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# An Assessment on the Cultivation of Black Cottonwood Cuttings in Nootka Lupine Fields in Conjunction with Site Preparation

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## Statement

*I hereby declare that this thesis was constructed based on my own observations, composed by me and has neither partially nor fully been submitted previously towards a higher degree.*

________________________________

Name of student

## Abstract

In Iceland, fields of Nootka lupine that were originally created for ecosystem rehabilitation can be utilized for afforestation purposes, provided that suitable plantation establishment methods are employed. Field experiments were conducted in South Iceland in which the planting of cuttings from two black cottonwood clones were prepared using three mechanical methods in addition to an undisturbed control plot. The first year results are reported here. Site preparation was effective in increasing survival and growth of planted cuttings at both sites. Rotavation generally was the most effective method employed as it provided the cottonwood plants with early relief from competing vegetation. Clone differences were found in plant growth, but these were site specific, most likely due to climatic differences between sites. However, the clones displayed no interaction with the site preparation methods. The results suggest that site preparation is an important factor during the plant establishment phase for black cottonwood plantations in fields of Nootka lupine.

## Acknowledgements

I would like to first and foremost thank my supervisor Úlfur Óskarsson, for his positive feedback throughout the whole process and giving valuable insight. Special thanks to Jóhanna Ólafsdóttir for assisting in the data collection and providing key information when required. Special thanks to Bjarni Diðrik for assisting in the data analysis and providing critical advice and also thank you to Járngerður Grétarsdóttir for assisting with the data analysis.

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# 1. Introduction

## 1.1. The Importance of Forests

Trees have been utilized as a form of land restoration in Iceland for many years; as they are important for a stable ecosystem in numerous areas. Woodlands are far more resilient to certain disturbances (such as the accumulation of volcanic deposit) than heathlands or grasslands, since they are able to withstand significant amounts of volcanic ash without being suffocated or buried (Ása Aradóttir & Ólafur Arnalds, 2001). Likewise, woodlands have a tendency to trap volcanic ash in their structures, trapping it to the vicinity and preventing the ash from traveling over large areas and having an ill effect on more vulnerable ecosystems (Ása Aradóttir & Þröstur Eysteinsson, 2005). Woodlands moderate the wind, reducing its speed and the interaction it has with the pertaining soil surface. For example, a reduction in wind speed can trap volcanic ash between trees, protecting vegetation from the abrasive properties of airborne volcanic ash (Ása Aradóttir & Þröstur Eysteinsson, 2001).

Trees have extensive root systems that help to bind soil and create biomass. These roots help to maintain the integrity of sloping lands by hindering solifluction and other cryogenic processes. Research shows that infiltration rates in woodlands are higher than in any other vegetation type. This is due to the loosening of soil from root activity, creating porous soils which allows for the rain to seep quickly into the ground and reduce excess runoff (Orradóttir, 2002). Trees provide protection against the erosive effect of water droplets on soil, which can close the cavities between soil particles and reduce air flow. The shelter provided by woodlands subsequently creates a microclimate that often provides a habitat for many other species. Snow tends to get trapped and accumulate around forests, which insulates the ground and ameliorates subsoil biology (Arnalds et al., 2001).

Land reclamation forestry focuses on the protection of the soil by creating and developing forest ecology, and storing carbon in the biomass of trees and soil. Although land reclamation forests are not necessarily intended for quality timber production, they can be financially profitable nonetheless. Vegetated land is more valuable than land which is barren. It also provides a cultural value, creating protected areas for visitors such as camping grounds, walking paths and other recreational areas (Þröstur Eysteinsson, 2017).

There are a number of factors however that can hinder tree growth, many of which are a result of land erosion. The instability of barren landscapes can make it difficult for young trees to bind their roots. Erosion due to wind and water processes aggravates the soil, and during winters the effects of frost heaving can create a lot of movement. The topsoil is often depleted and the lack of deposited organic material results in nutrient deficiency. The soil structure is often compromised, creating an insufficient hydrological system. Trees that lack the proper environmental qualifications have lower resilience thresholds, and therefore become vulnerable to pests and damage from frost (Reige & Sigurgeirsson, 2018). An existing method to enhance the survival and growth rates has been to use fertilizer, which gives nutrients to the soil while also increasing the microbial activity in the soil- leading to an increase in heat production. Subsequently, this heat production will reduce the impacts of frost heaving (Hreinn Óskarsson & Sigríður J. Brynleifsdóttir, 2009). Chemical fertilizer has predominantly been used by foresters when planting in large quantities, and when organic fertilizer is not readily available and/or too problematic to disperse. The growth rate of forests in the long run is largely dependent on nutrient and water availability. On barren landscapes that lack organic material, there must be nitrogen fixing plants in conjunction with the trees to maintain growth rates in the future.  Therefore, by utilizing pre-existing lupine patches, this can potentially mediate some of these factors and improve growth rates.

## 1.2. Overview of Black Cottonwood

Black cottonwood, *Poplulus trichocarpa,* is a fast growing deciduous tree species that originates from the Western coast of North America. It comes from the genus *Populus* and is comprised of 25-35 species of deciduous broadleaf trees from the willow family *Salicaceae* that grow in the Northern hemisphere (Auður Ottensen, 2006). The root system of black cottonwood is aggressive and shallow, which has proven to be problematic in cities where the roots destroy pathways, asphalt and water pipes in suburban areas (Guðrún Helgadóttir, 2001). Black cottonwood was first introduced to Iceland around 1944 and situated in Múlakot in Fljótshlíð. These individuals originated from the Kenai Peninsula showed promising results in regards to survival and growth.  Black cottonwood is currently one of the tallest growing tree species in Iceland (Pétur Halldórsson, 2016) and one of the species with the highest productivity rates, with an annual stem volume growth measuring at 6-20$m^{3/}$ha (Arnór Snorrason & Aðalsteinn Sigurgeirsson, 2006). Black cottonwood requires little in regards to summer temperatures and can grow up to 30m in Iceland. The stem grows straight and the crown can be either thin or wide, depending on the clone. It is a sun tolerant species, with high resilience to frost, wind, and salt; although it is suited best for the continental climate in which the cold winters maintain the plants dormancy. The irregular shifts in temperature during winter in Iceland have proven to be problematic on a number of occasions. For example, in 1963, a warm snap in April followed by a cold snap resulted in the premature blooming of many aspen trees in the Southlands which led to severe top remission (Halldór Sverrison, Guðmundur Halldórsson & Aðalsteinn Sigurgeirsson, 2006).

Until the late 90's, black cottonwood was primarily used as an ornamental garden species. Later, the species was introduced into commercial forestry and is now heavily used for both shelterbelts and timber production. The Icelandic forestry departments have great hopes for this fast-growing species, and efforts are in development to produce better adapted clones that are more resilient and economically beneficial (Auður Ottensen, 2006).

## 1.3. Overview of Nootka Lupine

Nootka lupine (*Lupinus nootkatensis*), is a legume that reproduces with self-fertilization. It has a symbiotic relationship with a bacterial species known as rhizobia, which forms nodules on the roots of the lupine that fix atmospheric nitrogen (50-100 kg N/ha). Lupine is important in its native environment and functions as a pioneer species in land that is devoid of vegetation, facilitating the colonization of other species in the future. Lupine thrives on dry land, sands and even well vegetated heathland. Rushes, low growing shrubs, sedges and lichen species are often removed by lupine introduction. High growing grass species and angiosperms are more likely to coexist with lupine. Species diversity is usually greatly reduced with lupine patches (Borgþór Magnússon, Sigurður H. Magnússon & Bjarni D. Sigurðsson, 2004). The overall species diversity decreases due to this competition but the community development also depends on regional abiotic factors, such as wind, rain, and temperature. In areas that have adequate temperature and precipitation, lupine can grow very robust. Therefore, the species diversity is lower than in areas that lack the abiotic factors to support lupine as much. The life expectancy of lupine patches varies depending on the climate, but it has been aggressive in most Icelandic ecosystems and can dominate other plant species for as long as 15-30 years (Karl Benediktsson, 2015).

Nootka lupine was introduced to Iceland in the late 19$^{th}$ century but it was not until 1945 when the forester Hákon Bjarnason realized the potentials this species had for land restoration in Iceland (Hákon Bjarnason, 1946, 1981). The Nootka lupine was introduced in different areas around Iceland to test what conditions it survives in. Its seeds were collected and used for land restoration in the early 2000's; 3kg of seeds were used yearly per hectare (Borgþór

Magnússon, Sigurður H. Magnússon og Bjarni Diðrik Sigurðsson, 2003). The Icelandic Forestry Service began active spreading of lupine after 1960; and in 1986, the lupine had been used in reclamation areas by the Soil Conservation Service of Iceland (Borgþór Magnússon, 2010). It is a controversial species, as it is often considered an invasive species as it has the capability to alter plant communities in ecosystems, displacing native species of small stature. The Icelandic heathland fauna is especially vulnerable to Nootka lupine colonization as it is low growing and the soil is typically low in nitrogen (Náttúrfræðistofnun Íslands, 2010). The seeds are quite large and the lupine will regenerate from the seed bank, which can last for many years. Due to their large size, the lupine seeds do not disperse far from the source unless it is via a stream or river (Bjarni D. Sigurðsson, Borgþór Magnússon & Sigurður H. Magnússon, 1995).

## 1.4. The Experiment

The experiment is a part of a larger project that focuses on developing fast and inexpensive ways to co-cultivate black cottonwood and Nootka lupine in various landscapes with the long-term goal of binding atmospheric carbon and producing commercial timber. The project is divided into four main research sections. 1) Investigating the selection of suitable clones of black cottonwood when co-cultivated with Nootka lupine. 2) Assessing the importance of cutting lengths that are planted directly. 3) Testing the results of various methods of introducing Nootka lupine to afforestation areas for nutritional benefits. 4) Testing various site preparation methods within lupine plots to decrease the competiveness of the lupine. The project is designed to provide results after two years of research, with data collection in both years. Once the initial experiments are completed, the sites will continue to be monitored, with an emphasis on carbon sequestration and tree growth rates. The findings will help to improve the understanding of the growth habits of these two species together.

The project section which this paper addresses focuses on the fourth part: the usage of different soil scarification methods to improve the competitiveness of cottonwood cuttings in pre-existing lupine fields. The objective of this experiment is to assess whether these methods are a feasible solution for the cultivation of black cottonwood in Iceland. The idea is to develop an inexpensive and simple method that, if proven successful, could potentially be an economically sound alternative to the common plantation methods.

For the present part of the project, two test plots in separate locations in the South of Iceland were used. One was located at Skarfanes in Rangárþing ytra, the other was located at Ytra Seljaland in Rangárþing eystra.

### 1.5. Research Questions

The main goal of this project is to evaluate different site preparation methods in lupine fields for planting black cottonwood cuttings in terms of efficiency and plant performance. The following research questions pertain to this evaluation.

- Does the site preparation method have an effect on survival and growth?
- Are any of these preparation methods a feasible alternative to traditional methods of afforestation?
- Is there a significant difference between the two clones regarding survival and growth, and response to different site preparation methods?

## 2. Materials and Methods

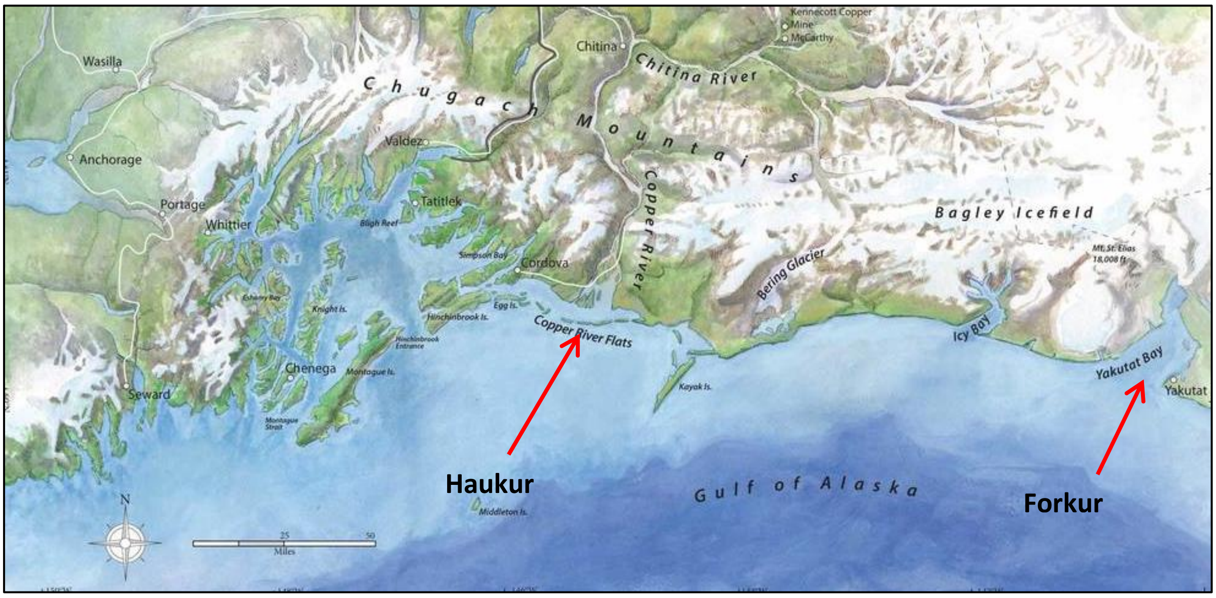
### 2.1. The Sites

The land of Skarfanes is situated on the south side of Þjórsá in South Iceland, in Rangárþingytra. The land has been owned by the Forestry department since the 1940's. The land is severely eroded and characterized by sands, exposed pumice deposits and lava outcrops, intermixed with vegetation and soil remnants. A small part of the area is now forested due to afforestation efforts and spread of natural birch, and a large part of the area has been seeded with Nootka lupine and lyme grass for ecosystem rehabilitation. The site chosen for the experiment was dominated by Nootka lupine, intermixed with some lyme grass and other grasses, a few forbs, and scattered young willows (Úlfur Óskarsson, personal communication, April, 23, 2018).

In Ytra Seljaland, the experiment is situated in an afforestation and ecosystem rehabilitation area. The area is part of the Markarfljótt river delta, in Rangáring-eystra, and underlying a thin topsoil layer are thick gravelly glacial river deposits. The experimental plots were grown with lush vegetation, predominately Nootka lupine, intermixed with several grass species and a few forbs (Úlfur Óskarsson, personal communication, April, 23, 2018).

## 2.2. The Clones

The two clones used were both originally from Alaska and brought over to Iceland in 1963. The male clone Haukur originated from the Copper River delta near Cordova. The place or origin was 20m above sea level and the coordinates are 60°20’ and 145°00’. The female clone Forkur originated from Yakutat, also 20m above sea level and its coordinates are 59’°24’ and 138°´59´ (Picture 1).




Picture 1: Map of the Gulf of Alaska indicating the origins of the both clones (Kristin Link, 2017).

The Forest Research centre at Mógilsá was the collection site of the cuttings for Haukur. This clone was characterized as being fast growing and wind resistant, with a straight trunk. The bark is dark brown and the crown is large. It was noted as being resilient to autumn frost damage. The collection site for the cuttings of Forkur was Tumastaðir and this clone was also characterized as being fast growing and wind resistant, but somewhat susceptible to autumn frost damage (Líneik A. Sævarsdóttir and Úlfur Óskarsson, 1990).

## 2.3. Methods of Site Preparation

Site Preparation is a method of preparing a vegetated land for planting trees which involves excavating the land to remove current herbaceous cover in order to create an open microsite. This preparation can be done anytime during the frost-free season. It functions as an ecological disturbance, and is widely used for natural regeneration in afforestation in boreal areas. The tracks created increase the surface heterogeneity, increasing soil moisture, exposure to sunlight and nutrient mineralisation. It also reduces soil density, increasing the aeration and decomposition of organic matter which in turn increases the overall soil temperature (Mullan and White, 2002).

Four types of methods were tested for site preparation: No preparation (control), TTS disc scarifier, rotavation, and a trenching machine (normally used for planting forest seedlings). The Ytra Seljaland plot did not include the trenching machine, and therefore only had three methods of site preparation.

No preparation: This method was implemented as a control group where the cuttings were planted directly into undisturbed lupine fields.

The TTS disc trencher is a continuous double row scarifier and is mostly used in heathlands that have dense vegetation and thick moss cover and also in shrub land with dwarf birch (*Betula nana*). The disks tear up the vegetation (two channels at a time) and put them to the side of the wound. It is advisable to leave the prepared area until after winter before planting. (Landssamtök Skógareiganda)

Rotavator: Basic soil preparation (rotavation) that reduces competition and increases heat and nutrition. The soil area is rarely fully broken up but rather it leaves behind an undisturbed space in between. Rotavation is more suitable than a TTS system where there is a risk of water erosion (Landssamtök Skógareiganda).

Trenching machine: A type of plough that creates a thin line in the soil designed to slightly open the soil and is normally used for planting forest seedlings. It scars the land the least of all the active methods and is barely visible in the lupine fields.

## 2.4. Experiment Design and Plant Materials

The Skarfarnes plot was composed of 5 blocks: 4 rows each with 8 individuals of each clone, in total, 320 cuttings were planted at this site. The plot consisted of 5 blocks: 3 rows each with 8 individuals for each, with a total of 240 cuttings.

The cuttings were approximately 20cm in length and were planted in the spring, rather than the autumn, to minimize the chance of frost heaving. The cuttings were then placed in a raised position high on the trenched track 2m apart and 2/3rds of the cutting was buried. No added fertilizer was used in this experiment. Wooden stakes were inserted into the ground at the beginning of each row to mark where the cuttings were planted. In Skarfanes, long, thin plastic pipes were added next to the stakes as additional markers in plots had very high lupine present.

## 2.5. Observations

The observations and measurements were conducted in the late summer of 2016, towards the end of the first growing season. There were three dependent variables measured: the survival rates, the length of shoot growth from stem, and the total height of the plant as a whole. All cuttings were assessed for survival. The plants that were not found at all were marked as 'missing', but classified as dead for the data analysis. If the cutting did not have any visible recent growth, then the bark was gently scratched to see whether the inner tissue was green and alive. New shoot growth was measured with a ruler both in length and height from the ground. The condition of the leaves was also assessed. In addition, it was documented if visible signs of disturbance from either a sheep or insect were present.

Additionally, estimations were recorded on the proportion of the original cuttings sticking out from the ground and the cutting diameter. The independent quantitative variables included the height of the cuttings from the ground and the diameter of the cuttings. Each cutting was approximately 20cm in length. It is important to note that the height of the cuttings when inserted into the ground varied slightly.

## 2.6. Statistical Analysis

ANOVA linear model was used (SAS Enterprise Guide 7.1) to test the effects of independent variables on the response variables. The independent variables were: clone type, method of site preparation, and block. In addition, the interaction of clone and site preparation was tested. Also included in the model, but not tested, were the height of the cuttings from the ground, and the diameter of the cuttings. The response variables were: the survival rate (the average of 8 cuttings from each experimental unit), the length of shoot growth of individual plants, and the total height of the whole plant. Least Squares Means were used to find significant differences between means.

# 3. Results

## 3.1. Overview of Model Output

The model significantly explained overall treatment effects at both sites, except for total plant height at Ytra Seljaland (Table 1). At the Skarfanes site, the method of site preparation significantly explained variation in all dependent variables, and clone type significantly explained variation in shoot growth and total plant height (Table 1). For the Ytra Seljaland site, the method of site preparation significantly explained variation in shoot growth and survival, and clone type significantly explained variation in shoot growth. In all cases, the effects of block and interaction between clone and site preparation proved to be insignificant (Table 1).

**Table 1: F values from ANOVA linear model analysis of classification and dependent variables in Skarfanes and Ytra Seljaland. ***p < 0.001, ** p < 0.01, * p < 0.05 , ns = not significant**

| Skarfanes | | | |
|---|---|---|---|
| **Classification variables** | **Shoot growth** | **Total plant height** | **Survival** |
| **Block** | ns | ns | ns |
| **Clone (C)** | 4.70 * | 5.04 * | ns |
| **Method of site preparation (SP)** | 7.44 *** | 5.37 ** | 9.95 *** |
| **C x SP** | ns | ns | ns |
| Ytra Seljaland | | | |
| **Block** | ns | ns | ns |
| **Clone (C)** | 4.78* | ns | ns |
| **Method of site preparation (SP)** | 11.67 *** | ns | 14.43 *** |
| **C x SP** | ns | ns | ns |

## 3.2. Shoot Growth

For shoot growth, the model gave a significant P = 0.0013 and P< 0.001 for Skarfanes and Ytra-Seljaland, respectively. At Skarfanes, the clone Haukur grew significantly better the Forkur (Fig. 1).

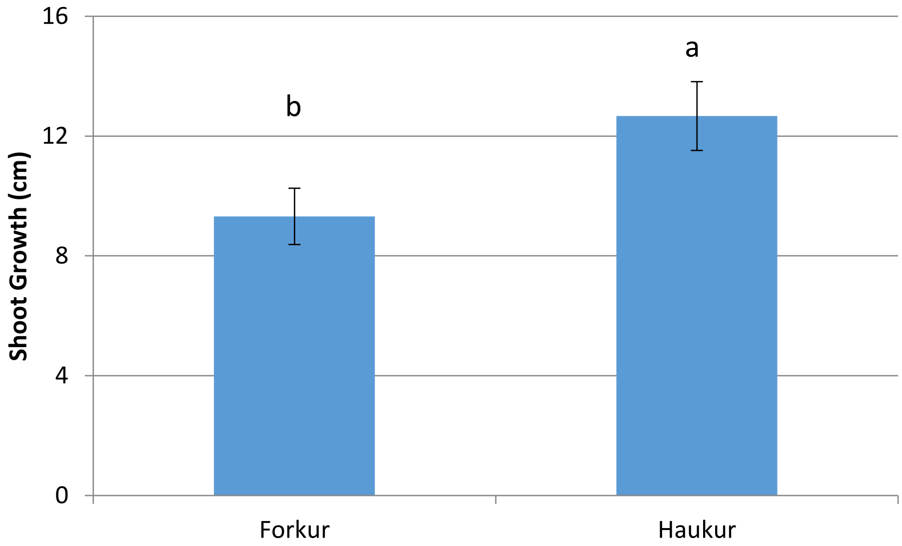



**Figure 1: Results of shoot growth for clones in Skarfanes. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).**

For the methods of site preparation, shoot growth was significantly greater for plants in plots prepared with rotavation (Fig. 2) compared with the trenching machine and undisturbed land (control). The TTS disc trencher was also significantly better for enhancing shoot growth than control (Fig. 2).

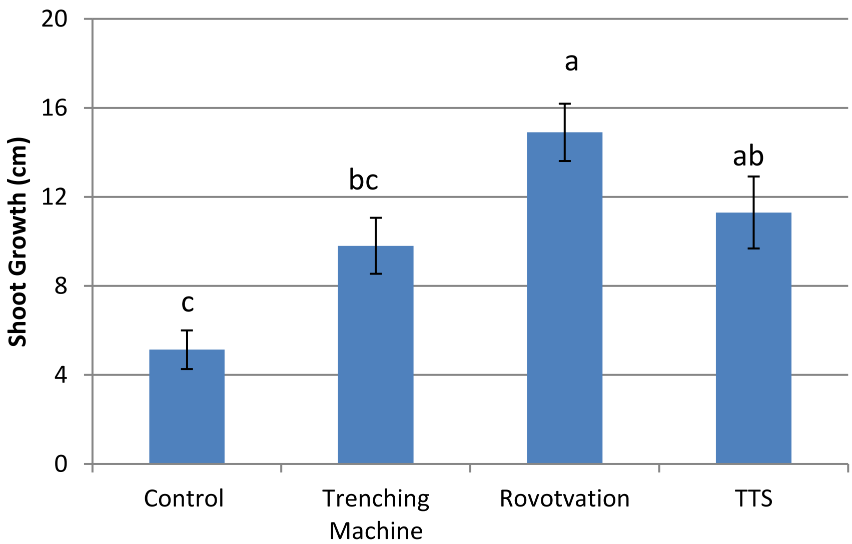



**Figure 2: Results of shoot growth for method of site preparation in Skarfanes. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).**

At Ytra Seljaland, Forkur grew significantly better than Haukur (Fig. 3), in contrast to in Skarfanes.

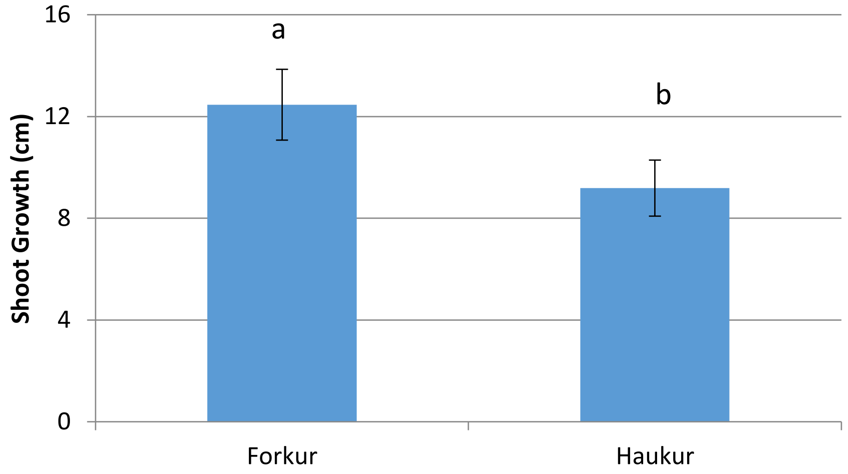



Figure 3: Results of shoot growth for clones in Ytra Seljaland. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).

For the methods of site preparation in Ytra Seljaland, the plant' growth showed more success better in land prepared with the rotavator than with the TTS disc trencher (Fig. 4).

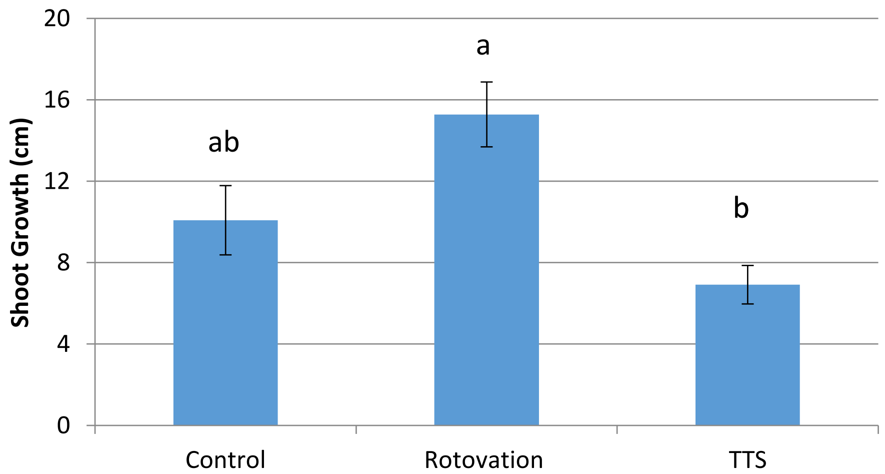



Figure 4: Results of shoot growth for method of site preparation in Ytra Seljaland. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).

## 3.3. Total Plant Height

The model effects gave P = 0.0025 and P = 0.089 for Skarfanes and Ytra-Seljaland, respectively, and this was only significant for the former site. At Skarfanes, plants of the clone Haukur were higher than those of Forkur (Fig. 5).

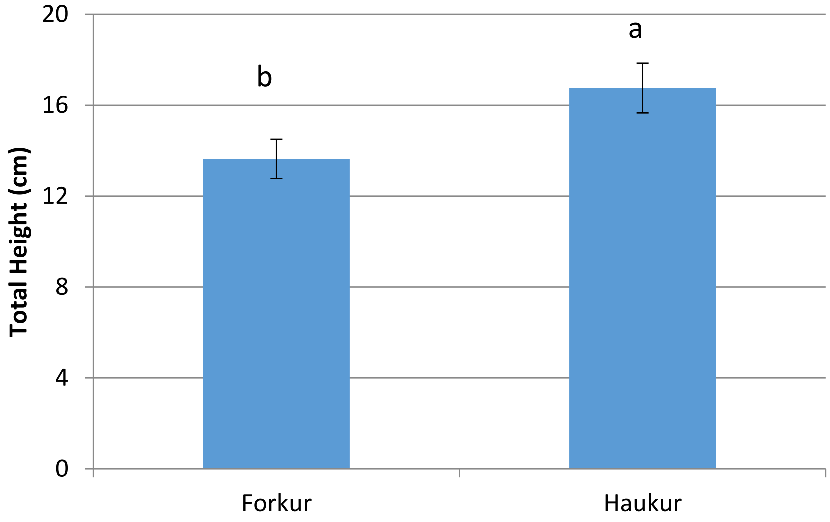



Figure 5: Results of analysing the total plant heightfor clones in Skarfanes. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).

For site preparation at Skarfanes, the plants were higher in plots prepared using the rotavation method compared to undisturbed control plots (Fig. 6).

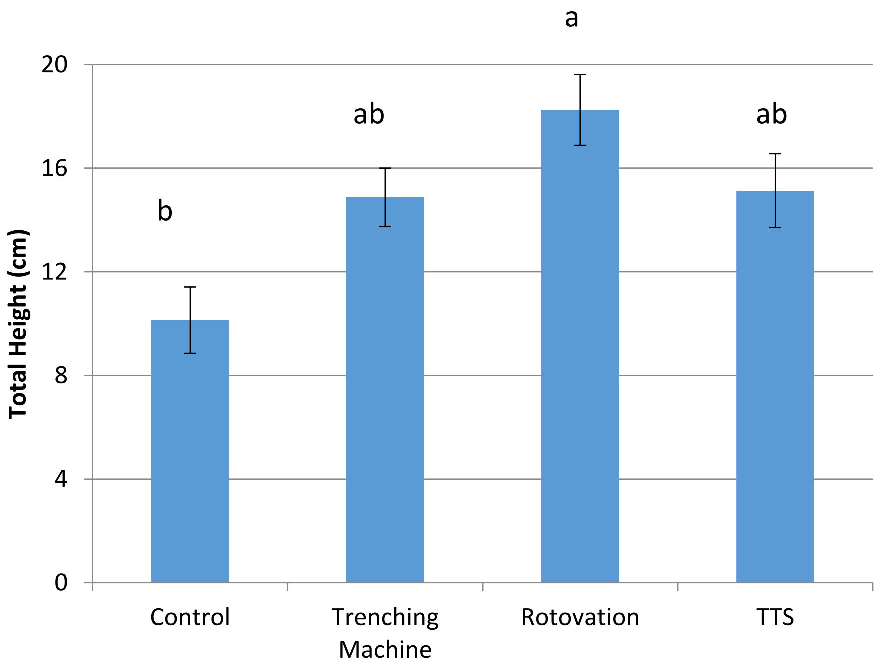



Figure 6: Results of total plant height for method of site preparation in Skarfanes. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).

### 3.4. Survival Rates

The model for survival analysis gave a significant P = 0.0034 and P = 0.0044 for Skarfanes and Ytra Seljaland, respectively. For Skarfanes, the only classification variable that had significant effects (Table 1) was the method of site preparation, where control plots had a lower plant survival than the other methods (Fig. 7).

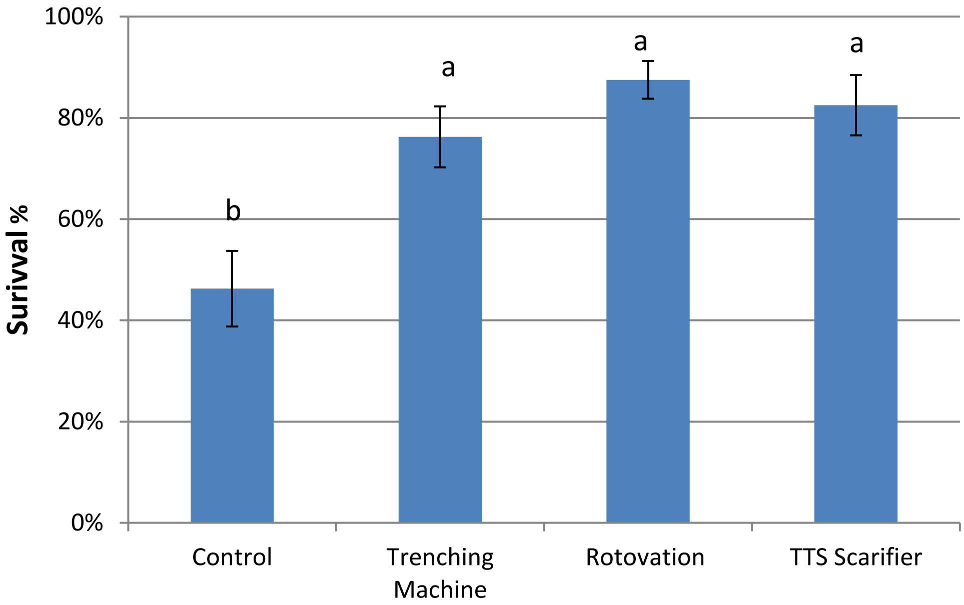



**Figure 7: Results of plant survival rates for the method of site preparation in Skarfanes. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).**

As with plant survival at Skarfanes, the only classification variable that had significant effects for Ytra Seljaland was methods of site preparation (Table 1). The survival in the control plot was significantly lower than for both rotavation and TTS (Fig. 8).

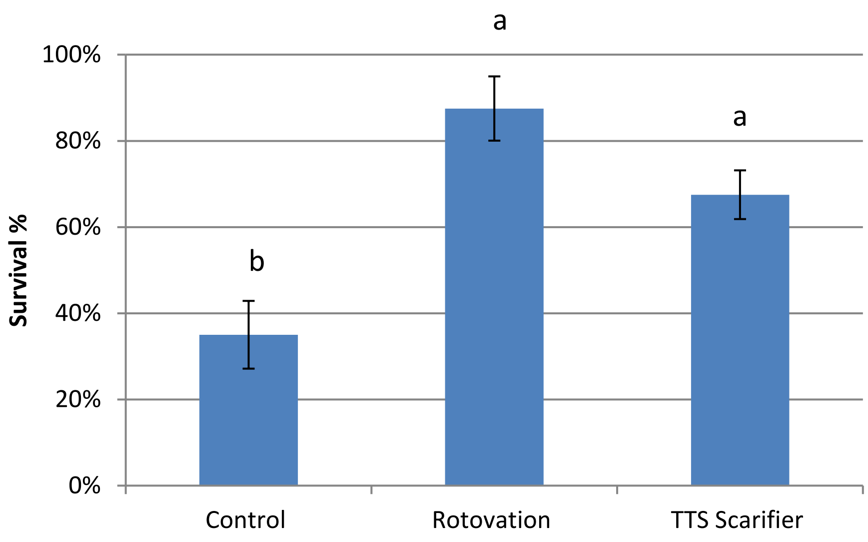



**Figure 8: Results of plant survival rates for the method of site preparation in Ytra Seljaland. Columns show variable means and their standard errors. Different column letters indicate significant differences between means (P<0.05).**

# 4. Discussion

## 4.1. Answers to the Research Questions

In light of these results, it is important to reiterate the research questions and assess to what extent they have been answered along with bringing to light any discrepancies and/or uncertainties that may have surfaced.

**Does the site preparation method have an effect on survival and growth?**

The statistical analysis revealed that there was a significant difference between the control plots and the site preparation methods regarding survival rates and shoot growth for both sites. In addition, a significant difference was found in the total height data for the clones and site preparation in Skarfanes. Out of the 5 sites that showed significant data for site preparation, 4 sites showed the control group as having the lowest averages. This suggests that the site preparation had a positive influence on the survival and growth of the black cottonwood cuttings.

Site preparation serves a number of purposes. In many countries, this is practiced in clear cut forests as a form of disturbance to open the land and encourage natural regeneration by creating microsites for seedlings to germinate. There are many associated benefits for preparing a site, especially if there is a need to reduce plant competition among species. The cultivating of the soil makes it easier for plants to reach the groundwater and the trenches might even provide shelter to some degree. Site preparation boosts the nutrient cycle, opening the soil and increasing oxygen exposure which assists in the breakdown of organic matter. The additional sun exposure also helps to increase the ground temperature and reduce the amount of frost in the ground (Löf et al, 2016).

**Are any of these methods a feasible alternative to traditional methods of afforestation in terms of cost efficiency and productivity?**

Rotavation was found to be the most successful of the three mechanical methods; and whilst there was no significant difference between the TTS and trenching machine, all methods generally provided better results than the control plots which were not subject to preparation. As aforementioned, disturbance of the lupine allows for the cuttings to situate themselves without competing for resources such as sunlight and water. The preparation also allows for a more efficient plantation regime, as it improves the ease and speed of the process. This is hugely beneficial as it reduces the manual labour involved and the time the plants are left in the field before being planted. A speedier planting routine also means that the planters can take full advantage of the days that are most preferable for planting and avoid conditions that are less preferable. Being able to utilize cuttings that are more readily available and easier to plant instead of growing seedlings from seed is a huge advantage in regards to cost efficiency. Site preparation also defines the orientation of the plantation and helps to plan ahead and makes it easier to find the planted cuttings later on (Mullan & White, 2002).

**Is there a significant difference between the two clones regarding survival and growth and response to different site preparation methods?**

Clone differences were found in plant growth, but these were site specific, and likely due to the climatic differences between sites. The clones, however, showed no interaction with the site preparation methods.

Previous studies have found that there is a substantial amount of variability regarding survival rates and growth between black cottonwood clones that have been introduced to Iceland, depending on their origin and where in Iceland they are situated (Halldór Sverrison, Guðmundur Halldórsson & Aðalsteinn Sigurgeirsson, 2006). A comprehensive study was conducted by the Forest Research Centre Mógilsá in 2011, assessing the survival and growth rates of 46 different clones of black cottonwood. The results suggest that in general the black cottonwood grows faster in the south where there is a higher average temperature and a longer growing season. Both Haukur and Forkur are coastal clones and display very similar results in most of the areas that were assessed (Sverrison et al, 2011).

## 4.2. Examination of Previous Studies

It is important to realize that these results are only based on one summer's growth; and future effects can likely diverge from the preliminary results. It is recommended to examine older studies that show the effects of the experiment over a longer period of time to assist researchers in the future to develop the most effective and cost-efficient management plan.

Mattson and colleagues (2007) conducted an experiment on an 18 year old Lodge pole pine (*Pinus contorta*) forest in boreal Sweden, where the trees were planted in Nootka lupine patches in conjunction with three site preparation methods (mounding, disc trenching, and ploughing). This study showed that, on average, the lupine increased the stem volume per hectare by 143%. Ploughing in conjunction with the lupine treatment resulted in a significant difference to disc trenching and mounding. There was also a significant difference to the cumulative stem biomass production (kg tree-1) with the plots treated with lupine and those untreated. The treated plots had on average 68% more biomass. For the areas without lupine, ploughing significantly increased the biomass compared to the other site preparation methods. Lupine also increased the mean annual increment (MAI) by 59%). Trees grown in lupine had a significantly lower stem basic density of 5% on average (Mattson, Bergsten & Mörling, 2007).

The growth curves of this experiment suggest that the lupine treatment provides nitrogen to the trees 20 years following its establishment. This is useful when considering the lack of nitrogen in many eroded and nutrient poor soils around Iceland. The site preparation methods showed to have a positive influence on the productivity; however other studies (Johansson M, 1994) suggest that these methods can reduce the long-term productivity on poor sites that are highly disturbed. These methods in conjunction with lupine might decrease the risk of this occurring. The effects of lupine were greatest on the mounded plots and least on the ploughed plots, indicating a correlation between lupine effectiveness and area/volume of disturbed soil. The paper theorizes that this may be due to fact that the larger disturbed soil area is exposed to more aeration which breaks down organic matter faster and therefore increases the amount of available nitrogen in the soil. This suggests that the increased nitrogen in the soils due to lupine introduction is more important for the trees growing on plots with less disturbed soils (Mattson, et al., 2007).

The experiment conducted by Sigurðsson (2004) involved planting the cuttings of three species, black cottonwood feltleaf willow (*Salix alaxensis*), and Tea-Leaved Willow (*Salix*

*phycilifolia*), in Nookta lupine fields in the South of Iceland. The dependent variables examined were survival, height and leader dieback. There were 600 cuttings from each species, each with three separate lengths; 20, 50 and 80cm. One of the variables included inserting half of the cuttings 1/3 of the way into the soil, and the other half 2/3 of the way into the soil. The effects of the lupine were evaluated by measuring the height and also the leaf area index (LAI), which predicts the photosynthetic capabilities of growth within canopy shade. Measurements concerning the LAI indicated that the shorter the cutting is, the lower the amount of sunlight available. A cutting that is 10cm from the soil will only be exposed to 15% of potential sunlight (Bjarni D. Sigurdsson, 2004).
The results showed that there was a significant difference of the survival rates for the black cottonwood depending on their situation. After 3 years, the survival rates were only 39%. The best results were those cuttings that were 80cm long and buried deep (2/3 of the way down), as this provided a platform for a substantial root system and reduced leader dieback from frost. This experiment showed that it is possible to use black cottonwood cuttings to establish forests in lupine fields without any site preparation involved. It does the raise the question however as to the whether the survival rates are somewhat compromised without the use of site preparation.

## 4.3. Recommendations for Future Research

The methodology and execution of this experiment was largely successful in producing relevant data with which to consider. There were a number of aspects that could have been implemented to potentially improve the quality of the experiment. It must be mentioned again however that this experiment is indeed one factor in a much larger and comprehensive study. The project includes testing various cutting lengths in conjunction with site preparation, which will hopefully complement the experiment of Sigurðsson (2004) with noteworthy results. Additional clone types are to be tested on both unfertile and fertile sites so as to contrast one another and test the environmental thresholds.

At times, it was challenging to search for the cuttings in the lupine patches: especially in the control plots. Having larger markers or a piece of string running along to outline where the cuttings are would be more ideal and time-efficient. Approximately 13% of the data was concluded missing, partially due to the fact that it was too difficult to find the cuttings. Ensuring the study plot is properly protected from sheep-grazing would be beneficial, especially when the cuttings grow larger and become more apparent. In addition, having data for the trenching machine in Ytra Seljaland would have proved interesting. Finally, it would have been more pragmatic to obtain a comparison of this experiment in different areas of Iceland. For example, the lupine fields in the north of Iceland are far less vigorous than in the South, due to the reduced precipitation that occurs there. Nootka lupine grows denser and higher in areas with high precipitation and therefore is more competitive for a longer time.

Below is a brief list of accompanying actions that are recommended to be included in future experiments.

- Cutting the lupine to reduce its growth capacity over the summer and reduce competitive edge. It must be implemented in during the flowering period when the seed pods are starting to form but before they have fully matured (Kristín Svavarsdóttir et al., 2016).
- Include black plastic mulch in lupine patches as an extra variable to determine whether it further facilitates productivity as it was shown to do in south-west Iceland (Riege and Sigurgeirsson, 2009). This will increase the cost and organization of the methodology however and must be evaluated as to where or not it complies with the goals of this project.
- Incorporate symbiotic mycorrhizal soil to the plot. Studies have shown that the mycorrhizal hyphae are much more efficient at nutrient uptake, capable of absorbing twice the amount of P as tree roots (Fisher and Binkley, 2000).
- Measure the amount of root growth in the cuttings after a number of years to assess subsoil activity.

When evaluating the results of silvicultural techniques, the ultimate goal of the plantation is important to bear in mind when interpreting the data. For timber forests, volume growth is typically more important than overall biomass. The wood density can often be compromised with increased growth rates showing a negative correlation between ring density and ring width (Mattson, et al., 2007). Results on wood tensile strength on Icelandic-grown black cottonwood suggests that the slower growth rates here produce substantially stronger timber than in their native countries as the cells are smaller and denser. However, in relation to other objectives such as shelterbelts, recreational areas or soil rehabilitation, the trees are less valued for their wood quality and more so for their growth capacities in order to provide shelter and create vigorous roots systems to bind the soil.

## 5. Conclusion

Afforestation methods in Iceland have been developing over the decades through trial and error and it is fair to say that this methodology still exists and is constantly providing useful data. These methods evolve and the effects of prior experiments provide pieces of the puzzle that symbolizes the path towards restoring an ecosystem that has been severely degraded. The analysis of this study revealed that site preparation contributes to survival and growth rates of black cottonwood and that the clone selection should be based on weather requirements for the corresponding clones. These conclusions are supported by the results from previous experiments mentioned throughout the paper.

There is a balance required for achieving something that is both productive and efficient but also cost effective. Further studies and experiments are needed to increase our understanding of what exactly is achievable, and which methods provide the optimal solutions that are required to fulfil whatever specific goals that have been defined

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