Dynamics of tree- and forest lines over time

A case study from Lærdal, Western Norway

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Abstract

Temperature is believed to govern the global distribution of tree- and forest lines, but the effect of the on-going global warming on the position of the lines is not yet fully understood. By repeating an 80-year-old study of tree- and forest lines in Lærdal, southwest Norway, this study provides new insights into the elevation, dynamics and properties of tree- and forest lines in northern areas.

Elevations of tree- and forest line were equally distributed along the Lærdal valley, and were mainly explained by annual precipitation, aspect and slope. Drought stress was shown to limit the amount of available area suitable for establishment of new trees, but a decline in precipitation was also associated with increased elevation of both tree- and forest lines.

On average, treelines had advanced by 55 m, while forest lines had advanced by 48 m, supporting the theory that treelines respond slightly faster to changes in their environment than forest lines. None of the tested variables could explain much of the observed variation in tree- and forest line shifts. Present elevation of trees was strongly, correlated to the recorded elevation of shrub lines in 1938, revealing shrub lines as possible early indicators of future elevations of the treeline. Correspondingly, present elevation of forest lines correlated strongly with previous elevation of the treeline.

Climate at the sites of the present tree- and forest lines varied considerably between 1901 and 2017, with an overall increase of both temperatures, length of growth season and precipitation during the last three decades. The 20 years prior to the most recent mapping were hotter and had longer growing seasons and more precipitation than the period prior to the years of mapping by Ve, but the changes in climate were not significantly correlated to shifts in tree- and forest lines.

It is not possible to conclude from this study whether climate or regrowth has caused the observed shifts in elevation of tree- and forest line in Lærdal, but it is probably a mixture of both. However, shifts are significantly structured by topographic features of the landscape. Increased temperatures and precipitation in the coming decades will likely expand habitable area for birch, both horizontally and vertically.

Takk

Denne oppgaven er dedisert til de to mennene i mitt liv: Yngve Øvregard og Søren Ve.

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Takk til mamma og pappa for penger.

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1 Introduction

Alpine vegetation covers approximately 3% (4 million km^2) of the terrestrial surface on earth, and is found on all continents at all latitudes (Körner, 1999). At lower elevations, the tree-less alpine vegetation transitions into tree-covered areas, signalling a considerable shift in growth conditions (Holtmeier & Broll, 2005; Körner, 2012; Moen, 1998). Important elements of this transition zone are the tree- and forest lines, which are generally understood as the upper limits to tree- and forest growth (Hofgaard, 1997; Holtmeier *et al.*, 2003).

Globally, these transition zones, which are often termed treeline ecotones, tend to be higher up in dry and/or continental areas than in moist or coastal areas, and they decrease in elevation with increasing latitude (Körner, 2012). At regional to local scales, elevation of the treeline ecotone is less predictable (Holtmeier & Broll, 2005). Currently, the world's topmost treeline is found at 4 810 meters elevation in the Andes Mountains of Bolivia (Hoch & Körner, 2005). At the other end of the spectrum, tree growth at high latitudes ceases entirely towards the arctic, at all elevations (Löve, 1970). In Norway, which is the country of interest in this thesis, the treeline ecotone exceeds 1 300 m a.s.l. in the central southern parts, and declines towards the coast and to the north (Moen, 1998).

Regardless of location, trees in the treeline ecotones are considered to be highly sensitive to changes in their environment, providing valuable knowledge about the growth conditions of their surroundings (Holtmeier & Broll, 2005; Paulsen & Körner, 2001; Tuhkanen, 1993). Treelines are of particular interest in this regard, because they may shift as a result of more or less spontaneous establishments of single trees at new elevations (Holtmeier & Broll, 2005). Such range expansions of trees are believed to be bellwethers for climate change (Hofgaard, 1999; Kullmann, 2001; Smith *et al.*, 2009). Forest lines usually run parallel with the tree lines (Odland, 1996), but a sufficient delay is expected of the reaction of forest lines to climate change compared to that of treelines (Holtmeier & Broll, 2005; Rannow, 2013). Consequently, the observed elevation of forest lines does not necessarily coincide with the climatic limits to forest growth, regardless of previous disturbances. In periods with rapidly changing climate, this also holds true for treelines.

Throughout the last century, upward shifts of varying magnitudes have been documented for both tree- and forest lines in several areas across the northern hemisphere (Harsch *et al.*, 2009), e.g. in Yukon Canada (Danby & Hik, 2007) and in the Swiss Alps (Gehrig-Fasel *et al.*, 2008). The effects of such changes may be extensive. For instance, the advancing trees will unavoidably acquire habitat from strictly alpine species, and will simultaneously facilitate the introduction of new ones (Forrest *et al.*, 2012; Hofgaard, 1997; Holten, 1990; Kullmann, 2012; Young & León, 2007). And while trees sequester large amounts of carbon, the cooling effect of the carbon uptake will be overruled in snow covered mountains by decreased albedo from the dark tree surfaces (Betts & Ball, 1997; De Wit *et al.*, 2014). Additionally, opportunities for human recreation in open alpine landscape could be diminished (Gautestad *et al.*, 2005), and sites of historical and agricultural value might disappear (Olsson *et al.*, 2000; K. Potthoff, 2007; Aas & Faarlund, 1995, 2000). Thus, more trees in the mountains could modify species distributions, diminish areas of cultural importance, alter outdoors habits and even enhance global warming.

No wonder, numerous studies have been executed in order to better understand and predict the response of montane trees to altered surroundings (e.g.Hofgaard, 1997; Körner, 1999; MacDonald *et al.*, 2008; Odland, 2017). At present, however, the progress of developing reliable dynamic vegetation models is restricted by lack of high-resolution empirical data (Bryn & Potthoff, 2018, in review; De Wit *et al.*, 2014; Graumlich *et al.*, 2006).

Tree- and forest lines in Norway

Mostly, mountain birch *(Betula pubescens spp. czerepanovii)* comprise the tree- and forest lines in Norway (Aas, 1969), often thriving as much as 200 m above the treeline of e.g. spruce and pine (Wielgolaski & Sonesson, 2001). In steep valley sides with heavy snowfall, birch may form may form wide forests spanning a vertical distance of several hundred meters (Aas & Faarlund, 1995). This is, for example, the case in areas along the fiords of Western Norway. Within the forests, distribution of birch seeds and density of seedlings is high, but the chance of successful germination decreases towards the treeline ecotone (Holm, 1994; Holtmeier, 2009; Kjällgren & Kullmann, 1998). However, mountain birch also readily spread through vegetative efforts, which could constitute an important mechanism for forest line expansion into higher elevations (Holtmeier & Broll, 2005; Kullmann, 1993).

Except for access to sufficient amounts of fresh soil water and light (Atkinson, 1992; Aas & Faarlund, 2000), mountain birch require relatively little of their surroundings, and are considered to be highly resistant to damage and disturbance (Kjällgren & Kullmann, 1998; Körner, 1998; Aas & Faarlund, 2000). Mountain birch also has a high tolerance to frost during winter and to quite low temperatures during summer (Børset, 1977; Wielgolaski & Sonesson, 2001). All these properties, combined with the birch´s fast growth rate, short life span and early maturation, means mountain birch are able to adapt quickly to shifting growth conditions (Aas, 1969). Still, the precise response of neither the birch limits nor other tree species limits is easily understood, as there are a multitude of different factors influencing the distribution of trees in the treeline ecotone (Holtmeier & Broll, 2007; Odland, 1996).

On a global scale, temperature correlates most strongly with tree- and forest line elevations (Miller, 2008; Skre, 1979; Tranquillini, 1979). Among the most prevalent thermal factors are length of growth season (Bandekar & Odland, 2017; Holtmeier, 2009), a seasonal lower thermal threshold of between 5.5-7.5°C (Körner & Paulsen, 2004) and a mean July temperature of 10°C (Grace *et al.*, 2002; Tranquillini, 1979; Tuhkanen, 1993). For mountain birch limits in Norway, Helland (1912) found a significant correlation with a lower threshold of 7.5°C from June to September. This is the same time period for which Odland (1996) documents a relationship between forest line elevation and a mean maximum temperature of 15.8°C. Regardless, on-going human induced climate change is expected to contribute to a rise of the treeline ecotones, particularly in the northern hemisphere (Bryn, 2008; Kjällgren & Kullmann, 1998).

At regional or local scales the effect of temperature is readily matched or overruled by other variables (Holtmeier & Broll, 2005; Paulsen & Körner, 2000), such as topography, wind, mountain height, continentality, aspect or natural disturbance (Körner, 2012; Aas & Faarlund, 2000). Consequently, local distributions of high elevation trees and forests can rarely be accounted for by climatic variables alone. Of particular interest in this regard, is the historical influence on the tree- and forest lines by humans– who have profited from the forests for thousands of years (Hofgaard, 1999). Their utilization of wood for e.g. agriculture, food production and construction has significantly altered the distribution of trees in mountain regions all over the world, simultaneously lowering tree- and forest lines (Hofgaard, 1999; Moen, 1998).

Norway is no exception. Here, grazing and cheese production at as many as 70 000 summer farms has demanded huge volumes of timber from nearby areas (Daugstad & Sæter, 2001; Reinton, 1961). Eventually, many such farms were moved or abandoned entirely, partly due to lack of available wood (Reinton, 1961; Ve, 1940). When most activity at remaining summer farms ceased in the first half of 20th century, tree- and forest lines in many areas had been considerably lowered (Reinton, 1961). Even today, more than 150 years after the peak in number of summer farms in Norway (Daugstad & Sæter, 2001), it is crucial that human impact is accounted for in studies of the dynamics of the treeline ecotone (Bryn, 2008; Hofgaard, 1999; Holtmeier & Broll, 2005).

Among the first to perform such studies in Norway, was Aas (1969), who found that forest lines in South Eastern Norway had risen by an average of 40 m since 1918. In conclusion, Aas asserted most of the observed expansion to climate change, but also underlined the significant influence of human activities to the elevation of the forests. In later studies in Norway, regrowth has been identified as the main contributor to advancing lines. (Bryn, 2008; Hofgaard, 1997; Rössler *et al.*, 2008) However, upward expansion has also been documented for tree lines in central Sweden by Kullmann (2001), who interpreted an observed treeline advance of 100-165 m as being a more or less direct effect of climate warming.

In 1940, Norwegian botanist Søren Ve published a comprehensive study on the distribution of trees and forests in the valley of Lærdal in Southwestern Norway. His descriptions included detailed information on the extensive negative impact of summer farming on the normally wide birch belt of the valley. However, Ve's overall conclusion was that most of the tree- and forest lines he had registered in the field, were climatically determined, and that tree- and forest lines had probably not shifted considerably in Lærdal during the last decades. Today, the reports by Ve of species and their growth limits in Lærdal, constitutes a thorough and rich insight into the elevation of tree- and forest lines at the end of the 1930s. Through remapping of the mountain birch tree- and forest lines described in Ve´s work, along with analyses of the environment at each site, this thesis is intended to contribute with new information and improved insight into the dynamics and characteristics of tree- and forest lines.

1. What characterizes and determines present tree- and forest lines and their distribution in Lærdal?
2. How are potential shifts in tree- and forest line elevations distributed across the valley, and what characterizes them?
3. What has caused the potential shifts?

2 Study area

The municipality of Lærdal is located in the inner parts of Sognefjorden in Sogn og Fjordane county, in the west of Norway (Figure 1). It is an elongated U shaped valley that spans more than 80 km in distance and 950 m in height along the Lærdal River, from Filefjell on the border of Oppland county in the east, to the community centre, Lærdalsøyri, in the west (Figure 2). The bedrock is divided between large areas of basement rock and of a wide thrust fault ("Jotundekket"), with areas of phyllite interspersed (geo.ngu.no, accessed 20.05.2018; Hauge & Austad, 1989). The relatively flat valley floor, is surrounded by steep hillsides, but the mountain landscape tends to level out at between 900–1 000 m a.s.l. The highest point in Lærdal is at the mountain of Høgeloft close to Hemsedal, at 1 921 m a.s.l. (Kartverket.no, accessed 02.04.2018).

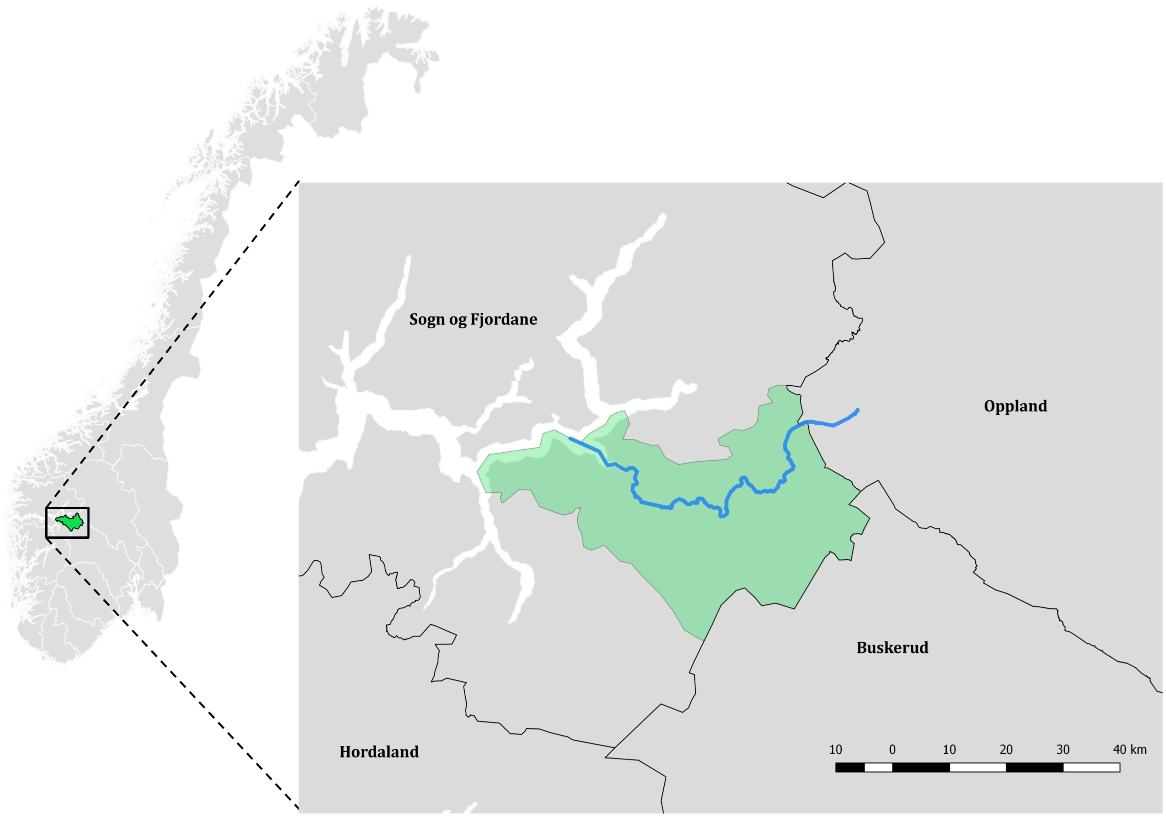

Figure 1: Location of the Municipality of Lærdal, and borders to Oppland, Buskerud and Hordaland Counties. The blue line represents the profile of the Lærdal valley, from a starting point in the fiord to Tyinnkrysset in Oppland.

Despite the location next to Sognefjorden, the climate of Lærdal is weakly continental (Moen, 1998). This is due to the protective effect of the surrounding mountains against the typically wet oceanic climate of Western Norway. Annual precipitation in Lærdal is among the lowest recorded in Norway (Hauge & Austad, 1989). At Tønjum, 36 m a.s.l and approximately 8 km from the fiord, annual precipitation during the last normal period (1961–1990) was 491 mm a year, in strong contrast to the county average of around 1 780 mm a year (Førland, 1993). Towards the east, precipitation increases gradually, with an annual measure of 510 mm in Borgund (400 m a.s.l.) up to 735 mm a year at Nedre Smeddalsvatnet (914 m a.s.l.) (Førland, 1993). Most of the precipitation arrives during autumn; while summers and winters are relatively dry (Hauge & Austad, 1989; Moen, 1998; Ve, 1940). From the valley floor up to the mountain plateaus, precipitation increases considerably, and depth of the snow cover may be up to 3 m in inner parts of the valley (Ve, 1940).

Average annual temperature is close to 8°C in the municipality centre Lærdalsøyri by the fiord, and decreases to around 2°C in the innermost parts of the valley (Moen, 1998). Annual, summer and winter temperatures are remarkably high compared to neighbouring areas (Ve, 1940).

Cultural history and the birch forest

Because of the convenient steady rise of the valley from the fiord in the west to the high alpine areas in the middle of Norway in the east, Lærdal has been populated for millennia (Hauge & Austad, 1989). Archaeological discoveries suggest human settlements existed in the valley as long as 7 000 years ago. Farming practices probably did not establish until 300 AD, but since then, agriculture has significantly altered the landscape in Lærdal, both along the valley floor and in the mountains (Hauge & Austad, 1989). According to Ve (1940), the normally wide birch belt of the valley was totally destroyed by logging in several areas during the first half of the 1800s, and the lack of wood forced many to abandon the use of summer farms completely. However, Ve also notes that the birch forest seemed to re-populate formerly logged areas quickly, approaching its previous elevation already at the time of his fieldwork from 1936 to 1938.

Figure 2: Map over the Lærdal valley. Yellow lines show the border of Lærdal Municipality, orange lines show the border of Sogn and Fjordane Municipality.

3 Methods

3.1 Preparations for fieldwork

Choosing sites for remapping

Ve (1940) registered the elevation of 54 treelines, 106 forest lines and 40 shrub lines in Lærdal. Several of these registrations were done in sites which were visibly affected by human activities, as noted by Ve. To remove the most obvious effects of human impact in the analyses of tree- and forest line dynamics, these areas were excluded from remapping. Beneath is an overview of all categories of Ves registrations which were not considered for remapping:

- Shrub lines.
- Registrations where tree species other than birch made up the tree- or forest line.
- Registrations in sites noted by Ve as being positioned close to summer farm.
- Registrations in sites noted by Ve as having been recently logged.
- Registrations in sites registered as being influenced by the so-called valley phenomenon (lowering of lines due to cold winds along the valley floor).
- In some areas Ve registered two tree- or forest lines in the same aspect. In these cases, only the topmost registration was remapped.

After removal of these types of registrations, 70 registrations of forest lines and 46 registrations of tree lines remained for remapping.

Locating sites to be remapped

Along with elevation and aspect at each site, Ve (1940) reported the names of the mountains or valleys and areas in which he registered tree- and forest lines. In order to locate the positions of his registrations for remapping, aerial photos of the different areas were examined on www.norgeskart.no and compared to the comments and map by Ve (1940). In cases where area names denoted by Ve did not exist on modern maps, landowners and other locals were contacted to identify the locality of his registrations.

3.2 Fieldwork

Fieldwork was conducted between July 7th and September 4th in 2016 and between July 31st and August 8th in 2017. Because Ve reported fewer treelines than forest lines, areas in which treelines had been registered were prioritized in the field. Apart from this, locations were visited in no particular order or direction. In field, sites for remapping were located using a map, a dry magnetic compass and a GPS (Garmin eTrex 30X). Binoculars and a clinometer were used to determine the properties and relative elevation of trees and forests across distances, to reduce time and energy spent in search of sites for remapping.

To provide data on both tree- and forest lines for potential future remapping, both types of lines were mapped in most places, even when Ve had only registered one of them.

At the site of each tree, the following information was recorded:

- Tree height, estimated to the nearest half meter using a measuring scale of 3 m. When tree height exceeded the length of the scale, height was estimated subjectively.
- Age of the tree, approximated by visual examination and categorized into one of the following age classes: 0–25 years, 25–50 years, 50–75 years, 75–100 years and >100 years.
- Degree of recruitment of new trees, sorted into negative recruitment (1), standstill (2) and positive recruitment (3).
- Elevation, recorded by the use of a GPS (Garmin eTrex 30X) and by a barometer, the latter to test the equipment used by Ve.
- Aspect, read off a dry magnetic compass divided into 360°.
- NiN (Nature in Norway) variables and type (see Chapter 2.5).
- Vegetation type and ancillary registrations (se Chapter 2.5).

3.3 Definitions of trees, treelines and forest lines

To ensure that elevations of the present tree- and forest lines in Lærdal could be accurately compared to the findings of Ve (1940), definitions applied in the present study were intended to match the ones used by Ve.

Trees in the treeline ecotone

Ve (1940) stated that a proper tree should be at least as tall as a man. This somewhat vague description was interpreted in this study as describing trees taller than 2.5 m. This interpretation is supported by e.g. Aas and Faarlund (2000), with Aas himself having used the measure "height of a man" during tree- and forest line mapping in the 1960s (Aas, 1969). Regardless of the precise height, the point in a lower limit to tree height is to make sure that only individuals which reach above the snow cover during winter, are mapped as trees (Holtmeier, 2009; Körner, 2012). Ve (1940) further required proper trees in the treeline ecotone to have one single, upright main stem.

Tree- and forest lines

Ve (1940) understood the treeline as the uppermost individuals of single trees conforming to the abovementioned criteria. His definition of forest lines is elaborated in Ve (1930), where he states that the forests should be made up of groups of minimum 14-15 individual trees. A lower limit of 15 trees was adopted in this study. Ve (1930, 1940) does not mention a maximum distance between trees in a forest line. According to Aas & Faarlund (2000), the distance to the closest tree at the forest line should not exceed 30 m. In the present study, a conservative distance limit of maximum 15 m between trees is applied.

An unpublished guide to mapping of tree and forest lines was used in fieldwork for this project (Bryn, 2013–2017, Appendix 10). In addition to the criteria mentioned above, the following criteria were considered for each tree, according to the mapping guide:

- Stem should not be too flexible at 1.5 m above ground.

- It should not resemble a bush, but have a clear crown (although not necessarily a wide one).
- There should not be too many side branches along lower parts of the main stem.

3.4 Collection of additional data

The last year of activity of the summer farms which were mentioned by Ve (1940) in his notes on tree- and forest line elevations, was identified through descriptions by Ve, communication with locals and through local literature (Appendix 2). The coordinates of 35 relevant summer farms were obtained from www.norgeskart.no, plotted in QGIS 2.18.13 (QGIS Development Team, 2017-2018), whereby the distance from each registered tree to the closest summer farm was calculated. For some registrations, the closest summer farm was located across the valley, while 10 summer farms turned out not to be the closest farm to any registered tree- or forest line. Distance to the remaining 25 summer farms, as well as time since abandonment of summer farms, were registered and subsequently included in further analyses.

Additional data were obtained from the following sources:

1. **Downscaled climate data from www.senorge.no.** The data had been prepared and structured according to the approach of WorldClim (Hijmans *et al.*, 2005). The downscaled data contained average values of the years 2004 – 2014. Data for each site was extracted in QGIS 2.18. The following information was obtained from this source:
    - Average annual temperature.
    - Length of growth season (number of days for which average temperature has been higher than 5°C during the past six days).
    - Average temperature of warmest three months (warmest quarter).
    - Average temperature of coldest three months (coldest quarter).
    - Monthly average temperatures.
    - Monthly maximum temperatures.
    - Proximity to coast.
    - Proximity to river.
    - Duration of snow cover.

2. **Historical climate data from The Norwegian Meteorological Institute (NMI)**. Data covered every year from 1901 to 2017, for all sites. The following information was obtained from this source:
   - Average annual temperatures
   - Length of growth season (the period between the first day for which temperatures exceed 5°C for five consecutive days, and the first day where mean falls below 5°C for ten days in a row)
   - Average temperatures of the warmest quarter
   - Average annual precipitation

3. **A digital terrain model (DTM 10).** Downloaded from www.geonorge.no. Data for each site was extracted in QGIS. The following information was obtained from this source:
   - Elevation
   - Slope
   - Distance to nearest summer farm
   - Distance to nearest hilltop
   - Incoming solar radiation per year
   - Incoming solar radiation from June to August (measures of solar radiation were generated with the Potential Solar Radiation module in SAGA GIS (Conrad *et al.*, 2015), with an automatically calculated sky view factor).

4. **Model of interpolated climatic forest line (Bryn & Potthoff, 2018, in review).** The elevation of the topmost modelled forest lines within a moving window of 20×20 km and interpolated to 500×500 m, was acquired by fitting 1 km wide buffers around each *in situ* registered forest line in QGIS 2.18.13. A batch process was used to extract the highest value from each buffer. The following information was obtained from this source:
   - Predicted elevation of climatic forest lines

3.5 Classifications systems

To attain information about the characteristics of the surroundings of tree- and forest line, vegetation at (and around) each tree was mapped with two different classification systems during fieldwork. The systems are presented below.

NiN: Nature in Norway

Nature in Norway ("Natur i Norge", NiN) is a system developed to describe and map nature in Norway (Halvorsen *et al.*, 2016). This is accomplished by structuring nature into different organizational levels, based on the assumption that species respond gradually to changes in their environment, as proposed by Whittaker (1967).

The system is divided into three overall levels, the microhabitat level, the ecosystem level and the landscape level (Halvorsen *et al.*, 2016). At the ecosystem level, there is a hierarchical system of major-type groups, major-types, and basic types. Basic types are distinguished based on levels of local complex environmental variables (LCEs). LCEs are groups of environmental variables which co-explain a certain amount of variation in species composition and turn-over.

LCEs registered in this project were (Halvorsen, 2016):

- **Lime richness (LR):** Describes acidity and content of minerals such as K, Na, Ca and Fe.
- **Risk of severe drought (SD):** Describes the risk of extreme drought incidents, in a perspective of 20–50 years.
- **Influence of spring water (SI):** Describes level of influence by water with spring water properties. Spring water may vary with regard to oxygen content, stability of temperature and water influx.
- **Water saturation (WS):** Describes the normal state of water saturation in the ground.
- **Mire gradient (MG):** Describes variation in mire species inventory from the least moist to the wettest areas within the mire.

For mapping purposes, basic types are combined into mapping units within each major type (Bryn *et al.*, 2018). The number of mapping units differs depending on the scale of mapping, with fewer types at larger scales, and vice versa. For NiN mapping of areas along the tree- and forest lines, there is a range of relevant major types. Among them are *Bare rock* (T1), *Forest* (T4), *Mire* (V1) and *Mountain heaths, leeside and tundra* (T3) (Figure 3).

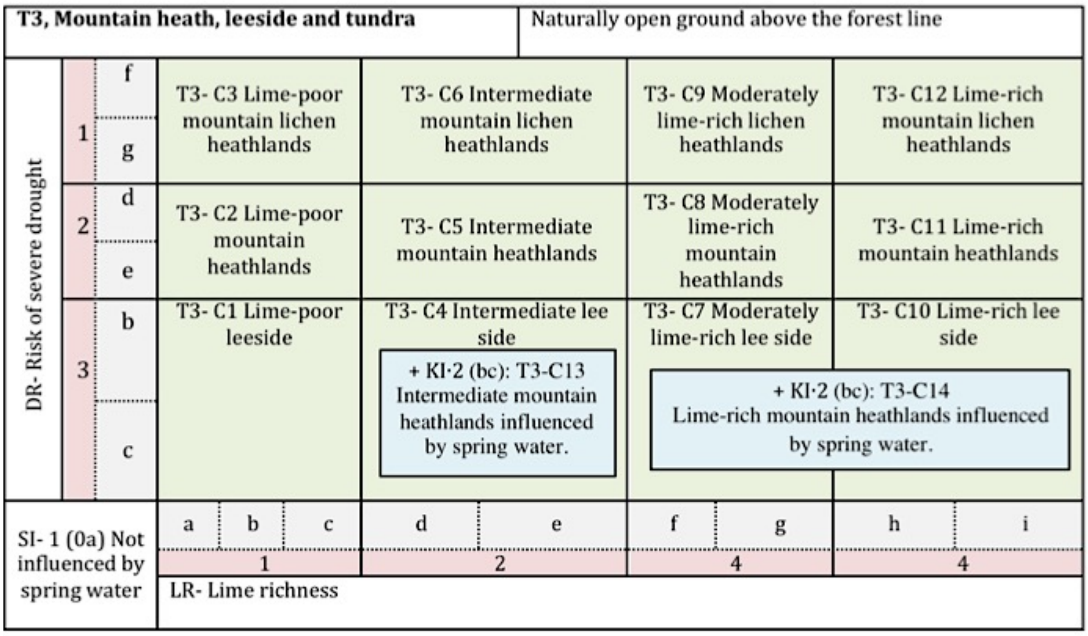

Figure 3: Example of a graphic representation of mapping units within a major type in NiN. The diagram shows the major type "Mountain heath, lee side and tundra", with mapping units adapted for mapping on a scale of 1:5000. The grey areas show the so-called basic steps along the gradients of Lime richness and Risk of severe drought, the pink areas show major type adapted classes compiled from the steps of each LCE. The green areas show mapping units, which are combinations of levels along relevant LDEs for each major-type. The blue areas depict mapping units which describe areas that are clearly influenced by influx of spring water.

During fieldwork, the level of all five LCEs was determined at the location of each registered tree through identification of plant species composition and specific LCE indicator species. The LCE levels, along with percentage of canopy cover and topographic features, were utilized to categorize nature at each site into different mapping units. To attain information about the qualities of the location of each tree compared to the background ecology at each site, LCEs and mapping units were also registered for sites 25 m to the left and to the right of each tree, at the same altitude.

NIBIO vegetation type mapping system (VK25)

Vegetation type mapping intended for mapping on scales between 1:20 000 – 1:50 000, can provide a rough overview of the vegetation were mapping is implemented (Rekdal & Larsson, 2005). Classification of types is based on the physiognomy of the vegetation, plant species composition, indicator species or a combination of all three. The types are influenced by a number of ecological processes through time and space (Rekdal & Larsson, 2005). The system covers 45 different vegetation types and nine land cover types, classified into twelve groups. In the treeline ecotone, relevant vegetation types are e.g. *Dwarf shrub heath* (2e), *Lichen heath* (2c), *Bilberry birch forest* (4b) and *Sedge and grass snow bed* (1b).

To explain within-vegetation-type variation between sites, ancillary registrations are applied. These are common for all vegetation types, and are used to describe e.g. presence of sand, rocks and boulders, cover of lichen, *Salix* sp. and grass, or tree species and level of logging (Rekdal & Larsson, 2005). Both vegetation types and relevant ancillary information was recorded for all sites of a tree- or forest line.

3.6 Preparation of data

After fieldwork and sampling of additional information, all data were proofread and structured. Variables and types registered for both NiN (Halvorsen, 2016) and Vegetation mapping (Rekdal & Larsson, 2005) were double-checked and edited when necessary, to make sure that application of the systems was concise and reliable throughout all sites.

Elevation profile of Lærdal valley

For the purpose of exploring the position along the valley for different variables, a shapefile line was drawn manually in QGIS from a starting point in Lærdalsfjorden and further along the Lærdal River up to Tyinkrysset in Oppland County (Illustrated in Figure 1). By application of the LRS plugin, all tree- and forest lines were projected onto the closest point along the line, so that distance to the fiord could be calculated for each site. The Profile plugin was used to produce an elevation profile of the line along the river, and thus, of the Lærdal valley. Values acquired from the profile were subsequently used in analyses.

From aspect to heat index

To estimate the significance of aspect on the elevation of trees, registered aspects were converted into a linear heat index, following the approach of e.g. Parker (1988) and Økland and Eilertsen (1993). Aspects were positioned between an estimated heat index peak at 202.5° (SSW) and an estimated least favourable aspect of 22.5° (NNE).

Translation of mapped ecosystem variables and tree properties

The denomination of basic steps along LCEs in NiN was translated from letters to numbers to prepare for analyses (Appendix 3). For each site, vegetation types and ancillary registrations were combined to derive estimations of Soil nutrient status (reflects the productivity of the vegetation at the site as regulated by available nutrients in the soil column) and Wetness (reflects available soil water for the vegetation), following Bryn *et al.* (2010) (Appendix 3).

Cleaning of data

A number of tree- and forest lines were mapped in addition to the registrations done for the purpose of remapping (discussed in Chapter 4.1). Most of these were retained in analyses of the present tree- and forest lines, in order to strengthen the foundation of statistical tests. However, several registrations were excluded from further analyses for other reasons, as listed below:

Adjacent registrations: The climate data produced from information at www.senorge.no cover grids of 100 m^2. To remove the risk of sampling the same information twice, the lowest of two or more treelines or forest lines, which were less than 100 m from another registration of the same type, were not included in analyses. Three treelines registrations and one forest line registration were removed in this process.

Registrations close to mountaintops: Tree growth is usually restricted near mountaintops, due to the so-called summit syndrome (Körner, 2012). To avoid influence by registrations close to mountaintops in analyses, all registrations closer than 50 m in vertical distance to nearest top were removed. This was the case for one treeline registration and two forest line registrations.

Transformation and standardisation of variables

All variables intended for use in model selection procedures, were transformed into zero-skewness data by application of a log or exponential standardisation. The transformed values were then standardised into numbers ranging from 0 to 1 (Økland *et al.*, 2003). See Appendix 6 for details.

3.7 Analyses

All statistical analyses were done in R (RCoreTeam, 2017).

Distribution of tree- and forest lines tested with linear regression

The tree- and forest line elevations, their shift in elevation over time and the predicted climatic forest line (Bryn & Potthoff, 2018, in review), was plotted against position in the valley. Elevation and shifts in elevation of tree- and forest lines were tested against position in valley through a linear regression model (Galton, 1886). Linear regression was also applied when testing the relationship between present treeline elevation and previously recorded elevation of the shrub line, as well as the present forest line and the previous tree lines.

Analyses of spatial patterns

Semivariograms were constructed to evaluate the magnitude of spatial dependence within elevation and change in elevation of tree- and forest lines across distances (Matheron, 1963). Distances between trees were assigned to distance classes (Table 1), with minimum 30 observations in each class. To obtain comparable plots, the variograms were standardised by division with the sample variance, and the x-axes were scaled to appropriate values through log-conversion of the scale of distance lags.

Table 1: Overview over intervals of distance classes into which geographical distances between tree- and forest lines were sorted.

Treelines	Distances of between 0- 32 768, m, dispersed by the following breaks: 0,256, 512, 1024, 2048, 4096, 8192, 16384, 32768
Forest lines:	Distances of between 0- 32 768 meters, dispersed by the following breaks: 2048, 1897, 4096, 5793, 8192, 11585 , 16384, 23170, 32768.
Treeline shifts	Distances of between 0- 32 768 meters, dispersed by the following breaks: 4096, 5793, 8192, 11585 , 16384, 23170, 32768.
Forest line shifts	Distances of between 0- 32 768 meters, dispersed by the following breaks: 4096, 5793, 8192, 11585 , 16384, 23170, 32768

Properties of trees compared with a χ2 test

Height, age and recruitment of new individuals around each tree, was compared between tree- and forest lines using a χ2 test.

Multiple linear regressions

To examine the contribution of different sampled variables to elevation and shift in elevation of tree- and forest lines, tests of linear regressions were applied separately on 29 and 27 explanatory variables (Appendix 8). Subsequently, multiple regression analysis with forward selection was conducted to construct multivariable models.

Analysis of Variance (ANOVA) was rendered to compare models at each step against the null model of no relationship between response- and explanatory variables. Conservative p-values following the approach of Bonferroni were applied throughout the procedure, to counteract the possibly problematic artefacts of multiple testing.

Correlations between variables were measured using Pearson correlation coefficient (Pearson, 1895) (Appendix 7).

NiN (Nature in Norway)

An unpaired Wilcoxon rank sum test (Wilcoxon, 1945) was used to test differences between values of LCEs at the site of each tree and the surrounding area, as well as for differences between treelines and forest lines. Further, Pearson correlation coefficient (Pearson, 1895) was used to measure the strength of correlations between distribution along valley and values of LCEs. Values of LCEs were subsequently plotted against position in the valley, and tested in regression analyses. A regression line was fitted to the plot.

Changes in climate tested with correlations and Wilcoxon rank sum test

Average values for climatic variables obtained from the Norwegian Meteorological Institute were calculated for periods of ten years, and plotted in R for every fifth year from 1910 to 2015.

For analyses of differences in climate prior to the mapping conducted in 1938 and the most recent mapping, average values for a period of 20 years prior to each mapping effort were calculated. The difference between these periods were compared to magnitude of shift in tree- and forest lines, using Pearson correlation coefficient and tested further by a Wilcoxon rank sum test.

4 Results

4.1 Overview of registrations

Elevation and properties of trees and their immediate surroundings was recorded at 152 sites during fieldwork. Eighty-two of the trees comprised treelines and 70 were the topmost trees of the forest lines (Table 2). Of these, 93 registrations were remapped sites.

Of the 61 additional registrations, 17 were sampled to provide information on treelines or forest lines in locations in which only one of them were reported by Ve. Sixteen were registered in the belief that they were the topmost lines, which later turned out not to be the case. In some areas, the topmost tree- or forest line was situated in sites with different aspects than the one Ve had registered. They were then registered in addition to the remapped sites, and are here categorized as "Trees with different aspect than 1940-registration". This category also contains registrations caused by misunderstandings in field. Four registrations were done in slightly different areas than the ones Ve reported from, mainly due to misunderstandings in field. Rowan made up two treelines and one forest line.

Table 2: Distribution of different types of registrations made in 2016 and 2017. At several sites, a common tree- and forest line was found. This is the case for seven of the registration in "Remapped sites", one of the registrations in "Tree- and forest lines added to 1940- registrations" and in two registrations in "Trees with different aspect than 1940- registrations".

Types of 2018-registrations	Forest lines	Treelines	Sum
Remapped sites	53	40	93
Tree- and forest lines added to 1940-registrations	5	13	17
Not topmost tree found in area	3	15	16
Trees with different aspect than 1940-registration	5	11	15
Registrations at new sites	3	1	4
Rowan (Sorbus aucuparia) makes up line	1	2	3
Total registrations	**70**	**82**	**152**

The 93 remapped sites comprise just slightly more than half of the tree- and forest lines reported by Ve (1940) (Table 3). Forty-four of the original registrations were ruled out for remapping prior to fieldwork, as discussed in Chapter 2. Twenty-three registrations were not remapped due to time constraints or problems with localization.

Table 3: Implementation of original registrations for remapping. Twenty-three sites were not remapped due to lack of time or problems in field.

Implementation of original registrations	Forest lines	Treelines	Sum
Remapped areas	53	40	93
Not remapped due to time constraints	13	2	15
Could not find correct area	4	4	8
Total registrations by Ve (1940)	**70**	**46**	**116**

No significant differences were found between elevations of tree- and forest lines recorded by GPS, barometer, or extracted from DTM 10. The elevation recorded by GPS was chosen for application in subsequent analyses. Average uncertainty in GPS position was 3.4 m.

4.2 What characterizes and determines present distribution and position of tree- and forest lines in Lærdal?

On average, treelines were found 1 168 m a.s.l., while the forest lines where found at 1 137 m a.s.l. (Table 4). This constitutes an average vertical distance of 31 m between the treelines and the forest lines. The topmost tree- and forest lines were both found in Øydalen, at 1 329 (Table 4, Figure 4, 6 & 7) and 1 268 m a.s.l. (Table 4, Figure 5, 6 & 7), respectively, while the lowest tree- and forest lines were found at Hovdungane in Vindedalen at 981 m a.s.l. and 967 m a.s.l. (Table 4, Figure 6 &7). The largest disparity between tree- and forest lines was recorded at Freibotn, where distance from topmost forest to topmost tree in the same slope was 189 m (Figure 6). In contrast, a joint tree- and forest line was found at seven sites. 22% of treelines were located higher than 1 200 m a.s.l, while 10% were found beneath 1 100 m a.s.l. (Appendix 1). Corresponding estimates for forest lines are 21% and 28%.

Table 4: Summary of measures of elevation above sea level for tree- and forest lines

	Min. elevation	Max. elevation	Mean elevation	Median elevation
Treeline	981	1 329	1 168	1 163
Forest line	967	1 268	1 137	1 140
Difference	14	61	31	23

Figure 4: Topmost trees (to the right) of the topmost registered forest line, found in Øydalen at 1 267 m a.s.l.

Figure 5: Topmost treeline. These are three individuals, growing close together. The innermost individual tree comprises the topmost treeline registered in field. It was found in Øydalen at 1 329 m a.s.l.

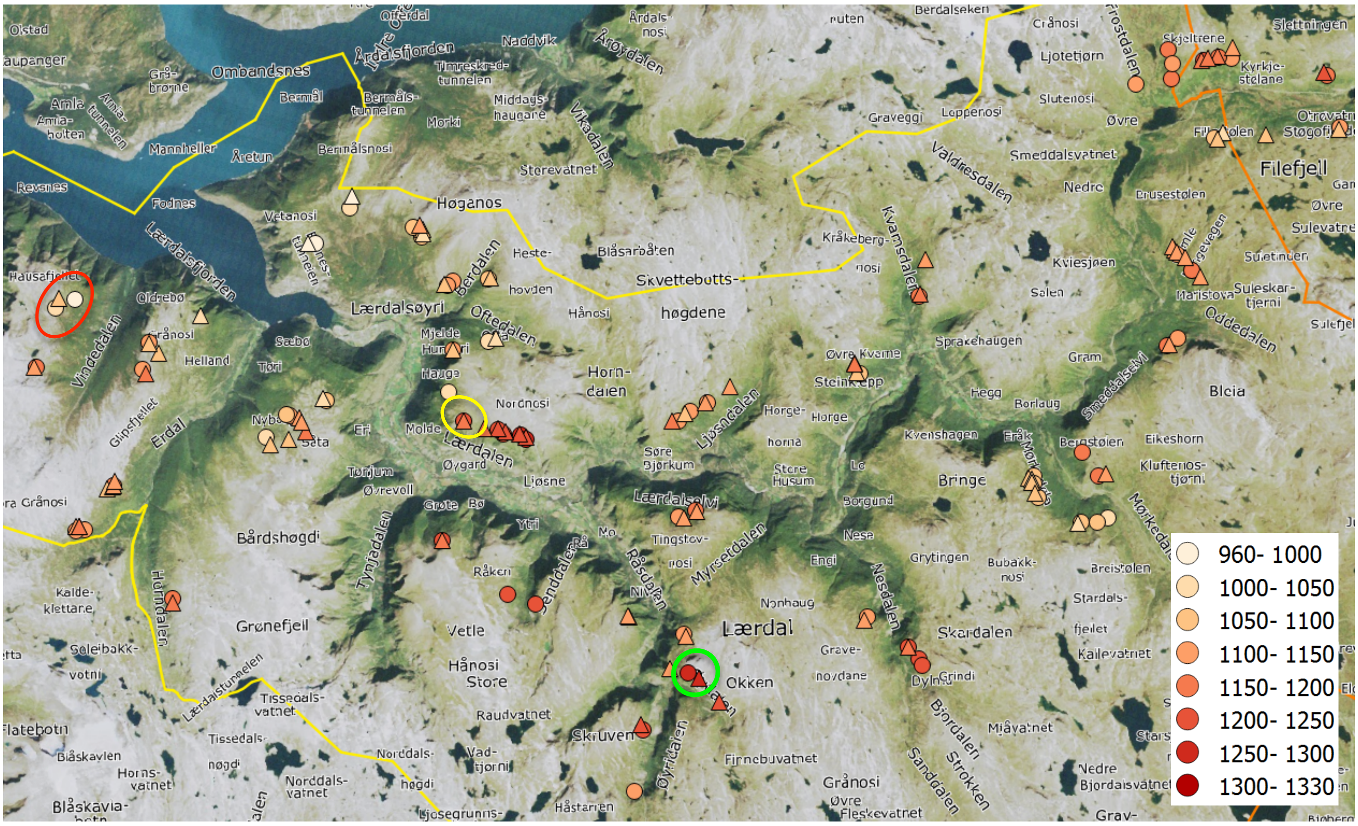

Figure 6: Distribution of treelines (triangles) and forest lines (dots) colour coded according to elevation. Green circle marks the location of the topp tree- and forest lines, red circle marks the location of the lowest tree- and forest lines. Yellow circle marks the location of the largest distance between treeline and forest line.

Both tree- and forest lines increased slightly in elevation along the Lærdal valley from the starting point at sea level to Tyinnkrysset (Figure 7). Several of the lower registrations are located close to the coast (Figure 6 & 7). The topmost lines were registered in areas along the valley that were 20 to 40 km from the starting point in the fiord, in the hillsides and valleys between Ljøsne and Borgund (Figure 6 & 7).

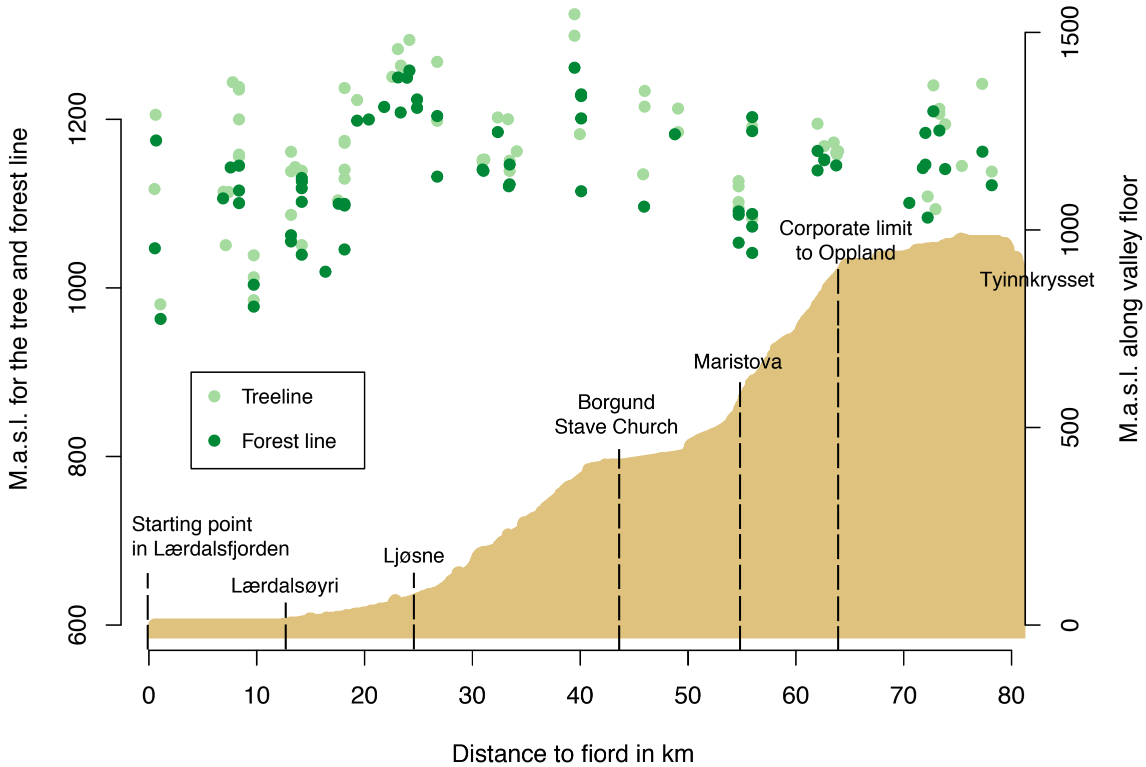

Figure 7: Elevation of treelines, forest lines and valley floor plotted against distance to starting point of valley, with corresponding regression lines for the tree- and forest lines. Both lines were found at a range of 0.5 to 78.2 km from starting point.

None of the linear models fitted to the plot of tree- and forest line elevations were significantly better than the null hypothesis of no relationship (Table 5).

Table 5: Summary of linear models fitted to distance from starting point, and Pearson's correlation coefficient for the relationships between line elevation and position.

	Intercept	Slope	Std. error	Slope p-value	Correlation
Treeline	1152	0.4577	0.3314	1.71E-01	0.0115
Forest line	1114	0.6025	0.3437	8.40E-01	0.0296

Observed forest line elevation compared to modelled elevation

The observed elevation of the highest forest lines in field fitted well with the upper limit modelled by Bryn and Potthoff (2017a), but overall, empirical forest lines were 87 m below the estimated elevation (Figure 8, Table 6). The largest discrepancies between observed and predicted were found in areas close to the coast. Seven forest lines were found above the estimated climatic forest lines (Table 6). The largest positive difference in elevation was found at Skjeltrane, 40 m above predicted elevation.

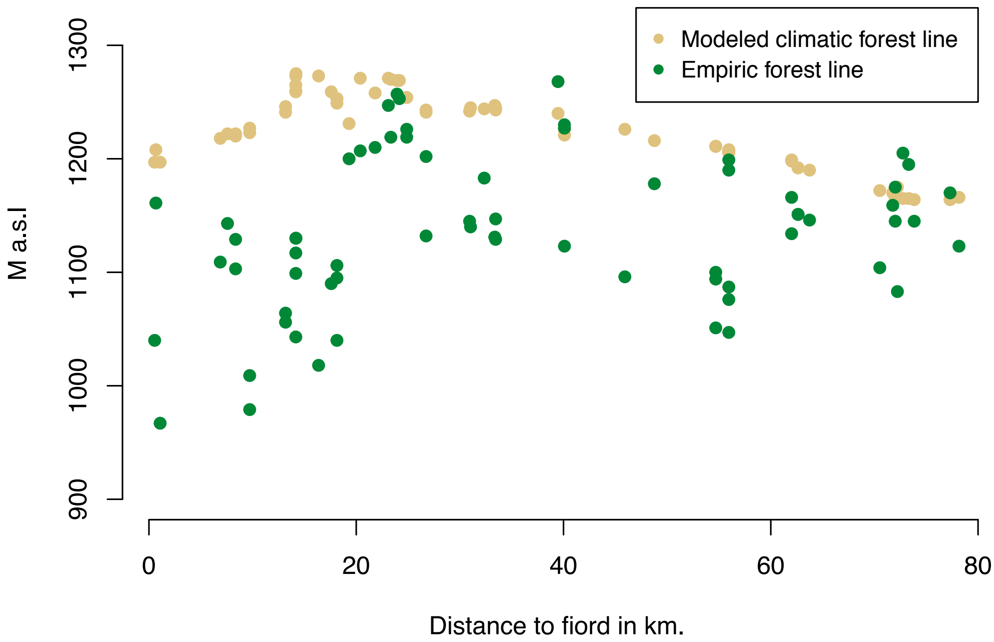

Figure 8: Observed and modelled tree- and forest line elevations plotted against distance to starting point of valley profile, at sea level.

Table 6: Summary of elevations of predicted and empirically determined forest lines.

	Min. elevation	Max. elevation	Mean elevation	Median elevation
Modelled climatic forest line	1164	1275	1224	1224
Observed forest line	967	1268	1137	1140
Difference	197	7	87	84

Height, age and seedling recruitment

Average height of each registered trees was significantly different between forest lines (4 m) and treelines (3.5 m) (Table 7). Overall, trees in the treelines were more frequently measured as being 3.5 m or shorter than trees in forest lines. Neither age nor recruitment of new trees was significantly different between treelines and forest lines. However, there is a slight tendency towards higher age and increased recruitment for trees in forest lines than in treelines (Table 7).

Table 7: Distribution of trees in categories of tree height, age and sapling recruitment, with corresponding X^2 test to evaluate differences in distribution of properties between treelines and forest lines. For sapling recruitment, 1= negative recruitment, 2= standstill, 3= positive recruitment.

Tree height	***<2.5***	***2.5***	***3***	***3.5***	***4***	***4.5***	***5***	***>5***	***NA***	**Avg.**
Treeline	3	12	21	16	13	4	1	8	1	3.5
Forest line	0	7	15	9	9	4	3	3	3	4.0

X-squared= 93.48, p-value=3.46E-15

Age	***0-25***	***25-50***	***50-75***	***75-100***	***100-150***	***NA***	**Avg.**
Treeline	29	32	9	2	3	1	Ca. 25
Forest line	16	26	10	8	2	3	Ca. 33

X- squared =8.43, p-value=7.70E-02

Recruitment	***1***	***2***	***3***	***NA***	**Avg.**
Treeline	*5*	35	32	4	2.4
Forest line	*3*	20	39	3	2.6

X-squared = 4.19, p-value= 1.23E-01

Age and height of trees were significantly negatively correlated with elevation for both treelines and forest lines, indicating that trees are younger and decrease in height with elevation (Appendix 7).

Recruitment of new individuals around trees was most significantly correlated with slope, indicating that recruitment increases with steepness (Appendix 7). Slope was also one of the best correlates for age of trees. For treelines, height was significantly positively correlated with different measures of temperature, most strongly to length of growth season. Such correlations were absent for forest lines.

Spatial structure

Semivariance for distance classes was estimated for elevations of both tree- and forest lines, depicting a clear autocorrelation between elevations of trees in the smallest distance classes, where semivariance was low (Figure 9 & 10). The plots suggest spatial dependence of tree- and forest line elevation weakens when distances between trees exceed 4 000 m.

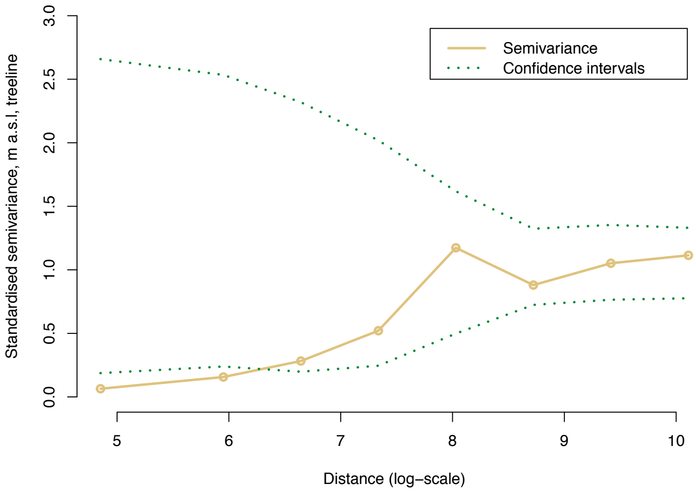

Figure 9: Standard semivariance for elevation between distance intervals of trees in treelines. The distance classes are separated by the following breaks: contain the following ranges of distances (in meters): 0-256-512-1024-2048-4096-8192-16384-32768.

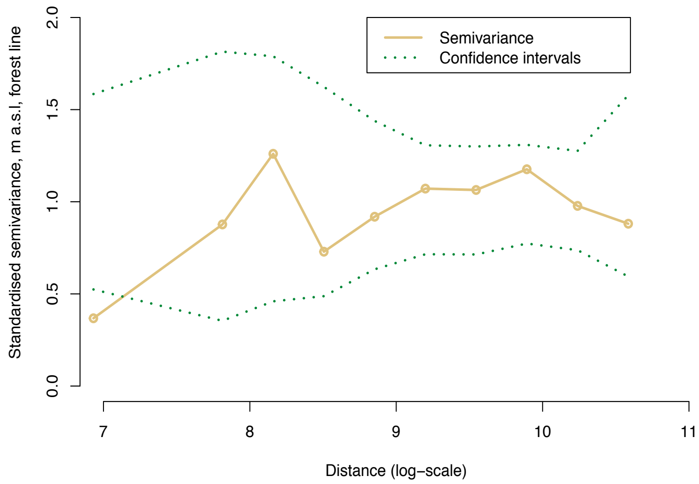

Figure 10: Standard semivariance for elevation between distanc intervals of trees in forest lines. The distance classes contain th following ranges of distances (in meters): 0-2048-2896-4096 5792-8192-11585-16384-23170-32768.

Linear regression analysis of variations in tree- and forest line elevation

Among 29 explanatory variables tested in linear regression, 13 were significantly better at explaining the distribution in treeline elevation than the null model of no relationship (Table 8). Nine of these were also significant when tested against forest line elevations, in much the same order (Table 8). Distinct differences between the tests for tree- and forest lines were that "distance to closest farm" explains more of the variation in forest line elevations than in treeline elevations, and vice versa for "time since farm closed".

Table 8: Overview over variables which were significantly better (p<0.05) predictors of tree- and forest line elevation (m a.s.l..) than the null model of no relationship. F= F statistics, R^2= Adjusted R-squared, Coeff. Sign = + or – according to slope of linear model fitted to the tested variables.

Explanatory variable	Treelines				Forest lines			
	R2	Coeff. sign	F	p-value	R2	Coeff. sign	F	p-value
Length of growth season	0.528	-	83.70	9.80E-14	0.443	-	51.9	8.90E-10
Slope	0.324	+	36.40	6.00E-08	0.273	+	25	4.80E-06
Time since farm closed	0.236	+	23.90	5.90E-06	0.164	+	13.5	4.90E-04
Duration of snow cover	0.222	+	22.10	1.20E-05	0.21	+	18.1	7.20E-05
Heat index	0.149	+	13.90	3.70E-04	0.159	+	13.1	5.90E-04
Annual precipitation	0.118	-	10.90	1.50E-03	0.15	-	12.3	8.40E-04
Temp. of coldest quarter	0.085	-	7.85	7.00E-03	0.047	-	4.27	4.00E-02
Latitude	0.078	-	7.21	9.00E-03	0.057	-	4.9	3,00E-02
Distance to closest farm	0.073	+	6.78	1.10E-02	0.245	+	21.8	1.6E-05
Annual insolation	0.072	+	6.71	1.20E-02				
Maximum temp. from June- September	0.058	-	5.52	2,20E-02				
Proximity to coast	0.054	+	5.22	2,50E-02				
Average annual temp.	0.051	-	4.99	2,90E-02				

Forward stepwise selection for modelling treeline elevation

A total of 82% of observed variation in treeline elevation was accounted for in the resulting model when explanatory variables were applied in forward model selection (Table 9). Only models with Bonferroni p-values lower than 0.05 were considered in the selection procedure. The final model included (in order of decreasing p-values) length of growth season, slope, an interaction between the aforementioned variables, annual precipitation, and heat index (Figure 11).

Table 9: Final model of significant (Bon. *p'* <0.05) explanatory variables for treeline elevation). F= F statistics, Df= degrees of freedom, Residual SE= Residual standard error, R^2= Adjusted R-squared, Coeff. Sign = + or – depending on the sign of the model coefficient, Bon. p' = p-value adjusted with Bonferroni method. Only significant results are displayed, see Appendix 8 for the entire selection procedure.

Round	Explanatory variable	Rank	Residual SE	Df	R^2	Coeff. sign	F	Bon. p'	p-value
1	Growth season length	1	47,6	73	0,53	-	83,70	2,7E-12	9,8E-14
2	+ Slope	1	38,5	72	0,69	+	39,20	1,3E-07	2,5E-08
3	+ Growth season length* slope	1	37,3	71	0,71	+	61,20	1,9E-02	1,9E-02
4	+ Annual precipitation	1	33,2	70	0,77	-	19,60	1,4E-04	3,5E-05
6	+ Heat index	1	29,4	69	0,82	+	20,20	8,4E-05	2,8E-05

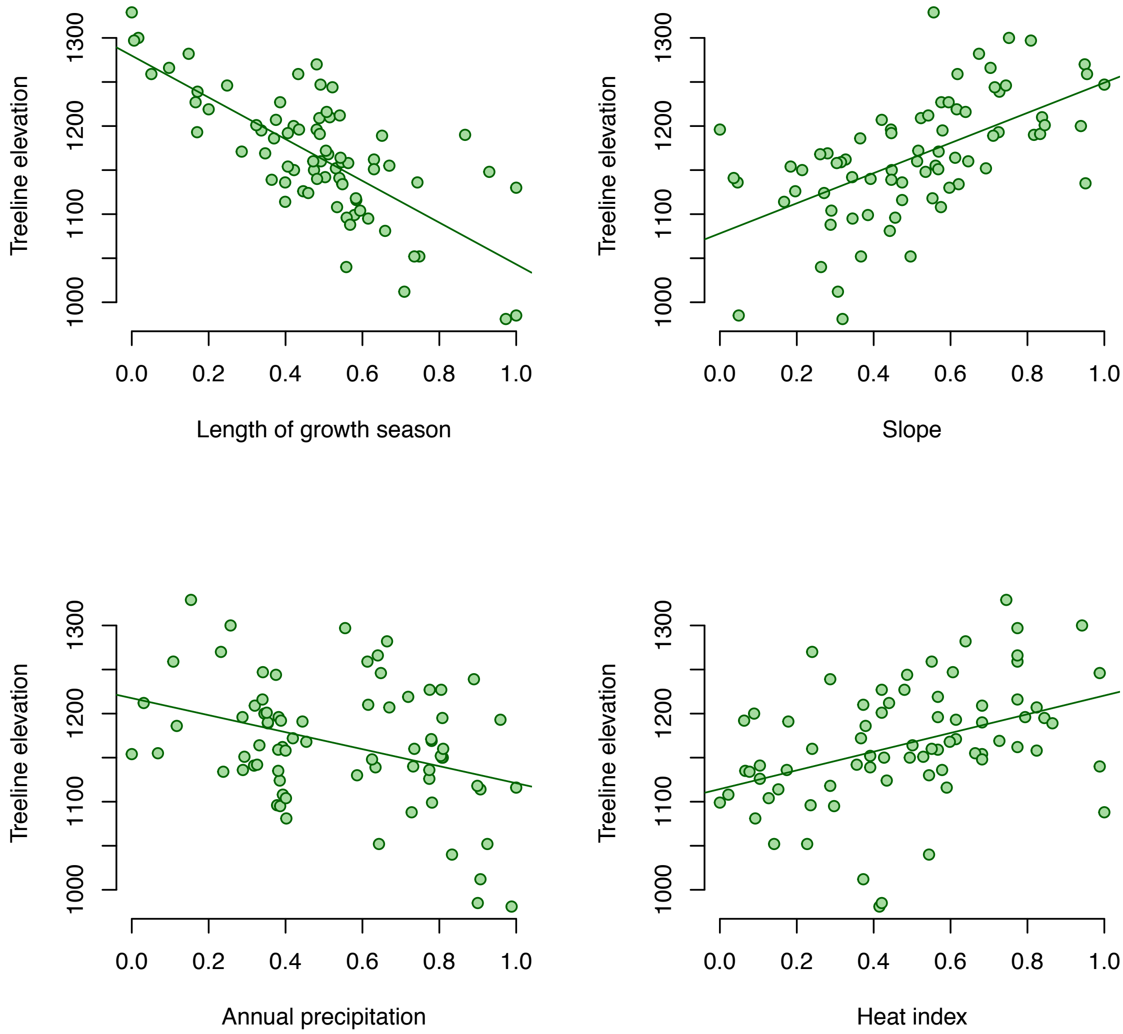

Figure 11: Linear models included in the final model of the forward selection procedure, explaining treeline elevation. Explanatory variables have been transformed, original range of values are:

- Length of growth season: 82 – 125 days
- Slope: 7.8° – 52.4°
- Annual precipitation: 768 mm –1217 mm
- Heat index: 2.5– 173.5

Forward stepwise selection for modelling forest line elevation

A total of 74% of observed variation in forest line was accounted for when testing explanatory variables in forward model selection (Table 10). The final model included (in order of decreasing p-values) length of growth season, annual precipitation, heat index, slope and an interaction between annual precipitation and slope (Figure 12).

Table 10: Final model of significant (Bon. *p'* <0.05) explanatory variables for forest line elevation). F= F statistics, Df= degrees of freedom, Residual SE= Residual standard error, R^2= Adjusted R-squared, Coeff. Sign = + or – depending on the sign of the model coefficient, Bon. p' = p-value adjusted with Bonferroni method. Only significant results are displayed, see Appendix 8 for the entire selection procedure**.**

Round	Explanatory variable	Rank	Residual SE	Df	R2	Cof, sign	F	Bon. p'	p- value
1	Growth season length	1	51	63	0,443	-	51,90	2,1E-08	8,9E-10
2	+ Annual precipitation	1	41,7	62	0,627	-	32,1	2,4E-06	4,0E-07
4	+ Heat index	1	39	61	0.674	+	10.00	7.2E-03	2.4E-03
6	+ Slope	1	36,1	60	0,721	+	11,10	1,5E-03	1,5E-03
7	+ Annual precipitation* slope	1	34,6	59	0,744	+	6,43	4,2E-02	1,4E-02

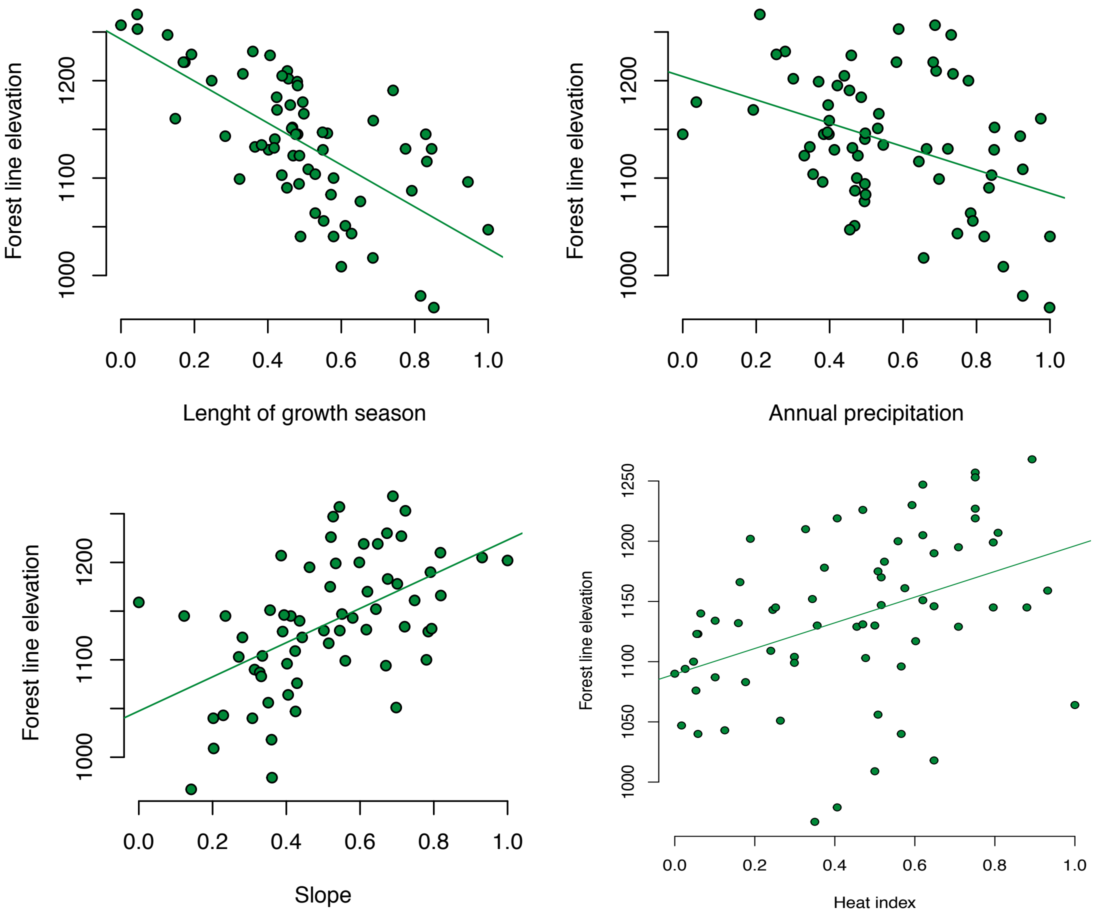

Figure 12: Linear models included in the final model of the forward selection procedure, explaining forest line elevation. Explanatory variables have been transformed, original range of values are:

- Length of growth season: 84 – 129 days
- Annual precipitation: 760 mm –1208 mm
- Slope: 2.3° – 50.1°

NiN-variables and types

NiN main types and levels of local complex environmental variables (LCEs) were registered for a total of 80 trees and their immediate surroundings, distributed across 45 treelines and 35 forest lines (Appendix 4). Eighty percent of all mapped locations were registered as belonging to the main type "Mountain heath" (T3). The other registered main types were Bare rock (T1, 8.5%), Forest (T4, 4.5%), Open fen (V1, 3.8%) and Boulder area (T27, 1%). A total of 22 different mapping units were registered. Except for the lack of tree- and forest lines in locations with "Bare rock" (T1), and missing treeline registrations in "Forest" (T4), mapping units were relatively equally distributed among treelines, forest lines and surrounding areas.

Wilcoxon rank sum test of both Risk of severe drought (DR) (Figure 13) and Lime richness (LR) (Figure 14), revealed significant differences ($p<0.05$) between basic levels at the site of each registered tree and the surroundings of the trees for both treelines and forest lines. Influence of spring water influence (SI) and Water saturation (WS) varied in almost the exact same manner, and were combined in analyses for convenience (Figure 15). The analyses showed a significant difference ($p<0.01$) between treeline locations and surrounding area, but not between forest line and surroundings. Level 3 along the mire gradient (MG) characterized the vegetation of two treelines and one forest line, and one and four locations in surrounding areas, respectively (Appendix 4). There was no significant difference between LCEs at treelines and forest lines.

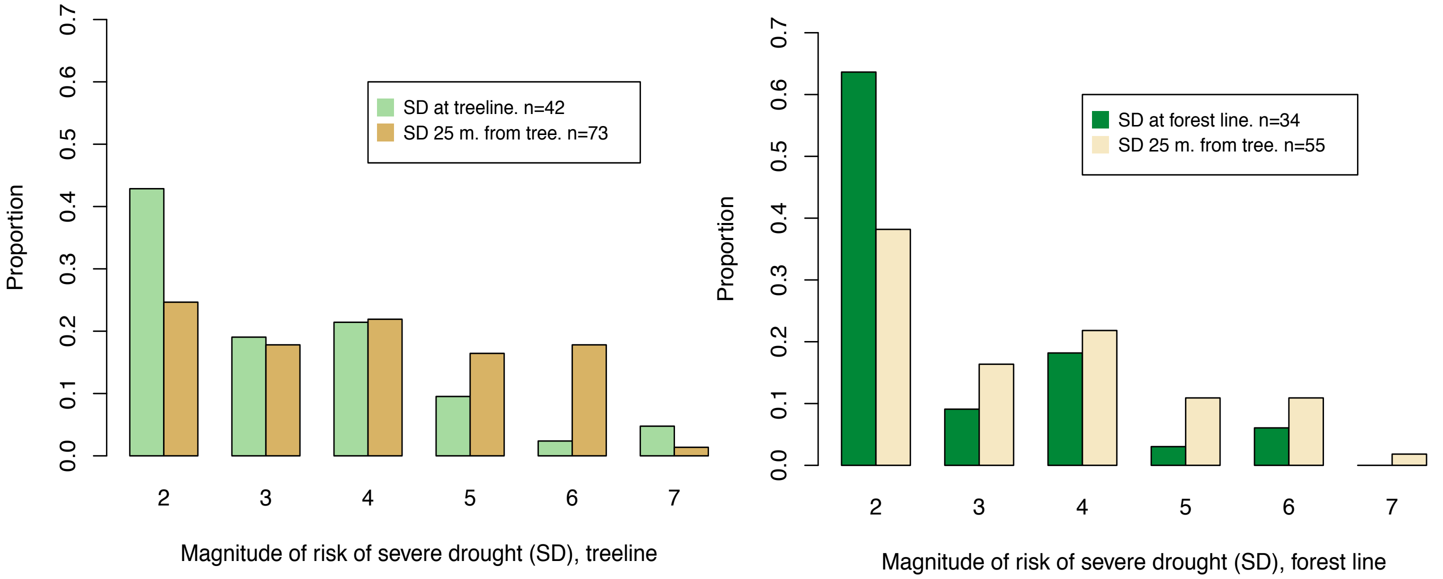

Figure 13 (above): Proportionate distribution of basic levels along the gradients of risk of severe drought (SD) between sites of trees in treelines and forest lines and their surroundings.

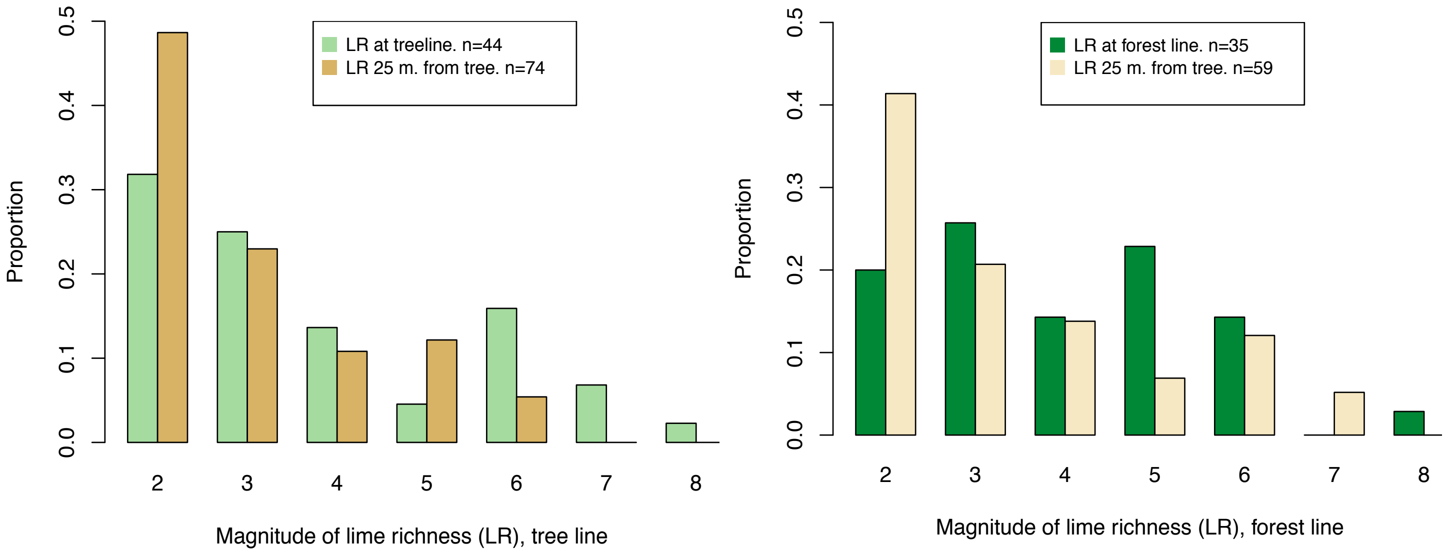

Figure 14 (above): Proportionate distribution of basic levels along the Lime richness (LR) gradient between sites of trees in treelines and forest lines and their surroundings.

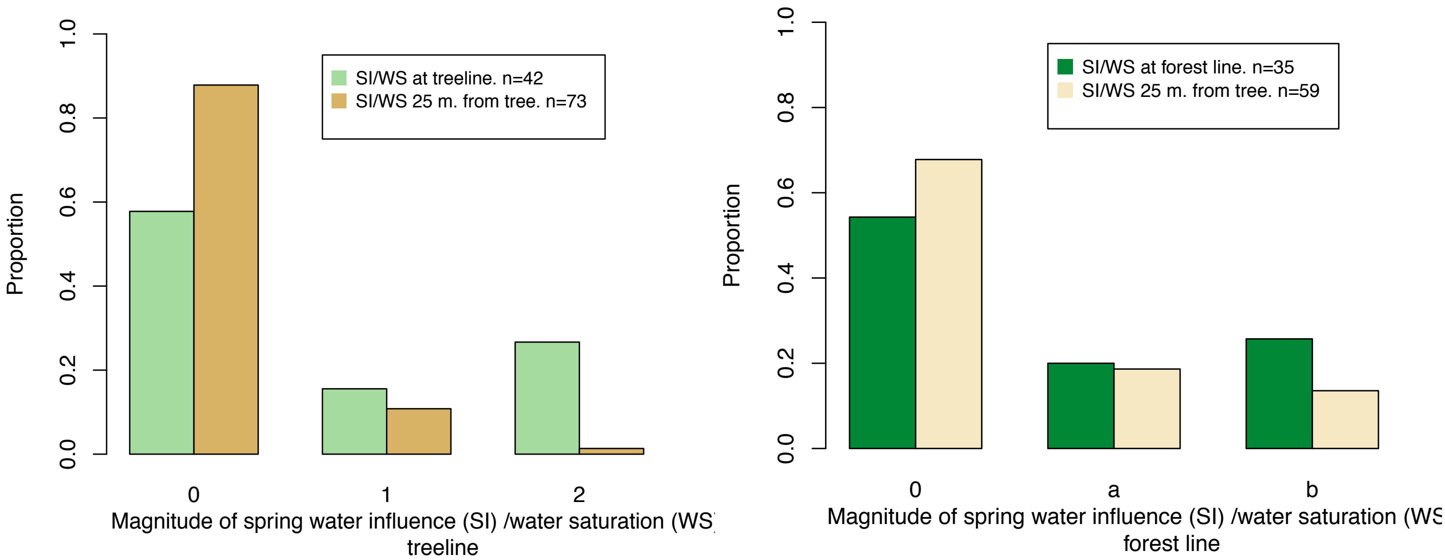

Figure 15 (above): Proportionate distribution of basic levels along the gradients of Spring water influence (SI) and Water saturation (WS) between sites of trees in treelines, forest lines and their surroundings. "0" represents locations in which SI and WS did not contribute to variation in the type.

Levels of LCEs along the valley

Higher levels of Lime richness (LR) were found more frequently close to the coast, declining towards the east (Figure 16, A & B). The opposite is true for Risk of severe drought (SD) and Spring water influence (SI)/ Water saturation (WS), for which frequency of registrations of higher levels increased from the coast towards the innermost parts of the valley (Table 11 and Figure 16, C & D, E, F).

Table 11: Summary of correlation tests between basic levels of LCEs and position along the valley. Correlation = Pearson correlation coefficient for the relationship between recorded climate change and tree- or forest line change, p-value = significance of correlation, Conf. iv. = Confidence intervals for the correlation tests.

Spring water influence/water saturation			**Lime richness**		**Risk of severe drought**	
	Tree	*Surround.*	*Tree*	*Surround.*	*Tree*	*Surround.*
Correlation	0.458	0.430	0.390	0.249	–0.490	-0.423
p-value	2.00E-05	5.00E-08	3.00E-04	3.00E-03	8.00E-06	2.00E-07
Conf. iv.	0.264, 0.617	0.3, 0.56	0.190, 0.569	0.086, 0.399	-0.645, -0.295	-0.551 -0.275

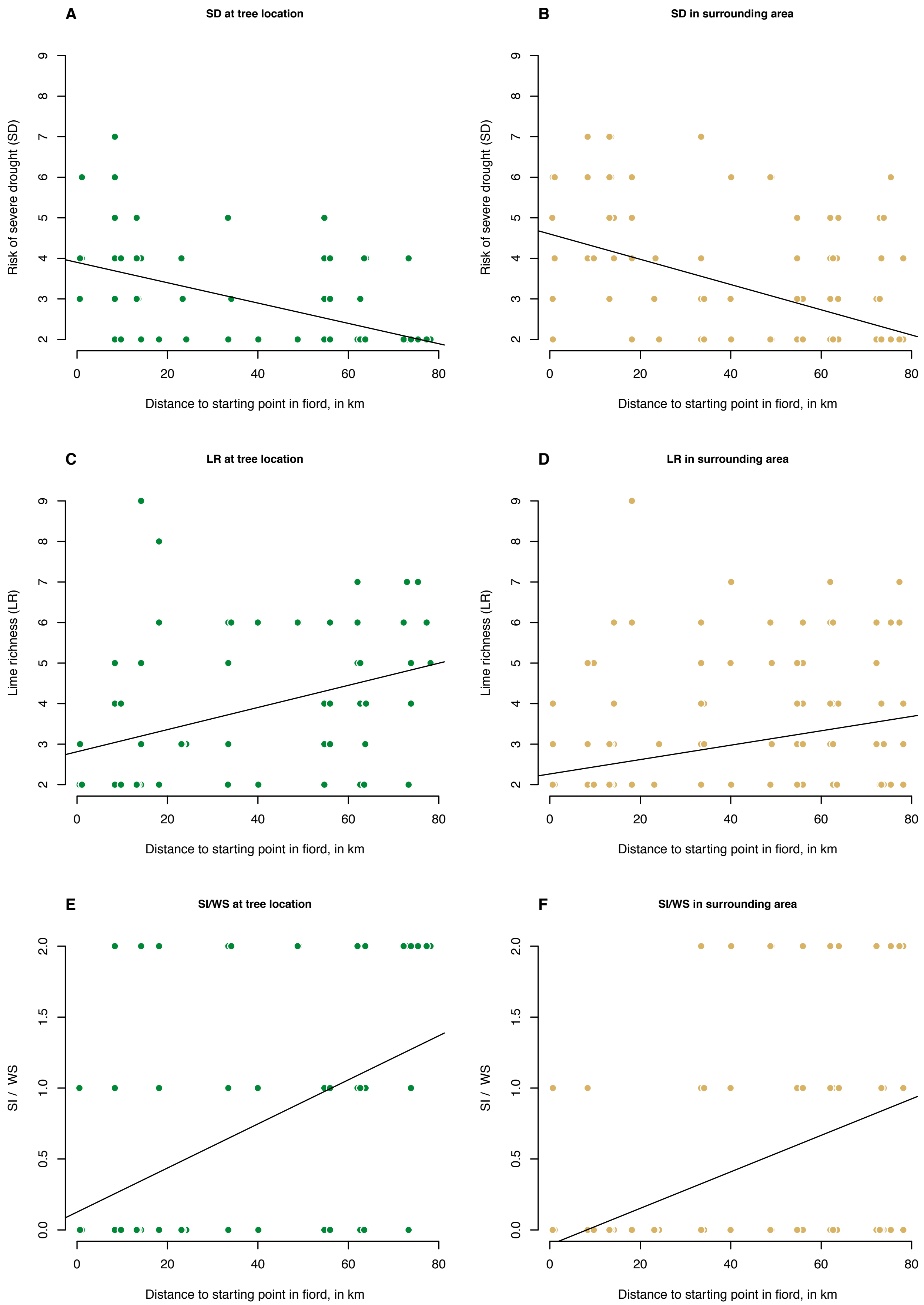

Figure 16: Distribution of basic levels of local complex environmental variables (LCEs) along the valley of Lærdal, for both tree- and forest lines, with corresponding regression lines. Plots to the left depict spread of basic levels at the location of each tree, while the plots to the right display the spread of recorded basic levels in the immediate surroundings of each tree. Top row: Distribution of basic levels along the gradient "Risk of severe drought (SD) Middle row: Distribution of basic levels along the gradient of Lime richness (LR). Bottom row: Distribution of basic levels along the gradient of Spring water influence (SI) /Water saturation (WS).

4.3 Distribution and characteristics of shifts in tree- and forest lines

Among remapped locations, present mean elevation of treelines was 1 164 m a.s.l., while mean forest line elevation was 1 143 m a.s.l. (Table 12). On average, the lines have advanced by around 54 and 48 m, respectively, during the last 80 years. The largest shift in tree line elevation was found at Glipsfjellet at 1 239 m a.s.l., 207 meters above the treeline Ve (1940) found. The largest negative shift in treeline elevation was found on the hillside of Glipsfjellets neighbouring mountain, close to Hovdungane, where the treeline had declined from 1 049 m a.s.l. in 1938 to 981 m a.s.l. today. Forest line elevation had, at most, advanced by 169 meters, from 930 m a.s.l. to 1 099 m a.s.l. on the eastern side of the Bliksdalen valley. The largest negative difference was found close to Geitåni in the valley of Myrkedalen, with a decline from 1 094 to 1 051 m a.s.l. Five tree lines and ten forest lines were registered with a shift of 10 m or less.

Table 12: Summary of measures of elevation above sea level for tree- and forest lines, and of the variation in magnitude of shift across registrations.

		Min. elevation/shift	**Max. elevation/shift**	**Mean elevation/shift**	**Median elevation/ shift**
Treeline	1938	1009	1233	1113	1110
	2016	981	1329	1165	1164
	Shift	- 28	+ 96	+ 55	+ 54
Shift properties		- 68	207	54.2	47
Forest line	1938	930	1248	1095	1092
	2016	979	1268	1142	1145
	Shift	+ 49	+ 20	+ 48	+ 52
Shift properties		- 43	169	47.4	42

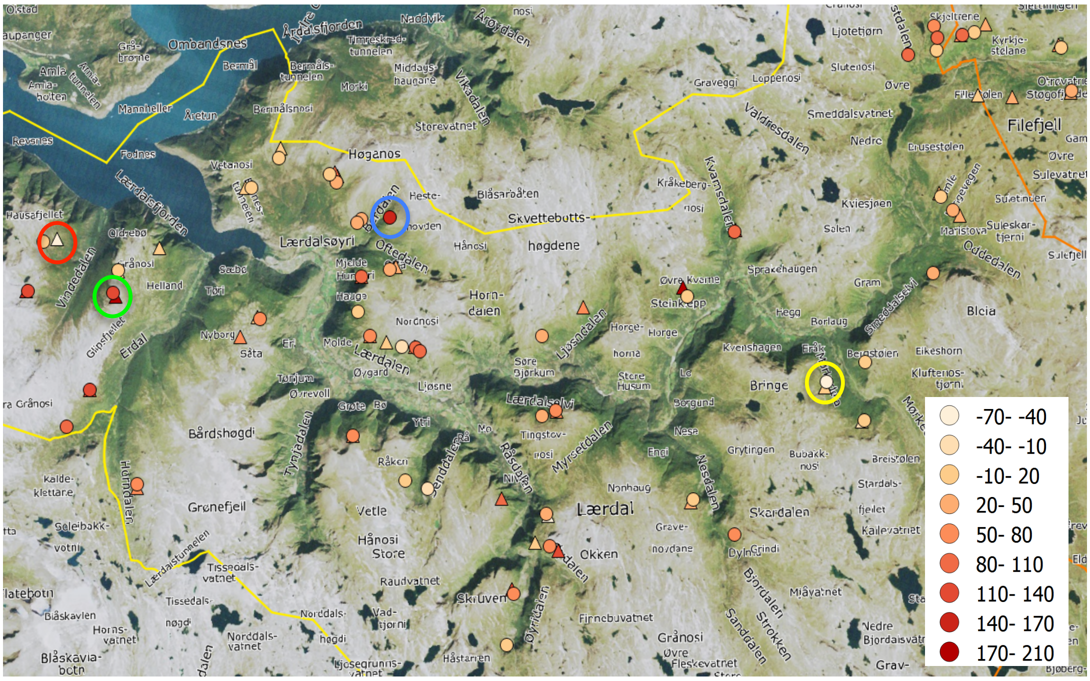

Figure 17: Distribution of shifts treelines (triangles) and forest lines (dots) colour coded according to magnitude of shift. Green circle marks the location of the largest upward shift in treeline elevation, red circle marks the location of largest negative shift in treeline elevation, Blue circle marks the location of the largest upward shift in forest line elevation and yellow circle marks the location of the largest negative shift in forest line elevation.

Tree- and forest line elevation from coast to inland

From Figure 17, shifts in elevation of both treelines and forest lines appear to be relatively equally distributed along the Lærdal valley. No significant correlations were found between magnitude of shift and position along the valley (Table 13).

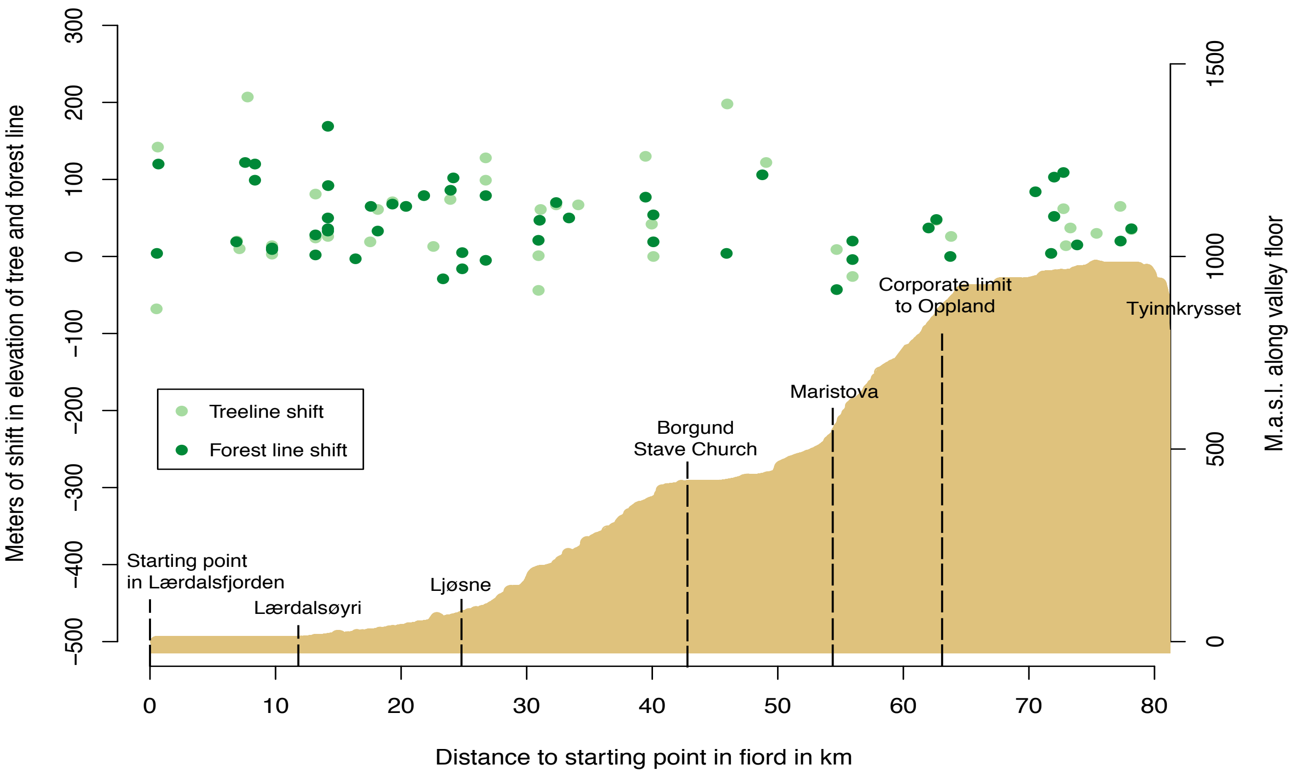

Figure 18: Magnitude of shifts in tree- and forest lines and elevation of valley floor, plotted against distance to starting point of valley, with corresponding regression lines for the tree- and forest lines.

Table 13: Summary of modelled of tree- and forest lines tested against distance to fiord. Correlation= Pearson correlation coefficient.

	Intercept	Slope	Std. error	p-value	Correlation
Treeline	62	-0.22	58	5.68E-01	-0.91
Forest line	56	-0.27	45	3.02E-01	-0.14

Previous shrub line and treeline compared to present treeline and forest line

The elevation of the shrub line registered by Ve in 1938, correlates strongly with the present elevation of treelines (Figure 7, Table 14). A similar correlation is found between the elevation of present day forest line and previous treeline (Figure 18, Table 14).

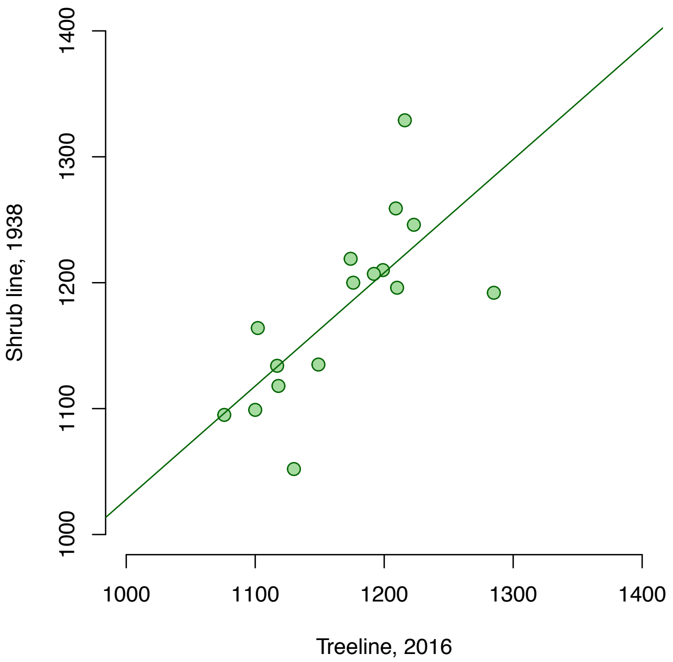

Figure 17: Elevation of shrub registered in 1938, plotted against the elevations of treelines observed in field in 2016.

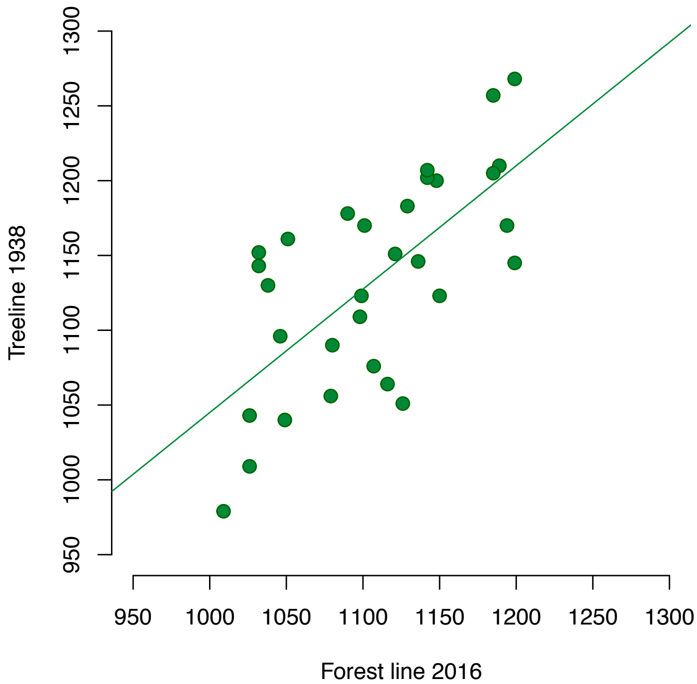

Figure 18: Elevation of treelines registered in 1938, plotted against the elevations of forest lines observed in field in 2016.

Table 14: Summary of correlation test between present elevation of treelines and previous shrub lines, and between present elevation of forest lines compared to previous treeline elevations. Correlation = Pearson correlation coefficient for the relationship between recorded climate change and tree- or forest line change, p-value = significance of correlation, Conf. iv. = Confidence intervals for the correlation tests.

Plots	Correlation	p-value	Confidence intervals
Treeline vs. shrub line	0.722	1.65E-03	0.354–0.897
Forest line vs. treeline	0.680	2.27E-05	0.434–0.835

Spatial structure

Calculated semivariance of shifts in tree- and forest line elevation showed that semivariance was relatively high throughout all distance classes for both tree and forest line. No spatial structure was visible in the plots (Appendix 5).

Regression analysis of shifts in tree- and forest lines

Among 25 explanatory variables tested in linear regression, four were significantly ($p<0.05$) better at explaining the variation in shifts in treeline elevation than the null model of no relationship (Table 15). Two of these and one additional variable were significant when tested against forest line elevations (Table 15).

Table 15: Overview over variables which were significantly better ($p<0.05$) predictors of shifts in tree- and forest line elevation (m a.s.l..) than the null model of no relationship. F= F statistics, R^2= Adjusted R-squared, Coeff. Sign = + or – according to slope of linear model fitted to the tested variables.

	Treeline shift				Forest line shift			
Explanatory variable	**R2**	**Coeff. sign**	**F**	**p-value**	**R2**	**Coeff. sign**	**F**	**p-value**
Length of growth season	0.251	-	13.7	6.90E-04	0.113	-	7.36	9.20E-03
Slope	0.144	+	7.41	9.80E-03	0.074	+	4.98	3.00E-02
Proximity to river	0.125	+	6.41	2.77E-02				
Temperature of warmest quarter	0.084	-	4.32	3.88E-02				
Elevation 1938					0.064	+	4.47	3.06E+03

Forward stepwise selection for modelling treeline elevation

When analysing the variation in treeline shifts with Bonferroni- adjusted p-values, only length of growth season was significantly better in explaining shift in treeline elevation than the null-hypothesis of no relationship. For shifts in forest line elevation, no models were better than the null hypothesis of no relationship after adjusting p-values according to the Bonferroni method.

4.4 Climate change and shifting lines

Average measures of temperature, growth season and precipitation revealed distinct variations in the climate throughout the last 117 years. Annual temperature (Figure 19), average temperature of June to August (the triterm, Figure 20) and length of growth season (Figure 21) all peaked at the beginning of the 20th century, with a triterm temperature of up to 8°C, annual temperatures of between 0.5°C and 1°C and growth seasons lasting close to 100 days. From around 1955 all measures declined considerably, with a relatively stable period of triterm and annual temperatures between 6.5-7°C and 0-0.5°C, respectively, and a length of growth season of around 90 days. However, during the late 1900s, temperatures rose markedly. Triterm temperatures reached almost the same values as in the beginning of the century, and annual temperatures, as well as length of growth season, reached their maximum values yet.

The plot of annual precipitation (Figure 22) showed a relatively stable increase in precipitation from around 580 mm a year in 1910 to almost 850 mm a year in 2015.

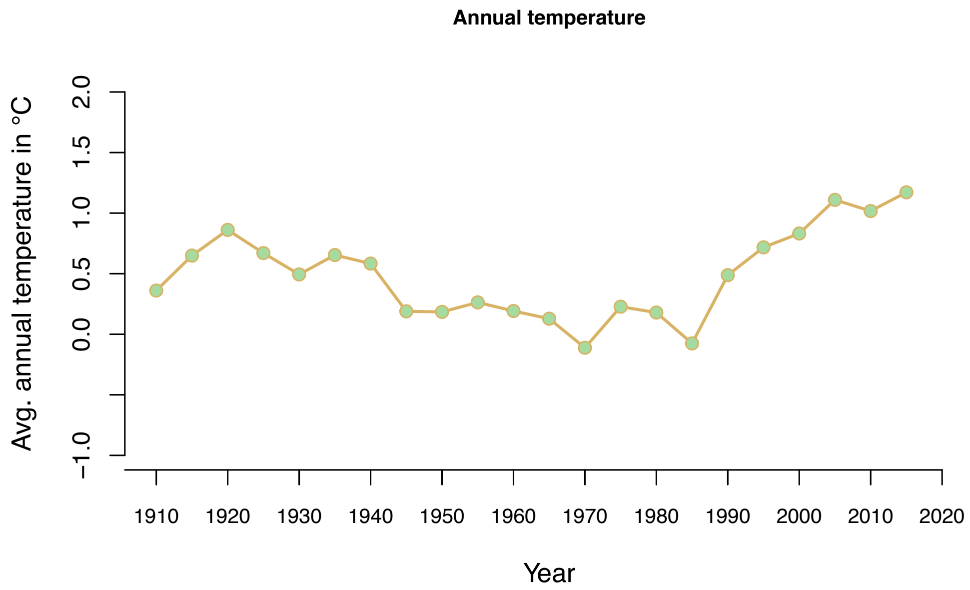

Figure 19: Average annual temperatures calculated over ten years, plotted for every fifth year.

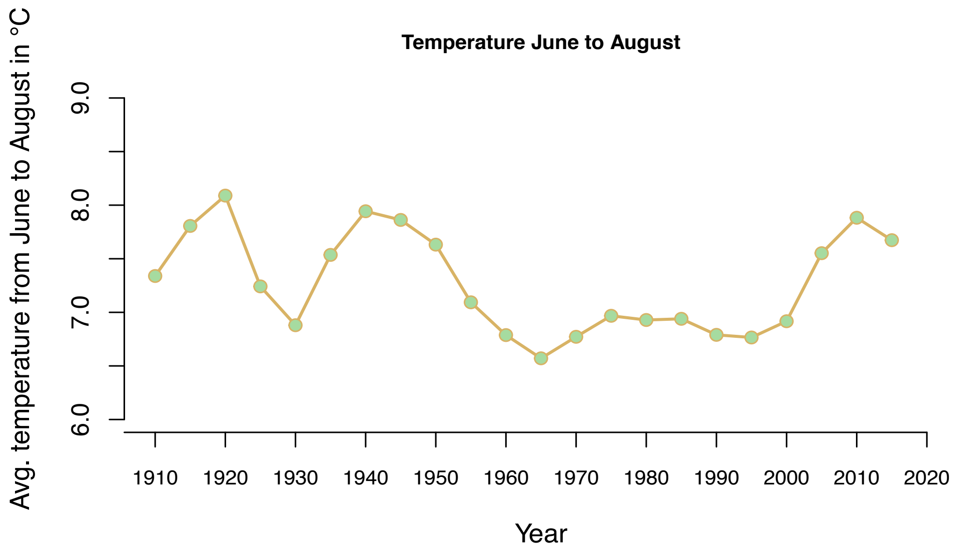

Figure 20 (above): Average temperatures from June to August, calculated over ten years, plotted for every fifth year.

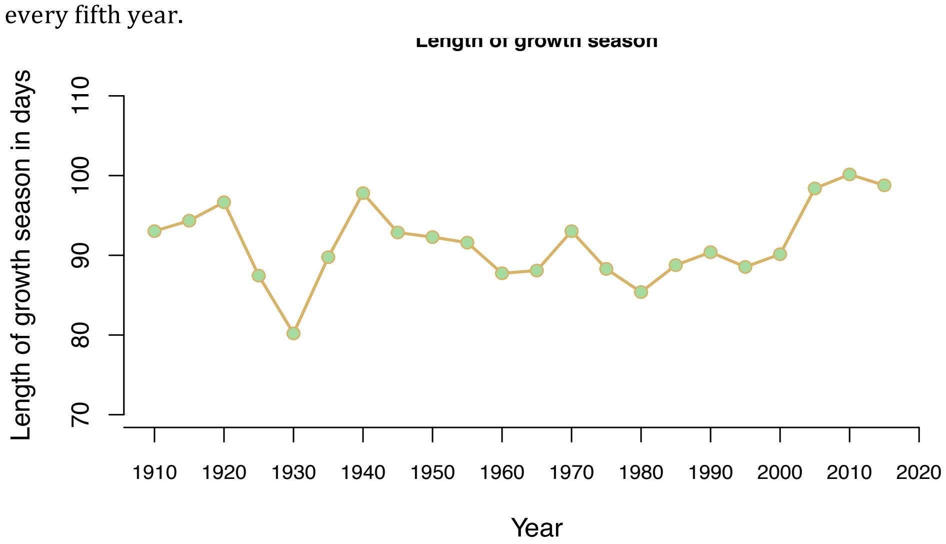

Figure 21 (above): Average length of growth season in days calculated over ten years, plotted for every fifth year.

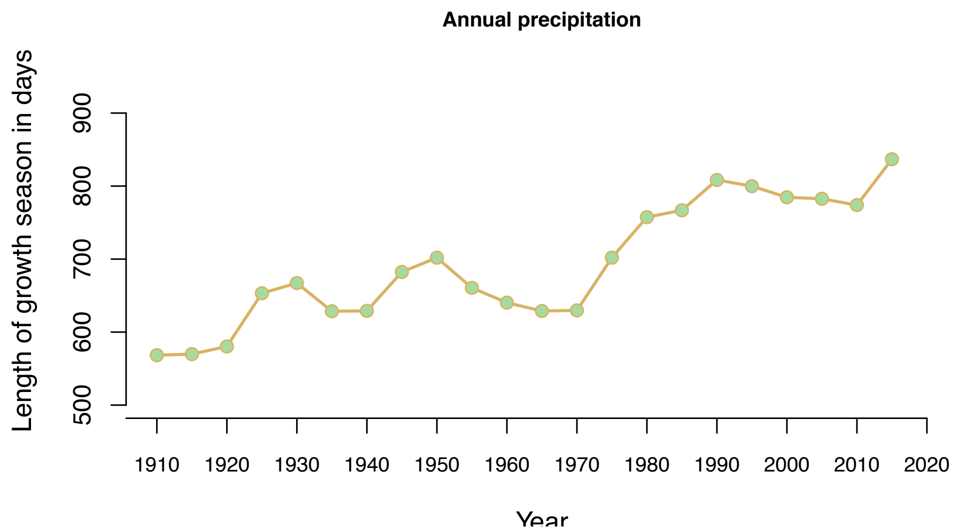

Figure 22 (above): Average annual precipitation calculated over ten years, plotted for every fifth year.

Analyses on average climate measures prior to each mapping effort (1938 and 2016) showed that only precipitation had increased significantly (p<0.01) during the last 20 years. This was also the only variable that displayed a clear difference between tree- and forest lines. Nonetheless, positive changes in climate are evident for all four variables: the years before the most recent tree- and forest line mapping were hotter and saw longer growth seasons and more precipitation than the corresponding period prior to the 1939-mapping (Table 16 & 17). This is true for both treeline locations and forest line locations. When comparing climatic changes at each location with the corresponding shift in treeline or forest line, no significant correlations were found (Table 7, Figure 23 (A-D) and Figure 24 (A-D)). However, some weak correlations were found between forest line shift and increase in annual temperature (Figure 23 A), triterm temperature (Figure 23 B) and length of growth season (Figure 23 C).

Table 16: Average values of climate variables in 1938 and 2016.

Climate variable	Treelines		Forest lines	
	1938	**2016**	**1938**	**2016**
Annual temp.	0.64°C	1.15°C	0.74°C	1.20°C
Triterm temp.	7.40°C	7.64°C	7.44°C	7.62°C
Length of growth season	88.8 day	93.6 days	89.2°C	98.8°C
Annual precipitation	620.0 mm	797.6 mm	640.5 mm	819.7 mm

Table 17: Summary of comparisons between changes in climate and in tree- and forest lines. 2015- 1938 = the average difference in the listed climate variables between the 20 years prior to 1938-mapping and to 2015-mapping. Cor. = Pearson´s correlation coefficient for the relationship between recorded climate change and tree- or forest line change. Conf. iv. = Confidence intervals for the correlation tests.

Climate variable	Treelines				Forest lines			
	2015–1938	**Cor.**	**p-value**	**Conf. iv.**	**2015– 1938**	**Cor.**	**p-value**	**Conf. iv.**
Annual temp.	+ 0.5 °C	-0.17	2.81E-01	-0.440, 0.145	+0.5 °C	0.19	2.04E-01	-0.103, 0.447
Triterm temp.	+ 0.24 °C	-0.08	6.33E-01	-0.482, 0.230	+0.18 °C	0.21	1.61E-01	-0.084, 0.462
Length of growth season	+ 5 days	-0.05	7.85E-01	-0.360, 0.286	+10 days	0.17	2.64E-01	-0.120, 0.441
Annual precipitation	+ 180 mm	-0.08	6.20E-01	-0.380, 0.239	+180 mm	0.00	9.60E-01	-0.290, 0.278

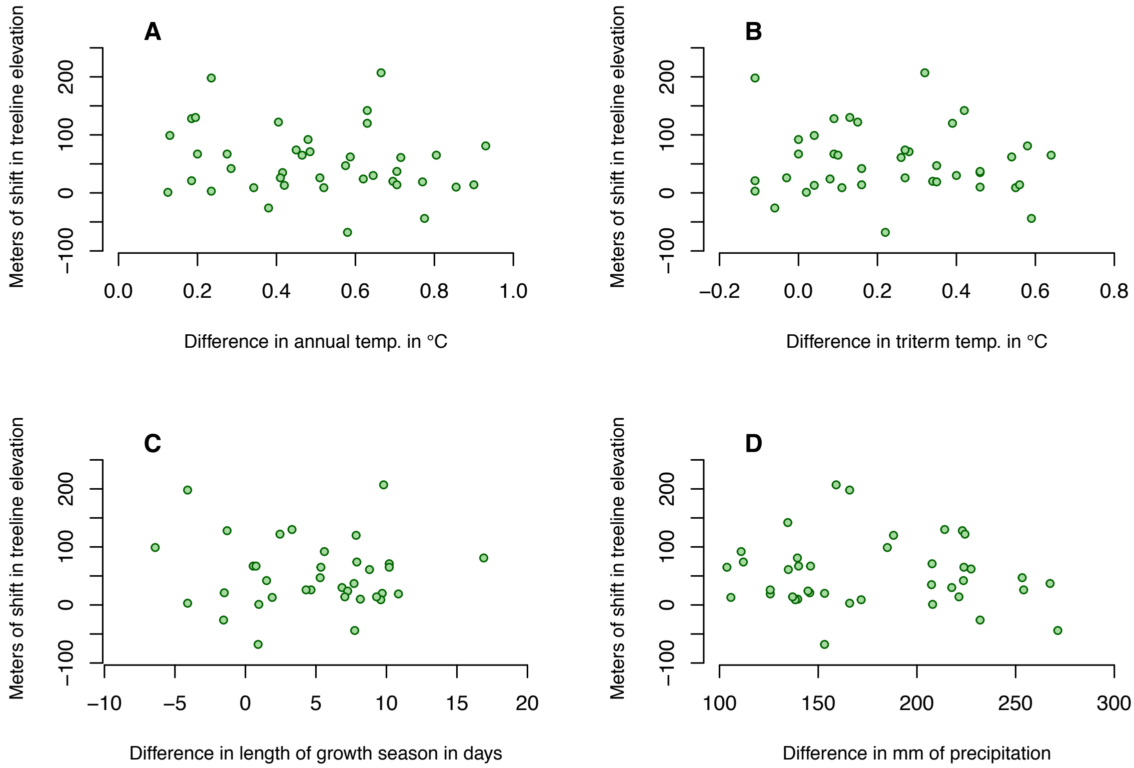

Figure 23: Shifts in treeline elevation from 1938– 2016 plotted against differences in climatic averages between the 20 years prior to 1938-mapping and 2016-mapping. Each point represents a treeline location. A = difference in annual temperatures, B = differences in triterm temperatures, C= differences in length of growth season, D= Differences in precipitation.

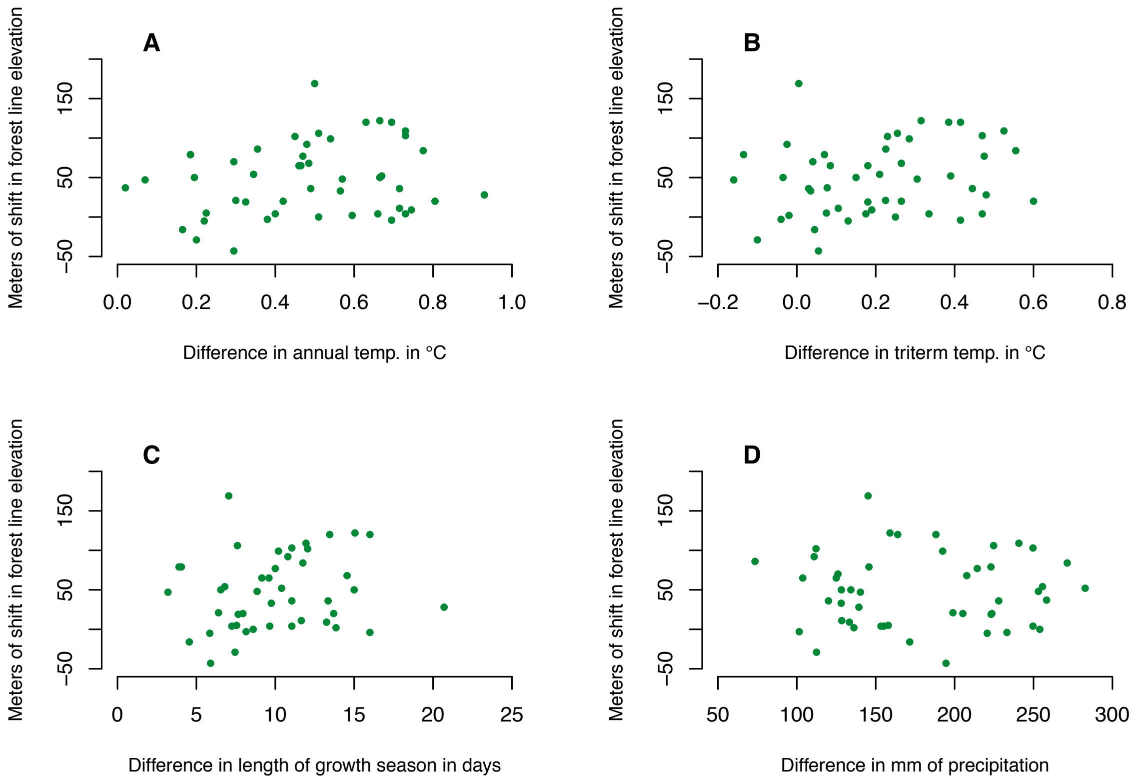

Figure 24: Shifts in forest line elevation from 1938– 2016 plotted against differences in climatic averages between the 20 years prior to 1938-mapping and 2016-mapping. Each point represents a treeline location. A = difference in annual temperatures, B = differences in triterm temperatures, C= differences in length of growth season, D= Differences in precipitation

5 Discussion

5.1 Distribution and characteristics of the present tree- and forest lines

Distribution

Tree- and forest lines are typically low close to the ocean, and increase in elevation with distance to coast and with increased elevation of the land (Odland, 1996). This pattern is mainly related to the higher daytime temperatures during growth season in continental areas compared to coastal areas (Tranquillini, 1979). In the present study, no significant difference in elevation was found between tree- and forest lines close to the fiord and those in the inner parts of the Lærdal valley. However, this does not mean that such a relationships does not exist in the study area. More likely, the lack of a significant distributional pattern is a consequence of the scale at which the tree- and forest lines have been investigated, as heterogeneity in tree- and forest line elevations increases from global to regional scales (Holtmeier, 2009). If the data were incorporated in analyses of tree- and forest line elevations at a larger scale, they would probably display the same tendencies as described by Odland (1996).

The average elevations of tree- and forest lines found in this study, with treelines at 1168 m a.s.l. and forest lines at 1137 m a.s.l. (Table 4), fit well with the descriptions by (Moen, 1998), who estimates that the elevation of tree- and forest lines in Lærdal should be between 1100 and 1300 m a.s.l. The distribution of the lines within Lærdal also coincides well with the findings of Ve (1940), with the lowest tree- and forest lines located close to the fiord, and the highest lines located in areas around Ljøsne. Ve attributes the distinct elevation of trees in this area to the remarkably high summer temperatures in the area, but this assumption is not supported by estimates in the present study as there are several sites throughout the valley with considerably higher summer temperatures than the ones found at the treelines and forest lines above Ljøsne (Appendix 9).

The average distance between treelines and forest lines found in the field (31 m), surpasses the calculations by Ve of 25.3 m, but the distance is not greater than Odland (1996) general estimate for the treeline ecotone in Norway of <40 m. Besides the possible effect of varying definitions on the calculation of this distance, the most plausible explanation for the increase is that treelines have expanded upwards faster than the forest lines. This will be discussed in more detail in chapter 5.2.

Despite a large average distance between observed and predicted (Bryn & Potthoff, 2018, in review)elevations of forest lines, the elevation of the topmost forest lines found in the field correspond quite accurately with the modelled elevation of climatic forest lines. This indicates that the very highest forest lines found in field may indeed be climatically determined. They are, however, not necessarily *limited* by climate, as forests lines are expected to have a delayed response to improved growth conditions (Rannow, 2013; Aas, 1969). Forest lines that do not reach the predicted elevations could also be climatically determined, since climatic conditions vary along the valley, and may not allow for the same elevations at all sites. However, micro topography and anthropogenic disturbance is considered by e.g. Holtmeier (2009) to have considerable influence on elevation of tree- and forest lines, and this is also the likely explanation for most of the comparably low empirical registrations of forest lines. Additionally, it might be that the forest lines found in the field are not the topmost lines in the area. Although Ve (1940) did not explicitly state it, it is assumed in the present study that he mapped the topmost trees and forests in each area. However, these are not necessarily the areas with the topmost lines today, and the study design might therefore have prevented sampling of the topmost trees and forests in some areas. I such cases, the distance between observed and predicted elevation would be misleading.

Distribution explained

Spatial autocorrelation was found between elevations of trees at short distances, for both tree- and forest lines. This indicates a structuring effect of the environment along the valley. Analyses provided four possible explanations for the observed variations in elevation of tree- and forest lines, length of growth season, slope, heat index (aspect) and annual precipitation.

Growth season

Length of growth season explained around 50% of the variation in elevations of both tree- and forest lines, but the correlation with elevation was negative. This implies that the association of growth season length with elevation is only a reflection of the mountain climate, and not a predictor of tree- and forest line elevations. Growth season is simply shorter higher up in the mountains.

Slope

The elevation of tree- and forest lines registered in this study significantly increases with slope, which may result from several different mechanisms. The most direct effect of slope on tree- and forest line elevations is that the angle of the slope, in combination with aspect, is believed to determine the amount of solar radiation which trees are exposed to, which, in turn, influences the elevation of the trees (Bandekar & Odland, 2017; Kjällgren & Kullmann, 1998). However, solar radiation did not come out as a significant predictor for present tree- and forest line elevations in Lærdal, and no significant interactions between slope and heat index occurred. Also, as remarked by (Körner, 1999), tree growth should be more influenced by interactions of solar radiation with the tree crown than with the interactions of solar radiation with the slope. Slope must therefore contribute to the observed variation in other ways.

A second possible explanation is the influence of slopes on snow accumulation. Trees and seedlings in the treeline ecotones are dependent on snow for protection from the harsh winter climate (Karlsson *et al.*, 2005; Kjällgren & Kullmann, 1998), but too much snow might limit tree growth by shortening the growth season (Tranquillini, 1979). In the present study, slope correlates positively with duration of snow cover (Appendix 7), which mean that the snow lasts longer in steeper areas. Data on wind in Lærdal was not collected for the present study, but according to Holtmeier (2009) and Meier *et al.* (2005), this characteristic of leeward slopes, where snow accumulates and is not easily swept away by wind (Holtmeier, 2009; Meier *et al.*, 2005). Consequently, slope might influence the conditions for establishment of trees at high elevations partly through the effect of different inclinations on the duration of snow cover. Considering the quite dry winter climate of Lærdal (Hauge & Austad, 1989; Ve, 1940), it seems likely that trees would favour sites with relatively deep and long-lasting snow cover at high elevations, as temperatures decreases. Additionally, wind has in itself been shown to influence tree growth and elevation of tree- and forest lines ((Holtmeier *et al.*, 2003; Körner, 1998). Thus, the elevation of tree- and forest lines may also be structured along slopes according the degree of protection against wind provided at different inclinations. An example of such impact of inclination was reported by (Bandekar & Odland, 2017), who found that the northernmost forest lines in their study area were located at sheltered terrain with a slope of more than 15 degrees. Lack of data on wind in the present study makes it impossible to conclude any further on the effects of wind on the elevations of tree- and forest lines in Lærdal.

Lastly, tree- and forest lines may be higher up in steep areas because such locations are less attractive for grazing, logging and farming than more moderate slopes (Holtmeier, 2009; Kjällgren & Kullmann, 1998). This last part is confirmed by Ve (1940, p. 65, translated): "The mountain sides of the narrow valleys are often so steep and rough that cattle avoid them, and some places they are impeded from grazing altogether. Mostly, goats climb these hills, but they rarely linger in the same place for long, and only grab a mouthful here and there. (…) as long as she [the goat] has plenty of mountain plateaus to explore, the effect of her grazing is hardly noticeable." Still, if human influence were the sole cause of the significant effect of slope on tree- and forest lines elevations, a non-linear relationship would be expected, with line elevations dropping notably at a certain inclination, where farming practises were no longer hindered by topography. The plots for both tree- and forest lines do show a tendency towards such a pattern (Figure 6 & 7), forest lines maybe more so than treelines. The difference between treelines and forest lines in this regard, could be attributed to the belief that treelines were generally less influenced by human activities than forest lines (Kjällgren & Kullmann, 1998; Ve, 1930) Differences could have been further amplified by the slow reaction of forest lines to altered surroundings compared to that of treelines (Rannow, 2013).

Heat index

The elevation of tree- and forest lines increases with increasing heat index, which, in terms of aspect, means they approach their highest elevations on mountainsides facing southwest. This coincides with previous research, which has shown that tree- and forest lines in northern regions are highest on south facing slopes and lowest on north facing slopes (Holtmeier, 2009; Odland, 1996; Paulsen & Körner, 2001; Ve, 1940). Most authors attribute this to higher temperatures following increased amounts of solar radiation (Tranquillini, 1979). However, according to Körner (2012), the heating effects of increased solar radiation will only be significant for vegetation at ground level. He claims that tree growth cannot draw advantage of this heat, and that the observed differences in tree- and forest line elevations with exposure must be caused by lowering of the lines at north facing slopes by snow packs and avalanches. In the present study, there were no correlation between duration of snow cover with and heat index, which indicates that the assumption of Körner does not hold true for tree- and forest lines in Lærdal. The topic of avalanches was thoroughly discussed in general by Ve (1940), but he does not seem to suspect avalanches to have any influence on the overall patterns related to exposure.

In the present study, heat index correlates significantly with all measures of temperature (Appendix 7). This means that sites with the highest heat index values are also the sites with the highest estimates of above-ground (2m) temperature, which Körner (2012) would undoubtedly agree influences tree growth. Consequently, avalanches are unlikely to be the only cause for the significance of aspect on the elevation of tree- and forest lines.

Precipitation

Precipitation contributes significantly in explaining tree- and forest line elevations throughout Lærdal. The correlation with elevation is negative, so that elevation of tree- and forest lines decreases with increasing precipitation. Such a trend has been observed in all areas of the world, even where precipitation is as low as 300 mm a year, and is generally attributed to the colder temperatures associated with cloud cover (Körner, 2012). Seemingly, aridity is not a limitation to tree growth, and trees establishing at high elevations will readily grow in dry areas as long as they have access to soil water (Körner, 2012).

NiN in the treeline ecotone

Levels of LCEs

The patterns of moisture preferences mentioned above are confirmed by the results of the NiN-mapping. Trees in the tree- and forest lines were found more frequently in less drought prone sites (Figure 13) and in sites influenced by soil water/high levels of water saturation (Figure 15) than what was generally available in their immediate surroundings. This means that trees are more likely to establish in more moist locations. Notably, the amount of sites influenced by spring water was not significantly different between trees in forest lines and their surroundings. This may be attributed to the more stable levels of soil moisture in forests compared to single trees (Holtmeier, 2009), although trees in forest lines may be just as isolated as trees in the treelines.

The significant difference between registered levels of Lime richness (LR) in tree- and forest lines and in their surroundings can be explained in two different ways. On the one hand, moist sites may be particularly nutrient rich, due to influx of nutrient-carrying water. If this is the case, the differences between trees and forests and their surroundings is merely an artefact of the trees´ preference towards moist locations. On the other hand, nutrient contents have been shown to affect the growth form of trees, with trees growing in more nutrient rich soils developing more stature growth forms (Weih & Karlsson, 2001; Wielgolaski & Nilsen, 2001). Consequently, the levels of Lime richness registered in tree- and forest lines in the present study may not represent the general nutrient demands of the mountain birch. It does, however, signal that upward expansion of "proper" trees and forests at high elevations might to some degree be dependent on sufficient access to nutrients.

LCEs along the valley

In the valley floor of Lærdal precipitation is extremely low close to the coast, and increases towards the inland, but the opposite pattern is observed at the sites of the tree- and forest lines (Appendix 7). With this in mind, the patterns of LCEs along the valley provide valuable insights into potential constraints for establishment of trees and forests at high elevations. Most registrations of higher levels of the LCE Risk of severe drought (SD), were made at locations close to the fiord, while very few trees and forests were found on sites with high levels of SD in the innermost parts of the valley. The opposite pattern is evident for Lime richness and Influence of spring water/Water saturation, with more registrations at higher levels in the inland than close to the fiord. This implies that in areas with high amounts of precipitation, trees are able to grow at more drought prone sites; while in areas with relatively little precipitation they are limited to more permanently moist sites. Thus, decreased precipitation improves conditions for tree establishment at high elevations, but it simultaneously limits the amount of available sites for tree growth. The birch´ nutrient requirements are not likely to vary along the valley, and the observed covariance with Influence of spring water/Water saturation is therefore mainly interpreted as an artefact of the nutrient carrying property of spring water. This does, however, not disprove the assumption that there might be a bias in registered levels of Lime richness in the study.

5.2 Distribution and characteristics of shifts in tree- and forest lines

During the last 80 years, treelines in Lærdal have advanced on average by 54 m and forest lines on average 48 m (Table 12), although in several locations, lines have also declined. There were no significant differences in magnitude of shifts from the fiord to the mountain plateau in Filefjell. However, it appears from Figure X that change has been slightly greater close to the fiord than further into the valley. The sites with the largest positive and negative decline in treeline elevation were found on each side of the same valley, Vindedal, which efficiently describes the great variability in magnitude and locations of shifts throughout the Lærdal valley.

While upwards shifts are usually attributed to regrowth and improved growth conditions, declining tree- and forest lines are ascribed to disturbance of some kind (Harsch *et al.*, 2009; Aas, 1969). Examples of such disturbance are accumulations of snow, logging, particularly early or late frost, biotic interactions, snow slides or rock debris (Holtmeier, 2009; Holtmeier & Broll, 2005; Odland, 1996; Tranquillini, 1979; Ve, 1940). Disturbance is considered the most likely cause for decline also in the present study.

Characteristics of shifts

Treelines in Lærdal have, in average, advanced vertically by six meters more than forest lines. This seems to confirm the general assumption that treelines react faster to altered surroundings than forest lines (e.g.Holtmeier, 2009; Rannow, 2013; Aas, 1969). Following this row of thought, the relatively short distance between the lines in 1938, as discussed in chapter 5.1, indicates that the environment in the treeline ecotone must have been more stable then than it is now. If regrowth alone were to affect the distance between tree- and forest lines, we would expect the forests to close in on the treeline over time, narrowing the gap. Since this is the opposite situation of what is observed in the present study, the lag between the two lines must have been caused by improved growth conditions.

The current difference between tree- and forest lines further indicates that present forest lines are probably not at their climatic limit. This is demonstrated by the simple fact that growth conditions are more or less the same in both the treeline and the forest line. Assuming that upward growth of forests is not restricted by other limiting factors than temperature, such as areas of bare rock or mires, forest lines evidently have the opportunity to grow higher up in the landscape. However, so do treelines. At least according to Holtmeier and Broll (2007) and Körner (2012), who believe that in times with rapid improvement of climate, as is the case today, upward shifts in both tree- and forest lines are delayed by several decades or centuries compared to their climatic potential.

Kullmann (2001) agrees, and states that at present, advancing treelines are mostly reflecting a phenotypic response of already established, previously shrub-like, individuals. This is by and large confirmed in the present study, with the elevation of the present treeline correlating strongly with the elevation of the shrub lines registered by Ve (1940). According to Holtmeier (2009, p. 326) such a change in stature of already established individuals does not constitute a “real upward shift” of the treeline (in contrast to regeneration by establishments of seedlings), and should rather be seen as a non-significant response to oscillations in climate. However, this seems like a rather limiting approach, since low-stature growth must necessarily also be limited by climate to some degree. Consequently, establishment of shrubs further up in the landscape could provide valuable information about the future position of trees.

Similarly, the strong correlation between the previous treeline and present forest line indicates that the treelines might reveal the future position of forests. Still, this depends depend largely on what ultimately explains the present position of shrubs and trees. The influence of farming practises is, for instance, clearly demonstrated by (K. Potthoff, 2017), who found that new trees were mostly reoccurring in sites where heavy grazing had previously restricted prostrate growth. Thus, trees establishing in sites where there were previously only shrubs, and occurrences of forests where there before were only single trees, does not necessarily reflect improved growth climate. Nonetheless, the opportunity to predict the future position of forests based on the present treeline should be explored further in future studies. Körner (2012, p 122) describes the issue well: "Perhaps, this is the central question of the treeline formation, what causes tree species to remain confined to the shrub layer rather than to grow into upright trees. What are they fighting against (…)?".

Shifts explained

Apart from length of growth season, which, for reasons described in chapter 5.1 will not be discussed any further, none of the collected variables could significantly explain the distribution of shifts in tree- and forest lines in Lærdal. Similarly, no spatial structure in shifts was found between different distance classes of tree- and forest lines. These results can be interpreted in four ways:

1. The shifts could be determined by factors that have not been explored in the present study, such as wind and winter precipitation.
2. The resolution of the data is too coarse, so that climatic "hot spots" (e.g. locally very high or low temperature) are missing.
3. The shifts could be structured according to climatic patterns too large to be visible in the semivariogram.
4. The shifts could be determined by highly local factors which could not be generalized for the entire study area in model selection.

The importance of microtopography and local climates has been heavily underlined by Holtmeier (2009) as more important than climatic factors in structuring tree- and forest lines at smaller scales. This patchiness is not taken into account by downscaled climate data nor by elevation models (Kjällgren & Kullmann, 1998), and point 2 and 4 are therefore likely interconnected. In fact, all of the proposed explanations probably play some role for the insignificant result, but it is not possible to separate their impact further in the present study.

5.3 What has caused the potential shifts?

Patterns in historical climate

In year 2100, annual temperatures in Norway are expected to have risen by ca. 4.5°C, while annual precipitation will increase by 18% (Hansen-Bauer *et al.*, 2017). A higher increase in precipitation is expected along the coast than in continental areas (Hanssen-Bauer & Tveito, 2001). Changes in temperature and precipitation are in them selves expected to have large effects on growth conditions in the mountains, and might also lead to e.g. rise in snowline, earlier snowmelt, unstable frost periods and more avalanches (Holtmeier & Broll, 2005; Junttila & Nilsen, 1993; Odland, 1994). The precise outcome of such changes on tree- and forest lines is hard to predict, but can be made easier by studying the effects of climate in the past, which is attempted in the present study.

The fluctuations visible in the plots of historical climate data (Figure 19–22), are consistent with the general fluctuations registered in the northern hemisphere (Skre *et al.*, 2005), with a relatively warm period at the beginning of the century, a colder period from 1950/60 and a subsequent rise in temperatures in the late 1900s. Registered increase in precipitation also matches what has been found in general for Norway (Hanssen-Bauer & Tveito, 2001).

Do shifts in tree elevations correlate with changes in climate?

Precipitation was the only variable which was significantly different between the period prior to mapping by Ve and the period prior to the most recent mapping. Contrary to attained data from wwww.senorge.no (Appendix 4), the information from The Norwegian Meteorological Institute showed that precipitation was higher in forest lines than in treelines (Table 16,). Differences in precipitation between the lines will therefore not be discussed further.

There were no significant correlations between shifts in the four tested climatic variables and shifts in tree- and forest lines, meaning that the periods and measurements tested in this particular analyses cannot, alone, explain the observed shifts.

What has caused the shifts?

Tree- and forest lines in Lærdal are clearly higher up now than they were 80 years ago, but it is difficult to pinpoint the exact causes for the shifts. As discussed earlier, the basic drivers of change is related to abandoned farming practises and changes in climate, but the present study also underlines the highly significant structuring effects of local factors, such as topography, wind velocity and solar radiation. Holtmeier & Broll (2005, p. 293) explain this complex relationship well: "Mountain topography determines the basic pattern of the spatial timberline structures, also under the influence of changing climate".

There are several different explanations as to why the correlation tests provided no further clue of the cause of the observed shifts in tree- and forest lines. The measured climatic variables might not be the most important ones for tree growth in Lærdal, or the analysed periods should perhaps have been structured differently. However, the most important explanations is that climate has varied considerably during the last 115 years, and it is almost impossible to relate complex climatic variables to only two different measures of tree- and forest line elevations. This relationship is further complicated when considering the possibly large effects of regrowth on the lines.

From a climate perspective, the cold period in the mid 1900s should have stabilized the elevation of tree- and forest lines, but just before this period started, summer farming in several parts of Lærdal ended more or less simultaneously (Appendix 2). This means that upward expansion of tree- and forest lines might have taken place even though climate had actually deteriorated since Ve's registrations in the 1930s. The impact of regrowth on tree- and forest lines is given some support by the fact that both distance to closest summer farm and time since last year of activity at the farm are significantly related to present elevation of lines (Table 8). Also, several authors (Bryn, 2008; Hofgaard, 1997) have previously concluded that regrowth is more important than climate change for the presently observed expansion of tree- and forest lines in Norway.

On the other hand, increased distances between treelines and forest lines is a strong indicator that changes in growth conditions must also, at some point, have played a considerable part in the upward expansion of tree- and forest lines. It is possible that such an effect of climate on the lines was not fully initiated until climate improved in the end of the 1900s. This is in part supported by (Kullmann, 2001), who reported a distinct increase in tree growth from 1988 to 1999, and by Bryn (2008), who reported an increased tree height growth rom mid 1990 and onwards.

Comparisons of climate prior to each of the two mapping efforts are simply too one-dimensional to explain shifts in tree- and forest line elevations. When considering the causes of the present distribution of tree- and forest lines the total influence of previous climate should be taken into consideration, along with estimates of regrowth.

Tree- and forest lines in future Lærdal

Precipitation in the locations of tree- and forest lines in Lærdal has increased significantly during the last 180 years, and is expected to increase further in the future (Hanssen-Bauer & Tveito, 2001). The present study has demonstrated that increased precipitation will likely expand the amount of available area for establishments by trees in the treeline ecotone, by reducing drought stress. At high elevations, however, trees are limited by the lower temperatures associated with cloudiness and moist air, and prefer to grow in relatively dry locations. Still, as long as temperature increases alongside precipitation, an increase in tree- and forest lines would be expected, as temperature is believed to be the ultimate factor regulating tree growth at high elevations (Körner, 2012).

The present study does not provide enough data to determine the total impact of regrowth on the observed shifts, but already in 1940, Ve concluded that the mountain birch quickly reclaimed previously forested areas, and he believed that several of his registrations reflected the climatic tree- and forest lines. If the assumptions of Ve are correct, it is likely that the birch trees in Lærdal have already managed to reclaim their formerly climatic limits. Regardless, tree- and forest lines in Lærdal are expected to rise to even higher elevations in the future.

5.4 Limitations of the data

The outcome of analyses on tree- and forest lines can vary greatly depending on what definitions are used (Holtmeier, 2009; Körner, 1998). The position of the tree- and forest lines will, for instance, be largely dependent on how one defines a tree (Holtmeier, 2009). In the present study, the low precision of the definitions provided by Ve (1940) poses a potential source of error. However, Ve himself mentions the importance of understanding ecological processes in order to correctly identify trees and forests in the treeline ecotone. By comparing the definitions of Ve to those applied in similar other studies and by implementation of ecological knowledge in assessments done in the field, it is assumed that the results attained in the present study can be relatively accurately compared to the results of Ve.

Additionally, there are great uncertainties related to relocating previously mapped sites. Without detailed information on position, it is possible that some tree- or forest lines have been incorrectly remapped. Coordinates obtained by a GPS may also be imprecise, with implications for subsequent collection of data for analyses.

Climate data downscaled from the nearest meteorological station is also a significant source of inaccuracy, as they will not pick up small variations in the immediate surroundings of the trees (Bowling, 1993). The discrepancy between the actual and modelled environment might be particularly large for mountain climate because the meteorological stations are often located in the lower parts of an area (Kjällgren & Kullmann, 1998).

5.5 Conclusion

What characterizes and determines the distribution of tree- and forest lines in Lærdal?

The elevations of tree- and forest lines were relatively equally distributed along the Lærdal valley. Slope, annual precipitation and heat index were most significant in explaining the distribution. Low amounts of precipitation limits the available area for tree establishment in lower areas, but increases chance of tree establishment at higher elevations.

What characterizes and determines the potential shifts in elevations of tree- and forest lines in Lærdal?

Treelines have advanced upward by 54 m, while forest lines have advanced upward by 48 m. Magnitude of shift was equally distributed long the Lærdal valley. No variables could significantly explain the variation in shifts, and no spatial structure was evident in the data. Elevation of the present treelines correlates with the elevation of the former shrub lines, and the elevation of present forests correlate with the elevation of the former treelines.

What has caused the potential shifts?

Differences in climate prior to the two mapping periods did not correlate significantly with shifts in tree- and forest lines. However, improved growth conditions is still a likely explanation for the shifts, in addition to effects by regrowth.

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Appendices

Appendix 1: Location and elevation of tree- and forest lines

Table 1.1: Summary of elevations found in 1938 and in 2016. Coordinates are for present tree elevation. Only 1938-sites which were remapped are included. The shrub line elevations included here are those who were compared with present treelines in analysis. Temp= mean temperature from June to September. Prec= annual precipitation.

		Elevation in 1938				Elevation in 2016			Tree coordinates	
Area	**Location**	**Forest line**	**Treeline**	**Shrubline**	**Aspect**	**Forest line**	**Treeline**	**Aspect**	**Easting**	**Northing**
Vindedal	Hovdungane						1116	S	407340	6776343
Vindedal	Hovdungane	1036			S	1040		S	407232	6776008
Vindedal	Hovdungane		1049		SE		981	SE	407840	6776124
Vindelda	Hovdungane					967		SE	407929	6776289
Vindedal	Djupedal		1051		S		1193	S	406379	6773871
Vindedal	Djupedal	1041			S	1161		S	406427	6773858
Vindedal	Glipsfjellet						1114	E	410971	6774262
Vindedal	Glipsfjellet		1032		NW		1239	NW	410492	6773521
Vindedal	Glipsfjellet	1021			NW	1143		NW	410364	6773672
Vindedal	Glipsskardet	1090			NW	1109		NW	410636	6774665
Vindedal	Glipsskardet		1098	1118			1118	NW	410633	6774615
Erdal	Ved Glip		1042	1130			1052	E	412560	6775577
Erdal	Storhovd						1150	SE	408949	6769306
Erdal	Storhovd						1150	SE	409131	6769384
Erdal	Storhovd	1032			SE	1152		SE	409200	6769414
Erdal	Storhovd	1051			SE		1152		409200	6769414
Erdal	Storhovd						1160	E	409245	6769575
Erdal	Sluppedalen	1004			SE	1103		SE	408075	6767807
Erdal	Sluppedalen					1129		S	407744	6767772
Erdal	Sluppedalen						1195	SW	407741	6767933
Erdal	Sluppedalen						1227	SE	407867	6767955
Erdal	Sluppedalen						1225	S	407884	6767956
Erdal	Horndalen	1132			W	1200		W	411258	6765194
Erdal	Horndalen		1148	1174	W		1219	W	411283	6765024

		Elevation in 1938				Elevation in 2016			Tree coordinate	
Area	**Location**	**Forest line**	**Treeline**	**Shrubline**	**Aspect**	**Forest line**	**Treeline**	**Aspect**	**Easting**	**Northing**
Erdal	Nordøst for Nyborg	1073			S	1106		S	415760	6771838
Erdal	Nordøst for Nyborg						1169	SW	416139	6771749
Erdal	Nordøst for Nyborg		1110		SW		1171	SW	416178	6771587
Erdal	Nordøst for Nyborg	967			N	1095		N	415646	6771884
Hovuddalen	Kvefarhaug	1025			N	1090		N	417118	6772352
Hovuddalen	Kvefarhaug		1080	1100	N		1099	N	417010	6772422
Hovuddalen	Middagshaugen	1131			W		1210	W	421312	6767113
Hovuddalen	Middagshaugen		1189	1199	W	1210		W	421312	6767113
Senddalen	Vestre dalside	1214			SE	1219		SE	423692	6765057
Senddalen	Østre dalside	1242			W	1226		W	424699	6764697
Hovuddalføret	Skjersfjellet	1075			NE	1170		NE	Na	Na
Hovuddalføret	Skjersfjellet						1191	NE	428163	6764134
Hovuddalføret	Skjersfjellet		1101	1176	NE		1200	NE	428135	6764172
Råsdalen	Skruven	1123			E	1202		E	428572	6759961
Råsdalen	Skruven		1142		E		1270	E	428531	6760141
Råsdalen	Dyrkollkleivi	1137			E	1132		E	428217	6757711
Råsdalen	Øydalen	1191			SW	1268		SW	430289	6762013
Råsdalen	Øydalen		1199	1216	SW		1329	SW	430696	6761804
Nytt punkt	Øydalen						1300	SW	431451	6760944
Råsdalen	Gulehaugane		1153		S		1154	S	429648	6762206
Råsdalen	Kjørlibotn		1199		SW		1155	SW	430243	6763369
Råsdalen	Kjørlibotn	1124			SW	1145		SW	430152	6763477
Hovuddalen	Seltafossen	1093			N	1140		N	430054	6767791
Hovuddalen	Seltafossen		1102		N		1163	N	430249	6767735
Hovuddalen	Seltafossen	1113			W	1183		W	430710	6768015
Hovuddalen	Seltafossen		1129		W		1196	W	430740	6767984
Nesdalen	Arbergstølen		1150	1164	NE		1192	NE	436878	6763835
Nesdalen	Arbergstølen	1104			NE	1123		NE	436986	6763961
Nesdalen	Grindi	1176			SW	1230		SW	438861	6762394
Nesdalen	Grindi					1227		SW	438981	6762152
Nesdalen	Grindi		1205		S		1205	S	438468	6762817
Nesdalen	Grindi					1205		S	438468	6762817

		Elevation in 1938				Elevation in 2016			Tree coordinate	
Area	**Location**	**Forest line**	**Treeline**	**Shrubline**	**Aspect**	**Forest line**	**Treeline**	**Aspect**	**Easting**	**Northing**
Myrkedalen	Geitåni						1124	SE	443034	6768967
Myrkedalen	Geitåni						1096	E	443153	6768953
Myrkedalen	Geitåni	1094			E	1051		SE	443248	6769067
Myrkedalen	Geitåni		1126	1149	NE		1135	NE	443152	6768807
Myrkedalen	Geitåni					1100		NE	443239	6768769
Myrkedalen	Heftingdøla	1080			N	1076		N	444949	6767315
Myrkedalen	Heftingdøla		1107		N		1081	N	444831	6767279
Myrkedalen	Erakerstølen					1047		NE	445969	6767470
Myrkedalen	Erakerstølen					1087		NW	445533	6767330
Myrkedalen	Mørkedøla						1108	NE	443265	6768425
Myrkedalen	Mørkedøla					1094		NE	443394	6768261
Myrkedalen	Hola	997			SW		1189	SW	445911	6769101
Myrkedalen	Eggjastølsnosi					1190		S	445633	6769017
Myrkedalen	Eggjastølsnosi						1190	S	445633	6769017
Myrkedalen	Eggjastølsnosi	1179			SW	1199		SW	445022	6769896
Hovuddalen	Maristovlidi						1191	NW	448310	6773830
Hovuddalen	Maristovlidi	1129			NW	1166		NW	448227	6773785
Hovuddalen	Maristovlidi					1134		NW	448629	6774041
Oddedalen	Gramstølen	1103			SW	1151		SW	449189	6776537
Oddedalen	Gramstølen		1121		SW		1168	SW	449503	6776280
Hovuddalen	Stovestølen		1136		SW		1162	SW	448539	6777292
Hovuddalen	Stovestølen	1146			SW	1146		SW	448631	6777133
Hovuddalen	Stovestølen						1159	W	448482	6777416
Hovuddalen	Stovestølen						1158	SW	448637	6777203
Hovuddalen	Stovestølen						1172	W	448933	6777034
Hovuddalen	Stovestølen					1151		W	449164	6776557
Hovuddalen	Øst for Fillestølen		1081	1076	NW		1095	NW	450396	6781586
Hovuddalen	Øst for Fillestølen						1104	NW	450181	6781366
Hovuddalen	Øst for Fillestølen					1083		NW	450091	6781386
Hovuddalen	Øst for Sula		1111	1139	N		1141	N	451998	6781502
Hovuddalen	Skavlegjeli	1087			NW	1123		N	454718	6781705
Hovuddalen	Skavlegjeli		1099	1117	NW		1134	N	454659	6781661

		Elevation in 1938				Elevation in 2016			Tree coordinate	
Area	Location	Forest line	Treeline	Shrubline	Aspect	Forest line	Treeline	Aspect	Easting	Northing
Hovuddalen	Kvernabekken	1150			SE	1170		SE	454279	6783619
Hovuddalen	Kvernabekken		1194		SE		1259	SE	454166	6783743
Hovuddalen	Øst for Grøna		1159		S		1196	S	450781	6784707
Hovuddalen	Øst for Grøna					1145		S	450751	6784294
Hovuddalen	Gønelidi	1180			S	1195		S	450273	6784344
Hovuddalen	Gønelidi						1209	S	450224	6784379
Hovuddalen	Skjeltrane		1185	1210	S		1247	S	449637	6784230
Hovuddalen	Skjeltrane						1216	S	449869	6784302
Hovuddalen	Skjeltrane	1155			SW	1159		SW	448518	6783598
Hovuddalen	Skjeltrane	1096			SW	1205		S	449727	6784245
Hovuddalen	Store Frostdal, østsida	1123			W	1175		W	448438	6784638
Hovuddalen	Store Frostdal, østsida	1042			NW	1145		NW	448586	6784133
Hovuddalen	Mellom Frostdalselvene	1020			SE	1104		SE	447241	6783409
Kvamsdalen	Ved Fosse						1186	W	439360	6777074
Kvamsdalen	Ved Fosse	1090			W	1212		W	439133	6775841
Kvamsdalen	Ved Fosse	1072			W	1178		W	439087	6775734
Hovuddalen	Horgjastølen		1046		SE		1244	SE	436682	6773341
Hovuddalen	Horgjastølen	1092			SE	1096		S	436885	6772918
Hovuddalen	Horgjastølen						1136	SE	436747	6772978
Hovuddalen	Horgjastølen						1222	SE	436692	6773313
Hovuddalen	Gråberg					1129		SE	430557	6771683
Hovuddalen	Gråberg	1081			SE	1131		SE	430130	6771331
Houddalen	Gråberg						1142	SE	430359	6771597
Hovuddalen	Gråberg						1201	SE	429884	6771315
Hovuddalen	Ljøsndalen		1097	1102	SE		1164	SE	432037	6772558
Hovuddalen	Ljøsndalen						1151	SE	431143	6771970
Hovuddalen	Ljøsndalen					1147		SE	431211	6771953
Hovuddalen	Krokagjeli	1171		1209	S	1257		S	424274	6770940
Hovuddalen	Krokagjeli	1151			SW	1253		SW	424470	6770761
Hovuddalen	Krokagjeli						1297	SW	424482	6770852
Hovuddalen	Krokagjeli		1185		S		1259	S	424257	6770953

		Elevation in 1938				Elevation in 2016			Tree coordinate	
Area	**Location**	**Forest line**	**Treeline**	**Shrubline**	**Aspect**	**Forest line**	**Treeline**	**Aspect**	**Easting**	**Northing**
Hovuddalen	Kattegjeli	1248			SW	1219		SW	423667	6770992
Hovuddalen	Kattegjeli						1266	SW	423711	6771065
Hovuddalen	Kattegjeli						1282	S	423450	6771187
Hovuddalen	Kattegjeli					1247		S	423454	6771125
Hovuddalen	Vest for Kattegjeli		1233	1223	S		1246	S	422926	6771205
Hovuddalen	Freibotnfjellet	1142			SW	1207		SW	422175	6771505
Hovuddalen	Freibotnfjellet						1207	SW	422175	6771505
Hovuddalen	Freibotn	1021			SW	1018		SW	421666	6772572
Hovuddalen	Vest for Lid	1038			W		1130	W	421840	6774119
Hovuddalen	Vest for Lid	1050			W	1130		W	421840	6774119
Hovuddalen	Vidsete	1007			N	1043		NW	423167	6774385
Hovuddalen	Vidsete		1026		N		1052	NW	423446	6774515
Hovuddalen	Østsida av Bliksdalen						1139	W	423301	6776749
Hovuddalen	Østsida av Bliksdalen	930			W	1099		W	423203	6776690
Hovuddalen	Vestsida av Bliksdalen	1080			SE	1130		SE	421887	6776625
Hovuddalen	Høganòs	1084			SE	1117		S	421705	6776480
Hovuddalen	Høganòs						1148	S	421599	6776513
Hovuddalen	Berdalslidi	1036			SE	1064		S	420804	6778289
Hovuddalen	Berdalslidi		1116	1240	SE		1140	S	420845	6778575
Hovuddalen	Berdalslidi						1088	S	420826	6778396
Hovuddalen	Nord for Berdal	1054			W	1056		W	420492	6778672
Hovuddalen	Nord for Berdal		1079		W		1160	W	420730	6778731
Hovuddalen	Langedalen		1026		S		1040	SE	418260	6779835
Hovuddalen	Langedalen	1000			S	1009		SE	418150	6779408
Hovuddalen	Vetanòsi	968			SE	985		SE	416856	6778135
Hovuddalen	Vetanosi		1009		SE		1012	SE	416588	6778154

Appendix 2: Summer farms tested in analyses

Table 2.1: List of name, year of abandonment and position of summer farms included in analyses.

Name of summer farm	Last year in use	Easting	Northing
Vardahaug	1955	408305	6768014
Vindedalsstølen	1958	408671	6776379
Fureset	1956	410230	6769300
Horndal	1958	410527	6765992
Glipstølen	1958	412742	6773836
Nyborg	1952	414242	6771479
Aspvikstølen/Fagerset	1965	416288	6779917
Hognåsen	1937	416289	6773383
Berdalen	1932	420565	6777844
Freibotn	1905	421768	6772458
Bøastølen	1885	421843	6767049
Liastølen/Lid	1949	422767	6774880
Oftedal	1934	423273	6775374
Dyrkoll	1890	427696	6757577
Horndalen	1957	428308	6771885
Byrkjastoelen	1895	428383	6768196
Heimre Ljøsndalen	1934	431718	6771361
Dalbotnen/Myrsete	1946	431966	6765786
Horgestølen	1955	436517	6772605
Aarbergstolen	1947	437110	6764788
Fosse	1947	438593	6776777
Eggjastoelen	1958	444428	6769001
Galdestoelen	1960	446382	6768058
Osen	1890	447190	6782564
Stovestolen	1962	448273	6776464
Gramstolen	1962	448620	6775263
Fillestølen	1962	448812	6781204

Appendix 3: Translations of NiN- and VK25-variables

Table 3.1: Translations of basic steps along LCEs used in analyses. 0 marks the endpoint steps, where the effect of the LCE is 0.

Variable name	0	1	2	3	4	5	6	7	8	9
Lime richness	0	a	b	c	d	e	f	g	h	i
Risk of severe drought	0	a	b	c	d	e	f	–	–	–
Spring water influence	0	b	c	–	–	–	–	–	–	–
Water saturation	0	b	c	–	–	–	–	–	–	–

Table 3.2: Translation key from Vegetation type (VT) and respective ancillary registrations (sign) to indexes of wetness and nutrient status in the ground. Types are transformed to a general index from 1 to 5 and adjusted based on the ancillary registrations. Wet = Wetness, Nutr = Soil nutrient status (sometimes referred to as Richness).

VT+sign	VT-Wet	Sign	Sign-Wet	Wet. (1-5)	VT+sign	VT-Nutr	Sign	Sign-Nutr	Nutr. stat (1-5)
2e	3		0	3	2e	3		0	3
2ej	3	j	-1	2	2ej	3	j	-1	2
2ec	3	c	1	4	2ec	3	c	0	3
2ex	3	x	-2	1	2ex	3	x	-1	2
2e<l>	3	<l>	-1	2	2e<l>	3	<l>	-1	2
2ev	3	v	-1	2	2ev	3	v	-1	2
2es	3	s	2	5	2es	3	s	1	4
2ecj	3	c	1	4	2ecj	3	c	0	3
2esj	3	s	2	5	2esj	3	s	1	4
3b	4		0	4	3b	5		0	5
3bsj	4	s	1	5	3bsj	5	s	0	5
3b<l>	4	<l>	-1	3	3b<l>	5	<l>	-1	4
3bsjg	4	s	1	5	3bsjg	5	s	0	5
3bc<l>	4	c	0	4	3bc<l>	5	c	0	5
3bs	4	s	1	5	3bs	5	s	0	5
4a	1		0	1	4a	1		0	1
4b	3		0	3	4b	3		0	3
4bc<l>	3	c	1	4	4bc<l>	3	c	0	3
4bj	3	j	-1	2	4bj	3	j	-1	2
4bs	3	s	2	5	4bs	3	s	1	4
4bc	3	c	1	4	4bc	3	c	0	3
4bsj	3	s	2	5	4bsj	3	s	1	4
4b<l>	3	<l>	-1	2	4b<l>	3	<l>	-1	2
4cc	4	c	0	4	4cc	5	c	0	5
4cj	4	j	-1	3	4cj	5	j	-1	4
4csj	4	s	1	5	4csj	5	s	0	5
4cs	4	s	1	5	4cs	5	s	0	5
9cs	5	s	0	5	9cs	3	s	1	4
12b <l>	1	<l>	0	1	12b <l>	2	<l>	-1	1
12c	1		0	1	12c	2		0	2
12c<<	1	<<	0	1	12c<<	2	<<	-1	1

Appendix 4: Mapping units of NiN and vegetation types found in field

Table 4.1: Overview of all mapping units of NiN registered in field. "Freq." = frequency of unit, % = percentage of registrations of a certain unit among all registrations whithin each category of mapping location. Unit titles have been freely translated from Halvorsen (2016).

Mapping units	Code	Treelines		Surrounding area		Forest lines		Surrounding area	
		Freq.	%	Freq.	%	Freq.	%	Freq.	%
Bare rock	T1	–	–	13	15%	–	–	10	14 %
Very lime-poor open fen margin	V1, C5	–	–	1	1 %	1	3 %	2	3 %
Lime-poor open fen margin	V1, C6	2	4 %	1	1 %	–	–	2	3 %
Lime-poor lee side	T3, C1	11	24 %	15	17 %	4	11 %	11	16 %
Lime-poor mountain heathlands	T3, C2	11	24 %	23	26 %	6	17 %	14	20 %
Lime-poor mountain lichen heatlands	T3, C3	3	7 %	12	14 %	1	3 %	5	7 %
Intermediate lee side	T3, C4	5	11 %	12	14 %	7	20 %	9	13 %
Intermediate mountain heatlands	T3, C5	1	2 %	3	3 %	–	–	1	1 %
Intermediate mountain lichen heatlands	T3, C6	–	–	–	–	–		1	1 %
Moderatly lime-rich lee side	T3, C7	2	4 %	–	–	–	–	1	1 %
Moderatly lime-rich mountain heatlands	T3, C8	–	–	–	–	–	–	1	1 %
Moderatly lime-rich lichen heatlands	T3, C9	–	–	–	–	–	–	1	1 %
Intermediate mountain heatlands influenced by spring water	T3, C13	1	2 %	2	2 %	4	11 %	1	1 %
Lime-rich mountain heatlands influenced by spring water	T3, C14	8	18 %	5	6 %	3	9 %	8	12 %
Bilberry forest	T4, C1	–	–	–	–	1	3 %	1	1 %
Sparse low-herb forest	T4, C2	–	–	–	–	1	3 %	1	1 %
Low-herb forest	T4, C3	–	–	–	–	1	3 %	–	–
Heather-bilberry forest	T4, C5	–	–	–	–	2	6 %	–	–
Heather forest	T4, C9	–	–	–	–	1	3 %	–	–
Fern forest	T4, C17	–	–	–	–	1	3 %	–	–
Tall-herb forest	T4, C18	–	–	–	–	2	6 %	–	–
Boulder area	T27	1	2 %	1	1 %	–	–	–	–
Total		**45**		**88**		**35**		**69**	

Table 4.2: Overview of all vegetation types registered in field, along with symbols describing additional variation. “Freq.” = frequency of types with additional sign. Names of types and descriptions of additional symbols have been freely translated from Rekdal & Larsson (2005).

Treeline vegetation types				**Forest line vegetation types**			
Type name	**Type code**	**Sign**	**Freq.**	**Type name**	**Type code**	**Sign**	**Freq.**
Dwarf shrub heat	2e		25	Lichen forest	4a		2
Dwarf shrub heat	2e	s	5	Bilberry birch forest	4b		28
Dwarf shrub heat	2e	j	1	Bilberry birch forest	4b	s	2
Dwarf shrub heat	2e	s, j	2	Bilberry birch forest	4b	j	3
Dwarf shrub heat	2e	c	3	Bilberry birch forest	4b	s, j	2
Dwarf shrub heat	2e	c, j	1	Bilberry birch forest	4b	c	4
Dwarf shrub heat	2e	v	4	Bilberry birch forest	4b	<l>	1
Dwarf shrub heat	2e	<l>	2	Bilberry birch forest	4b	c, , <l>	2
Tall-herb forest	3b		9	Meadow birch forest	4c	s	14
Tall-herb forest	3b	s	4	Meadow birch forest	4c	j	1
Tall-herb forest	3b	s, j	6	Meadow birch forest	4c	s, j	1
Tall-herb forest	3b	s, j, g	1	Meadow birch forest	4c	c	1
Tall-herb forest	3b	<l>	1	Grass fen	9c	s	1
Tall-herb forest	3b	c, <l>	2				
Lichen forest	4a		1				
Bilberry birch forest	4b		3				
Meadow birch forest	4c	s	1				
Grass fen	9c	s	1				
Boulder areas	12b	<l>	1				
Bare rock	12c	<<	1				
Sum			76				64

Translation of symbols

- s = Site covered by more than 50% *Salix* sp.
- j= Site covered by more than 50% *Juniperus communis*
- c = Site covered by more than 25- 50% *Salix* sp.
- v = Site covered by more than 25- 50% lichen
- g = Site covered by more than 50% grasses and hedges
- <l> =Site covered by more than 50-75% boulders and rocks
- << =Site with more than 50-75% bare rock

Appendix 5: Semivariograms of shifts

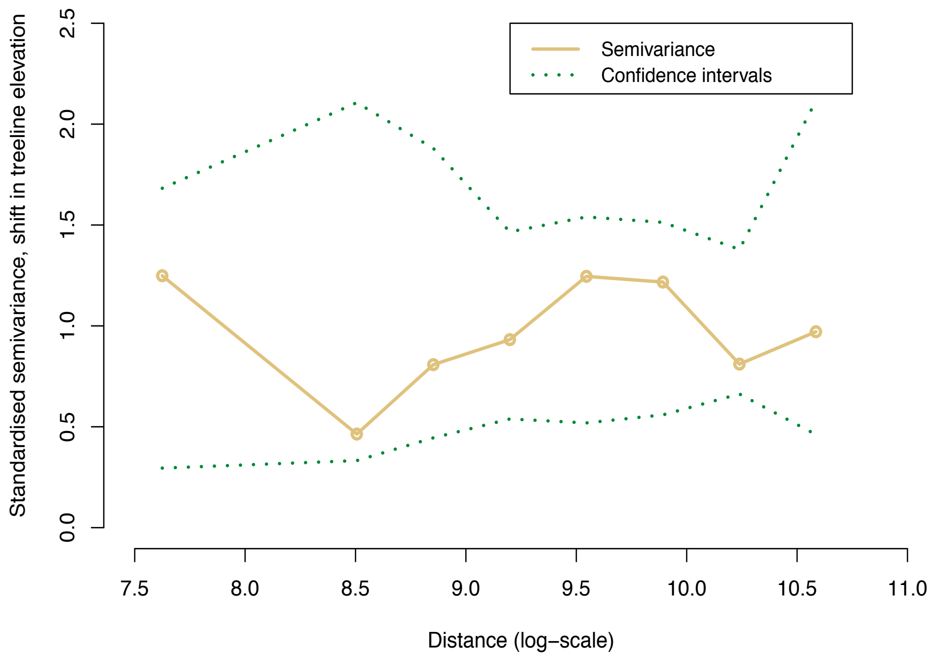

Figure 5.1: Standard semivariance for magnitude of shift between distance intervals of **treelines.** The distance classes contain the following ranges of distances (in meters): 0-4096-5792- 8192-11585-16384-23170-32768-.

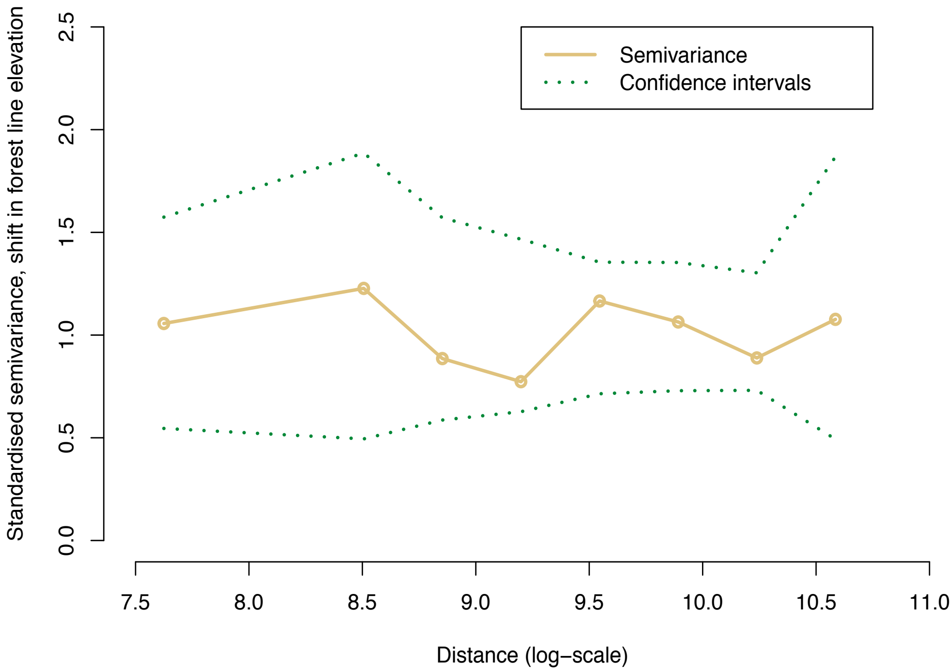

Figure 5.2: Standard semivariance for magnitude of shift between distance intervals of **forest line.** The distance classes contain the following ranges of distances (in meters): 0-4096-5792-8192-11585-16384-23170-32768.

Appendix 6: Summary and transformation of variables

The following four tables display summary statistics and transformation approach for explanatory variables applied in model partitioning of tree- and forest line characteristics and shifts.

Tree- and forest line characteristics

Table 6.1: Summary statistics of 29 explanatory variables tested against **treeline characteristics** (elevation, age, tree height and seedling distribution), with corresponding standardisation formula and applied constant (c) value. n=76.

Variable	Min.	Max.	Mean	Std.	Skew	Kur.	Formula	*c*
Growth season	81.7	125.4	110.3	9.1	-4.9	4.1	e^cx	4.17E-02
Average annual temp.	-2.8	0.3	-1.6	0.6	0.9	0.8	ln(c+x)	9.65E+00
Temp. of warmest quarter	7.5	10.9	8.9	0.7	1.3	0.0	ln(c+x)	-4.06E+00
Temp. of coldest quarter	-12.4	-9.5	-11.2	0.6	0.7	0.6	ln(c+x)	2.00E+01
Mean July temp.	8.7	12.1	10.1	0.7	1.0	0.0	ln(c+x)	-3.79E+00
Max July temp.	17.6	19.4	18.3	0.5	1.2	-0.6	ln(c+x)	-1.48E+01
Temp. sum, above 0 °C	25.5	45.4	33.7	4.2	0.7	-0.7	ln(c+x)	1.08E+01
Temp. sum, above 5 °C	16.5	38.4	29.7	4.5	-3.4	1.0	e^cx	8.91E-02
Temp. sum, above 7 °C	16.5	29.3	20.1	3.7	6.5	3.2	ln(c+x)	-1.63E+01
Temp. sum above 7,5 °C	16.5	31.4	19.8	2.8	10.0	14.3	ln(c+x)	-1.62E+01
Max. temp. June- September	14.4	17.0	15.5	0.5	0.5	-0.1	ln(c+x)	-4.98E+00
Mean temp. June-September	6.3	9.6	7.7	0.6	1.0	0.0	ln(c+x)	-1.46E+00
Heat index	2.5	173.5	105.4	44.8	-2.1	-1.3	e^cx	9.77E-03
Insolation, warmest quarter	413.9	844.8	740.4	91.3	-6.7	7.6	e^cx	7.96E-03
Annual insolation	657.3	1647.3	1280.2	249.8	-1.9	-1.3	e^cx	1.63E-03
Annual precipitation	768.0	1217.4	935.5	118.3	2.2	-1.3	ln(c+x)	-6.86E+02
Snow duration	6.0	12.0	7.6	1.7	6.3	4.0	ln(c+x)	-5.55E+00
Slope	7.8	52.4	26.1	10.9	2.3	-0.1	ln(c+x)	1.47E+01
Distance closest hilltop	51.0	625.5	237.8	135.3	2.3	-0.6	ln(c+x)	9.46E+01
Distance closest summer farm	438.2	5925.5	1831.2	1207.8	5.6	4.1	ln(c+x)	-2.00E+02
Time since summer farm closed	51.0	131.0	72.0	22.3	4.9	1.3	ln(c+x)	-4.94E+01
Proximity to coast	1118.0	25564.4	12592.4	8004.7	0.4	-2.8	ln(c+x)	3.43E+04
Proximity to river	0.0	1600.0	355.7	302.7	6.3	7.4	ln(c+x)	1.18E+02
Vegetation type: wetness index	1.0	6.0	3.4	1.2	-0.2	-1.4	e^cx	3.09E-02
Vegetation type: richness index	1.0	5.0	3.5	1.1	-0.3	-1.3	e^cx	-5.08E-02
Coordinates, easting	---	---	---	14822.6	0.6	-2.3	ln(c+ln(c+x))	-1.27E+01
Coordinates, northing	---	---	---	5873.5	0.1	-0.6	ln(c+ln(c+x))	-1.57E+01

Table 6.2: Summary statistics of 29 explanatory variables tested against **forest line characteristics** (elevation, age, tree height and seedling distribution), with corresponding standardisation formula and applied constant (c) value. n=65.

Variable	Min.	Max.	Mean	Std.	Skew	Kur.	Formula	c
Growth season	83.8	129.1	113.1	9.3	-3.6	2.7	e^cx	3.54E-02
Average annual temp.	-3.0	0.3	-1.5	0.7	0.8	0.5	ln(c+x)	1.12E+01
Temp. of warmest quarter	7.4	10.9	9.1	0.7	0.3	0.2	ln(c+x)	1.34E+01
Temp. of coldest quarter	-12.4	-9.4	-11.2	0.7	1.6	0.0	ln(c+x)	1.46E+01
Mean July temperature	8.7	12.1	10.3	0.7	0.1	0.1	ln(c+x)	3.93E+01
Max July temperature	17.4	20.0	18.5	0.5	1.4	0.6	ln(c+x)	-1.35E+01
Temp. sum, above 0 °C	25.5	45.4	34.7	4.3	0.5	0.1	ln(c+x)	5.71E+01
Temp. sum, above 5 °C	16.5	38.4	30.2	5.2	-3.7	1.3	e^cx	9.61E-02
Temp. sum, above 7 °C	16.5	30.6	21.1	4.3	4.0	-0.3	ln(c+x)	-1.61E+01
Temp. sum, above 7,5 °C	16.5	31.4	20.2	3.5	7.6	7.5	ln(c+x)	-1.60E+01
Max. temp. June- September	14.3	17.0	15.6	0.6	0.6	-0.4	ln(c+x)	-7.95E+00
Mean temp. June- September	6.3	9.6	7.9	0.7	0.2	0.2	ln(c+x)	2.86E+01
Heat index	2.5	172.5	109.2	47.3	-2.3	-1.1	e^cx	1.25E-02
Insolation, warmest quarter	396.9	854.8	737.6	96.1	-5.3	4.8	e^cx	9.35E-03
Annual insolation	534.2	1647.3	1246.7	265.9	-1.9	-0.4	e^cx	1.17E-03
Annual precipitation	760.7	1208.3	912.3	112.3	3.4	0.5	ln(c+x)	-7.21E+02
Snow duration	5.0	12.0	7.4	1.7	6.1	5.3	ln(c+x)	-4.60E+00
Slope	2.3	50.1	27.3	10.0	-0.4	-0.5	e^cx	4.67E-04
Distance closest hilltop	67.0	680.9	298.6	146.5	1.8	-0.7	ln(c+x)	1.64E+02
Distance closest summer farm	153.0	5976.6	1796.0	1216.0	4.7	4.1	ln(c+x)	2.50E+02
Time since summer farm closed	51.0	131.0	79.7	27.7	2.6	-1.7	ln(c+x)	-4.82E+01
Proximity to coast	1676.3	26087.0	13779.4	8113.1	-0.1	-2.5	e^cx	2.57E-06
Proximity to river	0.0	1503.3	402.2	334.3	4.6	3.6	ln(c+x)	2.10E+02
Vegetation type: wetness index	1.0	5.0	3.6	1.1	-0.4	-1.2	e^cx	6.84E-02
Vegetation type: richness index	1.0	5.0	3.6	1.0	-0.3	-0.7	e^cx	-1.13E-02
Coordinates, easting	---	---	---	14370.3	-0.1	-2.0	e^cx	2.64E-06
Coordinates, northing	---	---	---	6642.7	0.3	-0.9	ln(c+ln(c+x))	-1.57E+01

Elevational shifts in tree- and forest lines

Table 6.3: Summary statistics of 27 explanatory variables tested against **shifts in treelines** with corresponding standardisation formula and applied constant (c) value. n=39.

Variable	Min.	Max.	Mean	Std.	Skew	Kur.	Formula	*c*
Growth season	81.7	125.4	110.7	8.9	-3.6	3.6	e^cx	4.29E-02
Average annual temp.	-2.8	0.3	-1.6	0.7	1.0	0.7	ln(c+x)	6.81E+00
Temp. of warmest quarter	7.5	10.9	8.9	0.7	1.0	0.5	ln(c+x)	-3.56E+00
Temp. of coldest quarter	-12.4	-9.5	-11.2	0.6	1.0	-0.1	ln(c+x)	1.49E+01
Mean July temperature	8.7	12.1	10.1	0.7	0.8	0.5	ln(c+x)	-3.48E+00
Max July temperature	17.6	20.0	18.4	0.5	1.6	0.7	ln(c+x)	-1.24E+01
Temp. sum, above 0 °C	25.5	45.4	33.7	4.4	0.9	-0.1	ln(c+x)	-3.31E+00
Temp. sum, above 5 °C	16.5	38.4	29.2	5.1	-2.2	0.3	e^cx	7.51E-02
Temp. sum, above 7 °C	16.5	38.4	20.4	4.3	6.9	9.9	ln(c+x)	-1.62E+01
Temp. sum, above 7,5 °C	16.5	31.4	19.8	3.1	6.9	9.3	ln(c+x)	-1.61E+01
Max. temp. June- September	14.4	17.0	15.4	0.6	1.0	-0.2	ln(c+x)	-1.24E+01
Mean temp. June- September	6.3	9.6	7.7	0.7	0.9	0.5	ln(c+x)	-1.64E+00
Heat index	2.5	177.5	109.1	46.5	-1.7	-0.7	e^cx	9.37E-03
Insolation, warmest quarter	415.0	844.8	737.0	99.6	-3.5	2.4	e^cx	7.49E-03
Annual insolation	710.1	1625.8	1230.3	251.2	-0.7	-1.4	e^cx	8.30E-04
Annual precipitation	768.0	1205.7	934.1	125.9	1.6	-1.0	ln(c+x)	-6.83E+02
Snow duration	6.0	12.0	7.6	1.8	4.4	2.6	ln(c+x)	-5.65E+00
Slope	7.8	52.4	27.3	11.5	1.6	-0.3	ln(c+x)	1.39E+01
Distance closest hilltop	51.0	513.5	249.2	140.3	0.9	-1.2	ln(c+x)	2.63E+02
Distance closest summer farm	534.8	5925.5	2114.1	1390.4	3.1	1.3	ln(c+x)	-2.64E+02
Time since summer farm closed	51.0	131.0	74.8	25.0	3.0	-0.1	ln(c+x)	-4.88E+01
Proximity to coast	1118.0	25564.4	12252.0	8155.0	0.3	-2.0	ln(c+x)	3.25E+04
Proximity to river	0.0	1600.0	371.4	316.6	5.3	6.8	ln(c+x)	5.94E+01
Former elevation of treeline	1009	1233	1110	57.9	0.3	-1.0	ln(c+x)	-2.13E+02
Coordinates, easting	---	---	---	---	0.8	-1.4	ln(c+ln(c+x))	-1.28E+01
Coordinates, northing	---	---	---	---	-0.4	-1.0	e^c(e^cx)	2.15E-06

Table 6.4: Summary statistics of 27 explanatory variables tested against **shifts in forest lines** with corresponding standardisation formula and applied constant (c) value. n=51.

Variable	Min.	Max.	Mean	Std.	Skew	Kur.	Formula	*c*
Growth season	83.8	127.9	112.3	9.2	-3.5	2.9	e^cx	3.71E-02
Average annual temp.	-3.0	0.3	-1.5	0.8	0.5	-0.3	ln(c+x)	1.26E+01
Temp. of warmest quarter	7.4	10.9	9.1	0.8	0.2	-0.5	ln(c+x)	1.64E+01
Temp. of coldest quarter	-12.4	-9.4	-11.1	0.7	1.1	-0.4	ln(c+x)	1.53E+01
Mean July temperature	8.7	12.1	10.3	0.8	0.1	-0.5	ln(c+x)	4.80E+01
Max July temperature	17.4	20.0	18.5	0.6	0.9	-0.3	ln(c+x)	-1.38E+01
Temp. sum, above 0 °C	25.5	45.4	34.7	4.8	0.3	-0.5	ln(c+x)	7.73E+01
Temp. sum, above 5 °C	16.5	38.4	29.9	5.7	-2.7	0.1	e^cx	9.14E-02
Temp. sum, above 7 °C	16.5	30.6	21.5	4.6	2.8	-1.1	ln(c+x)	-1.60E+01
Temp. sum, above 7,5 °C	16.5	31.4	20.5	3.8	5.9	4.5	ln(c+x)	-1.59E+01
Max. temp. June- September	14.3	17.0	15.6	0.7	0.5	-0.7	ln(c+x)	-6.99E+00
Mean temp. June- September	6.3	9.6	7.9	0.8	0.1	-0.5	ln(c+x)	3.13E+01
Heat index	2.5	177.5	115.8	43.2	-2.5	0.0	e^cx	1.18E-02
Insolation, warmest quarter	396.9	854.8	754.9	86.8	-5.7	7.3	e^cx	1.09E-02
Annual insolation	570.5	1619.4	1241.8	251.8	-1.8	-0.2	e^cx	1.22E-03
Annual precipitation	760.7	1208.3	913.8	112.3	2.7	0.1	ln(c+x)	-7.04E+02
Snow duration	5.0	137.0	7.4	1.7	5.4	4.5	ln(c+x)	-4.61E+00
Slope	2.3	50.1	27.0	10.2	0.3	-0.1	ln(c+x)	2.14E+02
Distance closest hilltop	67.0	651.7	285.4	141.1	1.5	-0.9	ln(c+x)	1.72E+02
Distance closest summer farm	153.0	5976.6	1956.2	1305.9	3.5	2.5	ln(c+x)	5.64E+02
Time since summer farm closed	51.0	131.0	84.8	29.3	1.3	-2.2	ln(c+x)	-3.97E+01
Proximity to coast	1676.3	25662.8	12723.5	7684.3	0.3	-2.1	ln(c+x)	4.54E+04
Proximity to river	0.0	1503.3	413.8	358.3	4.1	2.6	ln(c+x)	1.64E+02
Previous forest line elevation	930	1248	1095	68	0.1	-0.1	ln(c+x)	3.06E+03
Coordinates, easting	---	---	---	---	0.6	-1.5	ln(c+ln(c+x))	-1.27E+01
Coordinates, northing	---	---	---	---	-0.1	-1.0	---	-1.00E-09

Appendix 7: Correlation matrixes

The following two tables display correlation matrixes for explanatory variables applied in analysis and discussion. The following abbreviations are used:

- **Age** =Age of tree, categorized. See Chapter 3 for details.
- **An. insol.=** Total annual insolation on a site.
- **An. temp =** Average annual temperatures.
- **An. prec=** Annual average precipitation
- **Avg. June- Sept. =** Average temperature from June to September.
- **Dist. farm. =** Distance to closest summer farm.
- **Dist. hilltop =** Distance to closest hilltop
- **Grow. seas =** Length of growth season in days.
- **Heat index =** Estimate of differences in insolation which are due to aspect. See Chapter 3 for details.
- **Height**= Heigh of tree, categorized. See Chapter 3 for details.
- **Insol. WQ=** Total insolation on a site throughout the warmest quarter.
- **Lat. =** Latitude
- **Long. =** Longitude
- **M a.s.l/ M a.s.l. 2016** = Present elevation of registered sites.
- **M a.s.l. 1938 =** Elevation of tree- and forest lines in 1938
- **Max. July =** Maximum temperature recorded in July.
- **Max. June- Sept. =** Average temperature across all four maximum temperatures recorded in June, July, August and September.
- **Mean July=** Average temperature of July.
- **Prox. coast=** Proximity to coast, in m.
- **Prox. river=** Proximity to river, in m.
- **Recruitment** = Level of recruitment of new trees at a site. See Chapter 3 for details.
- **Richness=** Indicator of amounts of nutrients in the soil estimated from ancillary registrations in combination with recorded vegetation type at each site. See Chapter 3 for details.
- **Shift=** Magnitude of shift of tree- or forest lines since 1938
- **Slope =** Slope at each site in degrees.
- **Snow duration =** Duration of snow cover in months.
- **Temp. CQ=** Average temperature of coldest quarter (three coldest months).
- **Temp. WQ =** Average temperature of warmest quarter (three warmest months).
- **T. sum 0 °C =** Sum of average temperature across all months with an average higher than 0 °C.
- **T. sum 5 °C =** Sum of average temperature across all months with an average higher than 5 °C.
- **T.sum 7 °C =** Sum of average temperature across all months with an average higher than 7 °C.
- **T. sum 7.5 °C =** Sum of average temperature across all months with an average higher than 7.5 °C.
- **Wetness =** Indicator of wetness of the ground, estimated from ancillary registrations in combination with recorded vegetation type at each site. See Chapter 3 for details.
- **Yr. closed =** The last year of activity at each summer farm.

Table 7.1: Correlations between variables applied in analysis and discussion about present distribution of tree- and forest lines. Values beneath the grey squares describe correlations between data collected from treeline sites, while values above the grey squares describe correlations between data collected from forest line sites. Significant correlations how been marked with ** (p< 0.01) and * (p<0.05).

Treeline/forest line	M a.s.l..	Age	Height	Recruitment	Grow. seas.	An. temp.	Temp, wq	Temp, cq	Avg. July	Max July	T. sum 0 °C
M a.s.l..		-0,243	-0,299*	-0,114	-0,671**	-0,21	-0,143	-0,252*	-0,148	-0,174	-0,159
Age	-0,333**		0,409**	-0,335**	0,08	0,108	0,059	0,159	0,073	0,077	0,083
Height	-0,366**	0,569**		0,039	0,187	0,104	0,12	0,036	0,111	0,05	0,097
Recruitment	0,35**	-0,168	-0,013		0,171	-0,117	-0,086	-0,18	-0,097	-0,151	-0,112
Grow. seas.	-0,73**	0,22	0,356**	-0,133		0,421**	0,452**	0,281*	0,448**	0,397**	0,435**
An. temp.	-0,252*	0,121	0,296**	-0,081	0,447**		0,975**	0,924**	0,979**	0,983**	0,987**
Temp, wq	-0,187	0,065	0,304**	-0,068	0,447**	0,97**		0,821**	0,998**	0,964**	0,994**
Temp, cq	-0,311**	0,199	0,206	-0,106	0,324**	0,88**	0,743**		0,835**	0,912**	0,866**
Mean July	-0,191	0,071	0,299**	-0,058	0,447**	0,977**	0,998**	0,764**		0,971**	0,997**
Max July	-0,219	0,102	0,263*	-0,04	0,398**	0,978**	0,942**	0,884**	0,954**		0,983**
T. sum 0 °C	-0,173	0,083	0,27*	-0,056	0,364**	0,894**	0,898**	0,733**	0,903**	0,875**	
T. sum 5 °C	-0,168	0,057	0,253*	-0,047	0,408**	0,974**	0,97**	0,814**	0,976**	0,963**	0,883**
T.sum 7 °C	-0,14	0,059	0,315**	-0,009	0,428**	0,914**	0,949**	0,682**	0,953**	0,908**	0,858**
T. sum 7.5 °C	-0,154	0,038	0,224	-0,023	0,412**	0,923**	0,942**	0,724**	0,948**	0,913**	0,856**
Avg. June- Sept.	-0,196	0,076	0,295*	-0,057	0,444**	0,981**	0,996**	0,781**	0,999**	0,962**	0,904**
Max June- Sept.	-0,265*	0,142	0,263*	-0,062	0,4**	0,968**	0,902**	0,932**	0,917**	0,989**	0,849**
Heat index	0,4**	-0,025	0,077	0,169	-0,242*	0,387**	0,394**	0,33**	0,399**	0,403**	0,456**
Insol wq	0,185	0,104	-0,074	0,043	-0,288*	0,154	0,098	0,276*	0,107	0,207	0,155
Ann. insol.	0,29*	-0,142	-0,131	0,23*	-0,064	0,22	0,216	0,205	0,217	0,213	0,182
Ann. prec.	-0,36**	0,207	-0,027	-0,097	0,013	0,04	-0,159	0,427**	-0,128	0,103	-0,056
Snow duration	0,482**	-0,202	-0,203	0,113	-0,302**	-0,459**	-0,348**	-0,611**	-0,376**	-0,499**	-0,401**
Slope	0,576**	-0,244*	-0,338**	0,416**	-0,252*	-0,224	-0,19	-0,256*	-0,19	-0,215	-0,158
Dist. hilltop	0,003	0,027	0,053	0,154	-0,118	-0,169	-0,124	-0,205	-0,131	-0,161	-0,194
Dist. farm	0,291*	-0,017	-0,057	-0,022	-0,337**	-0,176	-0,155	-0,179	-0,178	-0,237*	-0,102
Yr. closed	0,496**	-0,134	-0,19	0,21	-0,36**	-0,11	-0,139	-0,009	-0,119	-0,095	-0,062
Prox. coast	0,258*	-0,237*	-0,012	0,091	0,031	-0,243*	-0,027	-0,646**	-0,066	-0,294*	-0,155
Prox. river	0,176	0,069	-0,098	-0,003	-0,242*	0,235*	0,118	0,43**	0,137	0,248*	0,191
Wetness	0,088	-0,112	0,159	-0,096	0,03	-0,216	-0,112	-0,399**	-0,132	-0,256*	-0,213
Richness	-0,185	0,087	-0,129	0,048	0,065	0,235*	0,148	0,379**	0,169	0,271*	0,246*
Long.	0,155	-0,166	0,13	0,002	0,138	-0,018	0,193	-0,455**	0,154	-0,13	0,085
Latit.	-0,299**	0,014	0,233*	-0,204	0,311**	0,361**	0,342**	0,298**	0,327**	0,218	0,301**

Treeline/ forest line	T. sum 5 °C	T.sum 7 °C	T. sum 7.5 °C	Avg. June- Sept.	Max June- Sept.	Heat index	Insol wq	Ann. Insol.	Ann. Prec.
M a.s.l..	-0,13	-0,219	-0,124	-0,152	-0,214	0,414**	0,183	0,208	-0,404**
Age	0,085	0,173	-0,018	0,075	0,109	0,045	0,111	-0,173	0,253*
Height	0,086	0,15	0,124	0,102	0,044	-0,023	0,06	-0,053	-0,116
Recruitment	-0,123	-0,055	-0,077	-0,105	-0,156	-0,131	-0,14	0,127	-0,146
Grow. Seas.	0,41**	0,41**	0,448**	0,445**	0,381**	-0,239	-0,166	-0,037	-0,041
An. Temp.	0,976**	0,875**	0,938**	0,982**	0,981**	0,436**	0,354**	0,289*	0,034
Temp, wq	0,98**	0,882**	0,963**	0,997**	0,938**	0,436**	0,318**	0,256*	-0,148
Temp, cq	0,863**	0,75**	0,784**	0,846**	0,951**	0,433**	0,422**	0,339**	0,337**
Mean July	0,984**	0,887**	0,965**	0,999**	0,947**	0,439**	0,322**	0,258*	-0,123
Max July	0,971**	0,851**	0,936**	0,976**	0,991**	0,451**	0,378**	0,274*	0,045
T. sum 0 °C	0,987**	0,883**	0,96**	0,998**	0,964**	0,446**	0,341**	0,27*	-0,071
T. sum 5 °C		0,853**	0,944**	0,985**	0,955**	0,451**	0,336**	0,279*	-0,057
T.sum 7 °C	0,922**		0,88**	0,885**	0,84**	0,366**	0,232	0,175	-0,032
T. sum 7.5 °C	0,93**	0,932**		0,965**	0,905**	0,375**	0,219	0,21	-0,169
Avg. June- Sept.	0,978**	0,952**	0,948**		0,954**	0,439**	0,327**	0,259*	-0,104
Max June- Sept.	0,938**	0,859**	0,872**	0,928**		0,45**	0,395**	0,296*	0,148
Heat index	0,403**	0,395**	0,313**	0,401**	0,39**		0,707**	0,665**	-0,072
Insol wq	0,169	0,084	0,082	0,118	0,234*	0,564**		0,639**	0,053
Ann. Insol.	0,263*	0,202	0,163	0,218	0,216	0,685**	0,497**		0,017
Ann. Prec.	-0,043	-0,186	-0,187	-0,104	0,219	-0,044	0,233*	-0,043	
Snow duration	-0,378**	-0,311**	-0,345**	-0,393**	-0,536**	-0,054	-0,11	0,083	-0,409**
Slope	-0,216	-0,176	-0,174	-0,192	-0,232*	0,07	-0,194	0,138	-0,194
Dist. Hilltop	-0,179	-0,171	-0,119	-0,132	-0,188	-0,041	-0,079	-0,125	-0,199
Dist. Farm	-0,187	-0,217	-0,118	-0,186	-0,232*	0,018	-0,1	0,007	-0,255*
Yr. closed	-0,1	-0,081	-0,077	-0,113	-0,1	0,246*	0,035	0,112	-0,07
Prox. Coast	-0,157	0,005	-0,04	-0,093	-0,397**	-0,078	-0,275*	0,014	-0,828**
Prox. River	0,181	0,109	0,154	0,151	0,293*	0,189	0,229*	0,054	0,375**
Wetness	-0,18	-0,086	-0,096	-0,148	-0,309**	-0,177	-0,314**	-0,247*	-0,486**
Richness	0,218	0,137	0,123	0,183	0,318**	0,159	0,292*	0,23*	0,462**
Long.	0,05	0,176	0,122	0,123	-0,235*	-0,023	-0,349**	-0,026	-0,823**
Latit.	0,321**	0,211	0,198	0,317**	0,243*	0,057	-0,097	0,086	0,076

Treeline/ forest line	Snow duration	Slope	Dist. Hilltop	Dist. Farm	Yr. closed	Prox. Coast	Prox. River	Wetness	Richness	Long.	Lat.
M a.s.l..	0,471**	0,533**	-0,096	0,506**	0,42**	0,238	0,238	-0,016	-0,102	0,179	-0,268*
Age	-0,182	-0,329**	-0,114	-0,192	0,041	-0,332**	0,07	0,133	-0,052	-0,171	0,245*
Height	-0,184	-0,222	0,09	-0,243	-0,089	0,049	-0,188	0,149	-0,037	0,192	0,224
Recruitment	0,223	0,277*	0,163	-0,018	-0,141	0,242	-0,294*	-0,049	0	0,227	0,084
Grow. Seas.	-0,404**	-0,39**	-0,134	-0,408**	-0,313*	0,079	-0,187	0,021	0,11	0,157	0,212
An. Temp.	-0,472**	-0,336**	-0,276*	-0,12	-0,103	-0,3*	0,355**	-0,085	0,121	-0,089	0,356**
Temp, wq	-0,424**	-0,292*	-0,25*	-0,101	-0,118	-0,11	0,32**	-0,029	0,082	0,088	0,314*
Temp, cq	-0,511**	-0,354**	-0,284*	-0,12	-0,052	-0,609**	0,386**	-0,172	0,176	-0,417**	0,348**
Mean July	-0,442**	-0,296*	-0,255*	-0,117	-0,105	-0,141	0,323**	-0,035	0,087	0,056	0,307*
Max July	-0,502**	-0,299*	-0,254*	-0,164	-0,112	-0,3*	0,357**	-0,091	0,148	-0,158	0,22
T. sum 0 °C	-0,466**	-0,302*	-0,258*	-0,13	-0,097	-0,198	0,338**	-0,054	0,103	-0,007	0,293*
T. sum 5 °C	-0,445**	-0,303*	-0,249*	-0,125	-0,085	-0,212	0,361**	-0,019	0,061	-0,01	0,317**
T.sum 7 °C	-0,421**	-0,312*	-0,274*	-0,102	-0,103	-0,182	0,215	-0,038	0,093	0,049	0,385**
T. sum 7.5 °C	-0,415**	-0,235	-0,26*	-0,139	-0,106	-0,081	0,31*	-0,045	0,094	0,079	0,235
Avg. June- Sept.	-0,452**	-0,298*	-0,258*	-0,123	-0,103	-0,162	0,326**	-0,043	0,095	0,031	0,298*
Max June- Sept.	-0,512**	-0,325**	-0,273*	-0,157	-0,123	-0,394**	0,357**	-0,118	0,162	-0,238	0,274*
Heat index	-0,008	0,	-0,238	0,173	0,172	-0,163	0,238	-0,307*	0,265*	-0,083	0,136
Insol wq	-0,139	-0,156	-0,202	0,1	0,105	-0,294*	0,175	-0,185	0,222	-0,273*	0,037
Ann. Insol.	0,087	0,033	-0,435**	0,114	0,1	-0,173	0,015	-0,429**	0,333**	-0,112	0,213
Ann. Prec.	-0,267*	-0,221	-0,023	-0,289*	-0,135	-0,763**	0,097	-0,188	0,185	-0,752**	0,13
Snow duration		0,372**	-0,05	0,471**	-0,048	0,44**	-0,155	-0,007	-0,014	0,406**	0,074
Slope	0,296**		0,079	0,19	0,16	0,224	-0,085	-0,188	0,08	0,025	-0,461**
Dist. Hilltop	-0,089	0,143		-0,154	0,095	0,133	-0,025	0,149	-0,147	0,017	-0,323**
Dist. Farm	0,308**	0,149	-0,077		0	0,171	0,008	-0,024	-0,094	0,231	0,131
Yr. closed	-0,001	0,392**	0,286*	0,034		-0,243	0,338**	-0,118	0	-0,16	-0,177
Prox. Coast	0,612**	0,174	0,127	0,149	-0,225		-0,239	0,235	-0,16	0,874**	-0,126
Prox. River	-0,24*	0,108	-0,138	0,001	0,256*	-0,492**		-0,055	0,025	-0,159	0,005
Wetness	0,29*	-0,066	0,086	0,186	-0,006	0,474**	-0,387**		-0,867**	0,316*	0,157
Richness	-0,391**	-0,029	-0,106	-0,32**	-0,028	-0,435**	0,287*	-0,89**		-0,265*	-0,161
Long.	0,498**	0,076	0,053	0,199	-0,189	0,878**	-0,425**	0,48**	-0,427**		0,281*
Latit.	0,028	-0,261*	-0,405**	0,047	-0,345**	-0,03	0,006	0,094	-0,051	0,298**	

Table 7.2: Correlations between variables applied in analysis and discussion about shifts in elevation of tree- and forest lines. Values beneath the grey squares describe correlations between data collected from treeline sites, while values above the grey squares describe correlations between data collected from forest line sites. Significant correlations how been marked with ** (p< 0.01) and * (p<0.05).

	Shift	**Age**	**Tree height**	**Recruitment**	**Grow. Seas.**	**An. Temp**	**Temp, wq**	**Temp, cq**	**Avg. July**	**Max July**	**T. sum 0 °C**
Shift		-0,101	-0,113	0,01	-0,361**	-0,065	-0,103	0,038	-0,101	-0,056	-0,094
Age	-0,101		0,116**	-0,269	0,161	0,141	0,106	0,179	0,125	0,132	0,139
Tree height	-0,113	0,116		0,073	0,315*	0,184	0,197	0,119	0,192	0,149	0,184
Recruitment	0,278	-0,188	0,228		0,201	-0,162	-0,119	-0,248	-0,13	-0,2	-0,145
Grow. Seas.	-0,509**	0,17	0,199	-0,151		0,485**	0,503**	0,379**	0,502**	0,452**	0,493**
An. Temp	-0,306	0,075	0,142	-0,145	0,374*		0,981**	0,939**	0,984**	0,988**	0,99**
Temp, wq	-0,332*	0,087	0,156	-0,113	0,361*	0,979**		0,861**	0,998**	0,971**	0,994**
Temp, cq	-0,206	0,095	0,027	-0,209	0,296	0,925**	0,837**		0,871**	0,935**	0,896**
Avg. July	-0,313	0,045	0,216	-0,078	0,366*	0,982**	0,99**	0,851**		0,976**	0,997**
Max July	-0,27	0,095	0,107	-0,126	0,314	0,982**	0,958**	0,934**	0,961**		0,985**
T. sum 0 °C	-0,288	0,106	0,146	-0,116	0,308	0,941**	0,935**	0,848**	0,941**	0,929**	
T. sum 5 °C	-0,231	0,053	0,123	-0,108	0,322*	0,978**	0,973**	0,884**	0,976**	0,963**	0,941**
T. sum 7 °C	-0,313	0,05	0,22	-0,046	0,348*	0,926**	0,951**	0,766**	0,962**	0,915**	0,903**
T. sum 7.5 °C	-0,316*	0,08	0,151	-0,089	0,371*	0,939**	0,953**	0,8**	0,962**	0,927**	0,907**
Avg. June- Sept	-0,317*	0,071	0,174	-0,095	0,364*	0,988**	0,994**	0,864**	0,997**	0,971**	0,944**
Max. June- Sept	-0,262	0,07	0,131	-0,153	0,311	0,971**	0,922**	0,966**	0,935**	0,988**	0,908**
Heat index	0,057	-0,106	0,068	0,11	-0,339*	0,413**	0,418**	0,402*	0,434**	0,427**	0,479**
Insol wq	-0,149	0,404*	-0,537**	-0,235	0,047	0,15	0,204	0,129	0,079	0,178	0,129
Ann. Insol	0,131	-0,243	-0,176	0,171	-0,245	0,281	0,29	0,279	0,277	0,261	0,311
Ann. Prec	0,042	-0,106	-0,01	-0,158	0,065	0,027	-0,144	0,33*	-0,085	0,072	-0,022
Snow duration	0,203	-0,059	0,003	-0,121	-0,358*	-0,552**	-0,479**	-0,64**	-0,513**	-0,592**	-0,479**
Slope	-0,105	0,411**	-0,552**	-0,192	0,025	0,108	0,162	0,095	0,037	0,138	0,09
Dist. Hilltop	-0,153	0,405*	-0,536**	-0,231	0,048	0,147	0,203	0,126	0,078	0,176	0,126
Dist. Farm	-0,15	0,404*	-0,536**	-0,235	0,048	0,149	0,203	0,127	0,078	0,176	0,127
Yr. Closed	0,158	0,119	-0,232	0,249	-0,24	-0,124	-0,119	-0,069	-0,1	-0,079	-0,066
Prox. Coast	-0,008	-0,199	0,293	0,228	-0,069	-0,33*	-0,181	-0,629**	-0,19	-0,399*	-0,275
Prox. Riv	0,352*	0,116	-0,076	-0,102	-0,157	0,368*	0,281	0,517**	0,293	0,402*	0,32*
Long.	-0,14	-0,093	0,18	0,095	0,068	-0,071	0,091	-0,412**	0,048	-0,181	-0,022
Lat.	-0,17	0,119	-0,253	-0,285	0,211	0,3	0,309	0,266	0,219	0,221	0,239
M a.s.l 2016	0,651**	-0,138	0,052	0,366*	-0,732**	-0,313	-0,266	-0,35*	-0,238	-0,291	-0,242
M a.s.l. 1938	-0,159	-0,084	0,219	0,206	-0,43**	-0,114	-0,028	-0,267	-0,005	-0,128	-0,036

	T. sum 5 °C	T. sum 7 °C	T. sum 7.5 °C	Avg. June- Sept	Max. June- Sept	Heat index	Insol wq	Ann. insol	Ann. prec	Snow duration
Shift	-0,047	-0,138	-0,079	-0,097	-0,028	-0,11	0,046	-0,074	0,104	0,191
Age	0,133	0,21	0,031	0,128	0,159	0,061	0,148	-0,123	0,269	-0,231
Tree height	0,166	0,204	0,2	0,188	0,149	-0,012	0,06	0,036	-0,069	-0,357**
Recruitment	-0,172	-0,03	-0,124	-0,139	-0,216	-0,109	-0,161	0,138	-0,222	0,232
Grow. seas.	0,462**	0,526**	0,499**	0,5**	0,443**	-0,099	-0,018	0,069	-0,063	-0,49**
An. temp	0,982**	0,889**	0,95**	0,987**	0,984**	0,471**	0,232	0,308*	0,013	-0,474**
Temp, wq	0,982**	0,896**	0,966**	0,998**	0,951**	0,483**	0,26	0,278*	-0,146	-0,442**
Temp, cq	0,899**	0,784**	0,831**	0,88**	0,963**	0,444**	0,186	0,348*	0,297*	-0,497**
Avg. July	0,985**	0,9**	0,968**	0,999**	0,957**	0,481**	0,253	0,269	-0,125	-0,458**
Max July	0,977**	0,87**	0,947**	0,98**	0,993**	0,484**	0,23	0,283*	0,031	-0,496**
T. sum 0 °C	0,987**	0,895**	0,963**	0,998**	0,971**	0,486**	0,256	0,282*	-0,073	-0,473**
T. sum 5 °C		0,868**	0,949**	0,986**	0,967**	0,492**	0,236	0,293*	-0,053	-0,46**
T. sum 7 °C	0,927**		0,882**	0,899**	0,861**	0,361**	0,188	0,145	-0,029	-0,458**
T. sum 7.5 °C	0,935**	0,965**		0,968**	0,922**	0,402**	0,186	0,182	-0,176	-0,452**
Avg. June- Sept	0,979**	0,96**	0,961**		0,963**	0,48**	0,252	0,27	-0,107	-0,467**
Max. June- Sept	0,943**	0,874**	0,887**	0,943**		0,479**	0,217	0,304*	0,118	-0,504**
Heat index	0,435**	0,397*	0,349*	0,429**	0,44**		0,354*	0,615**	-0,058	-0,028
Insol wq	0,142	0,083	0,096	0,139	0,1	-0,047		0,336*	-0,169	-0,096
Ann. insol	0,318*	0,214	0,199	0,279	0,273	0,728**	0,091		0,046	0,082
Ann. prec	-0,033	-0,173	-0,191	-0,08	0,197	0,013	-0,276	-0,085		-0,223
Snow duration	-0,485**	-0,435**	-0,479**	-0,523**	-0,614**	-0,106	0,003	-0,001	-0,347*	
Slope	0,099	0,048	0,057	0,098	0,061	-0,063	0,993**	0,094	-0,276	0,032
Dist. hilltop	0,139	0,081	0,095	0,138	0,097	-0,05	0,999**	0,088	-0,279	0,001
Dist. Farm	0,141	0,082	0,095	0,138	0,098	-0,051	0,999**	0,088	-0,277	0,004
Yr. Closed	-0,096	-0,054	-0,066	-0,09	-0,1	0,182	0,044	0,065	-0,049	-0,005
Prox. coast	-0,28	-0,106	-0,13	-0,226	-0,469**	-0,149	-0,241	-0,059	-0,72**	0,558**
Prox. riv	0,337*	0,249	0,239	0,312	0,428**	0,317*	0,139	0,137	0,398*	-0,319*
Long.	-0,016	0,1	0,067	0,026	-0,28	-0,084	0,086	0,016	-0,799**	0,449**
Lat.	0,277	0,135	0,137	0,25	0,196	0,035	0,668**	0,211	-0,102	0,029
M a.s.l 2016	-0,225	-0,182	-0,232	-0,259	-0,306	0,37*	-0,303	0,28	-0,277	0,467**
M a.s.l. 1938	-0,075	0,073	0,009	-0,032	-0,152	0,418**	-0,287	0,209	-0,4*	0,408**

	Slope	Dist. hilltop	Dist. Farm	Yr. Closed	Prox. coast	Prox. riv	Long.	Lat.	M a.s.l 2016	M a.s.l. 1938
Shift	0,303*	-0,024	0,109	0,164	-0,182	0,201	-0,215	0,042	0,306*	-0,374**
Age	-0,375**	-0,1	-0,282*	0,087	-0,349*	0,066	-0,185	0,189	-0,295*	-0,213
Tree height	-0,259	0,148	-0,352*	-0,103	0,025	-0,171	0,138	0,184	-0,409**	-0,26
Recruitment	0,232	0,077	-0,012	-0,038	0,274	-0,361**	0,287*	0,111	-0,083	-0,087
Grow. seas.	-0,392**	-0,276*	-0,363**	-0,252	-0,017	-0,142	0,15	0,279*	-0,638**	-0,378**
An. temp	-0,372**	-0,271	-0,156	-0,187	-0,298*	0,389**	-0,016	0,397**	-0,25	-0,199
Temp, wq	-0,35*	-0,254	-0,144	-0,183	-0,135	0,346*	0,137	0,374**	-0,187	-0,113
Temp, cq	-0,361**	-0,267	-0,156	-0,181	-0,576**	0,448**	-0,323*	0,367**	-0,301*	-0,32*
Avg. July	-0,354*	-0,257	-0,16	-0,174	-0,163	0,352*	0,112	0,368**	-0,196	-0,123
Max July	-0,342*	-0,264	-0,193	-0,213	-0,309*	0,398**	-0,085	0,289*	-0,215	-0,171
T. sum 0 °C	-0,364**	-0,258	-0,178	-0,18	-0,214	0,362**	0,054	0,357**	-0,209	-0,14
T. sum 5 °C	-0,354*	-0,258	-0,161	-0,158	-0,241	0,378**	0,035	0,376**	-0,178	-0,142
T. sum 7 °C	-0,399**	-0,241	-0,169	-0,169	-0,2	0,237	0,107	0,437**	-0,334*	-0,232
T. sum 7.5 °C	-0,305*	-0,256	-0,171	-0,168	-0,111	0,349*	0,12	0,287*	-0,182	-0,124
Avg. June- Sept	-0,354*	-0,258	-0,166	-0,174	-0,182	0,358**	0,09	0,36**	-0,202	-0,131
Max. June- Sept	-0,363**	-0,278*	-0,19	-0,231	-0,39**	0,399**	-0,159	0,327*	-0,255	-0,229
Heat index	-0,143	-0,065	0,042	0,025	-0,083	0,23	0,013	0,182	0,298*	0,365**
Insol wq	-0,065	-0,124	-0,029	0,09	0,016	0,247	0,074	0,012	0,192	0,156
Ann. insol	-0,086	-0,318*	0,039	-0,059	-0,11	-0,004	-0,042	0,302*	0,049	0,098
Ann. prec	-0,19	-0,053	-0,275	-0,197	-0,809**	0,108	-0,786**	0,113	-0,41**	-0,47**
Snow duration	0,335*	-0,004	0,466**	0,059	0,411**	-0,2	0,307*	0,037	0,528**	0,386**
Slope		0,114	0,24	0,226	0,15	-0,097	-0,052	-0,498**	0,492**	0,274
Dist. hilltop	0,993**		-0,081	0,185	0,086	-0,017	-0,006	-0,293*	0,01	0,026
Dist. Farm	0,993**	0,999**		0,003	0,209	-0,04	0,208	0,078	0,471**	0,386**
Yr. Closed	0,094	0,048	0,044		-0,075	0,365**	0,019	-0,171	0,374**	0,254
Prox. coast	-0,238	-0,239	-0,24	-0,239		-0,328*	0,853**	-0,08	0,34*	0,455**
Prox. riv	0,148	0,135	0,138	0,189	-0,584**		-0,209	0,003	0,205	0,064
Long.	0,074	0,086	0,088	-0,196	0,836**	-0,408**		0,315*	0,212	0,352*
Lat.	0,642**	0,662**	0,668**	-0,309	-0,155	0,163	0,288		-0,298*	-0,319*
M a.s.l 2016	-0,252	-0,305	-0,304	0,392*	0,339*	0,049	0,152	-0,387*		0,767**
M a.s.l. 1938	-0,266	-0,285	-0,287	0,349*	0,474**	-0,306	0,355*	-0,353*	0,638**	

Appendix 8: Forward stepwise selection of multip

regression models

Table 8.1: Linear regression model of significant (Bon. *p'* <0.05) explanatory variables for **elevation**). F= F statistics, Df= degrees of freedom, Residual SE= Residual standard error, squared, Coeff. Sign = + or – depending on the sign of the model coefficient, Bon. p' = p-val with Bonferroni method. Significant results are emphasized.

Round	Explanatory variable	Rank	Residual SE	Df	R^2	Coeff. sign	F	B
1	Growth season length	1	47,6	73	0,53	-	83,70	**2,**
	Slope	2	56,9	73	0,32	+	36,40	**1,**
	Time since farm closed	3	60,5	73	0,24	+	23,90	**1,**
	Duration of snow cover	4	61	73	0,22	+	22,10	**3,**
	Heat index	5	63,8	73	0,15	+	13,90	**1,**
	Annual precipitation	6	65	73	0,12	-	10,90	**4,**
2	+ Slope	1	38,5	72	0,69	+	39,20	**1,**
	+ Annual precipitation	2	41,1	72	0,65	-	25,90	**1,**
	+ Duration of snow cover	3	43,9	72	0,60	+	13,80	**2,**
	+Time since farm closed	4	44,6	72	0,59	+	11,20	**6,**
	+ Heat index	5	45,1	72	0,58	+	9,20	**1,**
3	Growth season length: slope	1	37,3	71	0,71	+	61,20	**1,**
4	+ Annual precipitation	1	33,2	70	0,77	-	19,60	**1,**
	+ Heat index	2	33,6	70	0,76	+	33,60	**3,**
	+ Duration of snow cover	3	35,7	70	0,73	+	7,58	**3,**
	+ Time since farm closed	4	36,9	70	0,72	+	2,49	4,
5	Slope: annual precipitation	1	33	69	0,77	+	0,21	1,
	Growth season length :annual precipitation	2	33,5	69	0,77	-	9,65	1,
6	+ Heat index	1	29,4	69	0,82	+	20,20	**8,**
	+ Time since farming	2	32,6	69	0,78	+	3,84	1,
	+ Duration of snow cover	3	33	69	0,77	+	1,91	5,
7	Growth season length : heat index	1	29	68	0,83	+	3,27	2,
	Slope: heat index	2	29	68	0,82	+	2,99	2,
	Annual precipitation: heat index	3	29	68	0,82	-	2,96	2,

Table 8.2: Linear regression model of significant (Bon. *p'* <0.05) explanatory variables for **forest line elevation**. F= F statistics, Df= degrees of freedom, Residual SE= Residual standard error, R^2= Adjusted R-squared, Coeff. Sign = + or – depending on the sign of the model coefficient, Bon. p' = p-value adjusted with Bonferroni method.

Round	Explanatory variable	Rank	Residual SE	Df	R2	Cof, sign	F	Bon. p'	p- value
1	Growth season length	1	51	63	0,443	-	51,90	**2,1E-08**	8,9E-10
	Slope	2	58,2	63	0,273	+	25,00	**1,2E-04**	4,8E-06
	Distance to farm	3	59,3	63	0,245	+	21,80	**3,8E-04**	1,6E-05
	Duration of snow cover	4	60,7	63	0,21	+	18,10	**1,7E-03**	7,2E-05
	Time since closure	5	62,5	63	0,164	+	13,50	**1,2E-02**	4,9E-04
	Heat index	6	62,6	63	0,159	+	13,10	**1,4E-02**	5,9E-04
	Annual precipitation	7	63	63	0,15	-	12,30	**2,0E-02**	8,4E-04
2	Annual precipitation	1	41,7	62	0,627	-	32,1	**2,4E-06**	4,0E-07
	Distance to farm	2	47,2	62	0,523	+	11,60	**7,2E-03**	1,2E-03
	Heat index	3	48,1	62	0,505	+	8,84	**2,5E-02**	4,2E-03
	Distance to farm	4	48,3	62	0,501	+	8,31	**3,2E-02**	5,4E-03
	Duration of snow cover	5	48,3	62	0,483	+	5,94	1,1E-01	1,8E-02
	Time since closure	6	49,1	62	0,484	+	8,31	1,0E-01	1,7E-02
3	Growth season length *annual precipitation	1	41,1	61	0,638	-	2,91	9,3E-02	9,3E-02
4	+Heat index	1	39	61	0,674	+	10,00	**7,2E-03**	2,4E-03
	+Slope	2	39,9	61	0,658	+	6,67	**3,6E-02**	1,2E-02
	+ Distance to farm	3	41,3	61	0,635	+	2,36	3,9E-01	1,3E-01
5	Annual precipitation: heat index	1	39,2	60	0,67	-	0,2	1,3E+00	6,5E-01
	Growth season length :heat index	2	39,3	60	0,669	-	0,03	1,7E+00	8,5E-01
6	+ Slope	1	36,1	60	0,721	+	11,10	**1,5E-03**	1,5E-03
7	Annual precipitation: slope	1	34,6	59	0,744	+	6,43	**4,2E-02**	1,4E-02
	Growth season length: slope	2	35,9	59	0,724	+	1,64	6,0E-01	2,0E-01
	Heat index: slope	3	36,3	59	0,717	+	0,19	2,0E+00	6,7E-01

Appendix 9: Site specific variables

Table 9.1: Overview over values collected for different variables for treeline sites.

Area	Alt_GPS	Heat index	Dist. hilltop	Dist. farm	Yr. closed	An. temp	Temp. WQ	Temp. CQ	Max. July	T. sum 0	T. sum 5	T. sum 7	T. sum 7.5
Hovdungane	1116	137	185	1331	58	-1,6	8,6	-10,8	9,9	30,1	18,9	18,9	32,8
Hovd	981	112	322	869	58	-0,9	9,4	-10,2	10,7	33,1	20,4	20,4	37,4
Djupedal	1193	140	448	3398	58	-2,8	7,5	-11,8	8,7	16,5	16,5	16,5	25,5
Glipsfjellet	1114	57	61	1822	60	-1,9	8,4	-11,1	9,7	29,2	18,5	18,5	31,4
Glipsfjellet	1239	89	51	2272	60	-1,8	8,4	-11,0	9,7	29,3	18,5	18,5	31,5
Glipskardet	1118	89	58	2248	60	-1,0	9,4	-10,3	10,6	32,7	20,2	20,2	36,8
Ved Glip	1052	76	90	1750	60	-1,5	8,8	-10,8	10,1	30,8	19,3	19,3	33,8
Storhovd	1150	124	155	1281	60	-2,0	8,4	-11,2	9,6	29,0	18,4	18,4	31,1
Storhovd	1150	114	154	1102	60	-1,9	8,4	-11,1	9,7	29,4	18,6	18,6	31,7
Storhovd	1152	108	166	1036	60	-1,8	8,5	-11,1	9,8	29,7	18,8	18,8	32,2
Storhovd	1160	79	153	1023	60	-1,9	8,4	-11,2	9,7	29,2	18,5	18,5	31,5
Sluppedalen	1195	165	137	570	61	-1,6	8,7	-10,9	10,0	30,5	19,1	19,1	33,4
Sluppedalen	1227	122	103	442	61	-1,6	8,7	-11,0	10,0	30,4	19,1	19,1	26,7
Horndalen	1219	134	349	1228	58	-2,2	8,2	-11,6	9,5	23,4	18,1	18,1	28,5
Ved Nyborg	1126	43	394	1044	64	-1,8	8,6	-11,1	9,9	29,8	18,8	18,8	29,0
Ved Nyborg	1227	113	108	2100	64	-2,1	8,2	-11,4	9,5	23,6	18,2	18,2	34,9
Ved Nyborg	1136	63	269	1542	64	-2,0	8,4	-11,3	9,7	29,1	18,4	18,4	27,8
Nordøst for Nyb.	1169	153	79	1641	79	-1,7	8,7	-11,0	10,0	30,4	19,1	19,1	40,9
Nordøst for Nyb.	1171	140	81	1799	79	-1,9	8,5	-11,2	9,8	29,6	18,7	18,7	39,9
Kvefarhaug	1099	3	149	1201	79	-1,7	8,7	-11,0	10,0	30,2	19,0	19,0	29,6
Middagshaugen	1210	105	281	535	131	-2,8	7,6	-12,1	8,9	16,9	16,9	16,9	27,3
Skjersfjellet	1200	38	243	4032	121	-2,5	8,0	-12,0	9,3	22,8	17,6	17,6	27,3
Skruven	1270	79	217	2697	126	-2,5	8,1	-12,1	9,4	23,0	17,7	17,7	29,0
Øydalen	1329	155	338	4180	70	-1,6	9,1	-11,3	10,4	31,7	19,6	19,6	34,9
Øydalen	1300	174	364	4869	70	-2,7	7,9	-12,3	9,1	22,4	17,3	17,3	27,8
Gulehaugane	1154	148	514	4265	70	-0,6	10,2	-10,5	11,4	35,7	29,3	29,3	40,9
Kjørlibotn	1155	146	492	2968	70	-0,7	10,0	-10,6	11,2	35,0	28,8	28,8	39,9
Kjørlibotn	1196	134	158	2367	121	-2,4	8,2	-12,0	9,5	23,4	17,9	17,9	29,6
Arebergstølen	1192	29	398	981	69	-2,7	7,8	-12,4	9,0	22,1	17,1	17,1	27,3
Arebergstølen	1192	29	398	981	69	-2,7	7,8	-12,4	9,0	22,1	17,1	17,1	27,3
Geitåni	1124	115	396	1394	58	-2,4	8,1	-12,1	9,3	23,1	17,6	17,6	28,8
Geitåni	1096	78	428	1276	58	-2,3	8,3	-12,0	9,5	23,5	17,9	17,9	29,6
Geitåni	1135	30	402	1291	58	-2,3	8,3	-12,1	9,5	23,4	17,9	17,9	29,4
Heftingdøla	1081	39	504	1736	56	-2,2	8,4	-12,0	9,6	23,9	18,1	18,1	30,2
Mørkedøla	1108	13	314	1298	58	-2,4	8,1	-12,1	9,3	23,1	17,6	17,6	28,8
Hola	1189	167	176	1144	56	-1,1	9,8	-11,4	11,0	34,2	28,2	20,8	38,4
Eggjastølsnosi	1190	148	182	1205	58	-0,9	10,1	-11,2	11,3	35,3	29,1	29,1	40,2
Maristova	1191	64	625	1466	54	-1,6	9,1	-11,6	10,3	31,5	19,5	19,5	34,5
Gramstølen	1168	138	158	1244	54	-1,5	9,2	-11,5	10,4	31,7	19,6	19,6	34,7
Stovestølen	1162	158	69	870	54	-1,1	9,8	-11,2	11,0	34,2	28,3	20,8	38,4
Stovestølen	1159	134	65	975	54	-1,1	9,7	-11,3	10,9	33,8	28,0	20,6	37,9
Stovestølen	1158	163	66	824	54	-1,1	9,7	-11,3	10,9	33,8	28,0	20,6	37,9
Stovestølen	1172	104	154	872	54	-1,4	9,3	-11,5	10,5	32,3	19,9	19,9	35,5
Fillestølen	1095	91	190	1629	54	-1,6	9,1	-11,5	10,3	31,4	19,4	19,4	34,3
Fillestølen	1104	50	175	1379	54	-1,6	9,1	-11,5	10,3	31,4	19,4	19,4	34,2
Øst for Sula	1141	43	101	3200	54	-1,8	8,8	-11,6	10,0	30,2	18,8	18,8	32,4
Skavlegjeli	1134	34	239	5865	54	-2,0	8,6	-11,7	9,8	24,4	18,4	18,4	31,1
Kvernabekken	1259	132	58	5926	54	-1,7	8,9	-11,5	10,1	30,5	19,0	19,0	32,9
Øst for Grøna	1196	160	112	4018	54	-1,8	8,8	-11,5	10,0	30,1	18,8	18,8	32,4
Grønelidi	1209	148	104	3475	54	-1,6	9,0	-11,4	10,2	30,9	19,2	19,2	33,6
Skjeltrane	1247	139	146	2960	126	-1,6	8,9	-11,4	10,2	30,8	19,2	19,2	33,4
Skjeltrane	1216	158	174	3193	126	-1,7	8,9	-11,4	10,1	30,6	19,0	19,0	33,0
Ved Fosse	1186	106	293	822	69	-1,6	9,0	-11,4	10,2	31,1	19,3	19,3	33,9
Ved Fosse	1212	116	152	1081	69	-0,7	10,1	-10,8	11,4	35,6	29,3	29,3	40,6
Horgjastølen	1244	123	207	754	61	-1,9	8,7	-11,6	9,9	30,1	18,8	18,8	32,4
Horgjastølen	1136	135	306	438	61	-1,0	9,7	-10,9	10,9	33,8	27,8	20,6	38,0
Gråberg	1142	102	182	1379	82	-1,8	8,7	-11,4	10,0	30,1	18,9	18,9	32,6
Gråberg	1201	113	165	1676	59	-1,8	8,8	-11,4	10,1	30,6	19,1	19,1	33,2
Ljøsndalen	1164	125	263	1239	82	-2,3	8,2	-11,8	9,5	23,4	17,9	17,9	29,6
Ljøsndalen	1151	129	275	838	82	-1,6	9,0	-11,3	10,3	31,6	19,6	19,6	34,7
Krokagjeli	1297	158	267	3154	111	-1,5	8,9	-10,9	10,1	30,7	19,2	19,2	33,6
Krokagjeli	1259	158	307	2909	111	-1,8	8,7	-11,2	10,0	30,2	18,9	18,9	32,7
Kattegjeli	1266	158	286	2391	111	-1,5	9,0	-11,0	10,3	31,5	19,6	19,6	34,7
Kattegjeli	1282	143	263	2108	111	-1,7	8,9	-11,2	10,1	30,9	19,2	19,2	33,7
Vest for Kattegjeli	1246	178	302	1706	111	-0,9	9,7	-10,6	11,0	34,2	28,1	20,8	38,8
Freibotnfjellet	1207	163	349	1036	111	-1,1	9,5	-10,7	10,7	33,2	20,4	20,4	37,3
Vest for Lid	1130	131	185	1199	67	0,3	10,9	-9,5	12,1	38,4	38,4	31,4	45,4
Vidsete	1052	54	505	771	67	-1,4	9,1	-11,0	10,4	31,8	19,7	19,7	35,2
Øst for Bliksdalen	1139	108	368	1375	82	-1,3	9,2	-10,8	10,5	32,3	20,0	20,0	35,9
Høganós	1148	148	91	1685	84	-0,4	10,0	-10,0	11,2	35,1	28,8	21,3	40,2
Berdalen	1140	178	385	783	84	-1,0	9,4	-10,6	10,7	33,0	20,3	20,3	37,1
Berdalen	1088	179	433	611	84	-0,8	9,7	-10,4	10,9	33,9	27,9	20,8	38,4
Nord for Berdal	1160	132	358	902	84	-1,0	9,4	-10,6	10,7	33,1	20,4	20,4	37,2
Nord for Berdal	1040	131	107	1974	51	-1,2	9,2	-10,7	10,4	32,1	19,9	19,9	35,7
Vetanòsi	1012	105	120	1788	51	-1,0	9,4	-10,4	10,7	32,9	20,3	20,3	36,9

Area	Alt_GPS	Heat index	Dist. hilltop	Dist. farm	Yr. closed	An. temp	Temp. WQ	Temp. CQ	Max. July	T. sum 0	T. sum 5	T. sum 7	T. sum 7.5
Hovdungane	1116	137	185	1331	58	-1,6	8,6	-10,8	9,9	30,1	18,9	18,9	32,8
Hovd	981	112	322	869	58	-0,9	9,4	-10,2	10,7	33,1	20,4	20,4	37,4
Djupedal	1193	140	448	3398	58	-2,8	7,5	-11,8	8,7	16,5	16,5	16,5	25,5
Glipsfjellet	1114	57	61	1822	60	-1,9	8,4	-11,1	9,7	29,2	18,5	18,5	31,4
Glipsfjellet	1239	89	51	2272	60	-1,8	8,4	-11,0	9,7	29,3	18,5	18,5	31,5
Glipskardet	1118	89	58	2248	60	-1,0	9,4	-10,3	10,6	32,7	20,2	20,2	36,8
Ved Glip	1052	76	90	1750	60	-1,5	8,8	-10,8	10,1	30,8	19,3	19,3	33,8
Storhovd	1150	124	155	1281	60	-2,0	8,4	-11,2	9,6	29,0	18,4	18,4	31,1
Storhovd	1150	114	154	1102	60	-1,9	8,4	-11,1	9,7	29,4	18,6	18,6	31,7
Storhovd	1152	108	166	1036	60	-1,8	8,5	-11,1	9,8	29,7	18,8	18,8	32,2
Storhovd	1160	79	153	1023	60	-1,9	8,4	-11,2	9,7	29,2	18,5	18,5	31,5
Sluppedalen	1195	165	137	570	61	-1,6	8,7	-10,9	10,0	30,5	19,1	19,1	33,4
Sluppedalen	1227	122	103	442	61	-1,6	8,7	-11,0	10,0	30,4	19,1	19,1	26,7
Horndalen	1219	134	349	1228	58	-2,2	8,2	-11,6	9,5	23,4	18,1	18,1	28,5
Ved Nyborg	1126	43	394	1044	64	-1,8	8,6	-11,1	9,9	29,8	18,8	18,8	29,0
Ved Nyborg	1227	113	108	2100	64	-2,1	8,2	-11,4	9,5	23,6	18,2	18,2	34,9
Ved Nyborg	1136	63	269	1542	64	-2,0	8,4	-11,3	9,7	29,1	18,4	18,4	27,8
Nordøst for Nyb.	1169	153	79	1641	79	-1,7	8,7	-11,0	10,0	30,4	19,1	19,1	40,9
Nordøst for Nyb.	1171	140	81	1799	79	-1,9	8,5	-11,2	9,8	29,6	18,7	18,7	39,9
Kvefarhaug	1099	3	149	1201	79	-1,7	8,7	-11,0	10,0	30,2	19,0	19,0	29,6
Middagshaugen	1210	105	281	535	131	-2,8	7,6	-12,1	8,9	16,9	16,9	16,9	27,3
Skjersfjellet	1200	38	243	4032	121	-2,5	8,0	-12,0	9,3	22,8	17,6	17,6	27,3
Skruven	1270	79	217	2697	126	-2,5	8,1	-12,1	9,4	23,0	17,7	17,7	29,0
Øydalen	1329	155	338	4180	70	-1,6	9,1	-11,3	10,4	31,7	19,6	19,6	34,9
Øydalen	1300	174	364	4869	70	-2,7	7,9	-12,3	9,1	22,4	17,3	17,3	27,8
Gulehaugane	1154	148	514	4265	70	-0,6	10,2	-10,5	11,4	35,7	29,3	29,3	40,9
Kjørlibotn	1155	146	492	2968	70	-0,7	10,0	-10,6	11,2	35,0	28,8	28,8	39,9
Kjørlibotn	1196	134	158	2367	121	-2,4	8,2	-12,0	9,5	23,4	17,9	17,9	29,6
Arebergstølen	1192	29	398	981	69	-2,7	7,8	-12,4	9,0	22,1	17,1	17,1	27,3
Arebergstølen	1192	29	398	981	69	-2,7	7,8	-12,4	9,0	22,1	17,1	17,1	27,3
Geitåni	1124	115	396	1394	58	-2,4	8,1	-12,1	9,3	23,1	17,6	17,6	28,8
Geitåni	1096	78	428	1276	58	-2,3	8,3	-12,0	9,5	23,5	17,9	17,9	29,6
Geitåni	1135	30	402	1291	58	-2,3	8,3	-12,1	9,5	23,4	17,9	17,9	29,4
Heftingdøla	1081	39	504	1736	56	-2,2	8,4	-12,0	9,6	23,9	18,1	18,1	30,2
Mørkedøla	1108	13	314	1298	58	-2,4	8,1	-12,1	9,3	23,1	17,6	17,6	28,8
Hola	1189	167	176	1144	56	-1,1	9,8	-11,4	11,0	34,2	28,2	20,8	38,4
Eggjastølsnosi	1190	148	182	1205	58	-0,9	10,1	-11,2	11,3	35,3	29,1	29,1	40,2
Maristova	1191	64	625	1466	54	-1,6	9,1	-11,6	10,3	31,5	19,5	19,5	34,5
Gramstølen	1168	138	158	1244	54	-1,5	9,2	-11,5	10,4	31,7	19,6	19,6	34,7
Stovestølen	1162	158	69	870	54	-1,1	9,8	-11,2	11,0	34,2	28,3	20,8	38,4
Stovestølen	1159	134	65	975	54	-1,1	9,7	-11,3	10,9	33,8	28,0	20,6	37,9
Stovestølen	1158	163	66	824	54	-1,1	9,7	-11,3	10,9	33,8	28,0	20,6	37,9
Stovestølen	1172	104	154	872	54	-1,4	9,3	-11,5	10,5	32,3	19,9	19,9	35,5
Fillestølen	1095	91	190	1629	54	-1,6	9,1	-11,5	10,3	31,4	19,4	19,4	34,3
Fillestølen	1104	50	175	1379	54	-1,6	9,1	-11,5	10,3	31,4	19,4	19,4	34,2
Øst for Sula	1141	43	101	3200	54	-1,8	8,8	-11,6	10,0	30,2	18,8	18,8	32,4
Skavlegjeli	1134	34	239	5865	54	-2,0	8,6	-11,7	9,8	24,4	18,4	18,4	31,1
Kvernabekken	1259	132	58	5926	54	-1,7	8,9	-11,5	10,1	30,5	19,0	19,0	32,9
Øst for Grøna	1196	160	112	4018	54	-1,8	8,8	-11,5	10,0	30,1	18,8	18,8	32,4
Grønelidi	1209	148	104	3475	54	-1,6	9,0	-11,4	10,2	30,9	19,2	19,2	33,6
Skjeltrane	1247	139	146	2960	126	-1,6	8,9	-11,4	10,2	30,8	19,2	19,2	33,4
Skjeltrane	1216	158	174	3193	126	-1,7	8,9	-11,4	10,1	30,6	19,0	19,0	33,0
Ved Fosse	1186	106	293	822	69	-1,6	9,0	-11,4	10,2	31,1	19,3	19,3	33,9
Ved Fosse	1212	116	152	1081	69	-0,7	10,1	-10,8	11,4	35,6	29,3	29,3	40,6
Horgjastølen	1244	123	207	754	61	-1,9	8,7	-11,6	9,9	30,1	18,8	18,8	32,4
Horgjastølen	1136	135	306	438	61	-1,0	9,7	-10,9	10,9	33,8	27,8	20,6	38,0
Gråberg	1142	102	182	1379	82	-1,8	8,7	-11,4	10,0	30,1	18,9	18,9	32,6
Gråberg	1201	113	165	1676	59	-1,8	8,8	-11,4	10,1	30,6	19,1	19,1	33,2
Ljøsndalen	1164	125	263	1239	82	-2,3	8,2	-11,8	9,5	23,4	17,9	17,9	29,6
Ljøsndalen	1151	129	275	838	82	-1,6	9,0	-11,3	10,3	31,6	19,6	19,6	34,7
Krokagjeli	1297	158	267	3154	111	-1,5	8,9	-10,9	10,1	30,7	19,2	19,2	33,6
Krokagjeli	1259	158	307	2909	111	-1,8	8,7	-11,2	10,0	30,2	18,9	18,9	32,7
Kattegjeli	1266	158	286	2391	111	-1,5	9,0	-11,0	10,3	31,5	19,6	19,6	34,7
Kattegjeli	1282	143	263	2108	111	-1,7	8,9	-11,2	10,1	30,9	19,2	19,2	33,7
Vest for Kattegjeli	1246	178	302	1706	111	-0,9	9,7	-10,6	11,0	34,2	28,1	20,8	38,8
Freibotnfjellet	1207	163	349	1036	111	-1,1	9,5	-10,7	10,7	33,2	20,4	20,4	37,3
Vest for Lid	1130	131	185	1199	67	0,3	10,9	-9,5	12,1	38,4	38,4	31,4	45,4
Vidsete	1052	54	505	771	67	-1,4	9,1	-11,0	10,4	31,8	19,7	19,7	35,2
Øst for Bliksdalen	1139	108	368	1375	82	-1,3	9,2	-10,8	10,5	32,3	20,0	20,0	35,9
Høganós	1148	148	91	1685	84	-0,4	10,0	-10,0	11,2	35,1	28,8	21,3	40,2
Berdalen	1140	178	385	783	84	-1,0	9,4	-10,6	10,7	33,0	20,3	20,3	37,1
Berdalen	1088	179	433	611	84	-0,8	9,7	-10,4	10,9	33,9	27,9	20,8	38,4
Nord for Berdal	1160	132	358	902	84	-1,0	9,4	-10,6	10,7	33,1	20,4	20,4	37,2
Nord for Berdal	1040	131	107	1974	51	-1,2	9,2	-10,7	10,4	32,1	19,9	19,9	35,7
Vetanòsi	1012	105	120	1788	51	-1,0	9,4	-10,4	10,7	32,9	20,3	20,3	36,9

Table 9.2: Overview over values collected for different variables for forest line sites.

Area	Alt_GPS	Heat_index	Dist. hilltop	Dist. farm	Yr. closed	An. temp	Temp. WQ	Temp. CQ	Mean July	T. sum 0	T. sum 5	T. sum 7	T.sum 7.5
Hovdungane	1040	138,5	256	1486,1	58	-1,5	8,7	-10,7	10,0	33,4	30,4	19,1	19,1
Hovdungane	967	108,5	340	747,4	58	-0,8	9,5	-10,2	10,8	37,7	33,4	20,5	20,5
Djupedal	1161	139,5	478	3375,1	58	-2,8	7,5	-11,8	8,7	25,5	16,5	16,5	16,5
Glipsfjellet	1143	88,5	152	2383,6	60	-1,5	8,8	-10,8	10,1	33,6	30,6	19,2	19,2
Glipsskardet	1109	87,5	67	2263,3	60	-1,0	9,4	-10,3	10,6	36,8	32,7	20,2	20,2
Storhovd	1152	107,5	166	1036,3	60	-1,8	8,5	-11,1	9,8	32,2	29,7	18,8	18,8
Sluppedalen	1103	127,5	236	309,4	61	-1,3	9,0	-10,7	10,3	35,1	31,6	18,0	19,7
Sluppedalen	1129	153,5	222	611,0	61	-1,4	8,9	-10,7	10,2	34,8	31,4	19,6	19,6
Horndalen	1200	137,5	374	1082,2	58	-2,2	8,2	-11,6	9,4	29,9	23,3	18,0	18,0
Ved Nyborg	1040	32,5	478	781,9	64	-1,4	9,0	-10,8	10,3	34,9	31,6	19,6	19,6
Kvefarhaug	1090	2,5	153	1323,0	79	-1,9	8,5	-11,2	9,8	31,7	29,5	18,6	18,6
Middagshaugen	1210	104,5	281	534,8	131	-2,8	7,6	-12,1	8,9	26,7	16,9	16,9	16,9
Senddalen,vest	1219	117,5	487	2717,9	131	-3,0	7,4	-12,3	8,7	25,6	16,5	16,5	16,5
Senddalen, aust	1226	126,5	239	3699,8	131	-1,6	8,9	-11,3	10,2	34,4	31,3	19,5	19,5
Skruven	1202	75,5	281	2539,8	126	-2,3	8,4	-11,9	9,6	30,3	23,7	18,1	18,1
Dyrkollkleivi	1132	67,5	220	538,0	126	-2,8	7,8	-12,4	9,1	27,4	17,2	17,2	17,2
Øydalen	1268	169,5	402	4128,9	70	-1,3	9,5	-11,1	10,7	36,7	32,9	17,7	20,2
Kjørlibotn	1145	161,5	504	2936,3	70	-0,2	10,6	-10,2	11,8	43,4	37,3	30,6	30,6
Seltafossen	1140	35,5	332	1719,4	121	-2,5	8,1	-12,0	9,4	29,0	23,1	17,7	17,7
Seltafossen	1183	133,5	176	2334,0	121	-2,4	8,2	-12,0	9,5	29,6	23,4	17,9	17,9
Arberget	1123	32,5	467	836,2	69	-2,5	8,1	-12,2	9,3	28,6	22,9	17,6	17,6
Grindi	1230	141,5	315	2966,0	69	-1,6	9,3	-11,5	10,5	35,7	32,3	19,9	19,9
Grindi	1227	157,5	313	3232,5	69	-1,5	9,4	-11,4	10,6	36,1	32,6	20,0	20,0
Geitåni	1051	92,5	469	1181,8	58	-2,2	8,5	-11,9	9,7	30,6	24,1	18,3	18,3
Geitåni	1100	27,5	436	1211,4	58	-2,2	8,4	-12,0	9,6	30,3	23,9	18,2	18,2
Heftingdøla	1076	30,5	509	1614,2	56	-2,2	8,5	-12,0	9,7	30,5	24,0	18,2	18,2
Erakerstølen	1047	12,5	545	718,5	56	-1,5	9,4	-11,6	10,6	36,0	32,5	17,6	20,0
Erakerstølen	1087	49,5	499	1118,4	56	-1,7	9,1	-11,7	10,3	34,1	31,3	19,4	19,4
Mørkedøla	1094	17,5	328	1271,5	58	-2,5	8,1	-12,1	9,3	28,7	23,0	17,6	17,6
Hola	1190	147,5	182	1205,1	58	-0,9	10,1	-11,2	11,3	40,2	35,3	29,1	29,1
Eggjastølsnosi	1199	161,5	165	1074,2	58	-0,8	10,1	-10,9	11,3	40,2	35,4	29,2	29,2
Maristova	1166	68,5	652	1529,4	54	-1,6	9,1	-11,6	10,3	34,4	31,5	19,5	19,5
Maristova	1134	49,5	681	1222,0	54	-1,9	8,8	-11,8	10,0	32,4	30,1	18,8	18,8
Gramstølen	1151	144,5	175	918,9	54	-1,4	9,3	-11,5	10,5	35,5	32,2	19,8	19,8
Stovestølen	1146	147,5	81	758,8	54	-1,1	9,7	-11,3	10,9	37,9	33,8	28,0	20,6
Fillestølen	1083	72,5	200	1291,9	54	-1,6	9,1	-11,5	10,3	34,2	31,4	19,4	19,4
Skavlegjeli	1123	31,5	253	5927,2	54	-1,9	8,7	-11,7	9,9	31,8	24,8	19,9	18,6
Kvernabekken	1170	132,5	138	5976,6	54	-1,6	9,1	-11,5	10,3	33,9	31,2	19,3	19,3
Øst for Grøna	1145	168,5	165	3648,0	54	-1,4	9,3	-11,3	10,5	35,6	32,3	19,9	19,9
Gønelidi	1195	153,5	124	3463,3	54	-1,6	9,0	-11,4	10,2	33,6	30,9	19,2	19,2
Skjeltrane	1159	172,5	244	1683,1	126	-1,2	9,6	-11,2	10,8	37,0	33,2	27,5	20,3
Skjeltrane	1205	144,5	187	3043,4	126	-1,6	9,0	-11,4	10,2	33,6	30,9	19,2	19,2
Store Frostdal	1175	131,5	202	2420,5	126	-1,5	9,1	-11,3	10,3	34,4	31,5	19,5	19,5
Store Frostdal	1145	90	240	2100,1	126	-1,4	9,3	-11,3	10,5	35,4	32,2	19,8	19,8
Frostdalselvane	1104	99,5	432	846,5	126	-1,6	9,0	-11,4	10,3	34,1	31,3	19,4	19,4
Ved Fosse	1178	112,5	182	1154,1	69	-0,4	10,5	-10,6	11,7	42,5	36,8	30,3	30,3
Horgjastølen	1096	138,5	68	483,1	61	-0,9	9,8	-10,8	11,0	38,5	34,2	18,3	20,8
Gråberg	1129	124,5	198	1204,8	82	-1,7	8,9	-11,3	10,1	33,7	30,9	19,2	19,2
Gråberg	1131	126,5	242	1588,3	82	-2,1	8,4	-11,6	9,6	30,7	23,9	18,3	18,3
Ljøsndalen	1147	132,5	279	779,4	82	-1,6	9,0	-11,3	10,3	34,7	31,6	19,6	19,6
Krokagjeli	1257	157,5	311	2929,9	111	-1,8	8,7	-11,2	10,0	32,7	30,2	18,9	18,9
Krokagjeli	1253	157,5	303	3190,7	111	-1,1	9,3	-10,5	10,6	36,2	32,5	20,0	20,0
Kattegjeli	1219	157,5	338	2399,0	111	-1,1	9,4	-10,7	10,7	37,0	33,0	20,3	20,3
Kattegjeli	1247	144,5	302	2149,3	111	-1,7	8,9	-11,2	10,1	33,7	30,9	19,2	19,2
Fretibotnfjellet	1207	162,5	349	1036,3	111	-1,1	9,5	-10,7	10,7	37,3	33,2	20,4	20,4
Freibotnfjellet	1018	147,5	435	153,0	111	0,1	10,5	-9,6	11,8	43,4	37,2	30,4	30,4
Vest for Lid	1130	130,5	185	1199,4	67	0,3	10,9	-9,5	12,1	45,4	38,4	27,6	31,4
Vidsete	1043	57,5	520	636,4	67	-1,8	8,7	-11,3	10,0	32,7	30,1	18,9	18,9
Øst for Bliksdalen	1099	99,5	405	1317,9	82	-1,0	9,6	-10,6	10,8	37,8	33,5	27,6	20,5
Vest for Bliksdalen	1130	109,5	108	1798,2	84	-0,7	9,7	-10,3	11,0	38,6	34,1	28,0	20,8
Hognåsen	1117	142,5	116	1777,7	84	0,2	10,6	-9,4	11,7	43,2	37,1	30,4	30,4
Berdalslidi	1064	177,5	457	505,1	84	-0,8	9,7	-10,4	11,0	38,6	34,1	28,0	20,8
Nord for Berdal	1056	131,5	464	831,2	84	-0,7	9,8	-10,3	11,1	39,4	34,6	28,4	21,1
Langedalen	1009	130,5	140	1930,3	51	-0,8	9,6	-10,4	10,9	38,2	33,7	27,7	20,7
Vetanòsi	979	117,5	159	1870,3	51	-0,9	9,6	-10,4	10,9	38,2	33,8	27,7	20,7

Area	Alt_GPS	Heat_index	Dist. hilltop	Dist. farm	Yr. closed	An. temp	Temp. WQ	Temp. CQ	Mean July	T. sum 0	T. sum 5	T. sum 7	T.sum 7.5
Hovdungane	1040	138,5	256	1486,1	58	-1,5	8,7	-10,7	10,0	33,4	30,4	19,1	19,1
Hovdungane	967	108,5	340	747,4	58	-0,8	9,5	-10,2	10,8	37,7	33,4	20,5	20,5
Djupedal	1161	139,5	478	3375,1	58	-2,8	7,5	-11,8	8,7	25,5	16,5	16,5	16,5
Glipsfjellet	1143	88,5	152	2383,6	60	-1,5	8,8	-10,8	10,1	33,6	30,6	19,2	19,2
Glipsskardet	1109	87,5	67	2263,3	60	-1,0	9,4	-10,3	10,6	36,8	32,7	20,2	20,2
Storhovd	1152	107,5	166	1036,3	60	-1,8	8,5	-11,1	9,8	32,2	29,7	18,8	18,8
Sluppedalen	1103	127,5	236	309,4	61	-1,3	9,0	-10,7	10,3	35,1	31,6	18,0	19,7
Sluppedalen	1129	153,5	222	611,0	61	-1,4	8,9	-10,7	10,2	34,8	31,4	19,6	19,6
Horndalen	1200	137,5	374	1082,2	58	-2,2	8,2	-11,6	9,4	29,9	23,3	18,0	18,0
Ved Nyborg	1040	32,5	478	781,9	64	-1,4	9,0	-10,8	10,3	34,9	31,6	19,6	19,6
Kvefarhaug	1090	2,5	153	1323,0	79	-1,9	8,5	-11,2	9,8	31,7	29,5	18,6	18,6
Middagshaugen	1210	104,5	281	534,8	131	-2,8	7,6	-12,1	8,9	26,7	16,9	16,9	16,9
Senddalen,vest	1219	117,5	487	2717,9	131	-3,0	7,4	-12,3	8,7	25,6	16,5	16,5	16,5
Senddalen, aust	1226	126,5	239	3699,8	131	-1,6	8,9	-11,3	10,2	34,4	31,3	19,5	19,5
Skruven	1202	75,5	281	2539,8	126	-2,3	8,4	-11,9	9,6	30,3	23,7	18,1	18,1
Dyrkollkleivi	1132	67,5	220	538,0	126	-2,8	7,8	-12,4	9,1	27,4	17,2	17,2	17,2
Øydalen	1268	169,5	402	4128,9	70	-1,3	9,5	-11,1	10,7	36,7	32,9	17,7	20,2
Kjørlibotn	1145	161,5	504	2936,3	70	-0,2	10,6	-10,2	11,8	43,4	37,3	30,6	30,6
Seltafossen	1140	35,5	332	1719,4	121	-2,5	8,1	-12,0	9,4	29,0	23,1	17,7	17,7
Seltafossen	1183	133,5	176	2334,0	121	-2,4	8,2	-12,0	9,5	29,6	23,4	17,9	17,9
Arberget	1123	32,5	467	836,2	69	-2,5	8,1	-12,2	9,3	28,6	22,9	17,6	17,6
Grindi	1230	141,5	315	2966,0	69	-1,6	9,3	-11,5	10,5	35,7	32,3	19,9	19,9
Grindi	1227	157,5	313	3232,5	69	-1,5	9,4	-11,4	10,6	36,1	32,6	20,0	20,0
Geitåni	1051	92,5	469	1181,8	58	-2,2	8,5	-11,9	9,7	30,6	24,1	18,3	18,3
Geitåni	1100	27,5	436	1211,4	58	-2,2	8,4	-12,0	9,6	30,3	23,9	18,2	18,2
Heftingdøla	1076	30,5	509	1614,2	56	-2,2	8,5	-12,0	9,7	30,5	24,0	18,2	18,2
Erakerstølen	1047	12,5	545	718,5	56	-1,5	9,4	-11,6	10,6	36,0	32,5	17,6	20,0
Erakerstølen	1087	49,5	499	1118,4	56	-1,7	9,1	-11,7	10,3	34,1	31,3	19,4	19,4
Mørkedøla	1094	17,5	328	1271,5	58	-2,5	8,1	-12,1	9,3	28,7	23,0	17,6	17,6
Hola	1190	147,5	182	1205,1	58	-0,9	10,1	-11,2	11,3	40,2	35,3	29,1	29,1
Eggjastølsnosi	1199	161,5	165	1074,2	58	-0,8	10,1	-10,9	11,3	40,2	35,4	29,2	29,2
Maristova	1166	68,5	652	1529,4	54	-1,6	9,1	-11,6	10,3	34,4	31,5	19,5	19,5
Maristova	1134	49,5	681	1222,0	54	-1,9	8,8	-11,8	10,0	32,4	30,1	18,8	18,8
Gramstølen	1151	144,5	175	918,9	54	-1,4	9,3	-11,5	10,5	35,5	32,2	19,8	19,8
Stovestølen	1146	147,5	81	758,8	54	-1,1	9,7	-11,3	10,9	37,9	33,8	28,0	20,6
Fillestølen	1083	72,5	200	1291,9	54	-1,6	9,1	-11,5	10,3	34,2	31,4	19,4	19,4
Skavlegjeli	1123	31,5	253	5927,2	54	-1,9	8,7	-11,7	9,9	31,8	24,8	19,9	18,6
Kvernabekken	1170	132,5	138	5976,6	54	-1,6	9,1	-11,5	10,3	33,9	31,2	19,3	19,3
Øst for Grøna	1145	168,5	165	3648,0	54	-1,4	9,3	-11,3	10,5	35,6	32,3	19,9	19,9
Gønelidi	1195	153,5	124	3463,3	54	-1,6	9,0	-11,4	10,2	33,6	30,9	19,2	19,2
Skjeltrane	1159	172,5	244	1683,1	126	-1,2	9,6	-11,2	10,8	37,0	33,2	27,5	20,3
Skjeltrane	1205	144,5	187	3043,4	126	-1,6	9,0	-11,4	10,2	33,6	30,9	19,2	19,2
Store Frostdal	1175	131,5	202	2420,5	126	-1,5	9,1	-11,3	10,3	34,4	31,5	19,5	19,5
Store Frostdal	1145	90	240	2100,1	126	-1,4	9,3	-11,3	10,5	35,4	32,2	19,8	19,8
Frostdalselvane	1104	99,5	432	846,5	126	-1,6	9,0	-11,4	10,3	34,1	31,3	19,4	19,4
Ved Fosse	1178	112,5	182	1154,1	69	-0,4	10,5	-10,6	11,7	42,5	36,8	30,3	30,3
Horgjastølen	1096	138,5	68	483,1	61	-0,9	9,8	-10,8	11,0	38,5	34,2	18,3	20,8
Gråberg	1129	124,5	198	1204,8	82	-1,7	8,9	-11,3	10,1	33,7	30,9	19,2	19,2
Gråberg	1131	126,5	242	1588,3	82	-2,1	8,4	-11,6	9,6	30,7	23,9	18,3	18,3
Ljøsndalen	1147	132,5	279	779,4	82	-1,6	9,0	-11,3	10,3	34,7	31,6	19,6	19,6
Krokagjeli	1257	157,5	311	2929,9	111	-1,8	8,7	-11,2	10,0	32,7	30,2	18,9	18,9
Krokagjeli	1253	157,5	303	3190,7	111	-1,1	9,3	-10,5	10,6	36,2	32,5	20,0	20,0
Kattegjeli	1219	157,5	338	2399,0	111	-1,1	9,4	-10,7	10,7	37,0	33,0	20,3	20,3
Kattegjeli	1247	144,5	302	2149,3	111	-1,7	8,9	-11,2	10,1	33,7	30,9	19,2	19,2
Fretibotnfjellet	1207	162,5	349	1036,3	111	-1,1	9,5	-10,7	10,7	37,3	33,2	20,4	20,4
Freibotnfjellet	1018	147,5	435	153,0	111	0,1	10,5	-9,6	11,8	43,4	37,2	30,4	30,4
Vest for Lid	1130	130,5	185	1199,4	67	0,3	10,9	-9,5	12,1	45,4	38,4	27,6	31,4
Vidsete	1043	57,5	520	636,4	67	-1,8	8,7	-11,3	10,0	32,7	30,1	18,9	18,9
Øst for Bliksdalen	1099	99,5	405	1317,9	82	-1,0	9,6	-10,6	10,8	37,8	33,5	27,6	20,5
Vest for Bliksdalen	1130	109,5	108	1798,2	84	-0,7	9,7	-10,3	11,0	38,6	34,1	28,0	20,8
Hognåsen	1117	142,5	116	1777,7	84	0,2	10,6	-9,4	11,7	43,2	37,1	30,4	30,4
Berdalslidi	1064	177,5	457	505,1	84	-0,8	9,7	-10,4	11,0	38,6	34,1	28,0	20,8
Nord for Berdal	1056	131,5	464	831,2	84	-0,7	9,8	-10,3	11,1	39,4	34,6	28,4	21,1
Langedalen	1009	130,5	140	1930,3	51	-0,8	9,6	-10,4	10,9	38,2	33,7	27,7	20,7
Vetanòsi	979	117,5	159	1870,3	51	-0,9	9,6	-10,4	10,9	38,2	33,8	27,7	20,7

Appendix 10: Instructions for mapping of tree- and forest lines

Veileder for kartlegging av tre- og skoggrenser

Anders Bryn 2013-2017

Litt om å hva som menes med tre, og da med fokus på fjellbjørk:
Et tre er en fysiognomisk enhet – ikke en artsenhet eller tilsvarende. Det vil alltids finnes individer høyere opp enn de vi skal måle inn. Det er derfor viktig å tenke på hvorfor vi måler akkurat trær, og hva det da vil si å være et tre i grenseområdene mot fjellet.

- De skal stikke opp over snøen om vinteren og utsettes for klimatiske prosesser hele året – inkludert vinteren.
- De skal utsettes for atmosfærisk klima – ikke bakkenært klima. Normalt ligger meteorologiske stasjoner i Norge 2 m over bakken, men da på lokaliteter uten vegetasjon (eller med krypende vegetasjon under 10 cm). Normalt vil vegetasjonen i tre- og skoggrensa være på omkring 30 - 70 cm eller noe mer. Derfor bruker nesten alle forskere definisjoner på trær som > 2.5 m (mange 3 m og noen 3.5 m). Det er avstanden fra øvre tette vegetasjonsdekke som gjelder for å unngå bakkenært klima.
- I gjentaksstudier kan man også argumentere for at de skal oppleves som trær, ettersom definisjonene ser ut til å være rimelig subjektive.

I gamle studier brukes ofte lengdemålet «mannshøyde», og dette er ikke entydig definert. Fram mot 1900-tallet regnes en mannshøyde til 170-175 cm, mens den etter 1900 øker gradvis mot 180 cm. Følger man favnen fram til 1887, blir høyden omkring 180 cm.
Ifølge Børre Aas ble dette tolket som et høydekrav til 2 m, men da som fast stamme i 2 meters høyde. Den totale høyden vil da i nesten alle tilfeller være høyere. Min erfaring er at trær som regel er høyere 2.5 m, og at det ikke er en gradvis nedgang i trærnes høyde som funksjon av meter over havet. Det som avgjør er om trærne har kommet seg over snødekket og etablert seg «der» med en tydelig krone – og da er de som regel høyere enn 2 m.
Min erfaring er helt parallell til det Søren Ve skriver i 1940, og som de fleste andre som jobber med tre- og skoggrenser erfarer:
«*Normann (1895-1901) definerte slik: «- den øverste høide over havet, hvor der forekommer oprette i regelen enstammede og mer end mandshøie birker». Tengwall (1920, s. 319) segjer at ein må ha inngåande kjennskap til korleis dei økologiske faktorar utformar bjørki i kvart einskilt tilfelle for å kunna avgjera um ei bjørk skal reknast for tre eller buske. Men etter mi røynsle er det sjeldan at ein på desse kantar råkar meir enn mannshøge bjørker som ikkje kan reknast for tre. Dei aller fleste som ikkje har karakteren av tre – tunne skot med fåe sidegreiner -, vil som regel vera mindre enn mannshøge. Det er difor nærmast Normann sin definisjon eg har halde meg til.*»

Formål:
Formålet i denne fasen er å forstå **regional** variasjon, ikke lokal variasjon. Lokal variasjon vil registreres systematisk etter at den regionale variasjonen er registrert og undersøkt.

- Gjenta registreringer for å studere endringer, med særlig vekt på å tall-feste endringshastigheter
- Separere tre- fra skoggrenser, slik at endringshastighetene kan beskrives for henholdsvis den fysiognomiske enheten tre og for økosystemet skog (slik skog er definert her)
- Etablere nye registreringer for klimatiske tre- og skoggrenser, slik at vi kan studere koblingene mellom klima og tre- og skoggrenser
- Etablere nye registreringer for klimatiske tre- og skoggrenser, slik at andre kan bruke våre registreringer til gjentak om «noen» år (sannsynligvis 25 eller 50 år)
- Etablere et grunnlag for systematisk overvåking av tre- og skoggrenser. Vi skal **ikke** starte overvåkingen i denne fasen, men skaffe data for å kunne etablere en overvåking

Normalt vil det måtte registreres fra 5 – 15 trær per tregrenselokalitet, og tilsvarende per skoggrenselokalitet. Jeg har registrert opp til 50 punkter på en lokalitet(et fjell – et stedsnavn hos Aas) – hvor alle ulike eksposisjoner kommer i spill, og da ble det likevel bare ett gjentaks-punkt registrert. Dette gjør at mengden variabler som registreres i hvert punkt, må holdes på et absolutt minimum, men fange opp det som er nødvendig for å forstå regional variasjon.
I denne fasen er det viktigere å gjennomføre alle gjentak, heller enn å registrere nye lokaliteter eller nye eksposisjoner. Det er derfor viktig å se på klokka og framdriftsbehovet underveis i sesongen, og beregne hvor mye tid du kan gjøre per lokalitet (fjell). Normalt bør en klare to lokaliteter (fjell, eller stedsnavn) per dag, noen ganger langt flere, men innimellom bare en lokalitet.
Det er ikke om å gjøre å bekrefte endringer eller stillstand. Det er om å gjøre å dokumentere hvilke endringer som har skjedd. Se på hver lokalitet (fjell) med nye øyne. Avvik fra egne forventninger må påregnes.

Det som er avgjørende er å prøve å forstå hva Resvoll-Holmsen, Aas, og Ve har definert som et tre og skog, for å re-kartlegge dette. Samtidig bør vi legge igjen en mer objektiv definisjon for våre data, slik at det blir lettere å avgjøre hva et tre er for de som kommer etter oss. Det er dette kompromisset dere finner igjen i min definisjon av hva et tre er.

Litt om det å gjenfinne en lokalitet:
Det er vanskelig å vite nøyaktig hvor de har registrert tidligere. Prøv å tenke på tilgang, topografi m.m. når dere leter opp lokaliteter. Et godt utgangspunkt kan være å lese seg fram til hvor de har gått fra, eller tenke seg fram til beste sted å gå fra (på den tiden de registrerte). Dette er og blir en subjektiv øvelse.
Dersom du mener at det er nødvendig å justere høydene til Ve, Resvoll-Holmsen eller Aas, så skal dette kun gjøres dersom du er helt sikker på at tidligere målinger er feil. Ulike tilfeller:

- Gamle målinger går høyere enn selve topp-punktet, hvilket er umulig. Da må man inn å justere innlesingspunkt / kalibreringspunkt fra gamle gradteigskart. Slike lokaliteter må beskrives i kommentarfeltet. Høyden reduseres tilsvarende feilen i opprinnelig gradteigskart.
- Gamle og vitale trær som er eldre enn de tidligere registreringene, og som finnes høyere opp enn det som Ve, Resvoll-Holmsen eller Aas har angitt. Bruk trebor for å forsikre deg om at treet er minst 20 år eldre enn forrige registreringstidspunkt i brysthøyde. For Aas er dette mulig, men det er trolig vanskelig for Resvoll-Holmsen og Ve, ettersom trærne i de tilfellene vil måtte være svært gamle.
- Bjørk brytes normalt ned rimelig raskt (sammenliknet med f. eks furu). Likevel har jeg funnet døde trær på bakken over tidligere registrerte tregrenser. Da bør lokalitet registreres fullt ut, og så kan vi vurdere om tregrensemålingene fra gammelt av skal heves.
- Du står på en lokalitet som Ve, Resvoll-Holmsen eller Aas ikke oppdaget, men som er betraktelig høyere. Dette er vanskelig å vurdere, og her må en være konservativ.
    - Ligger lokaliteten slik til i terregnet at den er lett å overse?
    - Ligger lokaliteten bak en rygg / kam i terrenget f. eks?
    - Er det store gamle trær på lokaliteten? Bruk treboret ved behov....
    - Er det fysiske barriærer bort til lokaliteten som gjør at den kanskje ikke ble besøkt?

Tredefinisjon:

- Normalt skal de være enkelt stammet / en-stammet, men dersom fler-stammet – da bør hver stamme > 2.5 m høy (total lengde er ikke interessant)
- Opprette, men nederste del kan være krypende / bøyd før den strekker seg
- Stammen i brysthøyde skal ikke være for fleksibel eller bøyelig (ikke tynn)
- Ikke buskformet:
    - dette er en variabel fysiognomisk gruppe som kan ta mange former
    - oftest < 2.5 m i tregrensenivå, men særlig vier kan få høye former
- Skal stikke opp over snøen om vinteren og ha etablert en «krone» over snøen.
    - Krona trenger ikke å være bred
    - Hvis krona ender i «pisk» uten grønne blader, skal den helst ikke telle med (med mindre alle andre kriterier er tilfredsstilt).

- Dersom «pisken» henger, skal den ikke strekkes ved lengdemåling

- Toppen skal / bør ikke være buskformet
- Stammen skal / bør ikke ha mange sidegreiner
- Fast enkeltstamme skal være «mannshøy», før den går over i ett eller flere fleksibele toppskudd;
  - total høyde normalt > 2.5 m høy, men ikke alltid
  - diameter i brysthøyde normalt > 5 cm, men mindre kan aksepteres dersom alle andre kriterier er tilfredsstilt
- Men trehøyde måles, og trær under 2.5 måles også inn – så langt ned som de oppfattes som trær:
  - 10 cm nøyaktighet under 2.5 m,
  - 50 cm nøyaktighet over 2.5 m høye trær.
- Det er høyden som teller – ikke lengden på krypende stammer. Når høyden måles, måles den fra bakken hvor rota er festet, også når treet er krypende. Dette er spesielt viktig i bratt terreng og der det er store snømengder.
- Det er høyeste lokalitet som leses inn, stratifisert på 8 ulike hellingsretninger. Hellingsretning leses **ikke** av fra kart eller GPS, men fra kompass
- Rotskudd fra basis kan aksepteres som tre når alle andre kriterier er tilfredsstilt.

Skogdefinsjon

Alle trær som inngår skal tilfredsstille kravet til å være trær (se over). Det er de absolutt høyest voksende skogteiger eller skogtunger som skal registreres. Det er det øverste treet (i m o.h.) i skogteigen som skal registreres.

Det skal ikke være mer enn 15 meter avstand mellom trærne målt fra stammen, med mindre trærne har store trekroner – da måles avstand fra ytterste kant av trekronene. Høyde inngår ikke i avstandsmålet, så i bratt terreng kan det godt være noe lenger målt ved bakken (opp mot 20-25 meter). Avstand anslås – det måles ikke. Det tar for lang tid!

Skogteiger over sammenhengende skog skal registreres, men da skal det minst være 15 individuelle trær i populasjonen som utgjør skogen. Alle de 15 individene skal klart holde definisjonen til å være et tre (se over). De kan godt stå tett (og ha felles vegetativt opphav for lenge siden), men de bør kunne oppfattes som individer.

Registreringer av tregrense

1. Øverste tre av fjellbjørk, på hver tidligere registrerte hellingsretning, skal alltid registreres.

   Dersom det finnes andre treslag som vokser høyere enn fjellbjørka, og som holder alle krav til å være et tre, så skal det høyest voksende individet av hvert treslag også registreres. Andre parametere registreres som for fjellbjørka. Treslag som kan forekomme høyere enn bjørka er fremst gran og rogn, men også furu, osp og gråor er i sjeldne tilfeller observert høyt.
2. I tillegg skal det registreres øverste tre av fjellbjørk på andre hellingsretninger (nye) som er tilgjengelige m.h.t. gåavstand. Dette er for å etablere et bedre datasett, og å fylle inn de lokalt høyeste trærne.

3. Dersom det er mulig, bør en også forsøke å registrere øverste tre av fjellbjørk på fjell i regionen som antakeligvis er høyere enn der det tidligere er registrert av Resvoll-Holmsen, Aas eller Ve. Dette må imidlertid vurderes av hver enkelt ved å se på kart, bruke kikkert osv. Det er viktigere å repetere målingene til de andre, enn å etablere nye. Men for å legge igjen et bra utgangspunkt for andre, samt å finne klimatiske tre- og skoggrensenes, bør nye lokaliteter leses inn. Vi kan ikke ta for gitt av Resvoll-Holmsen, Ve og Aas leste inn kun klimatiske grenser (selv om de registrerte de høyeste i sin tid).

4. Følgende variabler registreres ved hvert tre:
   a. **Stedsnavn (lokalitetsnavn), dato for registrering og registratornavn**
   b. **Kode for punktet du leser inn**
      i. Det kan bli mange trær per lokalitet med samme hellingsretning.
      ii. Lag et enkelt kodesystem med en meget kort tekststreng som lett tastes inn på GPS

c. **Treslag**

d. **Altitude:** Høyde (meter o.h.) som leses av fra GPS **og** fra aneroid barometer (husk å kalibrere barometer hver dag på morgenen). Barometer kalibreres kun ved kjente høyder. La GPS stå på hele tiden fra du går fra bilen / hytta. Høyde interpoleres i tillegg fra kartbasen i etterkant.

e. **Treets høyde:** Total høyde på treet (men ikke lengde) – måles fra bakken der rota er festet uten å strekke ut toppen. Trær >2.5 m måles i 50 cm intervaller, trær <2.5 m måles i 10 cm intervaller. Ved bøyde eller krypende trær, måles høyden vertikalt fra toppen og ned til bakken.

f. **GPS usikkerhet i ± meter**

g. **Koordinater:** Lokalitetens koordinater og koordinatsystem brukt av GPS på punktet

h. **Hellingsretning** (bruk kompass – ikke GPS eller kart – se lenger ned)

i. **Vegetasjonstyper:** Alle registrerer vegetasjonstype etter Rekdal & Larsson (2005), inkludert alle tilgjengelige variabler.
   - i. Det er treets økologi som er poenget. Står f. eks treet på en rygg med rabbevegetasjon, men med tydelige røtter i næringsrikt vann, da registreres både 2c (rabbe) og 3b (høgstaudeeng).
   - ii. Poenget er å registrere det som i hovedsak påvirker individet. Normalt vil det holde med å registrere en vegetasjonstype m variabler, men enkelte ganger er det nødvendig med 2.
   - iii. Variablene er viktige å registrere og følger standard instruks fra Rekdal & Larsson (2005)
   - iv. Tregrenser registreres som åpne vegetasjonstyper (i gruppe 1, 2, 3, 9 eller 12)
   - v. Skoggrenser registreres som skogdefinerte typer (i gruppe 4, 6, 7 eller 8)

j. **NiN-typer:** Inger skal i tillegg registrere NiN-typer fra 1:5.000 målestokkområdet.
   - i. Vi kan diskutere i felt hvilke eventuelle uLKM'er og variabler som kan registreres ved henholdsvis tregrensa og skoggrensa

k. Ta **foto av tre med GPS**. Foto taes fra siden, ikke ovenfra eller nedenfra. Ta foto slik at lokaltopografi og vegetasjon blir tydelig i foto. Ikke stå for langt unna treet ved tregrenser, men ha større avstand ved skog, slik at hele øvre skogteigen kommer fram.

l. **Utvikling:** Registrer om populasjon er i:
   - i. Framgang (+): mange nye saplings (over 15 cm) på vei opp i umiddelbar nærhet eller over dagens grense. Årets nye individer teller ikke (germlings), og heller ikke individer under 15 cm høyde (seedlings). Disse kan ikke registreres systematisk i denne fasen. Nye individer bør være minst 15 cm høye (dvs saplings). Rotskudd fra det målte individet teller ikke, med mindre de er i ferd med å etablere seg som nye trær litt unna mor-individet.
   - ii. Tilbakegang (-): Bestand bestående av bare gamle trær, ingen rekruttering i umiddelbar nærhet. Tydelig tegn til sykdom, alderdom, skader, toppbrekk, døde trær på bakken, naturlige stubber m.m. Midlertidige skader gir ikke tilbakegang, men varig svekking av individ gir tilbakegang (tenk målerangrep, rustsopp m.m.)
   - iii. Stillstand (0): ingen nye individer på vei opp i umiddelbar nærhet, men for øvrig friske og sunne trær uten synlige tegn til skader, sykdom m.m.

m. **Alder:** Anslå treets alder subjektivt i 4 klasser etter beste evne (bruk trehøyde, diameter, barkstruktur, kronestruktur, forgreining m.m., men **ikke** bor for telling av vekstringer uten at dette er nødvendig for å endre tidligere høyde. Minimer bruken av trebor):
   - i. < 25 år
   - ii. 25 – 50 år
   - iii. 50 – 100 år
   - iv. > 100 år

n. Kommentarer:

i. Tydelig og omfattende beiting på øvre individer noteres. Legg særlig merke til sau og elg. Normal småbeiting kan tas for gitt og skal ikke registreres.

ii. Tydelig og omfattende soppangrep (rustsopper) og bjørkemålerangrep noteres (skill tidligere målerangrep fra dagens). Normale småskader kan tas for gitt og skal ikke registreres.

iii. Dersom lokaliteten er usikker m.h.t. tidligere registrering, skal dette registreres.

Normale definisjoner ved tregrensa / skoggrensa

- **Germlings:** årets nye spirer – dvs årets nye etableringsforsøk. Ikke mulig å observere systematisk i vår tilnærming. Alt fra 0 til 15 cm store, normalt mindre ved tregrensen.
- **Seedlings:** de første åra rett etter etablering. Normalt ikke mulig å observere systematisk i vår tilnærming. Som oftest registrert som individer opp til 15 cm høye.
- **Saplings:** buskforma individer over 15 cm, men under 2.5 meter (som oftest 3 eller 3.5 meter). Holder ikke definisjonen av å være et tre (se over). Som oftest settes et krav om at hovedstamme skal være under 10 cm diameter i brysthøyde, men dette er for strengt for fjellbjørk i henhold til Resvoll-Holmsen, Ve og Aas sin definisjon. Jeg har brukt opp til 5 cm diameter i brysthøyde.
- **Trees:** se definisjon over. Bør normalt ha >5 cm diameter i brysthøyde (dvs stiv stamme i brysthøyde), være > 2.5 m høyt, være rimelig rettvokst, være en-stammet eller med en klar sentral-stamme, ha en mer eller mindre etablert og tydelig krone, mangle tette smågreiner på stammen, mangle den lange topp-pisken osv osv

Registreringer av skoggrense

Alt det som registreres for trær skal også registreres for skogen. Alle tre-variablene registreres for det øverste treet i populasjonen.

Vegetasjonstypene og variablene registreres som dominerende for de 5-10 øverste trærne. Dersom det varierer, så bruk vegetasjonstypen ved det øverste treet. Det er også her det vurderes om populasjonen er i framgang, stillstand eller tilbakegang.

Vær oppmerksomme på skogens omtrentlige alder.

Hellingsretning

Både Resvoll-Holmsen, Aas og Ve har lest inn lokalitetenes hellingsretning, og det har de fleste andre som har gjennomført slike målinger også gjort. Dette skyldes antakelsen om at hellingsretning er viktig for tre- og skoggrensenes høyde. Jeg har fortsatt denne registreringen, men ikke registrert hvor bratt hellingen er. Bratthet vil avleses med hjelp av GIS fra høydemodeller i etterkant. Bratthet og hellingsretning kan kombineres til eksposisjon i GIS.

Alle, inkludert jeg, har delt hellingsretning inn i 8 klasser – de eksakte hellingsretningene avleder vi fra GIS i etterkant, slik at variabelen blir kontinuerlig:

Kategori	Fra	Til	Senter
Nord	337.5	22.5	360 / 0
Nord-øst	22.5	67.5	45
Øst	67.5	112.5	90
Sør-øst	112.5	157.5	135
Sør	157.5	202.5	180
Sør-vest	202.5	247.5	225
Vest	247.5	292.5	270
Nord-vest	292.5	337.5	315

Småtopografiske variasjoner teller ikke – det er dominerende hellingsretning som skal registreres. Trøbbelet består i hva småtopografisk variasjon er – den har særdeles mange former – og det går ikke an å beskrive alle. Her er noen utfordringer:

- I nederoderte bekkedaler er dette vanskelig. Nederoderte bekkedaler med tydelig hellingspåvirkning gir opphav til endringer i hellingsretning.
- I nedløpende slukeskere, morenerygger og berghammere er dette også vanskelig. Blir disse store og gir tydelig opphav til endrede vekstforhold for trærne, så skal hellingsretning registreres der treet står.
- Små topografiske forsenkninger som gir lokal leside og jordfuktighet, og hvor trærne alltid står rotfesta i nedkant av forsenkningen. Disse følger ofte normal hellingsretning, men kan avvike

Praktiske råd

- Ta alltid back-up av GPS, helst som avskrifter direkte i felt, og som avskrifter på kvelden. Det er fort gjort å miste GPS'en, og da må alle registreringer være sikret med back-up.
- Last opp foto fra kamera ofte. Det er fort gjort å miste kamera også.
- Legg alltid inn bilen som waypoint i GPS, og track hele tiden. Dette er viktig i tilfelle det blir tåke, og veien hjem er bratt. Da kan du følge ditt eget spor (track) tilbake med GPS'en. Ha alltid med ett ekstra sett med batterier til GPS.
- La GPS stå på hele tiden fra du kjører eller går fra telt el. hytte. Presisjonen øker når GPS står på hele tiden. Ved foto, må du vente til GPS-koordinater er inne på kamera, og dette tar noe tid. Mitt kamera angir GPS presisjon kontinuerlig, slik at jeg ser når jeg tar foto med gode koordinater. Ikke alle kameraer har dette, og da bør du skru på kamera i det du kommer fram, gjøre registreringene, og så ta foto. Da er GPS i kamera ok.
- Ha alltid noe ekstra mat og drikke liggende i bilen, samt tørre klær og ekstra sko m.m. Jeg pleier å ha en pose med epler i bilen hele tiden, samt ei full vannflaske. Ikke fyll vann fra bekker i områder med mye sau eller død lemen, og ikke fra breelver (grått vann).
- Det er særdeles sjelden at den raskeste veien mellom to punkter er den rette linje. Prøv å følge stier og veier fram til du er i nærheten av dit du skal, før du bykser ut av stien.
- Hold høyden mellom de ulike trærne. Jeg pleier å kartlegge tregrenser innover, og skoggrenser tilbake, så blir det mindre opp-og-ned gange.
- Det er utfordrende å finne de øverste uteliggerne av trær. Bruk kikkert. Uteliggerne av tregrensa kan ligge et par hundre meter høyere enn skoggrensen. Spesielt vanskelig kan dette være i nesten flatt terreng. Da kan tregrensa ligge flere kilometer unna skoggrensa!
- Snakk med lokalbefolkninga om følgende:
    - Gamle stier og veier opp til fjells, dersom terrenget er krevende
    - Når setra og beitinga opphørte dersom lokalitet er nær setrer
    - Hvor mye sau (beitedyr) som går i fjellområdet hvor tre- og skoggrenser skal registreres
    - Hvilke områder som var avskoget tidligere, og når gjengroinga startet
    - Bygdelitteratur, gamle kart, tidligere registreringer m.mMen, ta alle svar med en forvissning om at «manns minne er kort», og at informasjonen ikke nødvendigvis er gjeldende for akkurat de områdene som Resvoll-Holsem, Ve og Aas gikk i.