsstaðaskógur or Teigarhorn was determined.

4.3 Periods of Low Correlation and Outbreaks

Significant outbreaks of moth larvae on Birch in the forest Hallormsstaðaskógur were recorded by the head foresters in 1915-1916, 1934-1935, 1946, 1952, 1977, 1998 and 2001-2006 (Pálsson) (Loftsson) (Blöndal, Annual Reports of Forestry Officer in East Iceland) (Þorfinnson). Outbreaks are periods in which the population of pest organisms increases greatly, causing intense and/or widespread damage. The outbreaks in 1935 and 2001-2006 were widespread, intense outbreaks, while the outbreaks in 1916, 1934, 1952, 1977 and 1997-1999 were ranked as local intense outbreaks (Halldórsson, Sigurdsson und Hrafnkelsdóttir p. 75-76, 2013). According to the assessment of the forester Sigurður Blöndal, the worst outbreaks on Birch in the area, prior to 1979, were in 1935, 1952 and 1977, with the outbreak in 1935 being the largest and worst (Blöndal, Annual Reports of Forestry Officer in East Iceland, 1979). It is uncertain which species caused the larger outbreaks before 1998 (Halldórsson, Sigurdsson und Hrafnkelsdóttir p. 75, 2013).

While no records of outbreaks of larvae on Birch, or for that matter Rowan, in Ranaskógur exist, it is probable that, given the proximity of Hallormsstaðaskógur and Ranaskógur, larvae also occurred on Birch in Ranaskógur during major outbreaks. In the years 1952, 1998, 2002 and 2003 outbreaks occurred in Hallormsstaðaskógur. In these years, the tree-ring width and tree-ring index values of the Birch in Ranaskógur were found to be lower (outliers or pointer years). The tree-ring index of the Birch chronology in 1935 is visibly lower than the index of the Rowan chronology and the mean summer temperature in Teigarhorn in that year (Figure 19, Appendix F).

A possible reason why the index of Birch in 1952 was so extremely low might be that it was both an outbreak year and a very cold summer (Eggertsson 2014). It could be however, that the low correlation in 1952 is entirely due to it having been a cold summer and not due to larvae. For instance, the tree-ring width and tree-ring indices of both Rowan and Birch in 1993 were significantly low (pointer years and outliers). In 1993 there was an extremely cold summer but no outbreak (Eggertsson p. 52, 2014).

The foresters did not report damage on Rowan during the outbreaks listed. Rowan is generally considered to be unaffected by outbreaks of moth species which affect Birch. A possible exception might be 1977, in which the tree-ring index of Rowan is an outlier, with significantly low growth, without the summer temperature of that year being correspondingly low. The forester Sigurður Blöndal reports that, aside from the outbreak of larvae on Birch, some young Rowan in Hallormsstaður were damaged by larvae of the moth Haustfeti (*O. brumata*) (Blöndal, Annual Reports of Forestry Officer in East Iceland p. 8, 1977)[4]. Perhaps larvae of *O. brumata* damaged Rowan in Ranaskógur in that year.

As observed, the TRI chronology of Birch correlates least with the chronology of Rowan (Figure 19, Table 3) and summer temperature (Figure 25, Table 4) in the 1950s to 1980s. The TRI chronology of Rowan also has a low visual correlation with summer temperature in the 1960s to 1980s. Further, during crossdating it was found that the TRW Birch chronology from Ranaskógur and Eggertsson's chronology from Hallormsstaður correlated least from 1953 to 1970. Halldórsson et al. noted that, aside from the major outbreaks 1952 and 1977, few outbreaks occurred between 1960-1990, with most outbreaks in 1930-1947 and from 1996 onwards (Halldórsson, Sigurdsson und Hrafnkelsdóttir p. 75, 2013). The outbreaks in 1952 and 1977 could not have been the only cause of the unusually low correlation between the growth of Birch and Rowan or between the growth of both species and summer temperature in 1950-1980. The low growth of Birch in 1952 may have affected the growth in the following years, 1953-1955. Aside from that, however, it seems that some other factor affected the growth of Birch, and possibly also Rowan, in Ranaskógur in these years. This might possibly be linked to the fact that 1966-1971 was a cold period in East Iceland (Einarsson p. 679, 1984).

4.4 Improvements to the Method

More emphasis had been placed on temperature over precipitation in this study due to bias on part of the author. Because of this the short precipitation series (1950-1989) from the IMO station Hallormsstaður was used. There is rainfall data available for Hallormsstaðaskógur from 1943 onwards in the forestry reports. This had not been used due to the time and effort needed to copy all the data manually. It is possible though, to get the data. Using the precipitation data from Hallormsstaðaskógur would significantly improve the method, ensuring a greater reliability of the results.

A further improvement to the method would be to determine how tree-ring growth reacts to climate extremes, such as for instance frost or drought. Such values are lost or underrepresented when using mean monthly temperature or monthly precipitation.

[4] Icelandic: *Auk þess var reyniviðurinn fyrir nokkrum skemmdum af völdum haustfiðrildismaðks.*

A possible weakness of the study is that the age range of the sampled trees is very narrow. No trees younger than 80 years were sampled and the mean age was 109 years for Rowan and 113 for Birch. Since the trees are older as well as all similarly aged, it is possible that the chronologies were affected by this. For Rowan it was not possible to sample younger trees since no young Rowan trees were found. For Birch, however, it would be prudent to sample some younger trees to ensure a more reliable and consistently representative chronology in the later years, especially for 2003 to 2017 (Schweingruber, Kairiukstis and Shiyatov, 2.1 Sample Selection p. 27, 1992).

4.5 Further Research

An attempt was made to use the tree-ring chronology of Rowan in Ranaskógur to detrend (i.e. remove the climate signal) from the Birch chronology, in order to identify years in which Birch was defoliated through outbreaks of moth larvae. The attempt to use the climate-subtraction method of Thomas Swetnam and Ann Lynch in “A Tree-Ring Reconstruction of Western Spruce Budworm History in the Southern Rocky Mountains” was applied (Swetnam und Lynch 1989), proved largely unsuccessful, and as a result was not presented in the thesis. However, in future, it would be interesting to sample Rowan and Birch in areas with confirmed outbreaks to test if it is viable to use Rowan tree-ring chronologies to identify historic outbreaks.

Taking core-samples from elsewhere, outside of Ranaskógur would be a potential topic for future research. This way, regional chronologies could be produced. Through such chronologies a better understanding of the growth dynamics of Rowan and Birch in mixed forests, and the relationship between growth and climate can be gained. As found in this study, the TRW chronology from Birch in Hallormsstaðaskógur (used for crossdating, See Chapter 2.4) and the TRW chronology of Birch in Ranaskógur were very similar, with some exceptions though. By taking samples from Rowan and Birch elsewhere in the region, it could be determined which signals in the chronology are due to regional factors or due to local factors, unique to Ranaskógur.

5. Conclusion

The purpose of this study was to produce stand-level tree-ring chronologies of the native tree species Icelandic Downy Birch and Rowan from trees in Ranaskógur, one of the few forest areas in Iceland with many tall, old trees of Downy Birch and trees of the uncommon species, Rowan. Further, the purpose was to gain a greater understanding of the relationship between tree-ring growth of Birch and Rowan and climate in East Iceland, and to gain insight into past tree growth and the history of the Ranaskógur.

With the produced chronologies, the tree-ring growth of the two species was compared, and the response of both species to the climate variables temperature and precipitation was determined. The study found that, the tree-ring growth of both species is significantly similar. In regard to climate, Downy Birch responds most to the temperature in June as well as July, and the precipitation in May. The tree-ring growth of Rowan responds most to the temperature in July and August, and the precipitation in June. From this it was concluded, that the vegetation period of Birch and Rowan is June-July and July-August, respectively, and that the precipitation in the month before the start of the vegetation period is decisive for the tree-ring growth of that year.

While an overall significant response of tree-ring growth to temperature, and possibly also precipitation, was determined, it was found that the response is not absolute or consistently strong. The response of growth to temperature varies between species and between years. Factors other than the two climate variables appear to affect the growth of both species. One such factor is outbreaks of moth larvae of Birch. The other factors are, however, uncertain and do not appear to affect Rowan and Birch equally.

While the study was successful in producing master chronologies and in determining the response of growth to temperature, other aspects of the aim and research question were not fully addressed. The chronologies are weakened by the lack of younger trees in the sample. Further, only a short precipitation data series was used. In future, building on the results of this study, it would be beneficial to take more samples from Rowan and Downy Birch in Ranaskógur and elsewhere in the region, particularly younger trees. Through this, a more reliable precipitation analysis could be conducted, and further, it would allow for a proper study of growth performance, productivity, and stand dynamics of Downy Birch and Rowan in Ranaskógur and East Iceland over the last century.

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Appendices

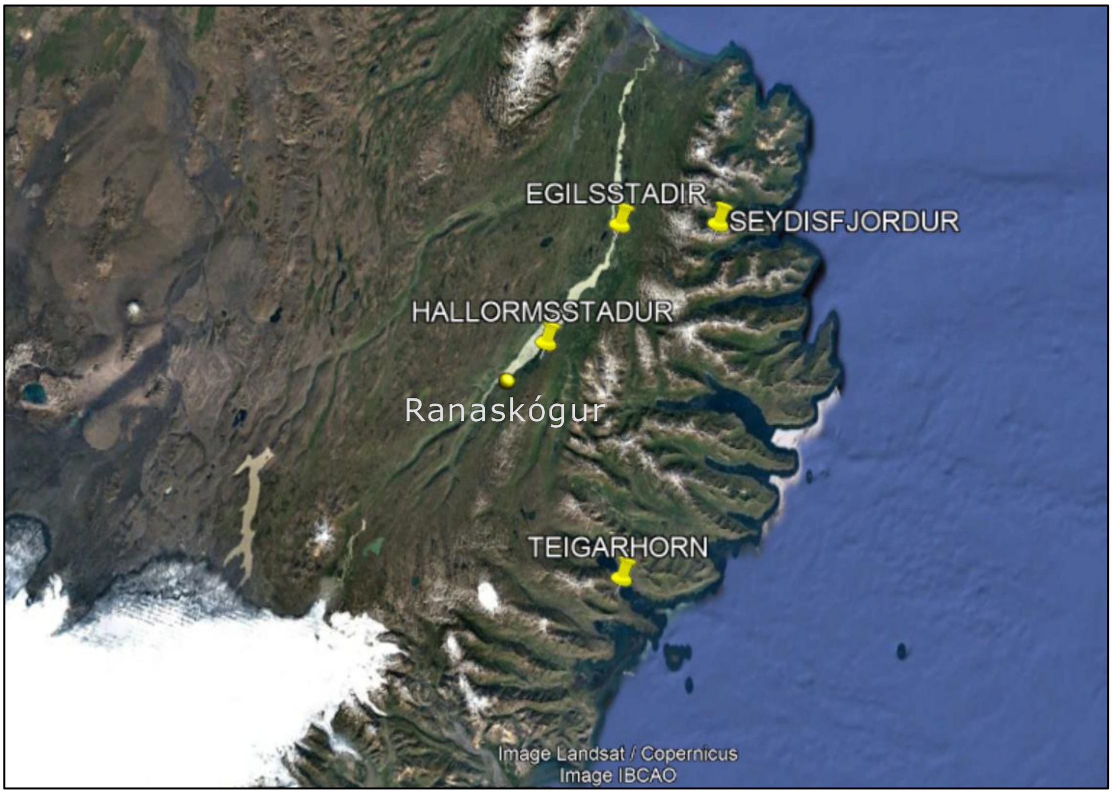
Appendix A. Verbal Stand Description of the old Birch Forest in the Sample Area, Ranaskógur

Verbal Stand Description		
Date	12.09.2018, 13.09.2018	
Stand type		Natural Birch Forest
Crown Closure		Medium to dense (≈ >50%) on the lower slope. Medium to low (≈ 20-50%) on the upper slope.
Canopy Layers		Single-layer stand, ≈ 9-10 meters high
Forest function		Private, recreation (hiking)
Exposition		North by North-West
Elevation		60 to 100 meters
Slope		Low to moderate incline (≈ 3-18°)
Main Species	Species	Downy Birch (*Betula pubescens*)
	Origin	Natural regeneration (seeds, basal shoots)
	Rejuvenation	Little to no rejuvenation
	Stem	Shrub-like growth on lower slope, and tall, straight(er) stems on upper slope.
	Crown	Varied crown form, often one-sided. Larger crowns on the upper slope.
Secondary Species (<10% of basal area)	Species	Rowan (*Sorbus aucuparia*)
	Origin	Natural regeneration (seeds)
	Rejuvenation	Some (0.5-1.0 m tall), mainly in the understorey of the adjacent conifer stand
	Stem	Straight, tall. Often forked at 1-2 m.
	Crown	Mostly well-developed, round crowns
	Distribution	Single-stem mixture, occasionally two stems from same root system.

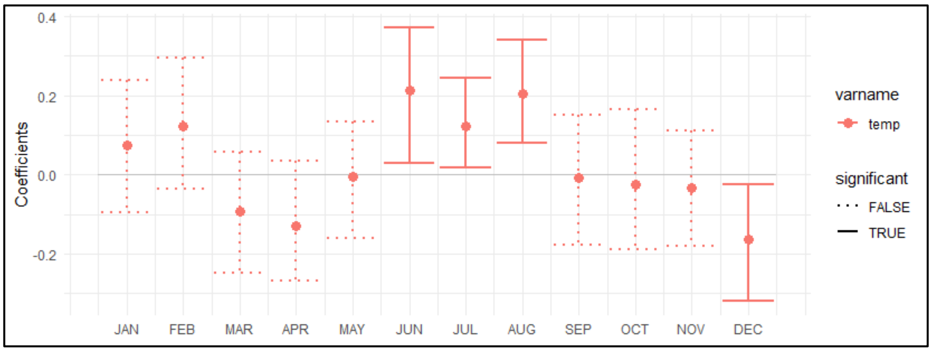
Appendix B. Icelandic Meteorological Weather Stations and Hallormsstaðaskógur Forest Station (Icelandic Meteorological Office (Vedurstofa Ìslands)) (Icelandic Meteorological Office (Vedurstofa Ìslands)) (Icelandic Meteorological Office (Vedurstofa Íslands))

Weather Station	Distance from Ranaskógur (km)	Start of temperature recordings	End of temperature recordings
Hallormsstaðaskógur	8	1942	2018-
Teigarhorn	45	1873	2018-
Hallormsstaður (580)	8	1961	1989
Egilsstaðir (570)	35	1955	1997

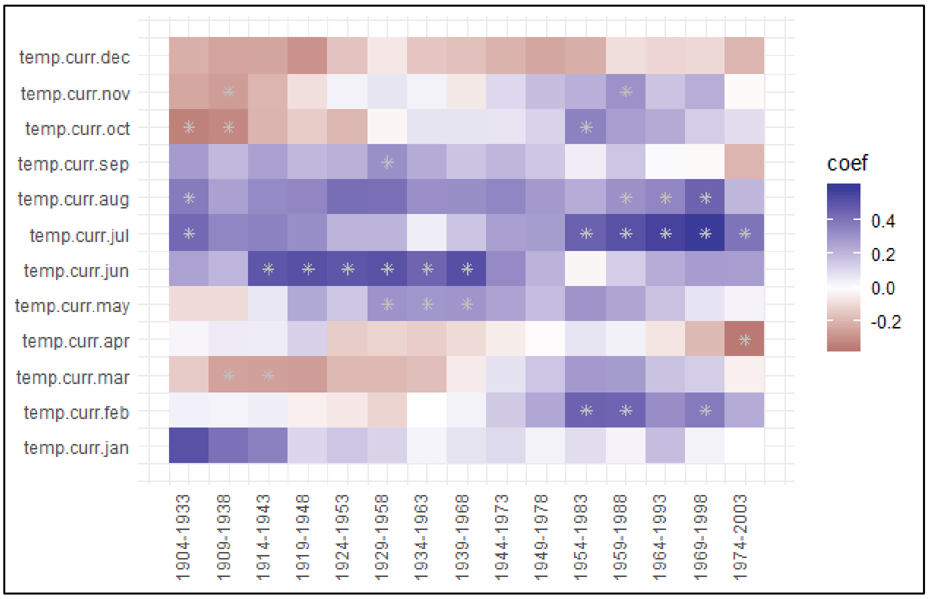
Appendix C Location of the Weather Stations Teigarhorn, Egilsstaðir and Hallormsstaður (Veðurstofa Ìslands) in relation to Ranaskógur (Extract from Google Earth 2018)



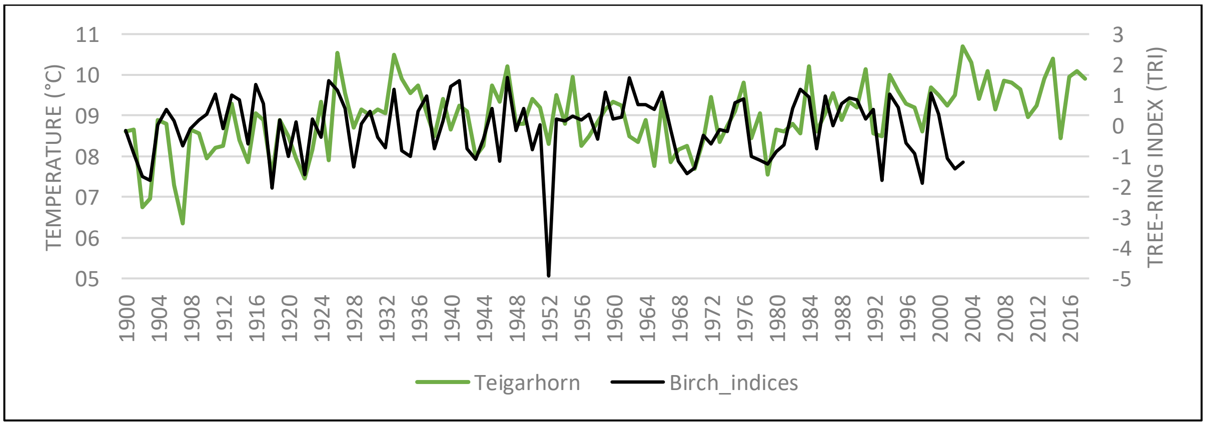
Appendix D Boxplot of the Response Coefficient of the Relationship between the Tree-Ring Index (TRI) of Downy Birch in Ranaskógur and the Mean Monthly Temperature (°C) at Teigarhorn, 1900-2003.



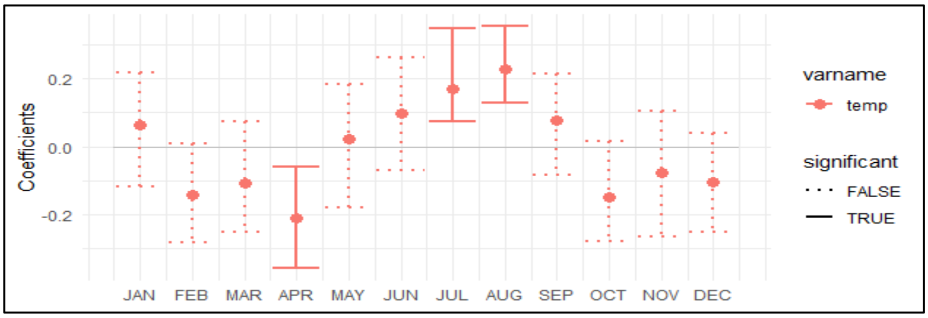
Appendix E Graph of Correlation analysis with moving time windows (40-year windows) of the correlation between the Tree-Ring Index (TRI) of Downy Birch in Ranaskógur and the Mean Monthly Temperature (°C) at Teigarhorn, 1900-2003.



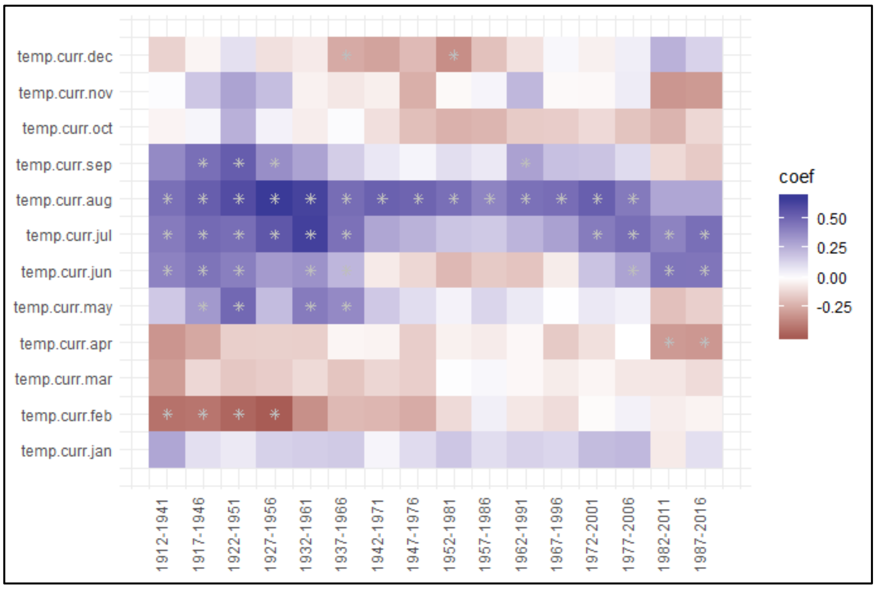
Appendix F Line Graph of Tree-ring Index (TRI) Chronology of Downy Birch and the Mean Summer Temperature (June-August) at Teigarhorn 1900-2003



Appendix G Boxplot of the Response Coefficient of the Relationship between the Tree-Ring Index (TRI) of Rowan in Ranaskógur and the Mean Monthly Temperature (°C) at Teigarhorn, 1907-2016.



Appendix H Graph of Correlation analysis with moving time windows (40-year windows) of the correlation between the Tree-Ring Index (TRI) of Rowan in Ranaskógur and the Mean Monthly Temperature (°C) at Teigarhorn, 1907-2016.



Appendix I Line Graph of Tree-ring Index (TRI) Chronology of Rowan and the Mean Summer Temperature (June-August) at Teigarhorn 1907-2016