Validation of basal area growth functions for larch in Heureka DSS

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Swedish University of Agricultural Sciences, SLU
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Validering av grundytetillväxtfunktioner för lärk i Heurekasystemet

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Abstract

Larch is getting more common in Sweden. This highlights the need of reliable growth models for larch species in Heureka DSS. Precise and accurate growth models are essential for long-term forest planning. The risk of using under- or overpredicted basal area growth in forest planning is that long-term projections could get more and more imprecise over time. This could, in turn, lead to suboptimal forest management and decision-making, leading to non-optimal choice of tree-species, early- or late timing of silvicultural treatments and ultimately to economic loss. The aim of this thesis was to validate Heureka's basal area growth function for Siberian larch (*Larix sibirica*), European larch (*Larix decidua*) and hybrid larch (*Larix x eurolepis*). To validate the growth function, field trials of larch from all over Sweden were used to compare basal area growth prediction errors between Heureka predicted growth and basal area measured in the field. A sample of plots were also chosen for simulation in Heureka StandWise for further analysis of basal area, height and volume growth. Age-related prediction errors along with ground vegetation type were tested and compared for the Heureka basal area function.

The results showed that basal area growth of Siberian larch was underpredicted at early age and overpredicted at old age, regardless of vegetation type. European larch basal area growth was neither under- nor overpredicted for the vegetation types but showed random error at young age. Basal area growth of Hybrid larch showed a general underpredicted with vegetation type bilberry while no such trend was seen for vegetation type no field vegetation. Heureka simulations showed a slightly higher underpredicted basal area growth than predictions from the growth function. This could be explained by that the predicted growth gets more imprecise over time or due to a too small sample size. There are possibilities to increase the precision of Heureka's growth predicted where one strategy would be to develop and apply species specific growth models in Heureka DSS.

Keywords: Validation, Heureka, *Larix*, *Larix sibirica, Larix sukaczewii, Larix decidua, Larix x eurolepis,* Siberian larch, European larch, hybrid larch, growth model validation, Heureka DSS, basal area growth.

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Abbreviations

DSS	Decision Support System
ha	hectare
NFI	National forest inventory
m^3sk	Forest volume in cubic meters, top and bark included
SIH	Site index based on dominant height
SIS	Site index based on site-dependent factors
MAI	mean annual increment
y	year

1. Introduction

The interest in larch is increasing in Sweden as an alternative to Scots pine and Norway spruce. In Sweden, the growing stock of Norway spruce is 1419 million m^3sk (39,7 % of total growing stock) and 1406 million m^3sk for Scots pine (39,3 % of total growing stock). For all larch species in Sweden the growing stock is around 2,7 million m^3sk (0,1 % of total growing stock) (SLU 2021).

After the hurricane Gudrun in 2005 many forest owners in Götaland started to look for alternatives to Norway spruce, as a measure to spread risks. This has led to larger interest in Hybrid larch due to its high production capacity and that it has similar site requirements as Norway spruce (Ekö et al. 2005). The rapid juvenile growth of Larch makes it possible to get early revenues from harvest. Larch is considered to be more windfirm than Norway spruce as they shed their needles before winter (Agestam et al. 2006).

A current issue in Northern Sweden is multi-damaged young pine forests. The combined effects of ungulate browsing, and Scots pine blister rust (*Cronartium flaccidum*) lower the vitality of pine (Skogsstyrelsen 2019). Siberian larch could be a viable option to plant as a complement to Scots pine in Northern Sweden on medium fertile sites to maintain production.

Sweden's forests are important for producing different values such as wood, biodiversity values, recreational aspects, biofuels and in mitigating climate change. Forest decision support systems (DSSs), such as Heureka DSS, are tools that provide a prediction of how these values develop and interact in a long-term perspective for different tree species.

Larch is relatively new in Swedish forestry with Siberian-, European- and hybrid as main larch species. In Heureka DSS, larch is today included as one species and has no specific basal area growth function but instead uses models for Scots pine to model growth. To give precise future growth predictions, Heureka's growth functions for Scots pine also need to be validated for Siberian-, European- and hybrid larch.

1.1 Larch species

1.1.1 Origin and distribution

Siberian larch can be distinguished as western Siberian larch (L. *sukaczewii* Djil.) and eastern Siberian larch (L. *sibirica* Ledeb.). Western Siberian larch, also called Russian larch, grows mainly west of the Ural Mountains, and meets eastern Siberian larch by the river Ob, east of the Ural Mountains (Karlman 2010; Martinsson 1995). This thesis will not differentiate between the two but refer to them as Siberian larch. In Russia, the growing stock of all Larch species is 25 billion m^3 and larch accounts for 36 % of Russia's forest area (FAO 2015).

Wood and cones from Siberian larch have been found in two places in the Scandes mountains in Sweden, dated by radiocarbon between 8700 to 7500 BP. This is evidence that Siberian larch has occurred naturally in Sweden, while there is no such evidence for European- or hybrid larch (Kullman 1998; Karlman 2010). The Swedish Forest agency has therefore decided that Siberian larch is to be considered as a native tree species while other larch species are considered as "exotic" or "foreign" (Skogsstyrelsen 2009). Consequently, the Swedish Forest agency needs to be informed about European- and hybrid larch plantations larger than 0,5 hectares (Rosvall et al. 2006; Skogsstyrelsen 2009). Predictions show that 19 % of the forest area in Northern Sweden (Norrland) could be used for planting larch, more specifically Siberian larch (Söderholm & Öhman, 2010).

European larch (L. *decidua* Mill.) grows naturally in the mountainous regions of central Europe and is distributed in the Alps, Sudeten, Poland, Romania and Slovakia as seen in figure 1 (Larsson-Stern 2003). European larch was one of the first exotic tree species to be used in Sweden. Larch canker (*Lachnellula willkommii*) has caused severe infections in south-western Sweden, which has led to a replacement of European larch by hybrid larch. There are no records of larch canker in northern Sweden (Karlsson & Karlman 2013). European larch has a relatively high genetic variation between and within provenances. Growth, drought tolerance and resistance to larch canker show large variability among different provenances (Matras and Paques 2008).

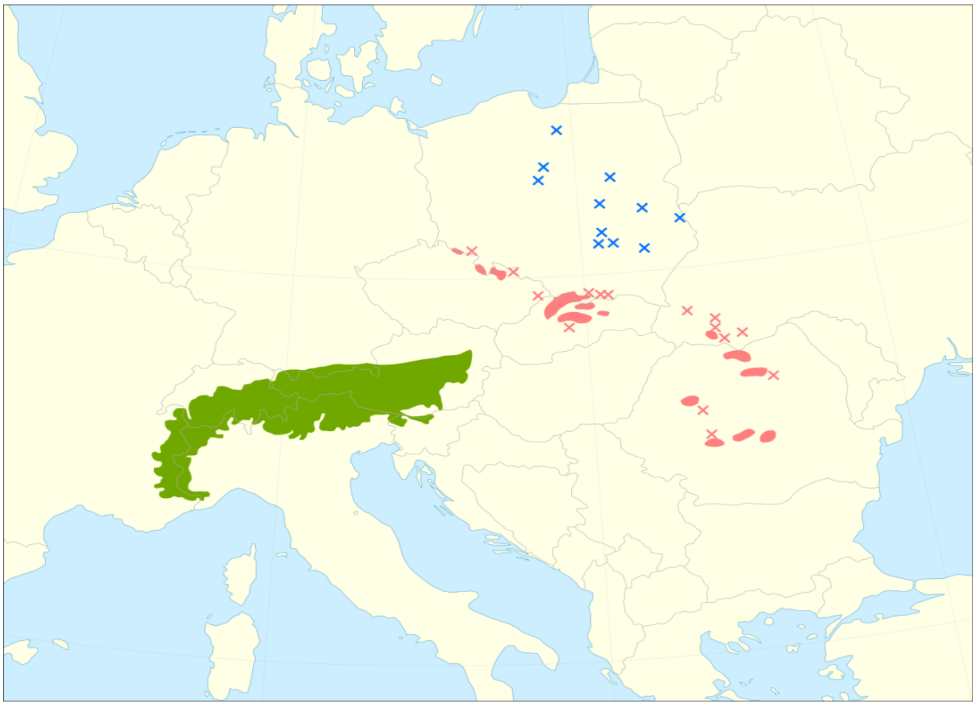


Figure 1. Distribution map of European larch in central Europe. Green area represents subspecies decidua, red represents subspecies carpatica and blue represents subspecies polonica. (Euforgen) (CC BY-SA 4.0).

Hybrid larch (L. × *eurolepis* Henry) is a crossbreeding between the Japanese larch (L. *kaempferi* (Lamb.) Carr.) and European larch (L. decidua Mill.) and was discovered in Scotland during early 1900s (Larsson-Stern 2003; Bergstedt & Lyck 2007). The crossing shows a higher growth compared to the parent species (Bergstedt & Lyck 2007; Ekö et al. 2004) and a higher resistance to larch canker compared to European larch (Larsson-Stern 2003; Ekö et al. 2004). Hybrid larch is today the most planted larch species in southern Sweden (Larsson-Stern 2003). Initially, hybrid larch was thought to show resistance towards root-rot, caused by *Heterobasidion annosum*. More recent studies show that hybrid larch is susceptible to root-rot on sites where Norway spruce was previously infected and on former agricultural land (Wang et al. 2012).

1.1.2 Site requirement and growth

As a pioneer tree species, larch requires a significant amount of light in order to grow well and is sensitive to shading. Water availability is important for Siberian- European- and Hybrid larch. Similar to Norway spruce, larch produces well when growing in slopes with lateral water (Larsson-Stern 2003). Larch is known to have a higher juvenile growth compared to many other conifer species. Mean annual increment of larch culminates early compared to Scots pine and Norway spruce (Bergstedt & Lyck 2007).

In Sweden, Siberian larch grows well on sites with field vegetation of bilberry (*Vaccinium myrtillus* L.) or better (Karlman 2010). The production of Siberian larch is relatively high on sites located on higher altitudes and in cold climate (Martinsson 1995). Field trials show large variations in production capacity of Siberian larch and that selecting suitable provenances is important in terms of yield. Expected maximum mean annual increment (MAI_{max}) of Siberian larch in northern and central Sweden with Vaccinium as the dominant ground vegetation is around 7-8 m^3 per hectare and year. On more fertile farm fields, an expected MAI_{max} is around 9-11 m^3 per hectare and year (Karlman 2010). Field trials show that MAI_{max} of Siberian could be up to 8 m^3 per hectare and year for a 100-year rotation on fertile sites in northern Sweden, which corresponds to a 10-25 % higher yield than Scots pine (Martinsson 1995). The rotation length of Siberian larch is around 55-75 years, however depending on site and goal it could be significantly longer (Westin et al. 2015). Bark thickness of Siberian larch is roughly twice as thick as for Scots pine, which means that excluding or including bark could have a relatively large effect when calculating and comparing growth (Martinsson 1995).

European larch is suitable for planting up to latitude 64°N in Sweden (Karlman & Karlsson 2013) and shows a relatively good growth on medium rich sites with not too compact soils (Larsson-Stern 2003). Expected MAI_{max} of European larch in northern Europe is in the range of 5-10 m^3 per hectare and year (Bergstedt & Lyck 2007). Typical rotation length for European larch is around 80-100 year depending on site but could be shorter (Westin et al. 2015). Experiments of larch species in New Brunswick, Canada, showed a significantly higher growth of European larch compared to Siberian larch (Carswell & Morgenstern 1995).

Hybrid larch grows well on mesic, moderately fertile to rich sites (Larsson-Stern 2003, Ekö 2005). Suitable sites for hybrid larch production are where site index for Norway spruce is G30-G32. MAI_{max} of hybrid larch reaches about the same values as for Norway spruce, but at an earlier stage (Larsson-Stern 2003; Rosvall et al. 2006). An expected mean annual increment on fertile soil (G34) is around 13 m^3 per hectare and year. Here, typical rotation length would be around 35-40 years (Rosvall et al. 2006; Larsson-Stern 2003; Ekö et al. 2004), or slightly longer to produce timber of high quality (Larsson-Stern 2003).

1.1.3 Larch growth models

Ekö et al. (2004) presents a specific basal area growth model for Hybrid larch in southern Sweden. As there is a lack of Hybrid larch field trials in Sweden, managed stands were also used to create the growth model. To predict basal area growth, the model uses the variables site index (SIH), basal area, top height, diameter at breast height and a thinning variable. These variables are relatively few compared to

Heureka's stand-based basal area growth model. For Siberian- and European larch there are currently no species-specific growth models for Swedish conditions.

1.2 Heureka decision support system

The Heureka decision support system (DSS) allows long-term planning of forests by projecting growth and treatment effects over time. Heureka DSS helps users and decision-makers to handle complex forest issues that lie in the future and optimize management based on specific objectives and/or constraints. The development of Heureka DSS was started by SLU in 2002, with the first version released in 2009. (Wikström et al. 2010). Today, Heureka DSS offers three applications for forest planning, RegWise, PlanWise and StandWise. RegWise is used to simulate forest development on a regional scale with various treatment scenarios. PlanWise aims at optimising forest management from the forest owner's perspective and StandWise aims to simulating individual trees and stand development (Elfving 2010). Heureka DSS is today used for research and by many Swedish forest companies for strategic and tactical forest planning.

Heureka DSS predicts growth by using stand-based growth models for basal area and height. These models are based on national forest inventory data measured from 1983-1987. To predict stand-based growth, Heureka DSS uses one general basal area function for all Sweden's forest tree species. The most important variables for the basal area growth function are age, basal area, and vegetation type. The function also used coefficients that include stand proportion of the tree species pine, spruce and birch. When stand-based basal area growth is predicted for larch and other conifers and hardwoods in Heureka, these do not use species-specific coefficients (Elfving 2010).

Height growth is along with basal area growth important as it affects volume growth. Height growth is predicted in Heureka by using height development curves for five-years periods. Input variables for height growth predictions are age and height at the start of the growth period. The larch height function is built on data from 77 permanent plots with the larch species Siberian- European- hybrid- and Japanese larch. Volume growth is predicted from diameter and height data (Elfving 2010).

One alternative approach to using the stand-based growth model in Heureka is by using aggregated growth for individual trees of various tree species. The advantage of using individual tree growth models is that they do not only predict total stand growth, but for also for specific tree species and tree sizes (Elfving 2010; Fahlvik et al. 2014). On the other hand, they tend to make underpredictions of total growth and make less precise growth predictions compared to stand-based growth models (Fahlvik et al. 2014).

1.3 Aim of thesis

The aim of this thesis was to validate the stand-based basal area growth function that is used for larch in Heureka DSS, as this has not been done before. Today, Scots pine is used to predict basal area growth of Siberian-, European- and hybrid larch. By not using species-specific growth functions in Heureka DSS there might be inaccuracies in predicting basal area and thereby volume, which then get more inaccurate over time. This thesis will also investigate how Heureka simulated basal area- height- and volume growth for the three larch species perform against field measurements.

Hypothesis

This thesis will test the hypothesis that basal area growth of Siberian-, European- and hybrid larch predicted in the Heureka DSS does not differentiate from recorded basal area growth of larch based on field measurements.

This thesis will:

- Validate how basal area growth is predicted by the Heureka growth function by comparing it with field measurements of Siberian-, European- and hybrid larch.
- Investigate how errors of predicted basal area growth is affected by age and perform a sensitivity analysis of how vegetation type affects predicted growth.
- Evaluate how simulated basal area-, height- and volume growth of Siberian-, European- and hybrid larch in Heureka compare against growth of field trials and the basal area growth model validation. The simulations will only be done for a sample of production plots and for the vegetation type no field vegetation.

2. Material and method

2.1 Study area

The larch data was collected from field trials from a total of 50 sites laid out over Sweden, as seen in Figure 2. The field trials with European and hybrid larch are mainly located in southern and central Sweden, up to Siljansfors in Dalarna. The field trials with Siberian larch are also located in southern and central Sweden but stretches further up northern Sweden. The field trials also differ in terms of age for the three larch species. The European larch field trials were established during the mid-19th century while the oldest field trials of Siberian- and hybrid larch are 87 and 56 years respectively. Detailed site information for each larch species is found in table 1.

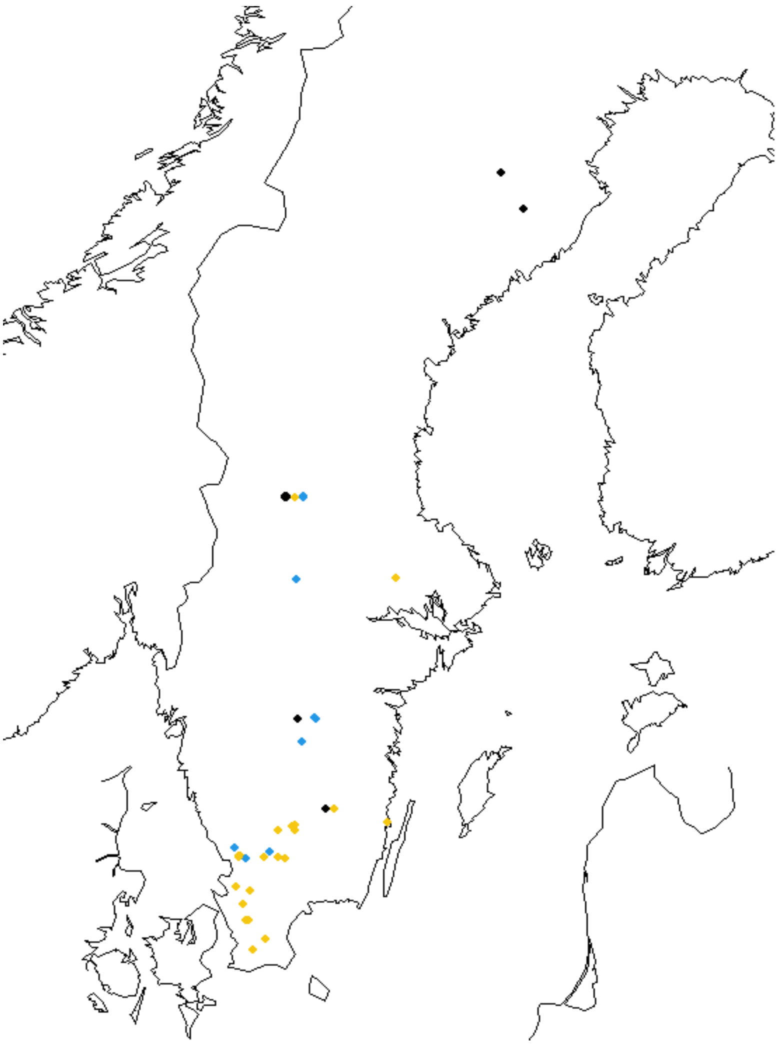


Figure 2. A map over the study area and where the field trials are located. Black dots represent Siberian larch, blue dots European larch and yellow dots hybrid larch.

The provenance choice among field trials was inconsistent for Siberian- and European larch.

Table 1. Site- and stand data for corresponding larch species from selected field trials.

Site- and stand Description	*Siberian larch*	*European larch*	*Hybrid larch*
Number of sites	*17*	*15*	*18*
Number of field measurements	*96*	*144*	*121*
Plot mean size (ha)	*0,124*	*0,149*	*0,092*
*Min-max (mean) age (years) **	*14-87 (41)*	*16-174 (55)*	*11-56 (25)*
Latitudinal range	*58-64 °*	*56-60 °*	*55-60 °*
Min-max altitude (m.a.s.l.)	*175-370*	*60-360*	*10-220*
Min-max (mean) basal area before thinning (m^2 ha^{-1})	*1,7-30,9 (18,9)*	*3,7-44.1 (22,1)*	*5,5-39,4 (24,7)*
*Min-max SIH (m) ***	*16,2–26,3*	*19,1–29,9*	*21,4–34,0*
*Min-max SIS (m) ****	*20,4-24,8*	*22,8-25.6*	*24,1-25,7*

** Age at growth period start*

*** Estimated SIH, H50 for larch*

**** Estimated SIS, H100 for pine with vegetation type no field vegetation*

2.2 Basal area growth model

Elfving (2010) describes the function used for predicting stand basal area growth in Heureka DSS. BEY2 is the adjusted and recalculated growth function of stand basal area and uses various variables and coefficients to explain basal area growth, as seen in table 2. Main variables and coefficients used for predicting growth are age, conifer proportion, vegetation type, basal area, stem number, SIS, and thinning variables. Remaining variables were left unused due to either lack of data or due to irrelevancy for this study (such as basal area proportion for birch and occurrence of peat). The basal area growth function only includes Scots pine-, Norway spruce- and birch- proportions. Therefore, larch uses variables and coefficients connected to pine.

Table 2. Basal area growth function used for predictions and variables explained (Elfving 2010).

BEY2 = exp (0,366 – 0,5842*lna + 8,374*barrdga – 0,0237*tdveg – 0,3192*bjdel2 – 10,8034*bjdkyl + 0,5002*lng – 0,00632*g0 + 1,376*nf + 0,0627*veg – 0,0244*torvveg – 0,0498*moist – 0,1807*wet + 0,0109*sis + 0,0542*dikat + 0,1396*hu0t10 + 0,0567*hu10t30 – 0,06*talldel – 0,03*grandel)

lna	= ln(a), a is age at start of the growth period
barrdga	= [conifer proportion of basal area (0-1)] / a
tdveg	= (pine proportion of basal area) · veg
bjdel2	= (birch proportion of basal area)^2
lng	= ln(g), g is basal area at growth period start (m^2/ha)
g0	= total basal area (m^2/ha) at start of the growth period
nf	= sn/(sn+80), sn is stem number per ha
veg	= NFI code for vegetation type, 0 =bilberry, 3 = no field vegetation
torvveg	= veg if there is peat on the plot, else = 0
moist	= 1 if the plot is moist, else = 0
wet	= 1 if the plot is wet, else = 0
sis	= site index according to site factors for site-indicative species (m)
bjdkyl	= bjdel·‖cold climate‖ = exp[-0.01·(tsumma-300)], where tsumma = temperature sum, day-degrees>+5 ºC = 4835 - 57.6·latitude – 0.9·altitude
dikat	= 1 if there is a ditch within 25 m from plot centre, else = 0
fertris	= takes a value between 0-1 on fertilized plots with veg <12
hu0t10	= 1 if the plot was thinned within 10 years before start of the growth period
hu10t30	= 1 if the plot was thinned 11-25 years before start of the growth period
talldel	= pine proportion of basal area
grandel	= spruce proportion of basal area

2.2.1 Estimation of site index based on site factors and sensitivity analysis of vegetation type

Both site index (based on site-dependent factors, SIS) and vegetation type influence Heureka's basal area growth function. As SIS was unknown for the sites, this value was estimated using the built-in function in Heureka StandWise. Site index was estimated by using latitude, altitude, soil moisture, vegetation type, bottom layer, occurrence of lateral water, soil texture and soil depth as input for each site. Vegetation type and bottom layer was not specified for all site descriptions, but soil moisture was assumed to be mesic, and bottom layer was assumed as mesic moss type for all sites. Vegetation type was assumed to be either bilberry type or no field vegetation. Latitude and altitude were specified in the field data for each site. Lateral water, soil texture and soil depth were not specified for each site but based on assumptions these were estimated to be lateral water in shorter periods, sandy loam till and deep (>70 cm).

A sensitivity analysis of vegetation type was performed to see what influence the two selected vegetation types had on basal area growth. Accordingly, two site indices was estimated for every site based on each vegetation type. Basal area growth validation in RStudio was done for each species and vegetation type, with corresponding site index.

2.2.2 Thinning variables

Heureka's basal area growth model uses the thinning variables hu0t10 and hu10t30 (see table 2) to include the effect of thinning 0-10 years or 11-25 years before the start of the growth-period. Whether plots had been thinned or not could be seen in the field data where volume had been thinned out. All plots and revisions were given a 1 or 0 for each of the two thinning variables hu0t10 and hu10t30, based on if or when they had been thinned within the time interval.

2.3 Validation of the stand-based basal area growth function in RStudio

The program RStudio (version 2022.02.1+461) was used to validate the Heureka predicted basal area growth function against the measured basal area growth of the field data. The basal area before thinning was used for comparing basal area growth. As some revisions had been thinned during the time of revision, the documented basal area was the one after thinning. Therefore, thinned basal area was added to the basal area after thinning to calculate basal area before thinning.

The plot revisions were not updated on a regular basis, which meant that there were deviations in period length between revisions. RStudio was used to calculate period lengths for field measurements. To avoid deviations due to short or long period-lengths, when predicting basal area growth, period lengths shorter than three years and longer than ten years were excluded. By including period lengths of only one, two or three years there is a risk of including years with extraordinary high or low basal area growth. By including period lengths longer than ten years could make it difficult to analyse trends in how basal area growth vary at certain ages. Revisions with insufficient data such as no documented basal area were excluded. Annual basal area growth for the revisions was determined by calculating the difference in basal area between revisions and dividing with years between revisions. As the Heureka basal area growth function make predictions over five-year periods, these values were then divided with five for comparison with measured values.

For each larch species, Heureka predicted growth was compared with field measured growth to locate differences at certain growth rates. For further analysis, prediction error basal area growth was used to examine how differences in growth among field measured- and predicted basal area growth varied over time. Prediction errors were calculated by taking the difference between field measured- and predicted basal area growth. Thus, a positive prediction error value meant that the Heureka growth function produced a lower basal area growth than field measurements. Growth prediction error with positive values were referred to as underpredicted growth and prediction error with negative values as overpredicted growth. For each of the three larch species, mean prediction errors and the prediction error standard deviation were calculated.

2.4 Simulating basal area-, height, and volume growth in Heureka StandWise

To further analyse Heureka growth functions and compare the results from RStudio, Heureka StandWise (version 2.18) was used to simulate basal area-, height, and volume for a sample of plots for the three species. Samples were chosen based on age to see variations in growth over time, but also on geographic location. For the samples, 11 plots of Siberian larch, 12 plots of European larch and 12 plots of hybrid larch were selected.

The default settings in the production model were used for simulations in Heureka StandWise such as Elfving's stand-based growth function, the height development model by Eriksson Elfving and Brandel Lesser for the volume function. This was to make it similar to the normal user experience. SIS was predicted in StandWise as explained in section 2.2.1. with the same assumptions. One major difference is that only vegetation type no field vegetation was used or StandWise simulations.

Simulations were performed in five-year periods for selected stands and compared with corresponding field measurement. StandWise simulations use the first growth period to predict growth for following periods. Therefore, first and following revisions are visualised separately in the results. As period length of the revisions of field measurements were often irregular, the simulated results from Heureka were not always matching. This was solved by interpolating values from the simulations that were located close in time, to give a prediction for a specific period-length. Prediction errors for basal area-, height- and volume growth were calculated by taking the difference between field measured- and simulated basal area growth. Prediction error growth was compared with age to see how growth is influenced over time.

Result type	Variable	Unit	Period 0	Period 1	Period 2	Period 3
Forest Data	Basal area (excl ...	m2/ha	15,53	20,92	25,49	29,35
Forest Data	Dgv Before	cm	15,6	18,6	21,1	23,3
Forest Data	DominantHeig...	m	14,12	16,91	19,4	21,6
Forest Data	Stand Age Before	yrs	18	23	28	33
Forest Data	Volume (excl o...	m3sk/ha	97,63	158	221,82	285,46

Figure 3. Example of a Heureka StandWise simulation from field trial 1693, plot 1, where Hybrid larch is the main species.

2.5 Statistical analysis

Statistical analysis was performed for the validation of the basal area growth function. The statistical analysis was conducted in RStudio by using whisker plots (mywhiskers) to determine whether prediction error basal area growth for larch species was significantly different from zero at different ages. The whisker plots used a 95 % confidence interval for age classes to determine statistical difference between prediction errors. If the whiskers overlapped zero, prediction error growth was not significantly different. By using whiskers enables the possibility to identify differences among independent variables, instead of just comparing the prediction error means. For the Heureka simulation results, no statistical analysis was conducted due to the small sampling size. Instead, the trend was compared ocularly against plots made in RStudio to identify similarities and differences.

3. Results

3.1 Comparing field measured- and predicted basal area growth

When comparing basal area growth from field trials and predictions from Heureka's function in Rstudio, there seems to be some differences and variations among species. For Siberian larch, there are variations in the growth trend as seen in figure 4. For both vegetation types bilberry and no ground vegetation, Heureka tends to overpredict growth at lower basal area growth. At intermediate basal area growth the field measured basal area growth is higher, which indicates that Heureka underpredicts growth.

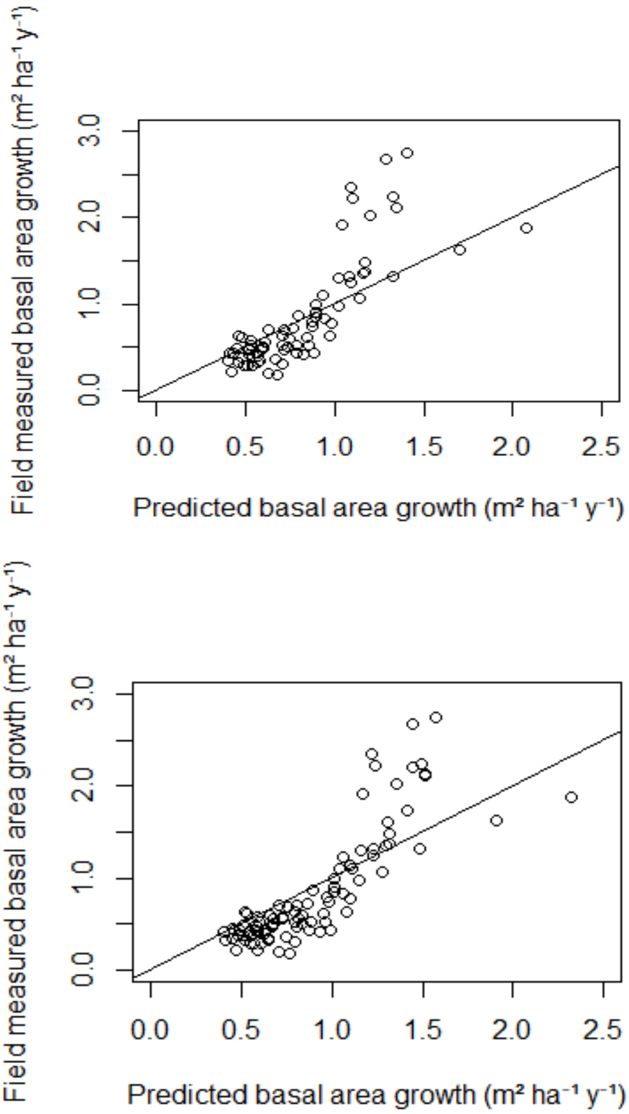


Figure 4. Siberian larch annual basal area growth (m^2 ha^{-1} y^{-1}) for field measurements versus Heureka growth function predictions. Vegetation type for upper plot is bilberry and no ground vegetation for bottom plot.

The basal area growth of European larch from Heureka predictions and field measurements showed a relatively good correlation with some deviations. By looking at figure 5 the Heureka basal area growth function fits well and it is hard to claim whether Heureka over- or underpredicts basal area growth for any of the vegetation types. One observation is that with higher values in basal area growth comes a larger variation between field measurements and heureka assessed basal area growth.

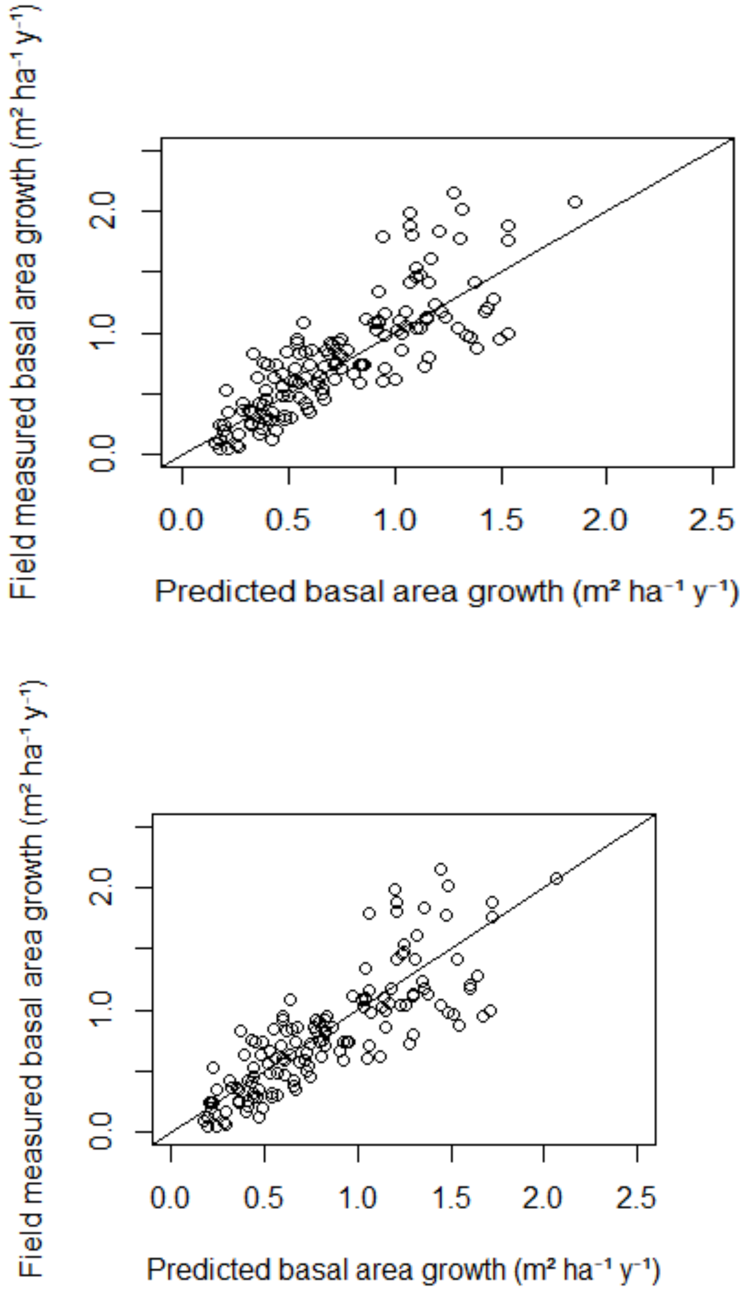
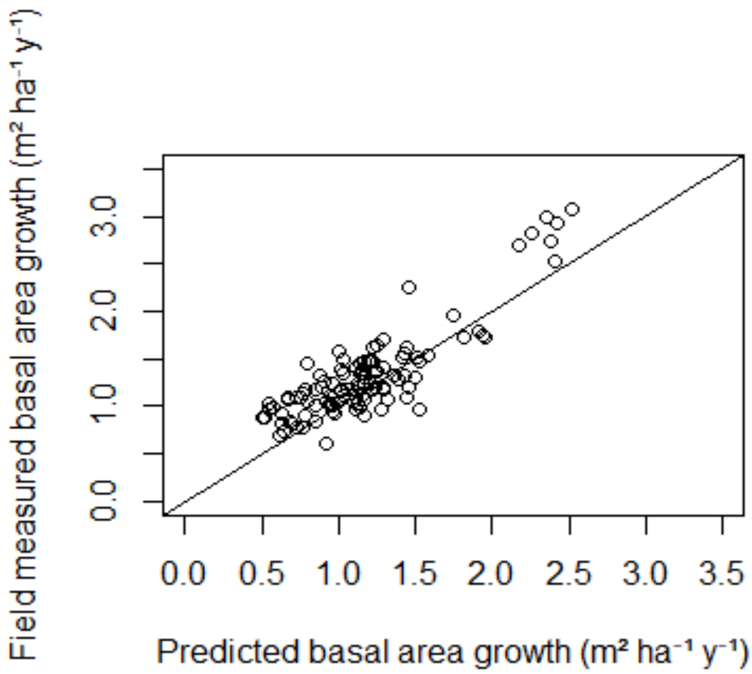


Figure 5. European larch basal area growth (m^2 ha^{-1} y^{-1}) for field data versus Heureka growth function predictions. Vegetation type for upper plot is bilberry and no ground vegetation for bottom plot.

Hybrid larch basal area growth shows some variations in Heureka growth predictions. With vegetation type bilberry, Heureka seems to underpredict basal area growth. On the other hand, with vegetation type set as no field vegetation it becomes harder to interpret if Heureka under- or overpredicts growth.



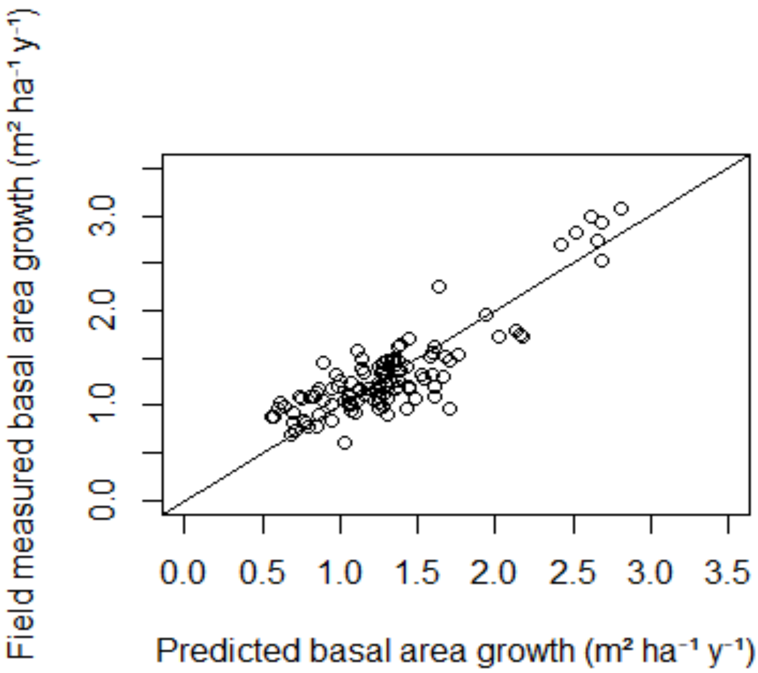


Figure 6. Hybrid larch basal area growth ($m^2\ ha^{-1}\ y^{-1}$) for field data versus Heureka growth function predictions. Vegetation type for upper plot is bilberry and no ground vegetation for bottom plot.

3.2 Age-related prediction errors

Basal area growth of Siberian larch varies with age, which is seen in figure 7 where prediction error of basal area growth is changing over time. The largest deviations among prediction errors are found area found at early- and later age. At early age Heureka underpredicts growth for vegetation-types bilberry and no field vegetation. This is seen where the plot whisker in figure 7 is coloured red and not overlapping with zero. At later age there is an overprediction for both vegetation types. All whiskers for vegetation type no field vegetation are separated from zero when age is 35 and above.

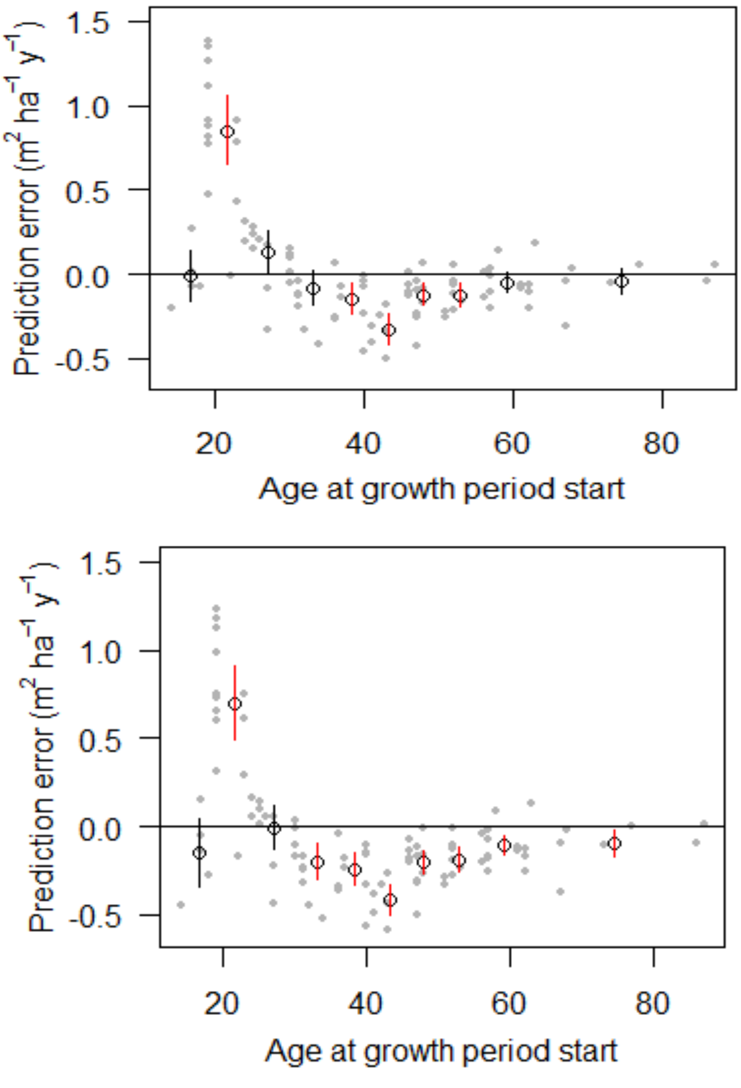
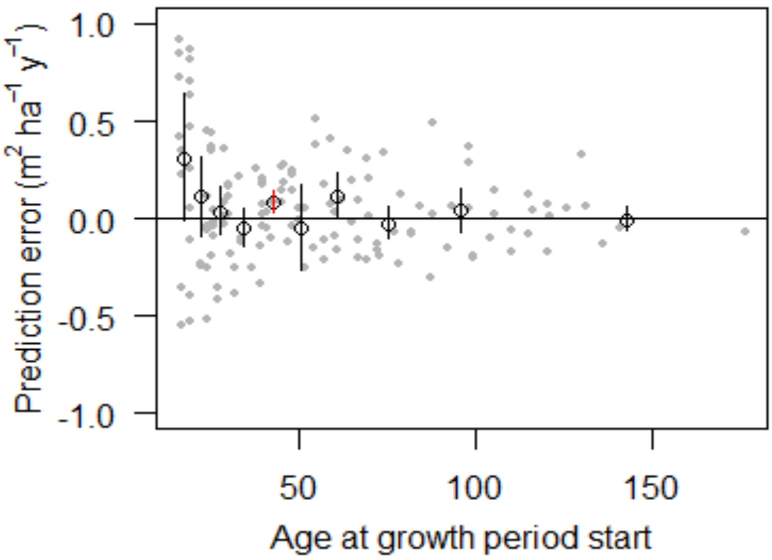


Figure 7. Prediction errors of Siberian larch basal area growth (m^2 ha^{-1} y^{-1}) over age at period start. Black whiskers indicate no significant difference from 0 and red whiskers indicate significant difference from 0. Underlying vegetation type for the Heureka function is bilberry for the top plot and no field layer for bottom plot.

Figure 8 visualizes how prediction error basal area growth of European larch develops over time. There is no clear under- or overprediction at any stage. At early ages there is a larger variation among prediction errors compared to later stages. There are no major differences between vegetation types.



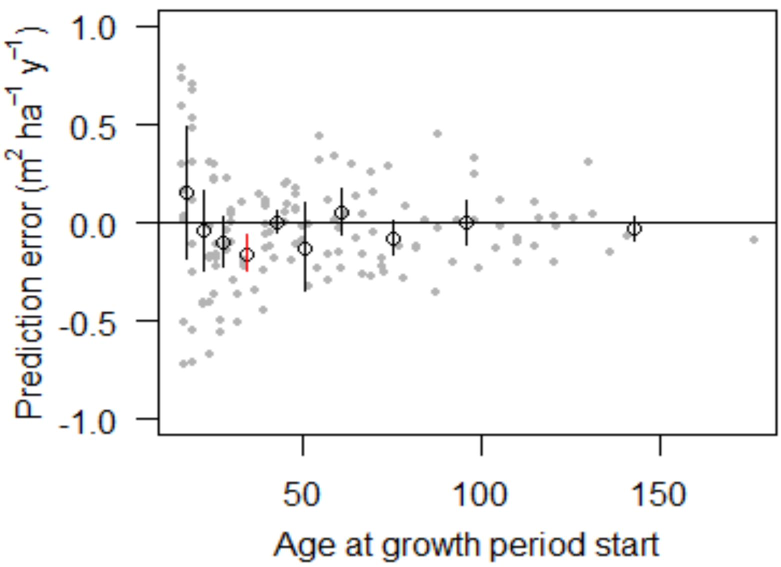
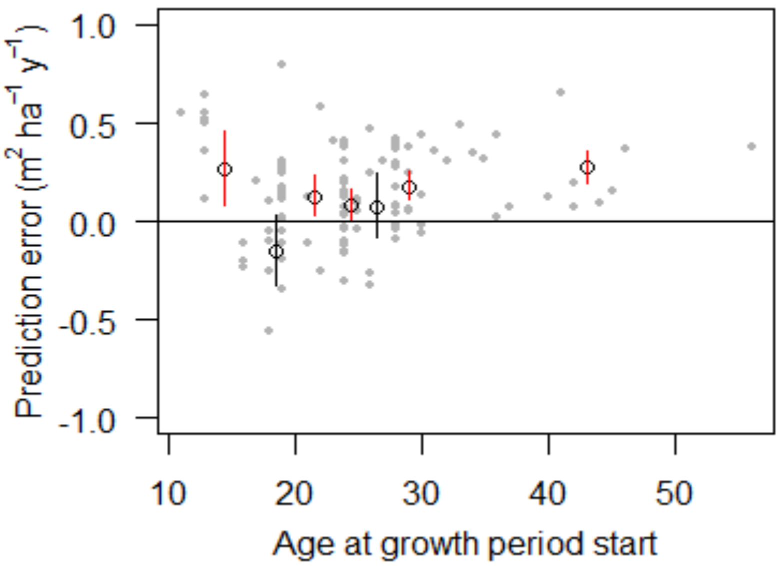


Figure 8. Prediction errors for European larch basal area growth (m^2 ha^{-1} y^{-1}) over age. Underlying vegetation type for the Heureka function is bilberry for the top plot and no field layer for bottom plot.

Results for hybrid larch indicate towards a general underprediction of basal area growth at different ages, when vegetation type is set as bilberry. For vegetation type no field vegetation it is not evident whether Heureka under- or overpredicts basal area growth.



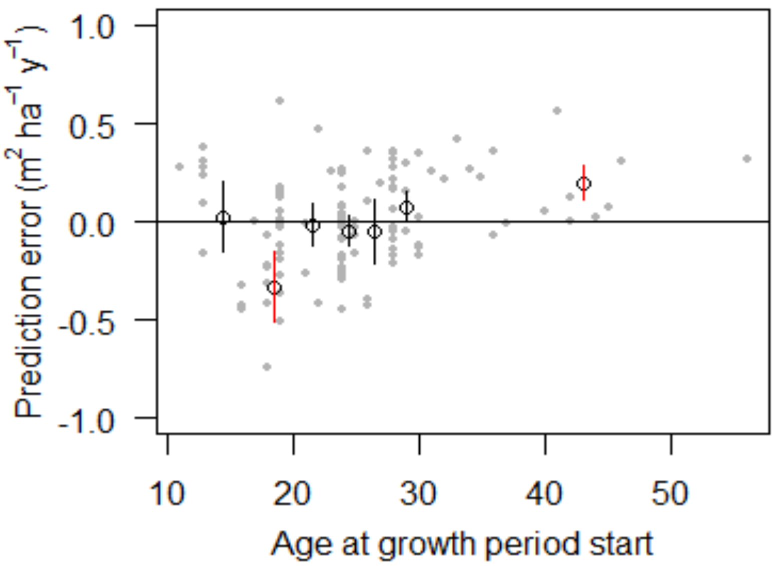


Figure 9. Prediction errors for hybrid larch basal area growth (m^2 ha^{-1} y^{-1}) over age. Vegetation type for upper plot is set as bilberry and as no ground vegetation for bottom plot.

Prediction error means and standard deviations vary for the larch species and vegetation types, as seen in table 3. Prediction error means were relatively close to zero for all larch species except for Hybrid larch with vegetation type bilberry. However, the standard deviation of prediction errors was relatively high. Minimum prediction error standard deviation was 0,367, 0,300, and 0,243 for Siberian, European and Hybrid larch, respectively.

Table 3. Prediction error mean values and prediction error standard deviation for basal area growth ($m^2\ ha^{-1}\ y^{-1}$) of Siberian-, European-, and hybrid larch for respective vegetation type. Mean prediction error and prediction error standard deviation of BEY2 is included as a reference.

Species, veg. type	*Mean res.*	*Std. dev. res.*
Siberian larch, bilberry	0,043	0,386
European larch, bilberry	0,045	0,301
Hybrid larch, bilberry	0,144	0,243
Siberian larch, no field vegetation	-0,055	0,367
European larch, no field vegetation	-0,044	0,300
Hybrid larch, no field vegetation	0,009	0,252
BEY2	0,003	0,156

3.3 Simulated basal area-, height- and volume growth in Heureka StandWise

Simulations in Heureka give similar results for basal area growth prediction error of Siberian larch as the projections in Rstudio. In figure 10 an underprediction is visible during early years but at later ages the prediction error s are relatively close to zero. For height- and volume growth, the trend looks similar with an early underprediction. The prediction error trend for Siberian larch looks similar for first- and following revisions.

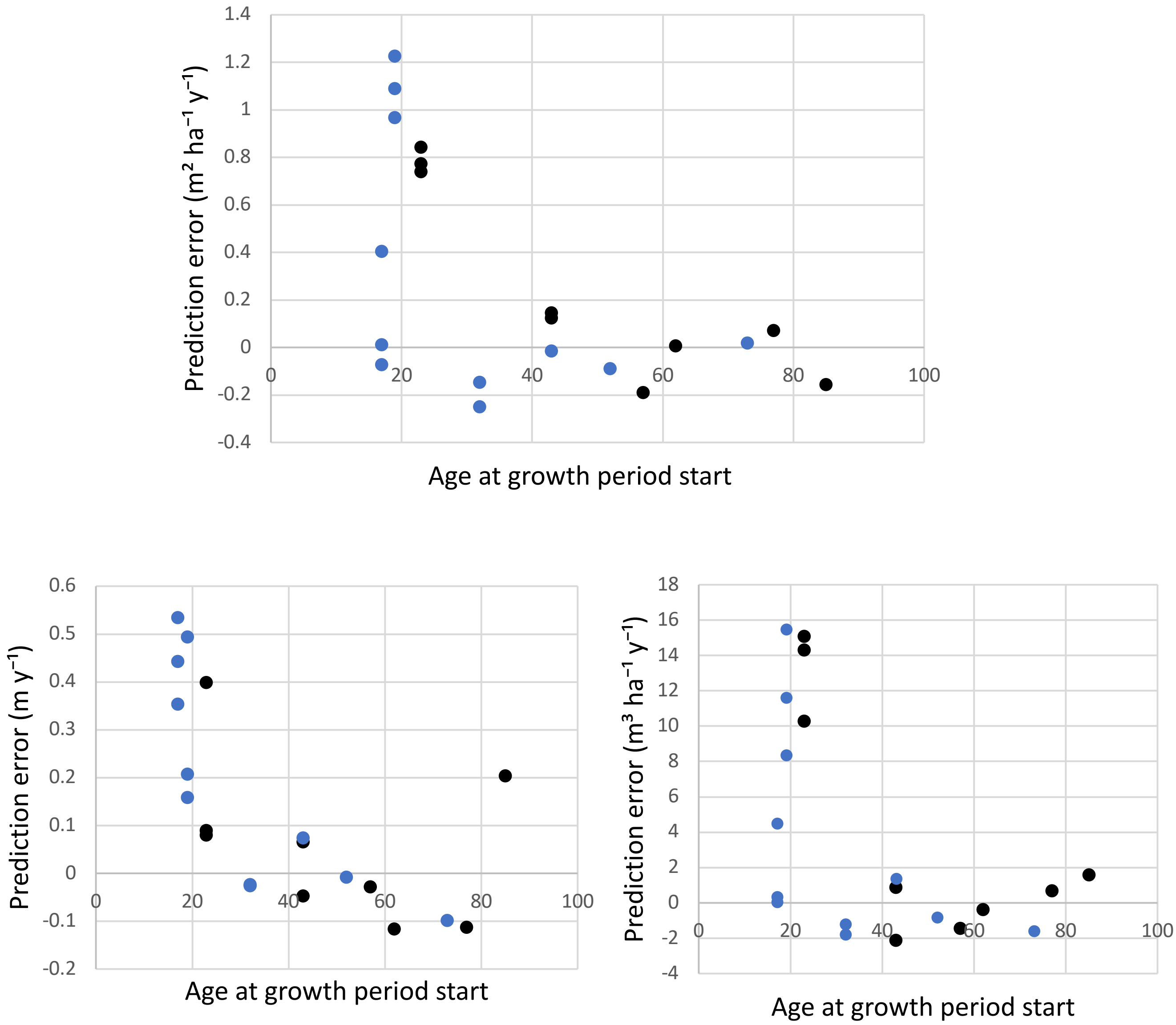


Figure 10. Prediction errors for basal area growth ($m^2\ ha^{-1}\ y^{-1}$), prediction errors for height growth ($m\ y^{-1}$) and prediction errors for volume growth ($m^3\ ha^{-1}\ y^{-1}$) of Siberian larch over time. Blue points represent prediction errors for the first revision and black points represent following revisions.

The results from Heureka simulations, as seen in figure 11, show that basal area growth of European larch is in general underpredicted. Height growth prediction errors of European larch show no real skewness and indicate neither an over- nor underprediction of height growth. Volume growth of European larch shows some variations with tendencies of underpredictions at later age. Volume growth of later revisions tend to be underpredicted more than for first revision.

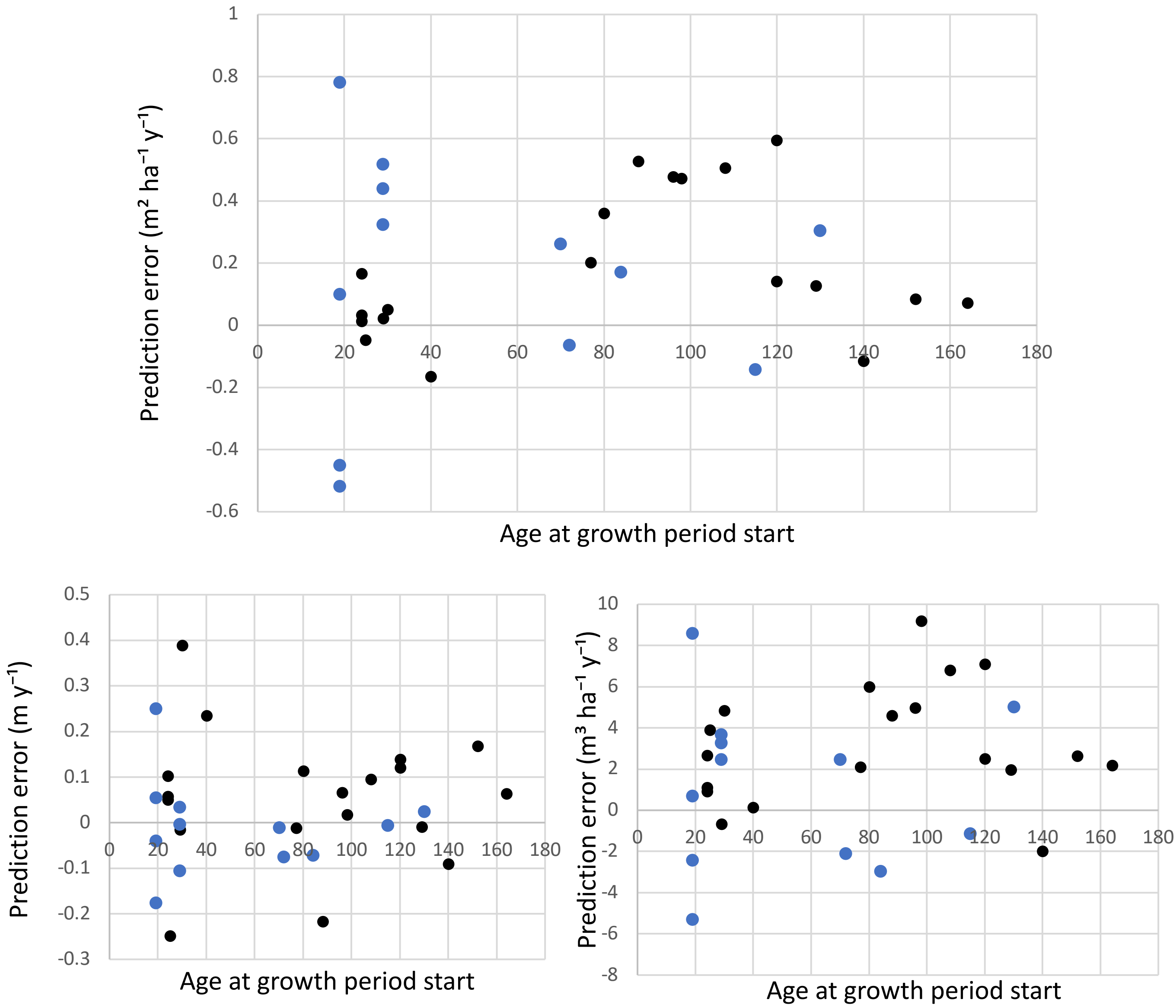


Figure 11. Prediction errors for basal area growth ($m^2\ ha^{-1}\ y^{-1}$), prediction errors for height growth ($m\ y^{-1}$) and prediction errors for volume growth ($m^3\ ha^{-1}\ y^{-1}$) of European larch over time. Blue points represent prediction errors for the first revision and black points represent following revisions.

Simulations of hybrid larch in Heureka show that most basal area growth prediction errors present positive values, as seen in figure 12. This could indicate a general underprediction of basal area growth. However, when only looking at points for the first revision this trend is not as clear.

Height- and volume growth of hybrid larch appear to be underpredicted as the majority of prediction errors are positive. All prediction errors of height- and volume growth for the first revision show positive values.

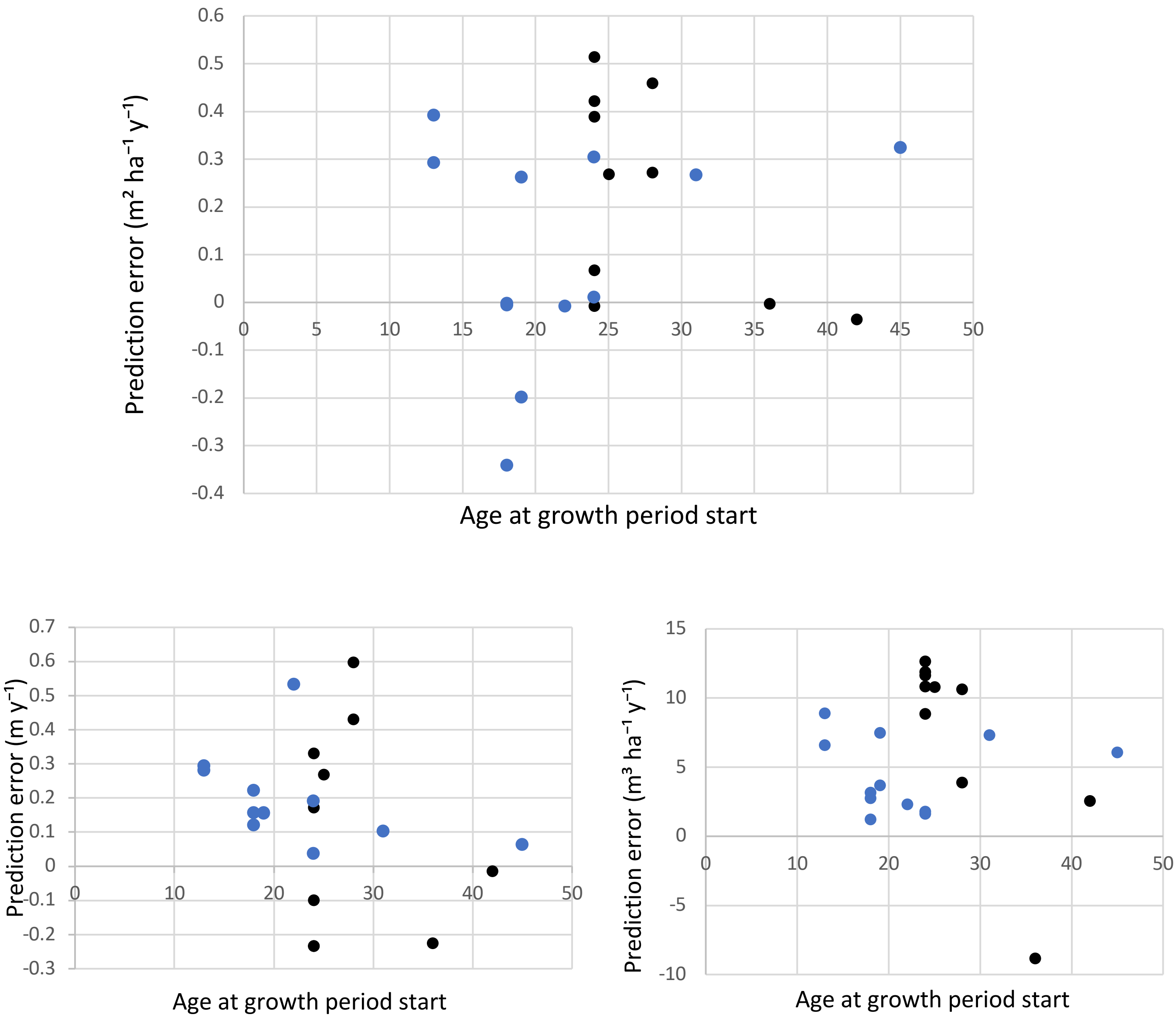


Figure 12. Prediction errors for basal area growth (m^2 ha^{-1} y^{-1}), prediction errors for height growth (m y^{-1}) and prediction errors for volume growth (m^3 ha^{-1} y^{-1}) of hybrid larch over time. Blue points represent prediction errors for the first revision and black points represent following revisions.

4. Discussion

4.1 Validation of basal area growth function in R

The results from validation in RStudio show differences in how well Heureka's stand-based basal area growth functions perform for the three larch species. The mean prediction errors for the larch species, as seen in table 3, show no major deviations for either vegetation type. One exception is for Hybrid larch with bilberry as vegetation type which show tendencies towards an underpredicted basal area growth.

Regarding age-related prediction errors it is evident that age has a high influence on larch basal area growth. This can be seen in the results at section 3.2 and goes in line with precious research (Ekö et al. 2004; Bergstedt & Lyck 2007). Basal area growth prediction errors seem to vary with age, especially for Siberian larch. Basal area growth of Siberian larch is underpredicted at early ages and then overpredicted at old ages. Hybrid larch basal area growth is generally underpredicted when vegetation type is set as bilberry, while no such trend is seen for vegetation type no field vegetation. Basal area growth of European larch is neither under- nor overpredict for the two vegetation types. The hypothesis that Heureka predicted basal are growth of the larch species do not differ to field measured growth can therefore be partly rejected, as European larch still provides reasonable predictions.

The sensitivity analysis shows that the selected two vegetation types play a role in how Heureka's stand-based basal area growth function performs. For the three larch species, vegetation type bilberry tends to underpredict basal area growth more than when using no field vegetation as vegetation type.

4.2 Simulations in Heureka StandWise

The simulations in Heureka StandWise show that basal area growth follows roughly the same trend as the results in RStudio but with a tendency of more underprediction among samples. This could be explained by that the simulations get more imprecise over time, thus leading to a general underprediction. It is however not unthinkable that the underprediction is due to a sampling-related issue and that too few samples were used. Therefore, these results should be treated as an example and not a validation. The results from Heureka simulations show that it is apparent that when both height- and basal area growth are predicted wrong this could, in turn, lead to that volume growth is heavily under- or overpredicted.

4.3 Comparison between results in RStudio and Heureka StandWise

Looking at the prediction error plots of basal area growth in RStudio and Heureka StandWise simulations, some differences are found. As all RStudio predictions are based on field measured values for all revisions, these predictions refer to the actual values. Heureka StandWise simulations instead uses the previous period as input for predicting future growth. If growth is substantially under- or overpredicted at early ages, this could lead to substantial errors in long-term predictions. The simulations use a substantially fewer number of sites and samples compared to RStudio validation.

The advantage with using RStudio is the possibility to calculate all period lengths for field measurements at once. Heureka StandWise simulations instead use a period length of five years, thus making it more time-consuming to manually fit the period length of field measurements. By implementing growth periods of one year instead of five years in Heureka StandWise would make it easier and more efficient to compare period length of simulations and field measurements.

Vegetation type bilberry was not used for simulating growth in Heureka StandWise due to lack of time. According to the results of basal area growth prediction errors from sections 3.1 and 3.2 there are reasons to assume that Heureka simulations with bilberry would underpredict growth more than when using no field vegetation.

4.4 Reasons behind differences in growth among larch species

The basal area growth function is highly influenced by age and basal area (see table 2, section 2.2.). For other species than Norway spruce, Scots pine and birch, the relationship between a certain basal area growth and age and/or basal area could differ substantially. The reasons behind the differences in growth among larch species are unclear. As the growth pattern of larch is more rapid at young age compared to other conifers (Bergstedt & Lyck 2007; Ekö et al. 2004) one might expect that this is not considered by the growth function. However, only Siberian and Hybrid larch are underpredicted at lower ages. European larch growth shows no tendency of under- or overprediction even though there is large variation among growth prediction errors at early age. For Siberian larch, the basal area growth model seems to function insufficiently at both young and old ages. One reason behind the early underprediction for Siberian larch at early growth could be related to provenance choice at field trials, as this might lead to a higher basal area growth at a certain age and basal area.

4.5 Sources of errors and limitations

One error for Heureka StandWise simulations is the small sample size for each, thus making it hard to draw any clear conclusions of how well height- and volume growth are predicted. There are also some errors concerning interpolated values used to compare predicted- and field measured growth, as Heureka's growth-period of five years did not always match field measured period-length. Another source of error is the interpretations of the results of age-prediction errors plots. From certain plots it is clear whether growth is under- or overpredicted while for other plots it is more difficult to determine. Therefore, it is important to look at multiple whiskers as single significantly different whiskers could be due to errors. The number of classes used in RStudio's whisker function also affect how and at which age whiskers are located, which means if fewer whiskers were used this could affect how the results are interpreted.

The assumptions that all sites would have vegetation types to be either bilberry or no field vegetation is not realistic. Among the sites there are most likely those that have other vegetation types, such as low herbs. As site productivity is generally higher in southern Sweden, it is likely that a larger proportion of the sites in the north have bilberry as vegetation type, while no field vegetation should be more common in southern Sweden. There are errors linked to estimating SIS such as assumptions about soil texture, soil moisture moss type and lateral water.

Among the field trials there are different provenances used for the various larch species. For example, it was not well-documented whether Siberian larch plant material was from Russian or Siberian seed sources. Therefore, under- or overpredictions of basal area growth could be connected to variations among provenances and how they perform at a specific site. One source of error is the small plot sizes among field trials, which could lead to edge effects. Edge effects could give small plots high productivity due to higher availability if light, water and nutrients per tree, while large plots might have a lower productivity. As the BEY2 function used in Heureka is based on NFI data and not for field data, there might be some differences when comparing predicted growth with measurements from field trials.

4.6 Implications and future research

This study highlights the need of precise and reliable growth models for long-term forest planning in Heureka DSS. The validation indicates that the stand-based basal area growth model show deficiencies in predicting Siberian- and hybrid larch growth but works acceptable for European larch. The consequences of not having precise growth models could imply a recurring under- or overpredicted stand basal area growth. An underpredicted basal area growth of 0,5 m² per hectare and year could have a considerable effect in a period of 50 years. If also height growth is underpredicted, this affects predicted volume to a large degree.

Silvicultural measures are to a large part based upon stand basal area and height. If growth is underpredicted the consequences could be that for example a thinning or final felling would be carried out 5 or 10 years later than recommended. This could, in turn, lead to more wind-throw damages due to late thinnings and suboptimal decision-making such as unsuitable choice of tree species. Consequently, this could result in lower economic yield, higher costs, lower production, less carbon sequestrated and so on. As Heureka DSS is a tool that today is used for research purposes and by forest companies, this further stresses the need of precise growth models.

To increase the precision of Heureka's basal area growth model one strategy could be to integrate species-specific stand-based models in Heureka, instead of changing the existing stand-based model. For hybrid larch, the growth model presented by Ekö et al. (2004) (see section 1.1.3.) could be a viable option. For Siberian larch the option might be to develop new growth models based on Swedish field trials. European larch performed satisfactory in the validation, but a long-term strategy would be to develop growth models for it as well, as prediction errors show a large variation at young age. One issue for both Siberian and European larch could be that there are not enough field trials or larch data from NFIs to develop new models. This highlights the need of establishing more long-term field trials for the three larch species at different sites in Sweden. One option when developing new models is to additionally use managed stands as a compliment to field trials to produce growth models, as described by Ekö et al. (2004).

This study emphasises that more studies are needed to further validate basal area-, height-, and volume growth of larch is simulated in Heureka. Furthermore, this study raises the question that Heureka's stand-based basal area growth function needs to be validated for more forest tree species that today use birch, Norway spruce and Scots pine to predict growth.

5. Conclusions

This study has validated basal area growth for Siberian-, European- and hybrid larch Heureka DSS. The null hypothesis that there is no difference between Heureka predicted – and field measured larch basal are growth can be partly rejected.

The results from RStudio show that prediction errors of basal area growth vary with age and vegetation type. Siberian larch basal area growth is underpredicted at young age and overpredicted at old age. Hybrid larch shows tendencies of underprediction for vegetation type bilberry. European larch neither under- nor overpredict basal area growth, regardless of age or vegetation type. It is unclear why there are such large differences among species. Heureka StandWise simulations indicate that under- or overpredictions of both basal area and height growth influence volume growth to a large degree.

For long-term forest planning it is important with precise growth predictions for decision-making. By using under- or overpredicted basal area growth in forest planning there is a risk that long-term projections could get more and more imprecise over time, thus leading to non-optimal forest management. To increase the precision and accuracy of predicted growth in Heureka DSS, one strategy is to integrate existing species-specific growth models or to develop new models.

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Can we afford to use unreliable data for long-term forest planning?

- Validation of basal area growth functions in Heureka DSS

INTRODUCTION

Long-term planning and predicted future growth are keystones in forestry. As larch is getting more common in Sweden there is a need of accurate and precise growth models. Consequences of not having precise predictions could lead to suboptimal forest management and economic loss.

AIMS

To validate the stand-based basal area growth function that is used for Siberian- European and hybrid larch in Heureka DSS.

HOW AND WHERE?

By comparing Age-related growth prediction errors from Heureka predictions with field measurements from all over Sweden.

RESULTS

Siberian larch basal area growth is underpredicted at young age and overpredicted at old age. Hybrid larch shows tendencies of underprediction for vegetation type bilberry.

CONCLUSIONS

- The validation indicates that the current function works decent for European larch but not for Siberian and Hybrid larch
- New species-specific growth models should be implemented for the larch species in Heureka.

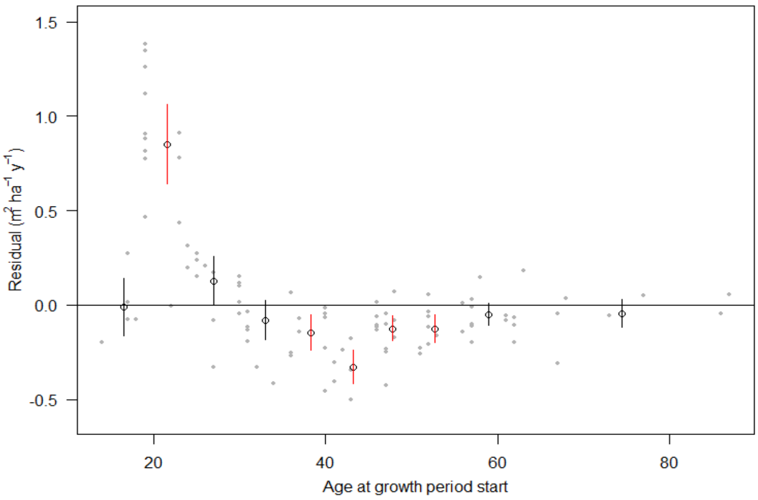

Figure showing age-related growth prediction error for Siberian larch

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