Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 10, Issue, 01, pp.63786-63792, January, 2018

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

RECENT TREELINE SHIFT IN THE KEBNEKAISE MOUNTAINS, NORTHERN SWEDEN – A CLIMATE CHANGE CASE

*Leif Kullman

Department of Ecology and Environmental Science, Umeå University, SE 901 87 Umeå, Sweden

ARTICLE INFO

Article History:
Received 15th October, 2017
Received in revised form
20th November, 2017
Accepted 03rd December, 2017
Published online 19th January, 2018

Key words:
Treeline change,
Climate warming,
Swedish Scandes,
Betula pubescens, ssp. *Czerepanovii,*
Sorbus aucuparia,
Populus tremula,
Prunus padus,
Lapland.

ABSTRACT

Elevational treeline change for different subalpine species over the past 100 years was assessed in the Kebnekaise-area of northern Swedish Lapland. The concerned species were mountain birch (*Betula pubescens* ssp. *czerepanovii*), rowan (*Sorbus aucuparia*), aspen (*Populus tremula*) and bird cherry (*Prunus padus*). The methodology relied on older published field measurements, checked for reliability by tree ring analyses, and compared with present-day assessments of uppermost tree growth at the same locations. All species showed various degrees of up shifts. *Betula* and *Sorbus* displayed maximum advances by 200 m in elevation, with smaller displacement for other tree species. A common pattern for all the concerned species was that treeline advance was achieved by phenotypic responses (rapid height growth) of old-established individuals, which had prevailed as krummholz prior to the temperature rise in the 1920s and 1930s. Age structure analyses evidenced a striking correspondence between summer temperature and the initiation of birch stems, which have gradually attained tree stature up to the present day. As a consequence, substantial densification of the upper birch forest took place, although without perceivable advance of the forest-limit. Overall, the results comply in detail with the outcome of analogous studies of the same and other species, further south in the Swedish Scandes. This inter-regional conformity contrasts with earlier claims of differential response between north and south, and support the contention that the ultimate reason is secular climate warming, common for the entire Swedish Scandes. There is little reason (as sometimes claimed) to invoke strictly local factors, e. g. reindeer grazing as superior driver of mountain birch population dynamics at the treeline. The finding that a subalpine clonal population of *Populus tremula* has existed for more than 6500 year, casts some doubt on recent claims that this species has recently expanded its elevational range in these mountains.

Citation: Leif Kullman. 2018. "Recent treeline shift in the kebnekaise mountains, northern sweden – A climate change case", *International Journal of Current Research*, 10, (01), 63786-63792.

INTRODUCTION

The common concern about global climate change and associated ecological and societal consequences (IPCC 2013) suffers from lack of historical perspective. Within the scientific community, great effort is currently allocated to generate predictive vegetation models or scenarios of future climate change and coupled impacts on the physical and living nature (Moen *et al*. 2004; ACIA 2005; Kaplan and New 2006). During the past 100 years or so, global temperatures have risen by about 0.85 °C (IPCC 2013), but disproportionally few studies have focused on firm observational science of changes in nature in response to factual climate change and variability during this period of time (but see e. g. Aas 1969; Kullman 1979, 2002, 2017; Tape *et al*. 2006; Kharuk *et al*. 2009; Aakala *et al*. 2014; Kirdyanov *et al*. 2012).

Corresponding author: **Leif Kullman,**
Department of ecology and Environmental Science, Umeå University, SE 901 87 Umeå, Sweden.

Against this background, alpine treelines and their dynamics, basically conditioned by heat deficiency (Holtmeier 2009; Körner and Paulsen 2004; Kim and Lee 2015), appear as ideal study objects in their roles as "bellwethers" of common biotic changes in northern and high-elevation regions (Smith *et al*. 2009). The elevational treeline dynamics integrates climate-vegetation interactions on scales of decades to centuries and longer (Holtmeier 2009; Harsch *et al*. 2009; Kullman 1979, 2010, 2017). This view has been challenged by age structure analysis by Van Bogaert *et al*. (2011), stressing superior importance of herbivory and only a minor impact of climate change on elevational treeline shifts. However, repeat analysis in the same area, with great care to approximate the germination point, has firmly evidenced the importance of high temperatures during the 20th century and up to the present day, for the instatement of new tree-sized birch stems at the treeline and consequent treeline rise (Kullman 2015a). Accordingly, Lehtonen and Heikkinen (1995) found that climate change is more important than reindeer grazing in this connection.

An interesting aspect of ongoing shifts in the subalpine tree cover concerns the performance of aspen (*Populus tremula*), which is claimed currently to expand its range by establishment of new individuals in the subalpine birch forest. It is stated that aspen, growing in the treeline ecotone, is a new phenomenon of European Subarctic (Van Bogaert *et al*. 2010), a view that needs further inquiry and confirmation.

In the southern Swedish Scandes, centennial treeline change of different tree species has been assessed and quantified for a large number of sites within a an extensive region, heterogeneous with respect to physiography and past human impact (Kullman 1979, 2017; Kullman and Öberg 2009). Maximum advance by 200-225 m in elevation corresponds nicely with summer temperature rise of about 1. 4 °C and a lapse rate of 0. 6 °C per 100 m elevational change (Laaksonen 1976). In perspective of reconstructed postglacial treeline history, this magnitude of secular treeline upshift implies tentatively that modern change may be unique for the past 7000 years (Kullman 2017). The definite and ultimate attribution of current treeline advance to centennial climate change should further gain in credibility if it could be repeated also for different species in more northern parts of the Scandes, with similar secular climate history, but with different conditions with respect to geology, geomorphology and soil properties. Thereby, the possible role of strictly local factors, e. g. highly variable land use history, may be assessed as primary forcings behind changes. That is the background and rationale of the present study, which focuses on treeline change of *Betula pubescens* ssp. *czerepanowii, Sorbus aucuparia, Populus tremula* and *Prunus padus,* in the northern part of the Swedish Scandes at sites with reliable early-20th century treeline records, as a basis for comparison with present-day conditions.

Study Area

The study was carried out in the Kebnekaise area of northern Swedish Lapland (Fig. 1), which contains the highest mountain of the country, Mt. Kebnekaise (2099 m a,s. l.). Investigated localities were on the south-facing flank of Mt. Kebnetjåkka (1531 m a. s. l.) in the valley Láddjuvággi, with its floor around 600 m a. s. l.

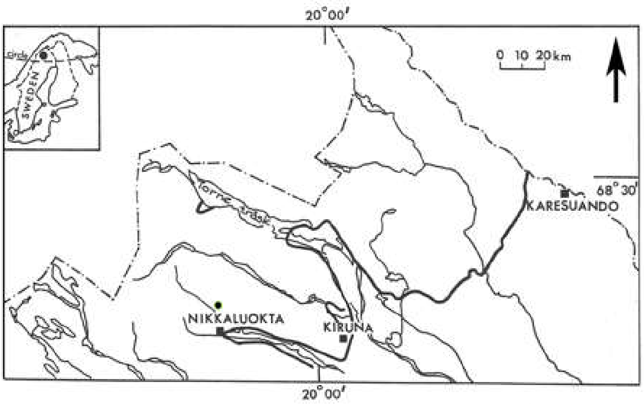

Fig. 1. Map showing the location of the study area (●) and the limit of coniferous forest, mostly pine (solid line)

The area has a rugged alpine geomorphology, with gentle lower slopes strongly dissected byglacifluvial drainage channels and boulder-strewn higher slopes (Fig. 2). The bedrock is predominantly built up of amphibolite and gneiss, which support a rather trivial alpine flora.

The ground cover around the treeline is dominated by fresh and dry dwarf-shrub heaths, extensive *Salix*-thickets, snow bed communities and meadow spots with low herbs. A westwards protruding wedge of mountain birch forest (*Betula pubescens* ssp. czerepanowii) covers the lower slopes of the valley (Fig. 2). Overall, the birch forest contains some subordinate tree species, e. g. *Sorbus aucuparia, Populus tremula* and *Prunus padus*. This forest is predominantly heath-type of a rather moist character in the slopes of Mt. Kebnetjåkka, maintained by melt water from extensive perennial high-elevation snow fields and glaciers. No coniferous trees exist today in the concerned slope of Mt. Kebnetjåkka. *Pinus sylvestris,* prevailing in the lower slopes during the Medieval climate optimum (Kullman 2015b), does not grow within the study area at the present day. The nearest occurrence of pine is a stand in the south-facing slope of Mt. Gármasbákte, 550 m a. s. l., 6 km to the west of the village Nikkaluokta. A small grove of *Picea abies*, with its "roots" in the early-Holocene, exists in the valley Visttásvággi, 490 m a. s. l., 9 km northwest of Nikkaluokta (Kullman and Öberg 2016). A distinct outcrop of mountainous character (Mt. Kaipak, 772 m a. s. l.) stands out on the lower slope of Mt. Kebnetjåkka (Fig. 10). Its south-facing slope supports a fairly rich vascular flora, with some southern affinities, described by Birger (1912).

Fig. 2. Overview of the study area in Láddjuvággi, with the south-facing slope of Mt. Kebnetjåkka to the right. Kebnekaise tourist station in the centre, surrounded by mountain birch forest. 2013-08-11

Kebnekaise tourist station, founded in 1907, is located at the western extent of the valley birch forest, 690 m a. s. l. Apparently, the birch forest was thinned all round here in connection with the building of the station, which was at the former site of a Sami habitation. However, the upper part of the tree line ecotone in these northern mountains bears few signs of older human utilization (cf. Fries 1913; Holmgren and Tjus 1986), except for still ongoing browsing by free-roaming semi-domestic reindeer (*Rangifer tarandus*). The area contains several mountain glaciers, the Holocene history of these is outlined by Karlén (1973). The postglacial arboreal and treeline history of this region is accounted for by Kullman (1999) and Kullman and Öberg (2015), using direct megafossil evidence. The climate of this region has warmed substantially during the past 100 years, as outlined by Figure 8 for the meteorological station Kiruna (442 m a. s. l., 35 km to the east), showing a somewhat oscillatorytrend of +1. 4 °C for the entire period.

Consistent summer warming took place during the first 3-4 decades of the 20th century. An all-time-high was reached in the late 1930s, followed by insignificant cooling or levelling out for some decades. As a consequence perceivable retrogressional impacts on northern ecosystems were recorded (cf. Kullman 1992). A new warming phase is discernible after the year of 2000.

METHODS

Treeline is a central concept in this study and defines as the elevation of the uppermost individual of a certain tree species with a minimum height of 2 m. Early-20th century treeline positions (m a. s. l.) were reconstructed for three specific sites, originally documented by Birger (1912). These data were checked for reliance by coring extant birches 2 m above ground level, within a 200 m wide transect running upslope from the position defined by the early-20th century. The highest positioned birch with 100 rings or more was taken as the treeline in about 1915. In addition some treeline trees of different species were cored at the stem bases, with the purpose to approximate their original time of establishment or possible local presence at the onset of 20th century warming phase, i. e. around 1915. At one site on the south-facing slope of Mt. Kebnetjåkka, the age structure of the uppermost closed birch forest, 715-720 m a. s. l, was assessed (2013) within a plot of 50x 100 m. For each birch taller than 2 m, the highest stem was cored close to or slightly below the ground level. Tree rings were counted in the laboratory under a stereo microscope. Since many individuals were multi-stemmed, with remnant stools of dead and living stems, this procedure does not in all cases truly represent the initial establishment of a specific birch individual. At best, this method gives a reasonable apprehension concerning the onset of accelerated height growth and progress towards tree-size. In fact, multi-stemmed "normal-looking" mountain birches may have endured as low-growing krummholz for centuries or even millennia (Öberg and Kullman 2011), which complicates the interpretation of age-structure analyses in terms of individual establishment histories. Radiocarbon dating of a subfossil woody remnant (*Populus tremula*) was conducted by Beta-Analytic Inc., Miami, USA. Original radicarbon date was converted to calendar years (cal. yr BP), with present = AD 1950, based on IntCal 13 (Reimer *et al*. 2013). For the sake of simplicity, the date is cited in "intercept" form.

RESULTS

Secular treeline change of different species was assessed at three separate sites (I-III), in the form of elevational transects, running between the old and the present treeline position.

Site I

This site is about 2 km west of Kebnekaise Tourist Station. By combining data given by Birger (1912) with present-day tree ring counts of extant trees, the treeline position at 1915 was estimated to 710 m a. s. l. (Fig. 3). Today, the uppermost tree-sized birch is located at 910 m a. s. l. (Fig. 3). Thus, treeline rise by 200 m in elevation can be inferred for the past 100 years. One stem at the new and higher treeline displayed 105 tree rings at the base, thereby sustaining establishment prior to the 20th century phase of climate warming. Scattered specimens of tree-sized rowan (*Sorbus aucuparia*) appear within this transect on the south-facing slope of Mt.

Fig. 3. Site I. Left. The old treeline of *Betula pubescens* ssp. *czerepanovii*, 710 m a.s.l. 2013-08-11.Right. The new and advanced treeline, 910 m a.sl. 2013-08-12

Kebnetjåkka. The highest present-day tree-line is at 890 m a. s. l. (Fig. 4), which is about 200 m higher than the treeline position reported by Birger (1912), who also observed low-growing bushes high above the contemporary treeline. The largest stem displays 136 tree rings at the base. Thus, current treeline specimens became established prior to the 20th century.

Fig. 4. Site I. The treeline of *Sorbus aucuparia*, 890 m a.s.l., representing secular treeline rise by 200 m. 2013-08-12

Site II

The concerned transect is about 2 km east of the tourist station. By the same procedure as described for Site I and complemented by data given by Fries (1913), the treeline around 1915 is inferred to have been 730 m a. s. l. (Fig. 5), which is to be compared with today´s 870 m a. s. l., represented by a specimen with 140 tree rings at the stem/ground surface interface. This means that the treeline has advanced by 140 m over the past 100 years.

Fig. 5. Site II. Upper. Birch representing the old treeline, 730 m a.s.l. 2008-08-13. Lower. The new and advanced treeline, 870 m a.s.l. 2013-08-13

The present-day static age structure of the uppermost closed birch forest was assessed within a plot at 715-720 m a. s. l. (Fig. 6). The result is given in Figure 7. It appears that some birches grew here by the 1880s. Thereafter instatement of new tree-sized birches increased to reach a peak in the 1930s, followed by a gradual decine to a nadir during the 1980s. Thereafter an upsurge of new fast-growing stems has occurred. This emergent pattern nicely compares with the corresponding regional summer temperature record (Fig. 8).

Fig. 6. View from the west of the sample plot where the age-structure analysis of the upper birch forest was carried out, 715 m a.s.l. 2013-08-14

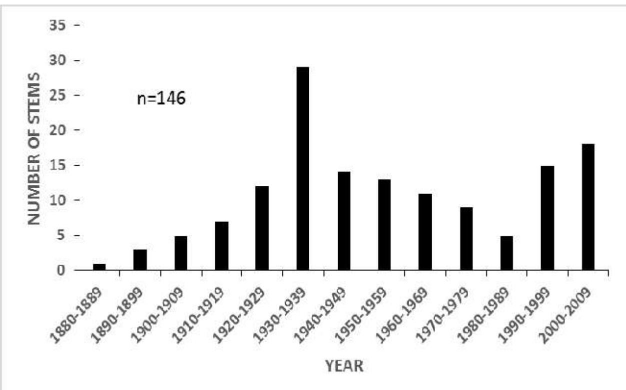

Fig. 7. Age-structure of the sampled birch population, 715-720 m a.s.l.

An interesting clonal stand of aspen (*Populus tremula*) was located and investigated in the south-facing slope of Site II, 795 m a. s. l.

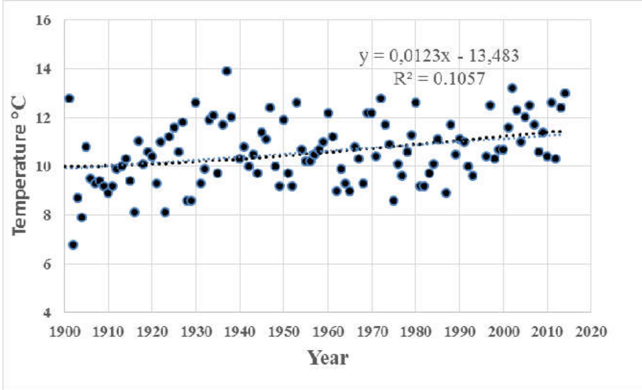

Fig. 8. Annual records of summer temperature (JJA) for the period 1901-2015) at the meteorological station Kiruna

The general character was an assemblage of more than 50 upturning shoots (0. 3-0. 5 m high), distributed in more or less circle-form around a virtually empty central space (Fig. 9). Many were interconnected by root suckers, indicating that they all belonged to the same genetical individual, which appears to have spread centrifugally. Right in the centre of this formation, dry wood fragments were partly exposed slightly above the ground surface, which prompted digging out of these pieces. Thereby distinct bark and wood fragments emerged, confidently confirmed as aspen from their characteristic bark structure (Fig. 9). Reasonably, they originate from an individual, higher and stouter than the current tiny shoots. These remnants were radiocarbon-dated to 6650 cal. yr BP (Beta-474253), indicating exceptional old age of this clonal aspen.

Fig. 9. Upper. Overview of the clone of *Populus tremula* , growing on the south-facing slope of Mt. Kebnetjåkka, 795 m a.s.l. 2013-08-12. Lower. Radiocarbon-dated megafossil remnants unearthed in the centre of the clone depicted to the left. 2013-08-13

Fig. 10. South-east facing slope of Site III, Mt. Kaipak, with its peak plateau at 773 m a.s.l. 2013-08-12

Fig. 11. The birch treeline on the peak plateau of Mt. Kaipak (Site III), 773 m a.s.l. 2013-08-14

Fig.12. Site III. The present-day treeline of *Sorbus aucuparia*, 765 m a.s.l., which is about 70 m higher than the treeline position prevailing by the early 20th century. 2013-08-14

Site III

This site comprises the south-facing slope and peak plateau of Mt. Kaipak, 773 m a. s. l. (Fig. 10). Between 1915 and 2013, the treeline of mountain birch advanced to 773 m a. s. l. (Fig. 11), right at the top of the mountain. This means a rise by 45 m in elevation. According to Birger (1912), a few creeping, prostrate birches grew at the wind-exposed top plateau by the early-20th century. Presence of these at about that time and earlier is confirmed by tree ring counting maximum after yielding 149 tree rings at the stem base. The north facing slope of Mt. Kaipak, was found to be totally devoid of trees around 1915, which was judged to be due to strong local winds and delayed snow melt (Birger 1912). Overall, the same impression is valid today, although a solitary tree birch (2. 3 m high) prevails at 755 m a. s. l. Several prolificly growing individuals of rowan (*Sorbus aucuparia*) prevail in the south-facing slope. By 2013, the uppermost tree-sized specimen was found at 765 m a. s. l., as a tiny specimen, obviously browsed by reindeer (Fig. 12).

Fig. 13. Site III. The new and raised (c. 20 m) treeline of *Populus tremula*, 725 m a.s.l. 2013-08-13

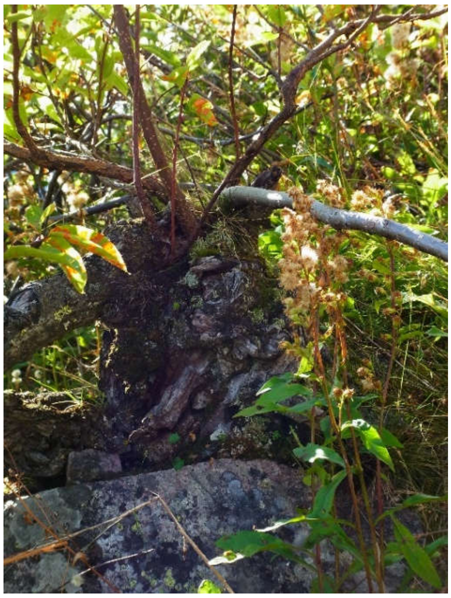

Fig. 14. Site III. The present-day treeline of *Prunus padus*, 725 m a.s.l., is 45 m higher that estimated by Birger (1912). The basal part is remarkably stout and probably represents an individual age, indicative of presence prior to the early 20th century.2013-08-13

This treeline position is about 70 m higher than reported by Birger (1912). At the stem base, one stem contained 114 rings, although due to rot, a higher age seems plausible. Birger (1912) recorded the upper limit of aspen (*Populustremula*) at 708 m a.s.l., as 0.5 m high creeping bushes, implicitly indicative of a treeline lower than that.At the present day, the treeline of aspen has advanced to 725 m a.s.l. (Fig. 13). This stem belongs to an extensive clone of low-growing shoots. Obviously, the local treeline has advanced by more than 20 m since the early 20th century.

Birger (1912) noted creeping specimens of *Prunus padus* in the lower south-facing slope of Mt Kaipak, 682 m a. s. l. Today, *Prunus* grows in low tree-size form at an elevation of 725 m a. s. l. The stools have a thickness, which makes one assume that this species was present as a prostrate shrub at today´s treeline position more than 100 years ago (Fig. 14), but was obviously overlooked by Birger.

DISCUSSION

Overall, the results of this study, obtained by direct observation for different species, signal general subalpine tree growth progression during the past 100 years, coincident with recorded air temperature rise. Maximum treeline upshift of 200 m in elevation by *Betula pubescens*ssp. *czerepanovii* and *Sorbus aucuparia*, is virtually identical with the largest treeline advances further north (Kullman 2015) and further south (Kullman and Öberg 2009; Kullman 2017). This similarity strongly argues for the action of a common inter-regional driver, e. g. climate change. Moreover, treeline rise by about 200 m is what should be expected from recorded secular temperature rise of 1. 4 °C and a summer temperature lapse rate of 0. 6 °C per 100 m elevation (Laaksonen 1976; Holmgren and Tjus 1986). In this connection, it should be noted that Dalen and Hofgaard (2005) and Hofgaard *et al*. (2009) suggested different responses and environmental controls of secular birch treeline population dynamics, between the northern and southern Scandes. This pattern is not consistent with the results of the present study. The contention of temperature as the principal agent behind treeline advancement gains further in credibility from the age-structure analysis of the uppermost birch forest. A striking covariance between instatement of new tree-sized stems and summer air temperature is evident. This relationship contrasts sharply with that of Van Bogaert *et al*. (2011), concluding that the population dynamics of *Betula* was principally driven by reindeer grazing rather than climate change. Possibly, differences in the accuracy of the dating procedures explain the widely different results for virtually the same population of subalpine birches (Kullman 2015a).

The magnitude of birch treeline upshift differed between the investigated sites in the landscape. This pattern compares with experiences from other dynamic treeline studies in the Swedish Scandes, covering the virtually the same period of time (Kullman 1979; Kullman and Öberg 2009). Locally different treeline responses to a common climate signal indicate that only at particularly types of habitats has the birch treeline a common and straightforward relationship with temperature changes. The complex geomorphology/wind/snow distribution pattern may locally modulate and constrain treeline and treeline rise to a lower elevation than would have been the case under more congenial conditions. The age structure analysis indicates substantial densification and infilling of gaps in the upper birch forest during the past 100 years, but little advance of the upper limit of closed birch forest. This state of affairs compares well with experiences from other parts of the Swedish Scandes (Kullman and Öberg 2009; Kullman 2010, 2015a). Concerning the mechanism of treeline rise, *Betula, Sorbus* and *Populus* responded with advanced height growth of old-established krummholz individuals, i. e. phenotypic plasticity, maintained by means of climate warming.

The role of vegetative reproduction in connection with recent treeline dynamics is emphatically maintained by the performance of clonal *Populus tremula*, as shrubby clones within the treeline ecotone, proved to have existed for more than 6500 years. Thereby, *Populus* mimics the performance of *Betula pubescens, Alnus incana* and *Picea abies* (Öberg and Kullman 2011, 2012; Kullman 2013). The finding of the above-mentioned multi-millennial *Populus* clone in the treeline ecotone casts some doubt on recent claims that *Populus* has drastically expanded its altitudinal range in the mountains by increased sexual regeneration. Growth of this species in the treeline ecotone is suggested to be a new phenomenon to the European Subarctic (Van Bogaert *et al*. 2010). This option is discarded by the present study. More likely, old-growth clones haveresponded with rapid height growth to modern warming and thereby have become more prominent in the birch forest matrix, particularly during the autumn (cf. Kullman, 2015a). Such a response is particularly likely as warm and dry conditions are found to promote asexual regeneration of the genus*Populus* in the treeline ecotone (Elliott and Baker 2004). Analogous, but undated occurencies of *Populus tremula* are reported from other parts of the Scandes (e. g. Smith 1920; Ve 1940; Selander 1950; Kilander 1955; Wistrand 1981). In most cases, these authors discard the possibility of recent dispersal to the favor of initial establishment during the climate optimum of the early Holocene. This option gains strong support from the present study.

Acknowledgements

This study was defrayed by a grant from the Gustafsson Foundation. Dr. Lisa Öberg is thanked for competent and constructive comments on an earlier version of the manuscript.

REFERENCES

Aakala, T., Hari, P., Dengel, S., Newberry, S. L,Mizunuma, T. and Grace, J. 2014. A prominent stepwise advance of the tree line in north-east Finland. *Journal of Ecology* 102, 1582-1591.

ACIA 2005. Arctic climate impact assessment. Cambridge University Press, Cambridge.

Birger, S. 1912. Kebnekaisetraktens flora. Ett bidrag till kännedomen om floran i öfversta delen afKalixälfens dal. Svensk Botanisk Tidskrift 6, 195-217.

Dalen, L. and Hofgaard, A. 2005. Differential regional treeline dynamics in the Scandes Mountains. Arctic, Antarctic, and Alpine research 37, 284-296.

Elliott, G. P. and Baker, W. L. 2004. Quaking aspen (*Populustremuloides* Michx.) at treeline: a century of change in San Juan Mountains, Colorado, USA. *Journal of Biogeography,* 31, 733-745.

Fries, T. C. E. 1913. Botanische Untersuchungen im nördlichsten Schweden. Almqvist and Wiksells, Uppsala.

Harsch, M. A., Hulme, P. E., McGlone, M. and Duncan, R. P. 2009. Are treelines advancing? A global meta-analysis of treeline response to climate warming. *Ecology Letters* 12, 1040-1049.

Hofgaard, A., Dalen, L. and Hytteborn, H. 2009. Tree recruitment above the treeline and potential for climate-driven treeline change. Journal of Vegetation Science 20, 1133-1144.

Holmgren, B. and Tjus, M. 1996. Summer air temperatures and treeline dynamics at Abisko. *Ecological Bulletins* 45, 159-169.

Holtmeier, F. -K. 2009. Mountain timberlines: ecology, patchiness, and dynamics. Springer, Dordrecht.

IPCC 2013. Climate change 2013. Cambridge University Press, Cambridge and New York.

Kaplan, J. and New, M. 2006. Arctic climate change with a 2 °C global warming; Timing, climate patterns and vegetation change. *Climatic Change* 79, 213-224.

Karlén, W. 1973. Holocene glacier and climatic variations, Kebnekaise Mountains, Swedish Lapland. *Geografiska Annaler* 55A, 29-63.

Kharuk, V. I., Ranson, K. J., Im, S. T. and Dvinskaya, M. L. 2009. Response of *Pinus sibirica* and *Larix sibirica* to climate change in southern Siberia alpine forest-tundra. *Scandinavian Journal of Forest Research* 24, 130-139.

Kilander, S. 1955. Kärlväxternas övre gränser på fjäll I sydvästra Jämtland samt angränsande delar av Härjedalen och Norge. *Acta Phytogeographica Suecica* 35, 1-198.

Kim, J. -W. and Lee, J. S. 2015. Dynamics of alpine treelines: positive feedbacks and global, regional and local controls. *Journal of Ecology and Environment* 38, 1-14.

Kirdyanov, A. V., Hagedorn, F., Knorre, A. A., Fedotova, E. V., Vaganov, E. A., Naurzbaev, M. M. and Rigling, A. 2012. 20th century tree-line advance and vegetation changes along an altitudinal transect in the Putorana Mountains, Northern Siberia. Boreas 41, 56-67.

Körner, C. and Paulsen, J. 2004. A world-wide study of high altitude treeline temperatures. *Journal of Biogeography* 31, 713-732.

Kullman, L. 1979. Change and stability in the altitude of the birch tree-limit in the southern Swedish Scandes 1915-1975. *Acta Phytogeographica Suecica* 65, 1-121.

Kullman, L. 1992. High latitude environments and environmental change. *Progress in Physical Geography* 16(4), 478-488.

Kullman, L. 1999. Early Holocene tree growth at a high elevation site in the northernmost Scandes of Sweden (Lapland): a palaeobiogeographical case study based on megafossil evidence. Geografiska Annaler 81A, 63-74.

Kullman, L. 2002. Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. J*ournal of Ecology* 90, 68-77.

Kullman, L. 2010.One century of treeline change and stability-experiences from the Swedish Scandes. Landscape Online 17, 1-31.

Kullman, L 2013. Ecological tree line history and palaeoclimate-review of megafossil evidence from the Swedish Scandes. Boreas 42, 555-567.

Kullman, L. 2015a. Recent and past trees and climates at the arctic/alpine margin in Swedish Lapland: An Abisko case study review. *Journal of Biodiversity Management and Forestry* 2015, 4. 4.

Kullman, L. 2015b. Higher-than-present Medieval pine (*Pinus sylvestris*) treeline along the Swedish Scandes. Landscape Online 42, 1-14.

Kullman, L. 2016. Climate change and primary birch forest (*Betula pubescens* ssp. *czerepanovii*) succession in the treeline ecotone of the Swedish Scandes. International Journal of Research in Geography 2(2), 36-47.

Kullman, L. 2017. Pine (*Pinus sylvestris*) treeline performance in the southern Swedish Scandes since the early 20thcentury. *Acta Phytogeographica Suecica* 90, 1-46. .

Kullman, L. and Öberg, L. 2009. Post-Little Ice Age tree line rise and climate warming in the Swedish Scandes. A landscape ecological perspective. *Journal of Ecology* 97, 415-429.

Kullman, L. and Öberg, L. 2015. New aspects of high-mountain palaeobiogeography: A synthesis of data from forefields of receding glaciers and ice patches in the Tärna and Kebnekaise Mountains, Swedish Lapland. Arctic 68, 141-152.

Kullman, L. and Öberg, L. 2016. Historical performance of an outlying subarctic spruce (*Picea abies*) population in northern Swedish Lapland. *International Journal of Information Research and Review* 3 (2), 1863-1872.

Laaksonen, K. 1976. The dependence of mean air temperatures upon latitude and altitude in Fennoscandia. *Annales Academiae Scientiarum Fennicae* A3 199, 1-19.

Lehtonen, J. and Heikkinen, R. K. 1995. On the recovery of mountain birch *Epirrita* damage damage in Finnish Lapland, with a particular emphasis on reindeer grazing. *Écoscience* 2, 349-356.

Moen, J., Aune, K., Edenius, L. and Angerbjörn, A. 2004. Potential effects of climate change on treeline position in the Swedish Mountains. Ecology and Society 16, 1-10

Öberg, L and Kullman, L. 2011. Ancient subalpine clonal spruces (*Picea abies*): sources of postglacial vegetation history in the Swedish Scandes. Arctic 64, 183-196

Öberg, L. and Kullman, L. 2012. Contrasting short-term performance of mountain birch (*Betula pubescens*ssp. *czerepanovii*) along an altitudinal continentality-maritimity gradient in the Swedish Scandes. Fennia 190, 19-40.

Reimer, P. J., Bard, E., Bayliss, A. *et al*. 2013. IntCal 13 and Marine 13 radiocarbon calibration curves 0- 50,000 year scale BP. *Radiocarbon* 55 (4), 1869-1887.

Selander, S. 1950. Floristic phytogeography of south-western Lule Lappmark (Swedish Lapland). *Acta Phytographica Suecica* 27, 1-200.

Smith, H. 1920. Vegetationen och dess utvecklingshistoria i det centralsvenska högfjällområdet. Almqvist and Wiksells, Uppsala.

Smith, W. K., Germino, M. J., Johnsen, D. N. and Reinhardt, K. 2009. The altitude of alpine treelines a bellwether of climate change effects. Botanical Review 75, 163-190.

Tape, K., Sturm, M. and Racine, C. 2006. The evidence for shrub expansion in northern Alaska and the Pan-Arctic. *Global Change Biology* 12, 686-702.

Ve, S. 1940. Skog og treslag i Indre Sogn fra Lærdaltil Fillefjell. Meddelelser fra Vestlandets Forstlige Forsøksstation 23, 1-224.

Van Bogaert, R., Haneca, K. and Hoogesteger, J., Jonasson, C., De Dapper, M. and Callaghan, T. V. 2011. A century of tree line changes in sub-Arctic Sweden shows local and regional variability and only minor influence on 20th century climate warming. *Journal of Biogeography* 38, 907-921.

Van Bogaert, R., Jonasson, C., De Dapper, M. and Callaghan, T. V. 2010. Range expansion of thermophilic aspen (*Populus tremula* L.) in the Swedish Subarctic. Arctic, Antarctic, and Alpine Research 42, 362-375.

Wistrand, G. 1981. Bidrag till Pite lappmarks växtgeografi. Växtekologiska Studier 14, 1-99.

****