The present and future resource situation in larch (*larix sukeczewii*) and lodgepole pine (*pinus contorta*) stands in eyjafjördur, northern Iceland

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Clarification of contribution

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Date 14.05.2012

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Abstract

The study took place at Eyjafjördur, Northern Iceland. In this area an afforestation project called “Nordurlandsskogar” started in year 2000 comprising an area of 936.5 hectares.

There were three main objectives of the present study. The first was to estimate the present standing volume and biomass of forests planted from 1983 to 2010. The second was to estimate the future volume and biomass production of the same area. The third was to estimate the wood supply for the next 60 years according to different assumptions for treatments of the forest.

Based on a systematic forest inventory carried out in 2011, the present resource status was determined. Three different simulation alternatives to estimate the future resource were carried out with IceForest, a planning program applicable for even- and uneven-aged forests. The planning period was 60 years divided into three 20-year growth periods for all simulations. The first simulation, standard thinning, had similar treatments to those usually done in Iceland over the years, i.e. thinning when basal area reaches 8, 21, 25, 26 or 27 m^2/ha for different site index classes with removal of 30 % of the standing volume. For the second simulation, extensive thinning, thinning was applied at the same basal areas as the first, but 50 % of standing volume was removed. For the third simulation, few thinnings at high basal area, thinnings were only allowed when basal area reaches 50 m^2/ha in order to thin as little as possible. 30 % of standing volume was removed.

Standing volume of the area today is 8161 m^3. Total predicted production of the area over a period of 60 years for the first simulation is 578480 m^3 and cutting volume was 220258 m^3. Total predicted production for the second simulation was 515608 m^3 and cutting volume was 283550 m^3 while they were 426743 m^3 and 4179 m^3, respectively for the third simulation

Both the growth models and the IceForest management planning system seem to work well, providing appropriate results regarding how different thinning programs affect total production and cutting volume.

Keywords: Iceland, IceForest, Russian larch, Siberian larch, *Larix sukeczewii*, Lodgepole pine, *Pinus contorta*, simulation, volume growth, production.

Samantekt

Rannsóknin fór fram á starfssvæði Norðurlandsskóga í Eyjafirði og er flatarmál rannsóknarsvæðisins 936,5 hektarar. Norðurlandsskógar voru stofnaðir árið 2000 og er megin markmið þeirra að byggja upp skógarauðlind á Norðurlandi.

Í þessari rannsók voru þrjú megin markmið. Það fyrsta var að reikna út standandi viðarmagn og lífmassa í lerki- og furuskógum sem var plantað á tímabilinu 1983-2010. Annað var að leggja mat á framtíðar standandi viðarmagn og lífmassa sömu svæða. Það þriðja var að finna hvernig skógarauðlind þessa svæðis myndi þróast næstu 60 árin miðað við þrjár mismunandi meðferðir.

Núverandi skógarauðlind var reiknuð út og hermilíkön voru látin meta framtíðar skógarauðlind svæðisins út frá mismunandi umhirðuaðgerðum. Hermilíkönin voru gerð í forritinu IceForest sem er áætlanagerðarforrit fyrir skógrækt og Skógrækt ríkisins hefur nýlega fest kaup á.

Með fyrsta hermilíkaninu, venjuleg grisjun var reynt að líkja eftir grisjun eins og hún er framkvæmd í dag. Grisjað var þegar grunnflötur náði 8, 21, 25, 26 eða 27 m^2/ha . Grisjunarstyrkur var 30 % af standandi rúmmáli. Fyrir hermilíkan tvö, mikil grisjun, var grisjað þegar grunnflötur náði 8, 21, 25, 26 eða 27 m^2/ha og grisjunarstyrkur var 50 % af standandi viðarrúmmáli. Markmiðið með þriðja hermilíkaninu, fáar grisjanir við háan grunnflöt, var að grisja sem minnst. Grunnflöturinn þurfti að ná 50 m^2/ha og grisjunarstyrkurinn var 30 % af standandi viðarrúmmáli. Skipulagstímabilið var 60 ár, deilt niður í þrjú 20 ára tímabil fyrir öll þrjú hermilíkönin. Úttektin var gerð haustið 2001.

Standandi rúmmál rannsóknarsvæðisins í dag er 8161 m^3. Áætluð framtíðar heildarframleiðsla svæðisins fyrir hermilíkan eitt er 578480 m^3 og grisjunarmagn er 220258 m^3. Áætluð heildarframleiðsla svæðisins fyrir hermilíkan tvö er 515608 m^3 og grisjunarmagn er 283550 m^3. Áætluð heildarframleiðsla svæðisins fyrir hermilíkan þrjú af nýtanlegum viði er 426743 m^3 og grisjunarmagn er 4179 m^3.

Vaxtarmódelin og áætlanagerðarforritið IceForest virðast gefa raunhæfar niðurstöður fyrir áhrif mismunandi grisjunar ferla á bæði heildarframleiðslu og grisjunarmagn.

Lykilorð: Iceland, IceForest, Russian larch, Siberian larch, *Larix sukeczewii*, Lodgepole pine, *Pinus contorta*, simulation, volume growth, production.

Abstrakt

Forskningen ble gjennomført på skogreisningsprosjektet "Nordurlandsskogar" sitt operasjonelle område. Studieområdet er 936,5 hektar. Nordurlandsskogar ble etablert i år 2000 med hovedmålsetning å bygge opp en skogressurs i området.

Det var tre hovedoppgaver som skulle utføres i denne forskningsoppgaven. Det første var å beregne stående volum og biomasse av lerk- og contortafuru-bestander plantet mellom 1983-2010. Det andre var å estimere stående volum og biomasse for de samme bestandene. Det tredje var å vurdere hvordan skogressursen på disse områdene vil utvikle seg over de neste 60 årene.

Dagens ressurser ble beregnet og framtidige ressurser ble estimert med simulasjon av tre forskjellige behandlingsmetoder. Planleggingsprogrammet IceForest ble brukt til å utføre simulasjonene. Planleggingsperioden var på 60 år, delt opp i tre 20 års vekstperioder for alle tre simulasjonene.

Den første simulasjonen skulle være tilsvarende dagens behandlingsmetoder på Island. Tynning ble gjort ved grunnflatemål 8, 21, 25, 26 eller 27 m^2/ha. Tynningsstyrke var 30 % av stående volum. Den andre simulasjonen innebærer tynning ved det samme grunnflatemål som den første men med uttak av 50 % av stående volum. Den tredje simulasjonen innebærer få tynninger. Tynninger ble bare foretatt når grunnflatemål nådde 50 m^2/ha med uttak av 30 % av stående volum.

Stående volum på arealet i dag er 8161 m^3. Estimert totalproduksjon for arealet over 60 år i den første simulasjonen ble 578480 m^3 og uttak ble 220258 m^3 . Total estimert produksjon i den andre simuleringen ble 515608 m^3 og uttak ble 283550 m^3 mens de ble 426743 m^3 og 4179 m^3 respektivt, for den tredje simulasjonen.

Både tilvekstmodellene og planleggingsprogrammet IceForest ser ut til å virke godt i forhold til oppnådde verdier for produksjon og uttak ved forskjellige forvaltningsregimer.

Nøkkelord: Iceland, IceForest, Russian larch, Siberian larch, *Larix sukeczewii*, Lodgepole pine, *Pinus contorta*, simulation, volume growth, production.

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1 Introduction

Iceland has a short afforestation history and the country was almost treeless in the 18th century after long time of sheep overgrazing, tree cutting and climate changes. Before human settlements, Icelandic birch forests and woodlands are believed to have covered between 25 and 40 % of the land area (Eysteinsson 2009). In year 1899 three Danish foresters planted "the Pine stand" at Þingvellir. This is considered to be the beginning of organized forestry in Iceland (Eysteinsson 2009).

In 1908 the Icelandic forest service was established. The first years after establishment the focus was on protecting the remaining of the birch forest (*Betula pubescens*) and on small scale planting of exotic tree species. From 1950 the attention has been on afforestation by planting trees (Eysteinsson 2009). Since 1990 annual planting in Iceland has amounted to between 5 and 6 million plants (Eysteinsson 2009). For comparison, in Norway around 20 million plants were planted in 2010 (*Statistics Norway* 2012). Today 1.3 % of the land area is covered with forest. Estimated planted forest area is 47319 hectares and native birch forest covers around 85000 ha (*Iceland forest service* 2009; Traustason 2011).

The official Icelandic policy on afforestation from 1999, revised in 2006, was to increase forest area to cover at least 5 % of the lowlands 40 years from now (*Alþingi Íslands: Lög um landshlutabundin skógræktarverkefni* 2012; Eysteinsson 2009). This plan has now been set aside due to lack of funds for afforestation projects from the Icelandic government.

In Iceland there are two larch species that have been planted most over the last 113 years, Russian larch (*Larix sukeczewii*) and Siberian larch (*Larix sibrica*) (Norðurlandsskógar 2010; Pétursson 2007; Snorrason 1986). In the early years of Icelandic afforestation history experiments with both species and different provenances were established, and results of these experiences showed no statistical difference between the growth of these two species (Eysteinsson 2009; Sigurdsson & Snorrason 1990). All growth and volume equations are also the same for the species. Because of the similarities, the two species will be handled as one, referred to as larch or Russian larch, in this thesis.

In the year 1900, 300 larch trees were planted in northern Iceland on the farm Grund (Snorrason 1986), which is about 20 km south of Akureyri (figure 2). This is considered to be the first larch planting in Iceland. Neither the species nor the provenance was known, but these plantings are considered to be either *L. sukeczewii* or *L. decidua* (Snorrason 1986). The first known provenance of larch (*L. sukeczewii*) seeds from Russia was seeded in Hallormsstadur 1913. Larch (*L.sukeczewii*) has been the most planted tree species in Iceland over the last decades and seeds have been imported to Iceland almost continuously from 1949. This is due to the species capability to grow on infertile, poor and eroded land (Loftsson 1991; Snorrason 1986). The origin of almost all seeds imported to Iceland over the last decades are from Finnish seed orchards. The origin of these orchards is Raviola provenience, although there has never been seed delivered directly to Iceland from the famous Raviola stand (Pétursson 2007). In the inland of north- and east Iceland, larch is the most successful and most important species and will have increasing commercial value in the coming years.

Lodgepole pine (*Pinus contorta*) has its origin from sea level up to 3900 m above sea level in western North America. This makes the Lodgepole pine unique regarding altitudinal range (Karlman 1981). That is one of the reasons why Lodgepole pine can survive under the tough climate conditions in Iceland. The first Lodgepole pine (*Contorta pine*) stand was planted in eastern Iceland in 1940. Most of the Lodgepole pine seeds used in Icelandic forestry is from the Skagway area in southeast Alaska. Lodgepole pine is a popular tree to grow in Iceland because of its ability to grow on poor sites and also because it is used much as a Christmas tree (Loftsson 1991).

There are three main forests projects or organizations that have been planting and conserving old forest remaining in the northern part of Iceland; Nordurlandsskogar (Regional afforestation project), Skógræktarfelag Eyfirdinga (Forest associations of Eyjafjördur) and Iceland Forest Service. They have all similar objectives, but have been established in different periods.

Nordurlandsskógar (NLS) is a regional afforestation project founded in year 2000. The main goal of the project is to create a new resource which in the future will make rural settlements in Iceland stronger, and also to develop economic values in terms of forest (Norðurlandsskógar 2010). Afforestation on farms in the northern part of Iceland began in 1983 and these areas were brought into the regional afforestation project in the year 2000. NLS has made contracts for afforestation comprising 8400 ha on 156 farms. In the year 2010 they had planted about 3500 ha (Norðurlandsskógar 2010). Over 30 different tree species have been planted, but Russian larch is the most planted tree species (48 %), spruce is the second (13 %), pine is the third (9 %) while the remaining species constitute 30 %. (Norðurlandsskógar 2010).

Skógræktarfelag Eyfirdinga (Forest associations of Eyjafjördur) was established in 1930. For the first 30 years the main goal of this project was to conserve the remaining of the birch (*Betula pubescens*) forest, to plant birch (*Betula pubescens*) but also, on a smaller scale, to plant exotic species (Guðleifsson 2000). They have planted about 850 ha since 1930 (Iceland forest service 2012. Icelandic forest research 2012).

As previously mentioned the Icelandic forest service was founded in 1908. Their main goal the first decades was to conserve the remaining of the old birch forest (*Betula pubescens*), but since 1950 the effort has been on afforestation and planting trees (Eysteinsson 2009). They have planted about 405 ha in the northern part of Iceland (Iceland forest service 2012. Icelandic forest research 2012).

Some of the forests that have been developed under these projects have now reached the point that they need to be treated and therefore it's necessary to make a forest inventory to assess the present situation of the forests of north Iceland. It is also important to know about the future production of these forest and different products which may give the forestry industry valuable information about future yield and different products. To do that we need to use tools that can describe the dynamics and future developments of the forest based on the present resource situation.

Recently the Icelandic Forest Service has bought the first forest management planning system for use in Icelandic forestry. The system, called Monte, was originally developed in Finland (Pukkala 2008), but are now developed for Icelandic conditions (Heidarsson, Larus, forest consultant at Icelandic forest service, Email, 25.April 2012). The present work is the first attempt to use the system to simulate the future growth of a larger forest area. Over the years there have been a numbers of tools for this purpose developed in other Nordic countries. In Norway there is a tool called Gaya-Sgis (Gobakken 2003; Hoen & Eid 1990; Hoen & Gobakken 1997) and Avvirk2000 was a development from Avvirk3 in 1999 (Eid & Hobbelstad 2000). Heureka was developed in Sweden in 2005 (*Heureka Forestry DSS*).

There are therefore three main objectives of this research. The first objective is to estimate the present volume and biomass of the larch and pine forests in northern Iceland. The second is to estimate the future volume and biomass production. The third is to estimate the potential supply of wood for the next 60 years according to different assumptions for treatments of the forest.

2 Material and Methods

2.1 Study area description

The study area is located in the northern part of Iceland, 65°N and 18°W, in Eyjafjördur and Fnjóskárdalur (figures 1 and 2). Most of the plantings are located along Eyjafjördur, which is one of the longest fjords in Iceland. Some other plantings are located in the valleys adjacent to the fjord.

The biggest part of the terrain in Eyjafjördur and Fnjóskárdalur is *Betula nana* heath and *Kobresia myosuroides* heath. *Betula nana* heath*:* More than 50 % of the species is *Betula nana* other species that are often in this type of vegetation are *Vaccinium uliginosum, Kobresia myosuroides, Empetrum nigrum,* grasses and willows. The soil is wetter than in other heath types. *Kobresia myosuroides* heath: Usually more than 50% of the vegetation is *Kobresia myosuroides* other species in this type of vegetation are *Empetrum nigrum, Dryas octopetala, Juncus trifidus* and grasses. This type of vegetation is usually very dry and infertile (Snorrason 1993). According to (Helgason 1981); Snorrason (1986) and the Icelandic soil is relatively nutritious when considering the cold climate on the island.

The study area is 936.5 ha where 3.6 million trees have been planted since 1983 (Norðurlandsskógar 2010). Mean annual temperature between 1949- 2011 was 3.60°C, mean annual rainfall was 509 mm and mean annual moisture content was 79.6 %. The meteorological station that provides this weather data is inside the biggest town in north Iceland, Akureyri, located at 65°41.135' N, 18°06.014' W (figure 2). The meteorological station lays 23 m.a.s.l. Most of the rainfall comes in wintertime as both snow and rain. For the last thirteen years weather conditions have both been warmer and wetter than the average basic (*Icelandic Met office* 2012a). Rainfall measuring has been done from 1927 and temperature measurements have been made from 1882 (*Icelandic Met office* 2012b)

Figure 1. Study area.

2.2 Data collection

2.2.1 The distribution of the sample plots

Data collection was done between 24th and 28th October 2011. The measured forests (936.5 ha) are all parts of the regional forest project called Nordurlandsskogar, comprising areas planted between 1983 and 2010.

Sample plots were distributed over the area and did cover 38 different farm forests. The average forest stand is about 53 hectares in this area. The sample plot size was 100 m^2. A minimum of three sample plots was laid out for each age class (based on year of planting) and species. First, 180 of the sample plots were distributed proportionally to the size of the area planted with larch or Lodgepole pine for the different age classes (table 1). In addition, we needed manually to add in more sample plots because some of the planted areas were too small and therefore got zero or only one sample plot. All together 19 sample plots were therefore manually added to the sample plots. After this action the lowest number of sample plots per age class was three. The total number of sample plots was 199 with 163 sample plots with larch and 36 sample plots with Lodgepole pine (table 1).

In some cases the distributed sample plots could not be measured in field. The reason for this was mainly inaccurate registration of the location of the planted area. Therefore only 162 sample plots with larch and 31 with Lodgepole pine, a total of 193 sample plots, were measured.

Table 1. Distribution of the sample plots, age classes and species (S.P.Plan denotes the number of sample plots that were distributed. S.P.M denotes the number of sample plots that actually were measured in field. Ha denotes the number of hectares of forest in each of the age classes.

	Larch			Lodgepole Pine		
Age classes	Ha	S.P. Plan	S.P.M	Ha	S.P. Plan	S.P.M
1983-1985	8,5	3	3	6,1	3	3
1986-1988	9,5	3	4	4,8	3	3
1989-1991	19,1	3	3	3,6	3	3
1992-1994	137,3	27	26	3,7	3	3
1995-1997	111,9	22	22	9,8	3	3
1998-2000	58,1	11	14	12,0	3	0
2001-2003	109,7	22	21	10,4	3	3
2004-2006	187,6	38	38	29,3	6	6
2007-2010	168,5	34	31	46,9	9	7
Total	810,0	163	162	126,5	36	31

Because of large variations in age, diameter and height in the study area, the age classes were divided into two groups; older forest defined as sample plots with more than 50 % of the trees larger than 3 cm in diameter and the younger forest defined as sample plots with 50 % of the trees less than 3 cm in diameter. These two groups are then divided into nine different age classes. Each age class includes three planting years. The first age class ranges from 1983-1985, the second age class 1986-1988 and etc. The last age class was planted between the years 2007 and 2010.

The ArcGIS data program was used to distribute the sample plots randomly. To do that a layer had to be made in the ArcGIS program that only contains the planting of larch. The next step was to make nine layers for each age class and use the command "merge" to make one polygon for each age class. The next step was to make a negative buffer approximately -5 meters around the whole polygon. The area of the polygon and the risk of sample plots landing outside the planted area were thus reduced.

The program "ET GeoWizard "was used to put the right number of sample plots randomly for each age class "random points in polygons". This gave 163 sample plots for larch. The same method gave 36 sample plots for pine. In addition, the 19 previously described sample plots were manually inserted.

The location data of the sample plots were loaded into a GPS device using a program called GPSU, and the GPS was used to locate the sample plots on field. Figure 3 shows how the sample plots were distributed in the area. For some sample plots the GPS coordinates did not locate the plot center inside the planting. In such cases, we walked 30 steps inside the stand, starting from the nearest edge of the plantation.

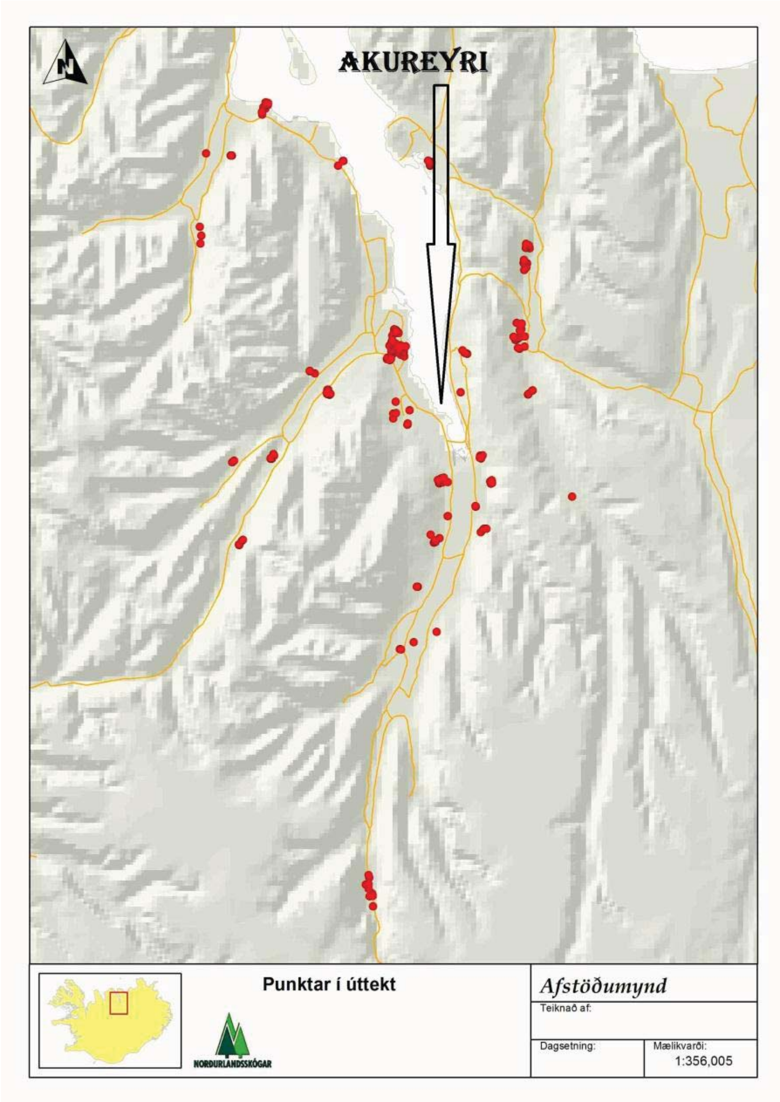

Figure 2. Sample plot distribution and location of Akureyri.

2.2.2 The measurements

The sample plots were circular with a fixed radius of 5.64 m (i.e. the area of one plot is 100 m^2) measured with forest worker tape. On all plots the following registration was done:

- Species registration was done by counting the total number of each species on every sample plot.
- Soil depth was measured with metal stick especially made for that purpose. Soil depth was divided into three classes; first class depth from 0-25 cm, second class depth from 26-50 cm and third class depth 51 cm and more.
- Vegetation classification was checked and registered.

For sample plots defined as older forest diameter at breast height ($d1.3$) over bark for trees larger than 3 cm was measured on every living tree to nearest cm. Trees with diameter less than 3 cm were counted and registered. A tree was measured only if its midpoint was inside the plot. When measuring the diameter it is important to not always measure in the same direction. We therefore turned the handle of the instrument towards the center of the plot when measuring.

On every plot height was measured for the basal area median tree and the smallest and the three largest trees with respect to diameter. The height was measured with a height measuring stick. The basal area was calculated from the diameter measurements and the tree nearest to the middle basal area was measured as the basal area median tree.

For sample plots defined as younger forest all trees within the sample plot were counted, species distribution registered and height was measured on every third tree. In all sample plots the height of the highest tree was measured. This height was classified as dominant height of the sample plot.

All data from the sample plots was put into the data program Excel and classified according to age classes and species. Mean height, dominant height, mean diameter at breast height, basal area and average trees per ha was calculated for the older forest. For the younger forest mean height, dominant height and trees per ha was calculated.

Mean height is average height of all measured trees of each species and age class. Dominant height is the average height of the highest tree of all sample plots in each age and species class. Mean diameter at breast height (d 1. 3) is the average diameter of all measured trees in the sample plots for each age and species class. Basal area (m^2) was calculated for each tree with formula$((D/2)^\wedge 2) * P$. D stands for diameter (d 1. 3) and P is a factor 3.14159265. After that basal area for each sample plot was found by summing up for all trees and divided with 100 to get m^2/ha. Then average m^2/ha was calculated for each age and species class.

2.3 IceForest software and its history

To do the forecast of future timber resources a data program called IceForest was used. IceForest is a calculation and planning program for even- and uneven-aged forests and was developed in Finland by Prof. Timo Pukkala (Pukkala 2000).

The base of the software is a Finnish forest planning system called Monsu (Management Planning Programme for Multiple-Use Forestry).

Monsu was originally developed for tree plantations in Malawi but have also been used in many other countries. Other programs have been developed from Monsu for example Monte and MMForest, which was used by Finnish forestry students to make a forest management plan for a part of Hallormsstadur forest in eastern Iceland. IceForest is the Icelandic version of Monte (figure 3). The program may calculate the present status of a forest area. However, the main use of the program is to help in the compilation of management plans for forests. The following description of the program is based on the user guide for Monte (IceForest) (Pukkala 2008).

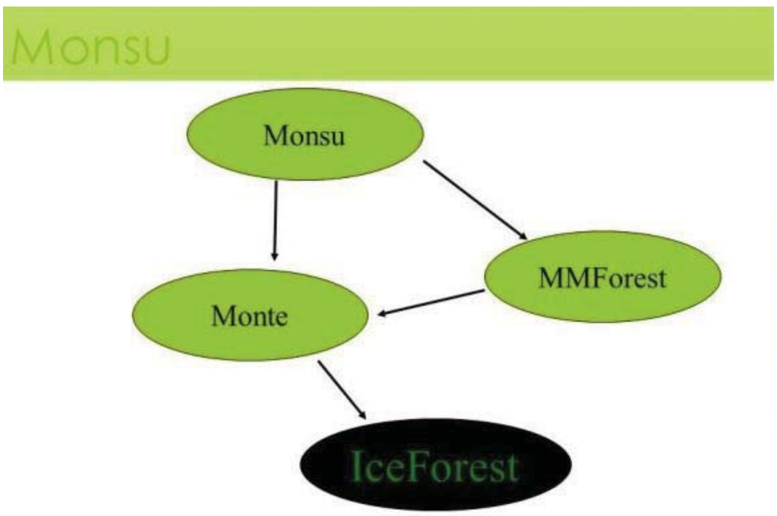

Figure 3. Development of IceForest.

IceForest is suitable for even-aged and uneven-aged single-species stands or species mixtures. In even-aged stands, one species is nominated or selected as the dominant species. The development of a stands dominant height is simulated with the model of the dominant species. When IceForest simulates management alternatives for stands, the instructions that guide the simulation are selected on the basis of the main species, both in even-aged and uneven-aged stands.

IceForest is an open system in the sense that the user can change the names of tree species and their codes, models used in calculation, management instructions (which guide the simulation of treatment schedules) and several other parameters. Therefore, IceForest can be easily adapted to other countries (Pukkala 2008). The main functions of IceForest are:

Data input and Management
Calculation of current status of the forest
Planning (simulation and optimization)

Figure 4 shows the main features and data processes in IceForest.

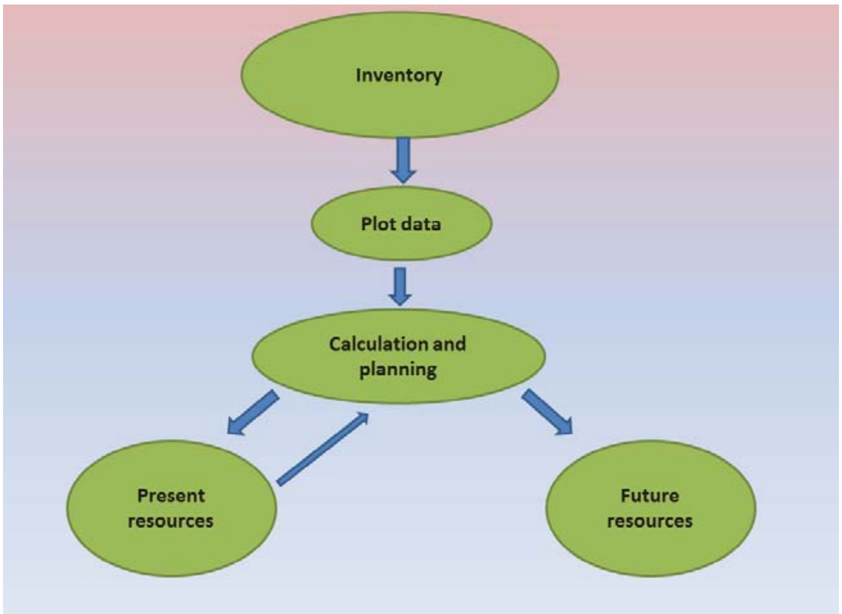

Figure 4. Data process in IceForest.

2.4 Data input

Which plot data that are required in IceForest depends on the variables used in growth models. In this study the following data was required for every stand:

- Stand number
- Province number
- Area of the stand
- Main species
- Age
- Dominant height
- Management system
    - Even-aged management
    - Uneven-aged management
- Main use
    - Production forest
    - Recreation forest
- Distance to road
- Year and month of inventory
- Diameter distribution
    - Species code
    - Diameter
    - Number of trees per hectare in different diameter classes

The diameter measurements of every stand were grouped into diameter classes of 1 cm in this study.

Calculation of present status is based on the empirical diameter distributions of different stands. This way of computing results may be called the diameter distribution approach or tree list approach (a list of trees represents the whole growing stock).

The data of each tree is computed as follows:

- The stand age is used as the age of every tree.
- Tree heights are calculated using a single tree height model.

- The stem volume and assortment volumes are calculated with a taper function.
- Biomasses of various tree components (stem, branches, leaves, roots) are calculated with expansion factors and from that information the carbon content is calculated.

From these characteristics, a set of stand level results is calculated in a straightforward way. Mean diameter and mean height are calculated using tree basal area as a weight variable.

The simulation of treatment schedules uses treatment instructions specified by the user. The instructions can be specified according to rotation length, thinning model, regeneration method, planting density, thinning limit and thinning percentage. There can be up to ten different treatment scenarios.

The growth models used to predict the future yield of larch were made by Pesonen et al. (2009) and consist of a dominant height model, a single tree height model, a diameter increment model and a bark thickness model. The taper models used to predict diameter at any point along the tree stem were made by Heiðarsson and Pukkala (2011). From the taper models volume and assortment structure can be calculated. These models were made for Hallormsstadur eastern Iceland but the growing conditions in Eyjafjördur are similar, so the growth models should give fairly accurate results.
The growth models used to predict the future yield of Lodgepole pine were made by Juntenen (2010) and the sample trees were selected from different locations in Iceland. These growth models consist of a dominant height model, a single tree height model, a diameter increment model, a bark thickness model and a self-thinning model.

2.5 The simulations

The first step of the planning is to simulate treatment schedules for the stands. Different treatment schedules are produced by varying the thinning limit and rotation length decided by the user. Simulation of one treatment schedule for one stand proceeds as follows. If first year of the plan is later then the inventory year the program up-dates the data to the first year of the plan and stand variables are calculated. Then tree growth is simulated to the middle of the first sub-period and the program checks if thinning limits are exceeded. If this being the case the program simulates a thinning treatment and harvested volume is calculated. The remaining trees are left to grow till the end of the sub-period and the stand characteristics are calculated again. After simulating treatment schedules for stands one or several management plans at forest level may be specified. Choosing the best plan is done by defining goals related to treatment and state of the forest. Possible goal variables related to the treatments that can be specified by the user are:

Total harvest
Harvest of saw logs
Harvest of poles
Harvest of firewood
Net income
Cutting area
Regeneration area

Possible goal variables related to the state of the forest in a sub-period are:

Total volume
Volume of saw logs
Volume of poles
Volume of firewood
Stumpage value of the growing stock
Annual volume increment
Annual value increment

The user can put a special weight or goals on the above variables. The goals concern the whole forest area under planning, not individual stands. This means that the optimal treatments of stands are derived from forest-level goals. In figure 5 the first row gives the current status of particular stand. These are standing volume, amount of different products, growth, value today and the value growth. A special weight has been put on standing volume in the forest in all sub-periods. That means that the user want to have high standing volume in the forest in the future. If selecting sawlog in the line below means that the user wants to have as much as possible sawlog production. In figure 6 the orange bar indicates that a special weight has been put on total volume in the 3 sub-periods, in year 2072. That means that the user is especially interested in high standing volume in the third sub-period and the program is then aiming for that in the simulations. The light green bars on the right are the goal aiming for and the dark green bar indicates if the goal can be reached. In this case it will be hard to achieve in the 3 sub-period because the bar does not go very far to the right.

Figure 5. Description of forest status.

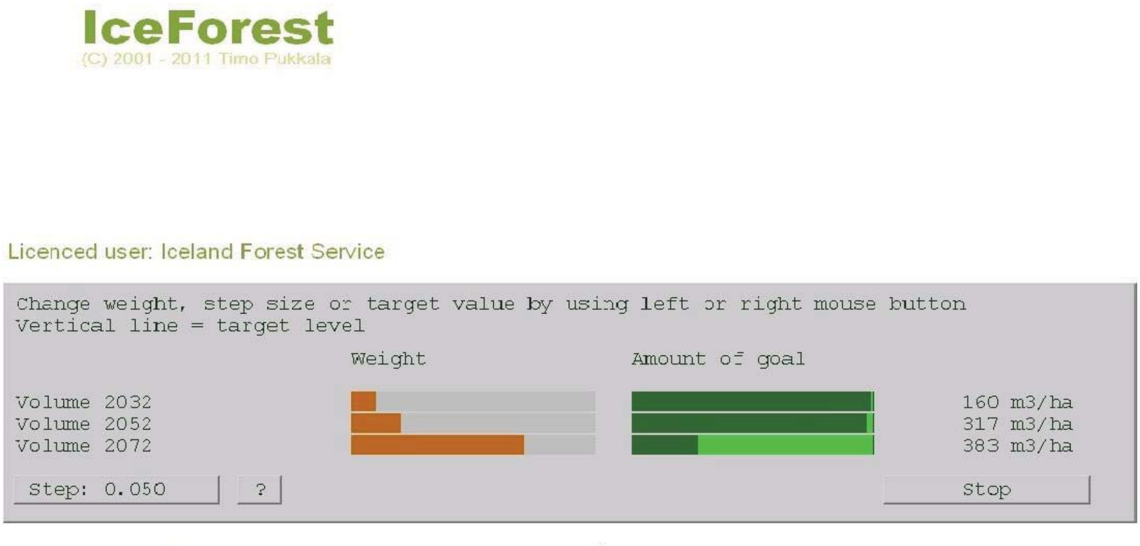

Figure 6. Optimization of volume for the forest stands.

In the present work, three different simulations were done to get varying results according to different treatments of the forest. Those are as follows;

1. Standard thinning. This alternative is similar to the treatments that usually have been done in Iceland over the years. That is thinning when stand basal area reaches 8, 21, 25, 26 or 27 m^2/ha and 30 % of the standing volume is removed. The planning period was 60 years divided into three 20-year growth periods (table 2).

2. Extensive thinning. For this alternative thinning was done when stand basal area reaches 8, 21, 25, 26 or 27 m^2/ha while 50 % of standing volume was removed. The second alterative had the same planning period as the first (table 2).

3. Few thinnings at high basal area. The aim for this alternative was too thin as little as possible. The stand basal area threshold was therefore set to 50 m^2/ha and 30 % of standing volume was removed. Also the third alternative had the same planning period as the first (table 2).

Table 2. Three different simulations.

Simulation	Standard thinning	Extensive thinning	Few thinning's at high basal area
Basal area (m^2/ha)	8, 21, 25, 26 or 27	8, 21, 25, 26 or 27	50
Thinning strenght (%)	30	50	30
Period (years)	3*20	3*20	3*20

Figure 7 shows the settings for the standard thinning simulation. Recommended treatment should be executed when stand basal area reaches certain amount on basal area (m^2/ha) or when the dominant height reaches certain height meters. Iceforest always choses the alternative that reaches the target limit first. In this case Iceforest can recommend treatment in five different basal area parameters and dominant height parameters. First if the basal area reaches 8 m^2/ha or dominant height reaches 4 meters. Second if the basal area reaches 21 m^2/ha or dominant height reaches 9 meters. Third if the basal area reaches 25 m^2/ha or dominant height reaches 12 meters. Fourth if the basal area reaches 26 m^2/ha or dominant height reaches 15 meters and fifth if the basal area reaches 27 m^2/ha or dominant height reaches 18 meters. Settings for side index was set as showed in figure 7 in all sub-periods.

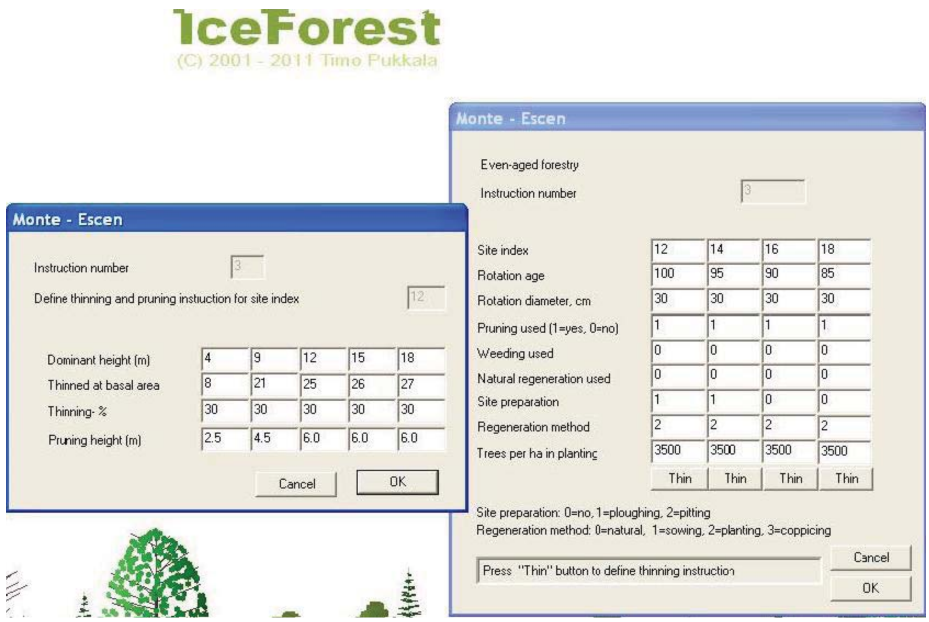

Figure 7. Settings for thinning.

Table 3 shows the settings for the parameters that IceForest needs in order to classify the trees to certain products. The Icelandic timber market is relatively small related to other countries but demand of saw logs is higher than supply from Icelandic larch forests today. This is the reason why the length of the larch saw logs is set to 1.2 meters, the minimum piece length which the log saw can handle (Þorfinnson,Þór, Ranger at Iceland forest service, personal communication by phone. 24.04.2012).

Table 3. Parameters for the products.

Species	Larch			Lodgepole pine		
Product	Log	Pole	Tritu	Log	Pole	Tritu
Length (M)	1,2	3	3	2,4	3	3
Top diameter (Cm)	13	6	2	13	6	2

3 Results

3.1 The present resources

3.1.1 The older forest

Table 4 shows the present resources for the older larch stands. The areas planted were relatively low in the early periods but increased considerably in the period from 1992 to 1997. In general it can also be seen from the table that the stocking parameters (number of trees, basal area, volume etc.) are highest for the stands planted first. Biomass, for example, increases from 22 tons/ha for stand plated in 1998-2000 to 86 tons/ha for stand planted in 1983-1985.

The volume per ha is smaller in the age class 1992-1994 than in the age class 1995-1997 and also the biomass in the same age class is smaller (table 4). The reason for that is possibly that the stands planted in period 1992-94 had a lower number of trees than those planted in 1995-1997. The reason for that can be things such as plant quality, unsuitable provenance or frost in the autumn which had led to higher mortality after planting for stands planted in period 1992-94. The age class 1998-2000 was the only age class that was measured both as old forest classification and young forest classification. This age class is on the boundary of younger and older forest classification and therefore around half the sample plots were classified as older forest (tables 4, 7 and 9).

Table 4. Present situation of the older larch stands.

Year of planting	1983-1985	1986-1988	1989-1991	1992-1994	1995-1997	1998-2000
Area (ha)	8,5	8,4	19,1	124,3	111,9	35,0
Trees/ha	1167	1700	1433	1609	2000	2000
$D_{(1,3)}$ (cm)	11,5	9,7	8,3	5,8	5,8	5,0
Basal area (m^2/ha)	14,0	12,5	7,9	5,1	5,9	4,4
Dom. height (m)	7,5	7,4	6,2	5,2	5,2	4,6
Height (m)	6,2	6,3	4,9	4,3	4,3	3,8
Volume (m^3/ha)	65,0	46,0	29,0	17,0	22,0	17,0
Biomass (tons/ha)	86,0	61,0	38,0	23,0	29,0	22,0

Table 5 shows the present results for the older Lodgepole pine. It can also been seen from the table that the stocking parameters (number of trees, basal area, volume etc.) are lower for the age class 1983-1985 than for age classes 1986-1988. The reasons for that can be many for example, the seedlings may have been of low quality or an unsuitable provenance has been used or the sample plots for Lodgepole pine were very few an gave not statistically representable results (table 1).

Table 5 also shows that there is a higher volume in the age class 1992-1994 than the age class 1989-1991. The probable explanation for that is the density which is quiet larger in age class 1992-1994 than in age class 1989-1991.

Table 5. Present situation of the older Lodgepole pine stands.

Year of planting	1983-1985	1986-1988	1989-1991	1992-1994	1995-1997
Area (ha)	6,1	4,8	3,6	3,7	9,8
Trees/ha	1733	1150	1036	1967	1800
$D_{(1,3)}$ (cm)	7,6	10,1	6,3	7,0	5,1
Basal area (m^2/ha)	8,3	9,7	7,3	7,6	3,6
Dom. height (m)	4,5	6,3	4,5	4,8	4,1
Height (m)	3,8	5,1	3,6	4,1	3,4
Volume (m^3/ha)	15,0	37,0	24,0	26,0	13,0
Biomass (tons/ha)	14,0	35,0	23,0	25,0	12,0

Table 6 shows the present resources for the older mixed Lodgepole pine and larch stands. Only two age classes 1986-1988 and 1992-1994 had sample plots with mixed stands (table 6). This is because there are few mixed stands in northern Iceland and it was not planned especially on the planning process to measure mixed stands. Table 6 shows that there is higher density in the two mixed stands than in same age classes for larch (table 4) and Lodgepole pine (table 5). The reason for that are the planting methods.

Table 6 Present situation of the mixed Lodgepole pine and larch stands.

Year of planting	1986-1988	1992-1994
Area (ha)	0,9	13,0
Trees/ha	2200	2600
$D_{(1,3)}$ (cm)	8,5	6,6
Basal area (m^2/ha)	13,9	10,1
Dom. height (m)	6,8	6,3
Height (m)	5,2	4,0
Volume (m^3/ha)	55,0	38,0
Biomass (tons/ha)	62,0	48,0

3.1.2 The younger forest

Table 7 shows the present resources for the older larch stands. Table 6 shows also that planted area increases rapidly from 35.5 hectares in age class 1998-2000 to 176.8 hectares in the age class 2004-2006 and then declines again to 168.5 hectares in the age class 2007-2010. The reason for that is lower economical budget from Icelandic government for planting in the regional afforestation projects in Iceland. In general it can also be seen from the table that the stocking parameters (number of trees, basal area, volume etc.) are highest for the stands planted first. The period from 2004-2010 had too young forest to get any measured volume (table 7).

Table 7. Present situation of the younger larch stands.

Year of planting	1998-2000	2001-2003	2004-2006	2007-2010
Area (ha)	31,5	109,7	176,8	168,5
Trees/ha	2367	1950	2446	2193
Dom. Height (m)	3,6	2,1	1,3	0,6
Height (m)	2,1	1,4	0,9	0,4
Volume (m^3/ha)	6,0	2,0	0,0	0,0
Biomass (tons/ha)	7,0	2,0	0,0	0,0

Table 8 shows the present resources for the younger Lodgepole pine stands. In table 7 is a large difference in trees/hectare. The same table shows how planted area of Lodgepole pine increases with younger stands although the total planting in Iceland over the period 2007-2010 has decreased after the finance crises. All the stands in table 8 were too young to measure any volume or biomass. Very few measured sample plots support this data (table 1).

Table 8. Present situation of the younger Lodgepole pine stands.

Year of planting	2001-2003	2004-2006	2007-2010
Area (ha)	10,4	21,6	46,9
Trees/ha	2567	1560	1617
Dom. Height (m)	0,5	0,5	0,2
Height (m)	1,0	0,7	0,3
Volume (m^3/ha)	0,0	0,0	0,0
Biomass (tons/ha)	0,0	0,0	0,0

Table 9 shows the present resources for the younger mixed Lodgepole pine and larch stands. There were only two age classes measured in table 8. The reason for that is an inaccurate planting registration. The areas planted were larger or 18.5 hectares in age class 2004-2006 than in the age class 1998-2000 or only 3.5 hectares. The age class 1998-2000 was measured to a low volume but the age class 2004-2006 was too young to get any volume measured (table 9).

Table 9. Present situation of the younger mixed Lodgepole pine and larch stands.

Year of planting	1998-2000	2004-2006
Area (ha)	3,5	18,5
Trees/ha	3300	1875
Dom. Height (m)	2,4	0,7
Height (m)	3,8	1,5
Volume (m^3/ha)	4,0	0,0
Biomass (tons/ha)	0,0	0,0

3.2 The estimation of future resource situation

All results in this chapter is based on the total study area (936.5 ha) and summarized for both species.

3.2.1 Simulation alternative: Standard thinning

Table 10 shows the development of the standing volume (divided into sawlogs, poles, firewood and waste) and biomass for each sub-period over a period of 60 years for the alternative with standard thinnings. It can be seen from the table that the volume is expected to increase from a little more than 8000 m^3 in 2012 to almost 360000 m^3 in 2072. A similar increase is seen for the biomass.

Table 10. Standard thinning: Expected development of standing volume and biomass over a period of 60 years.

Year	2012	2032	2052	2072
Volume (m^3)	8161	149855	296920	358222
Sawlogs (m^3)	393	83938	271119	347012
Poles (m^3)	1979	59230	17969	1751
Firewood (m^3)	4430	2073	6237	9193
Waste (m^3)	1360	4614	1595	266
Biomass (t)	10614	193156	378138	455867

Table 11 shows the expected cutting volumes divided into sawlogs, poles, firewood and waste for each sub-period and in total. It can be seen from the table that the cuttings will increase considerable over time from about 8000 m^3 in the period from 2013 to 2032 to almost 130000 m^3 in the period from 2053 to 2072.

Table 11. Standard thinning: Expected drain and cuttings for the different periods.

Year	2013-2032	2033-2052	2053-2072	Total (m^3)
SawLog (m^3)	1789	63045	122462	187296
Poles (m^3)	5902	17068	3845	26815
Firewood (m^3)	53	795	3288	4136
Waste (m^3)	429	1191	391	2011
CutVol (m^3)	8173	82099	129986	220258

Table 12 shows the suggested treatment areas for thinnings in each of the sub-periods.

Table 12. Standard thinning: Thinnings treatment areas for the different periods.

Period	2013-2032	2033-2052	2053-2072
Normal low-thinning (ha)	191,1	889,5	936,4

Figure 8 shows as an example of development in one age class (planted in 1998-2000) of larch over the 60-year period. The volume growth increases from 6 m^3/ha/year to 18 m^3/ha/year in the first sub-period (2012-2032). In sub-period 2032-2052 the volume growth decreases from 18 m^3/ha/year to 15 m^3/ha/year and in the last sub-period 2052-2072 the volume growth decreases from 15 m^3/ha/year to 13 m^3/ha/year. Total trees per ha decreases over the whole period 2012-2072 from 2000 trees per hectare to 397 trees per hectare.

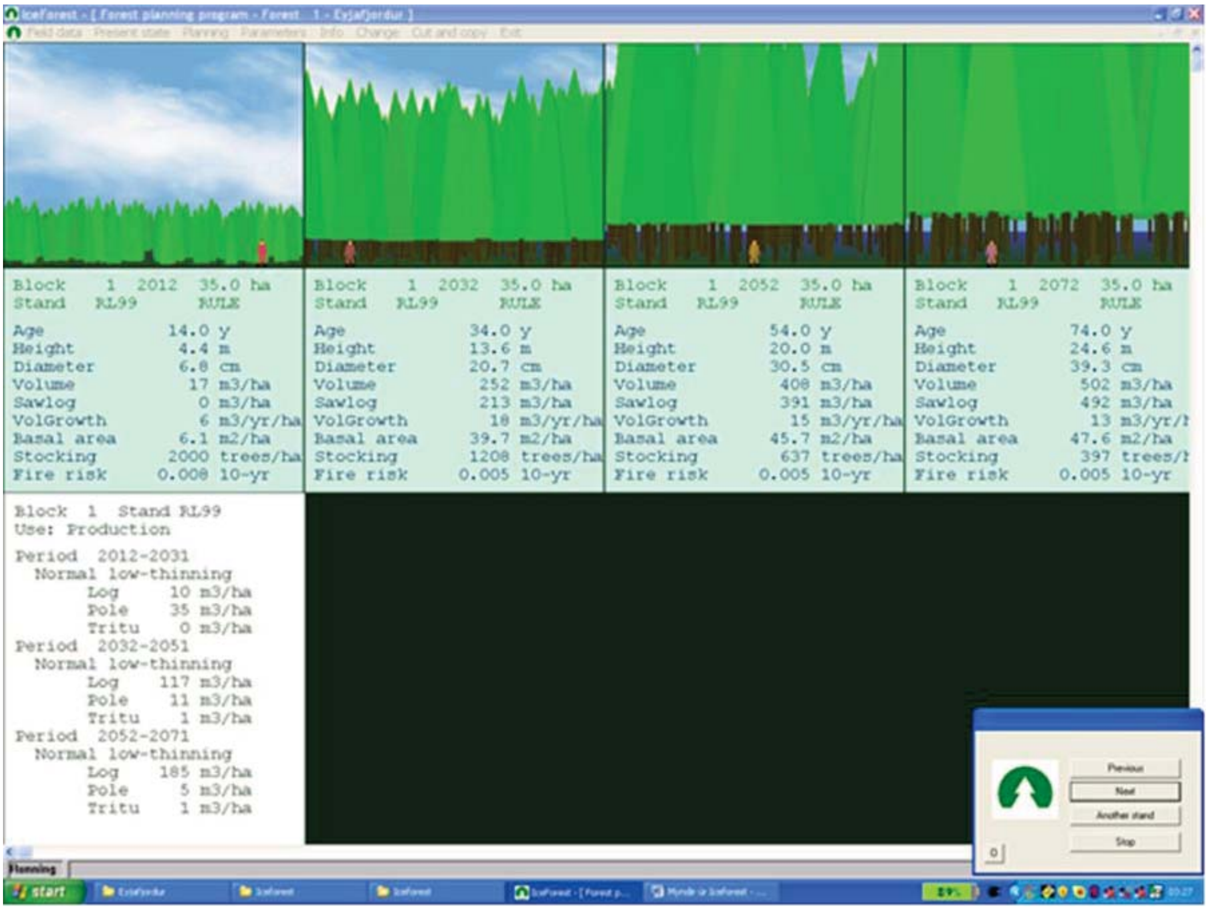

Figure 8. Example of development: Standard thinning, age class 1998-2000, for older larch. The light green columns under the forest picture show the same data as table 9 and a little bit more. The light column in the bottom to the left shows the recommended treatments over the whole period.

3.2.2 Simulation alternative: Extensive thinning

Table 13 shows the development of the standing volume (divided into sawlogs, poles, firewood and waste) and biomass for each sub-period over a period of 60 years for the alternative with standard thinnings. It can be seen from the table that the volume is expected to increase from a little more than 8000 m^3 in 2012 to over 232000 m^3 in 2072. A similar increase is seen for the biomass.

Table 13. Extensive thinning: Expected development of standing volume and biomass over a period of 60 years.

Year	2012	2032	2052	2072
Volume (m^3)	8161	138198	211849	232058
Sawlogs (m^3)	393	74793	194387	225503
Poles (m^3)	1979	56936	11518	91
Firewood (m^3)	4430	2025	4855	6404
Waste (m^3)	1360	4444	1090	60
Biomass (t)	10614	178226	268649	295848

Table 14 shows the expected cutting volumes divided into sawlogs, poles, firewood and waste for each sub-period and in total. It can be seen from the table that the cuttings will increase considerable over time from about 13000 m^3 in the period from 2013 to 2032 to almost 150000 m^3 in the period from 2053 to 2072.

Table 14. Extensive thinning: Expected drain and cuttings for the different periods.

Year	2013-2032	2033-2052	2053-2072	Total (m^3)
SawLog (m^3)	3207	93640	141491	238338
Poles (m^3)	9049	24459	3611	37119
Firewood (m^3)	78	985	4304	5367
Waste (m^3)	608	1745	373	2726
CutVol (m^3)	12942	120829	149779	283550

Table 15 shows the suggested treatment in each sub-period for the extensive thinning simulation.

Table 15. Extensive thinning: Thinnings treatment areas for the different periods.

Period	2013-2032	2033-2052	2053-2072	Total (ha)
Clear felling (ha)	0	0,9	0	0,9
Heavy low-thinning (ha)	191,1	871,7	823,6	1886,4
Plowing (ha)	0	0,9	0	0,9
Planting (ha)	0	0,9	0	0,9
Young stand thinning (ha)	0	0	0,9	0,9

Figure 9 shows as an example of development in one age class (planted in 1998-2000) of larch over the 60-year period. The volume growth increases from 6 m^3/ha/year to 13 m^3/ha/year in the first sub-period (2012-2032). In sub-period 2032-2052 the volume growth decreases from 13 m^3/ha/year to 10 m^3/ha/year and in the last sub-period 2052-2072 the volume growth decreases from 10 m^3/ha/year to 6 m^3/ha/year. Total trees per ha decreases over the whole period 2012-2072 from 2000 trees per hectare to 156 trees per hectare.

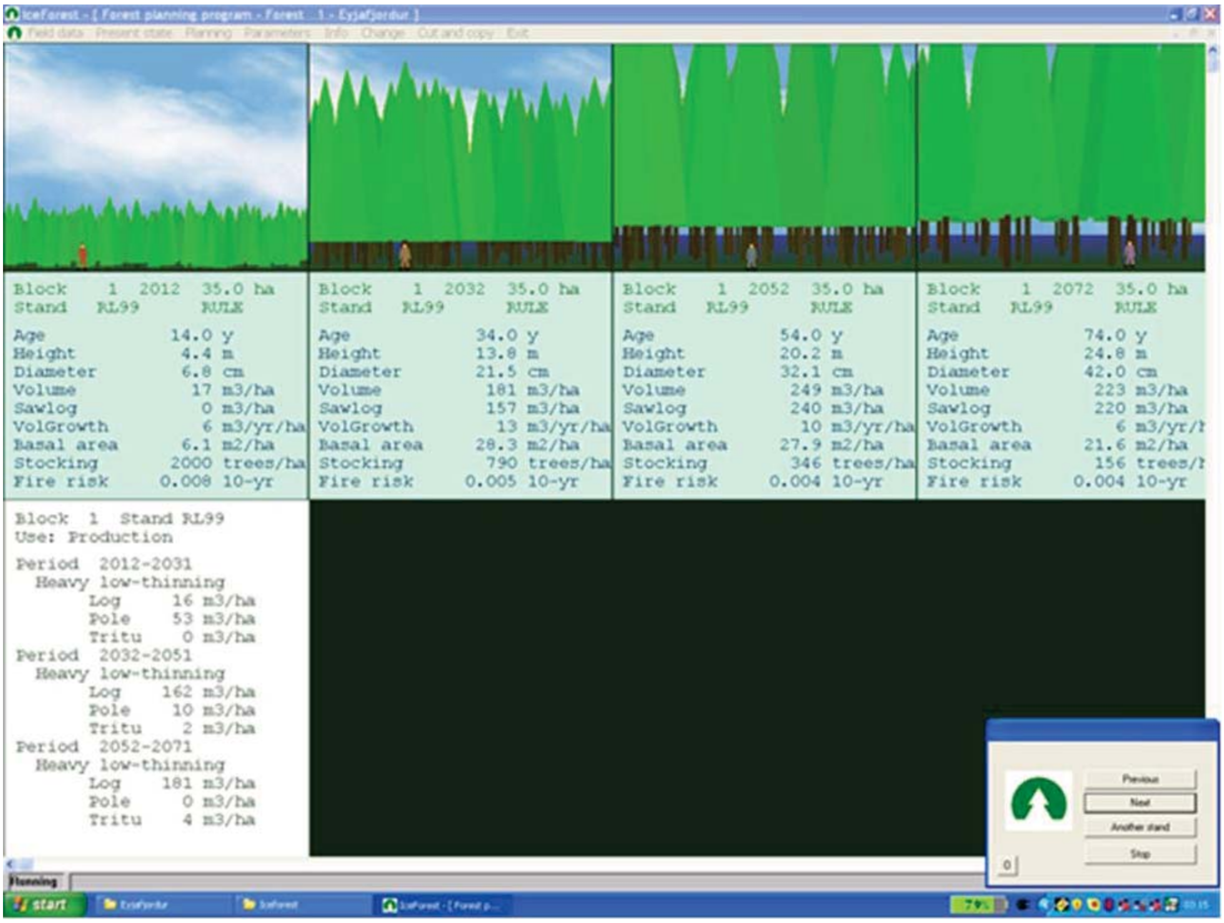

Figure 9. Example of development: Extensive thinning, age class 1998-2000, for older larch. The light green columns under the forest picture show the same data as table 9 and a little bit more. The light column in the bottom to the left shows the recommended treatments over the whole period.

3.2.3 Simulation alternative: Few thinnings at high basal area

Table 16 shows the development of the standing volume (divided into sawlogs, poles, firewood and waste) and biomass for each sub-period over a period of 60 years for the alternative with standard thinning. It can be seen from the table that the volume is expected to increase from a little more than 8000 m^3 in 2012 to almost 232000 m^3 in 2072. A similar increase is seen for the biomass. This simulation was an attempt to make the program wait as long as possible with thinning.

Table 16. Few thinnings at high basal area: Expected development of standing volume and biomass over a period of 60 years.

Year	2012	2032	2052	2072
Volume (m^3)	8161	155603	316821	422564
Sawlogs (m^3)	393	86146	284720	405158
Poles (m^3)	1979	62576	24679	7785
Firewood (m^3)	4430	2056	5310	8737
Waste (m^3)	1360	4824	2113	885
Biomass (t)	10614	200481	403814	538692

Table 17 shows the expected cutting volumes divided into sawlogs, poles, firewood and waste for each sub-period and in total. It can be seen from the table that the cuttings will increase over time from about 717 m^3 in the period from 2013 to 2032 to over 2000 m^3 in the period from 2053 to 2072.

Table 17. Few thinnings at high basal area: Expected drain and cuttings for the different periods.

Year	2013-2032	2033-2052	2053-2072	Total (m^3)
SawLog (m^3)	152	1277	1946	3375
Poles (m^3)	526	129	13	668
Firewood (m^3)	0	20	64	84
Waste (m^3)	39	11	2	52
CutVol (m^3)	717	1437	2025	4179

Table 18 shows the suggested treatment in each sub-period for the few thinnings simulation.

Table 18. Few thinnings at high basal area: Thinnings treatment areas for the different periods.

Period	2013-2032	2033-2052	2053-2072
Normal low-thinning (ha)	13	13	13

Figure 10 shows example of larch forest in age class 1998-2000. For this age class no treatment is recommended and therefore is no removal of wood from this forest stand. Total trees per ha decreases over the whole period 2012-2072 from 2000 trees per hectare to 634 trees per hectare. The differences between total trees/ha in the first sub-period and the last sub-period of this example is 1464 trees/ha. All those trees are dead wood.

The volume growth increases from 6 m^3/ha/year to 20 m^3/ha/year in the first sub-period (2012-2032). In sub-period 2032-2052 the volume growth decreases from 20 m^3/ha/year to 18 m³/ha/year and in the last sub-period 2052-2072 the volume growth decreases from 18 m³/ha/year to 16 m³/ha/year.

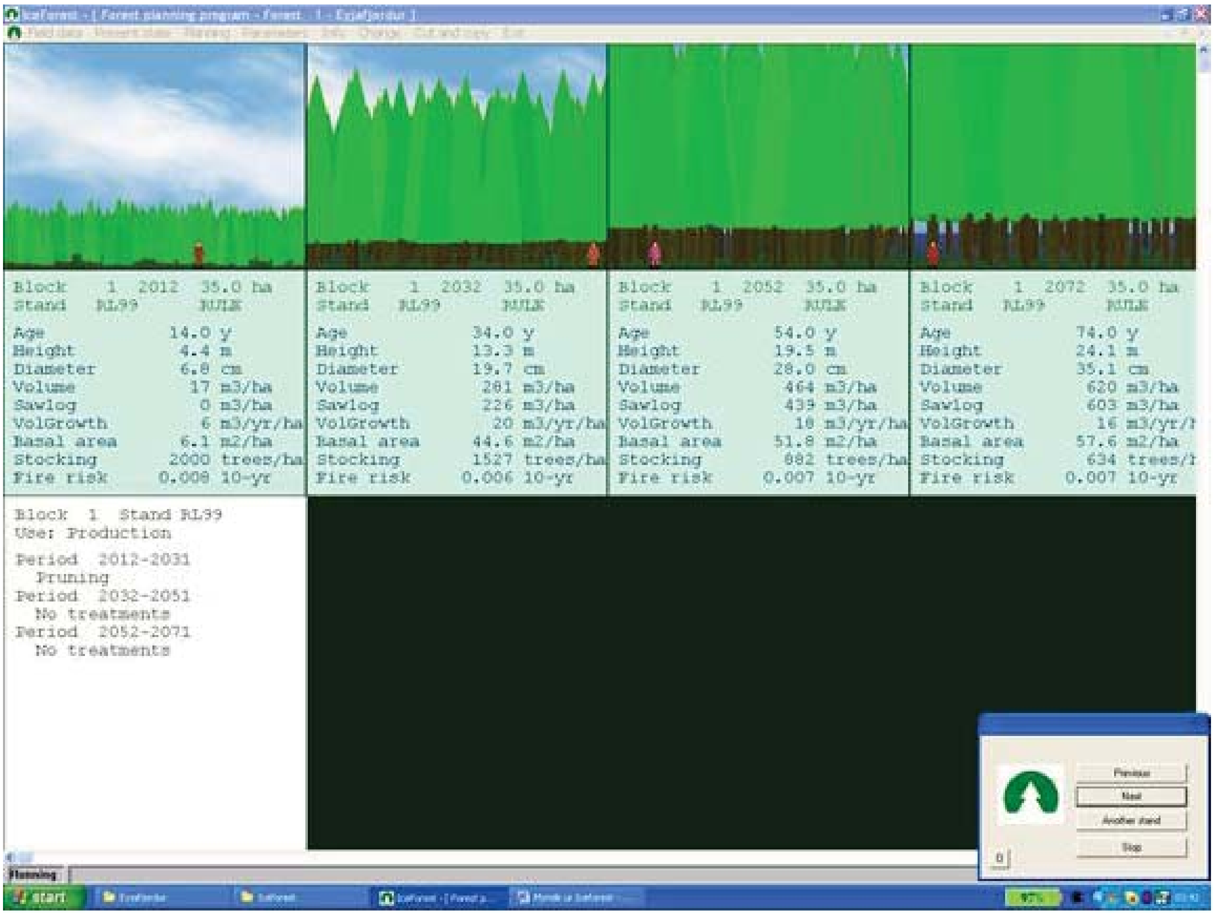

Figure 10. Example of development: Few thinnings at high basal area, age class 1998-2000, for older larch. The light green columns under the forest picture show the same data as table 9 and a little bit more. The light column in the bottom to the left shows the recommended treatments over the whole period.

Table 19 shows the summarized results from all three simulations alternatives at the end of the whole period in 2072.

Standing volume in the end of the simulation period is highest for simulation alternative " few thinnings" with over 420000 m³ in 2072 but "standard thinning" gives almost 360000 m³ and "extensive thinning" gives over 230000 m³ over the whole period. The "few thinnings" alternative gives the lowest summarized cutting volume or only 4179 m³ over the whole period but "standard thinning" gives over 220000 m³ and "extensive thinning" gives over 280000 m³ over the whole period.

“Few thinnings” alternative gives the most biomass or almost 540000 tons over the whole period but the simulation alternative “standard thinning” gives almost 460000 tons and simulation alternative “extensive thinning” gives almost 300000 tons over the whole period. The simulation alternative “standard thinning” gives highest total production (standing volume + cutting volume) in the end of the simulation period or almost 580000 m^3. Total production is defined as “standing volume + cutting volume, excluding natural mortality of the forest stands”. That’s because IceForest does not include dead wood in the volume calculations. Simulation alternative “extensive thinning” gives over 515000 m^3 in total production and the simulation alternative “few thinnings” gives almost 430000 m^3 in total production for the same period. Using these numbers the “standard thinning” alternative gives the highest average volume growth of all the three simulations alternatives or 10.3m^3/ha/year while simulation alternative “extensive thinning” gives 9.2 m^3/ha/year and the simulation alternative “few thinnings” gives the lowest volume growth or 7.6 m^3/ha/year.

Table 19. Summarized results from all three simulation alternatives.

Simulation	Standard thinning	Extensive thinning	Few thinnings at high basal area
SawLog (m^3) total cuttings in the period 2012-2072	187296	238338	3375
Poles (m^3) total cuttings in the period 2012-2072	26815	37119	668
Firewood (m^3) total cuttings in the period 2012-2072	4136	5367	84
Waste (m^3) total cuttings in the period 2012-2072	2011	2726	52
CutVol (m^3) summarized cut/vol from the 4 products above	220258	283550	4179
Standing volume (m^3) in the period 2012-2072	358222	232058	422564
Biomass (t) in the period 2012-2072	455867	295848	538692
Total production (m^3) in the period 2012-2072	578480	515608	426743
Avarage volume growth (m^3/ha/year) in the period 2012-2072	10,3	9,2	7,6

4 Discussion

4.1 Present resources

4.1.1 The older forest

In the older larch stands there was a significantly larger area planted in the period 1992-1994 and 1995-1997 followed by a significant decrease in the period 1998-2000. The density of the age classes has a range from 1167 to 2000 trees/ha (table 4). This high variance between the age classes should not be surprising. Some of the older stands have been thinned and also it is known that the mortality level of young seedlings in Iceland is between 30 and 50 % (Norðurlandsskógar 2010).

The volume (m^3/ha) for larch is smaller in the age class 1992-1994 than in the age class 1995-1997 and also the biomass in the same age class is smaller (table 4). In this case the sample plots measured were relatively many for both age classes, 26 sample plots for age class 1992-1994 and 22 sample plots for age class 1995-1997. The probable explanations for lower volume and biomass in this age class is fewer trees/ha in 1992-1994 than in 1995-1997. The age class 1998-2000 was the only age class that was measured both as old forest classification and young forest classification. This age class is on the boundary of younger and older forest classification and therefore around half the sample plots were classified as older forest.

The oldest Lodgepole pine age class has a smaller volume per hectare than age classes 1986-1988, 1989-1991 and 1992-1994, and almost the same volume per hectare as the youngest Lodgepole pine stand in the older forest (table 5). The oldest age stand has lower height, lower dominant height and smaller diameter than the next age class (table 5). Two explanations are most likely to have caused these results. The first is very few sample plots measured for Lodgepole pine (table 1) and second that some of the stands have been thinned at an earlier stage. The sample plots are so few for the Lodgepole pine that the results could be uncertain. For example no measurements were done in age class 1998-2000 even though three sample plot measurements were planned for this class. The reason for this is inaccurate location of the planting area. In such cases the sample plots lay outside the planting area.

Only a few measurements were done for mixed stands of larch and Lodgepole pine. In the planning process it was not planned especially to measure mixed stands but we did know there would be a few sample plots with mixed stands. Only two age classes were measured for mixed stand, 1996-1998 and 1992-1994 Mixed stands with larch and Lodgepole pine have not been part of the planning process of Icelandic afforestation for a few years because both species are light demanding (*Forestry Commission* 2012) and the experience have showed that the larch shades out the Lodgepole pine (Skúlason, Brynjar, forest consultant at Nordurlandsskogar, Email, 9 May 2012). The densities for mixed stands are a lot higher than for both larch and Lodgepole pine stands. The reason for that is because the pine was often planted year or two later then the larch and often it is difficult to see the small plants of larch. Because there is a higher density in the mixed stands, there is also a higher volume (m^3/ha) and higher biomass (ton/ha) for both the age classes.

4.1.2 The younger forest

For younger larch stands the planted area increases for the first two age classes but decreases in the last age class. The reason for this is the effect of the finance crises that struck Iceland in 2008, giving lower economical budget for planting in the regional afforestation projects. Two of the age classes in the younger larch stands were too young to get any calculated volume (table 7). The density varies between age classes and is almost 500 trees/ha more in the age class with highest density than the age class with the lowest density. The probable explanations for this are weather conditions and mortality of the seedlings. Since the mortality measurements started with NLS in 2001, the highest mortality has been in the years 2003 and 2004 with only 62 % and 65 % of the seedlings surviving (Norðurlandsskógar 2010).

The younger Lodgepole pine (table 8) stands has large variations in density. In the same table it shows how planted area of Lodgepole pine increases with younger age classes. In the last age class the planting of Lodgepole pine is still increasing though total planting in Iceland during that period declined very much from former age classes due to lower budget from the government to afforestation projects. Very few sample plots were measured in the younger Lodgepole pine stands and that might cause the data to be not representable (table 1). There were no measurements of volume (m^3/ha) or biomass (ton/ha) for the younger Lodgepole pine stands. The probable explanations are young forest and small trees.

Measured sample plots for mixed stands in the younger forest were only done in two age classes. The reason for few sample plots measured is low total planted area with these two species mixed and the distribution of the sample plots which was not taken into account in the planning process. To get more sample plots in the mixed stands we would have to measure more sample plots or distribute the sample plots manually. The age class 1998-2000 was measured with little volume but the age class 2004-2006 was too young to get any volume measured (table 9). There is a large variance in density between the two age classes, 3300 trees/ha in 1998-2000 and 1875 trees/ha in 2004-2006. Three explanations are the most probable causes of high density in the 1998-2000 age class. First, very few sample plots measured and those measured had very high density, second different planting methods by local land owners and contractors which is a known factor in some areas an third mortality rate of the seedlings. Unfortunately measurements for mortality don't reach further back than 2001, therefore there is no information recorded for mortality rate of older stands. (Norðurlandsskógar 2010)

4.2 Simulations and estimation of future resource situation

IceForest allows many different assumptions regarding forest status and treatments of the forest. In this paper only a few options were used, and therefore only three different simulations were made. In future research it might be possible to take a closer look at other options and the effect they have on the results from the simulations. Because of very little knowledge about the volume growth of the Icelandic forest stands, it was decided to put the main effort in this thesis on observing the volume growth of Icelandic larch and Lodgepole pine stands to be able to estimate the future resources. The three simulations had different assumptions and accordingly gave different results.

The standard thinning alternative was supposed to simulate treatments similar to what have been done in practice over the last decades. The results showed that the standing volume increases rapidly over the tree sub-periods even though the cutting volume is relatively high (table 19).

Standing volume increases in "extensive thinning" simulation but not as much as in "standard thinning". There is a 22 % higher cutting volume in the second simulation compared to the first simulation. Quantities of different products from the forest are also larger in the second simulation than in the first simulation (table 19).

In the third simulation alternative the attempt was to make a very few thinnings to see the development of the forest if there is little or no treatments over long period. IceForest waited with thinnings until the basal area reached 50 m^2/ha and that reason way the cutting volume is

the lowest of all three simulations or just 1.9 % of the cutting volume in the first simulation and only 1.5 % of the cutting volume in the second simulation. The third simulation has the highest level of standing volume and biomass among all three simulations (table 19).
Figure 10 shows how the larch forest planted in 1999 develops without thinning. Most of the trees in this simulation dies (68 %) from self-thinning caused by lack of light and nutrition (figure 10). Those trees will not become a part of the valuable production in form of for example sawlogs or poles for the forest owner. The third simulation might be well suited if the aim was to promote biodiversity because there is a lot of dead wood in stands with such treatments and dead wood is very important for the survival of rare species and species in danger of extinction (Blindheim et al. 2002). On the other hand it increases the risk of forest fire.

In the first simulation the recommended treatment was normal low-thinning in all periods (table 12). In the second simulation with 50 % thinning, the recommended treatment was clear felling on a small area in period 2033-2052 and heavy low-thinning in all periods. Young stand thinning in period 2053-2072 and planting and plowing in period 2033- 2052 all in small scale (table 15). In the third simulation normal low thinning was recommended in all periods but on a small scale or 13 hectares/period (table 18).

The results from the simulations of treatments of the forests stands were unsurprising. IceForest recommended the same treatment for the first simulation and the third simulation (tables 12 and 18). The only differences were the numbers of hectares recommended for thinning, which was much more in the first simulation. In the second simulation IceForest recommended a quite large range of treatments.

The average annual volume growth for total production over the 60 years simulation period for both species is 10. 3 m^3/ha/year for the first simulation. For the second simulation the average annual volume growth is 9. 2 m^3/ha/year and for the third simulation the average annual volume growth is 7. 3 m^3/ha/year.
One of reasons for this large variation between the alternatives “standard thinning” and “few thinnings” is that IceForest excludes dead wood from the simulation alternatives. This applies specially to the third alternative “few thinnings”.

When the results from this paper are compared with the volume growth tables made by Parviainen (2007) the volume growth for simulation 1 is higher than the average growth measured in that study. For simulation 2 the growth is similar and for simulation 3 the growth is 2 m^3/ha/year lower than the average growth measured.

IceForest recommends different treatments in all the three simulations which give different standing volumes in all the simulations and different amounts of products (table 19). In all the simulations a special weight was set to the variable standing volume. That means the program seeks to maximize standing volume in the simulations for the planning area.
The results of the different scenarios indicate a lot of thinnings in the future for the first and second simulation. The thinnings are essential for good quality forests and continuing the good growth.

4.3 Weaknesses

There are few weaknesses in this study that should be discussed, for example the assumptions for the timber quality of the trees. For the calculations in this thesis there are no evaluations on the tree timber quality added to IceForest. According to Birgisdóttir (2005) there are only on average basis around 281 trees/hectare that are suitable as quality trees for final cutting in large stands in eastern Iceland. This might mean that the amount of saw logs and high quality timber in reality is lower than the results in this study. But Birgisdóttir (2005) also says that the characterization of the trees might have been too harsh and given fewer trees per hectare of high quality. This could mean that there are more than 281 quality trees in each hectare. This is interesting because in standard simulation IceForest recommends 397 trees/ha at the final year of the simulations in a larch stand planted in 1999 and then there is not much left of the growth period. This stand will be 73 years old in 2072 or the final year of the simulations. It’s important for Icelandic forest industry to make more studies to understand better the relationship between total trees per hectare witch have suitable quality for final cutting and the volume growth of those trees to know more about future economical advances of the productions from the forest.

The growth models used to predict the future yield of larch were made by (Pesonen et al. 2009). However, it was recently discovered that these models may overestimate the growth of dense stands and underestimate the growth variation between trees within a stand. The average overestimate of the diameter growth are 0.93 cm in a 5 years growth period

(Heiðarsson & Pukkala 2012). A new model has been made by Heiðarsson and Pukkala (2012) but in order to write this paper in time the old formulas had to be used. That should not give a difference between the simulations but a higher standing and cutting volume for the simulations period than it will be in reality.

Sample plots for the Lodgepole pine stands are too few and that makes the Lodgepole pine measurements not statistically representable (table 1). Even fewer sample plots are measured in the older forest of Lodgepole pine which might give more inaccurate results than for the younger Lodgepole pine stands.

Table 5 shows that the volume for the oldest Lodgepole pine age class is much lower than the younger age classes except for the youngest age class. Thinnings and unstable provenance and bad material of seedlings could explain some of the variance, but in this case most likely too few sample plots gave the somewhat ambiguous results regarding this.

In this thesis prices for the timber are not presented but the program calculates the prices for the wood in relationship to quality and use. Today the Icelandic timber market is quite young and the prices are not reliable, which is why the prices and values were not presented in this paper.

In table 3 the parameters for the top diameter and length of different products from the forest stands are shown. Here the settings for saw logs are assuming a relatively short length. This kind of log, however, can be sold in the timber market in Iceland today where the saw log can saw minimum 1. 2 meter lengths. The market is very small compared to the other Scandinavian timber markets and demand for Icelandic saw logs from larch is higher than supply.

Today no forest industry exists in the study area. With the forest growing like this it might be a good idea to establish companies that can produce from Icelandic forest. It might also be good idea to make more studies like this to get more accurate results.

5 Conclusion

Both the growth models and the IceForest management planning system seem to work well, providing appropriate results regarding how different thinning programs affect total production and cutting volume.

Although there are a few uncertainties related to the inventory, the results regarding the present resources indicate that the forest is growing well in most areas. The present standing volume in the study area is 8161 m^3 and the present biomass is 10614 tons.

The simulation alternative "standard thinning" gave the highest predicted total production (578480 m^3) and the highest predicted average annual volume growth per hectare (10.3 m^3/ha/year) over the 60 years simulation period. The simulation alternative "extensive thinning" gave the highest predicted cutting volume (283550 m^3), but a lower predicted total production at the end of the period (515608 m^3) than "standard thinning" over the 60 years simulation period. The alternative "few thinnings" gave the lowest predicted total production (426743 m^3) over the 60 years simulation period and lowest predicted cutting volume (4179 m^3), but this simulation gives the highest predicted values for standing volume (422564 m^3) and predicted biomass 538692 tons at the end of the planning period. This alternative might be a good treatment to promote biodiversity because there is only a small amount of wood removed.

In this study thinned forests give higher total predicted volume and higher predicted volume suitable for cutting than forests with no or few thinnings.

The volume growth model applied probably overestimates the volume of the forest in this paper, however the results are an indicator for future wood supply from larch and Lodgepole pine stands in North-Iceland. More research is needed on this matter, especially with the new models for volume growth of larch and simulations based only on larch stands, since larch is the most planted species in North-Iceland or almost half of all seedlings in the area.

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