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On a lichen collection from the summit of Glittertinden (Norway, Oppland / Innlandet) – baseline data for a high mountain top

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Abstract. A set of 44 taxa of lichenized fungi and 5 species of lichenicolous fungi was gathered in 1984 in the summit area of the mountain Glittertinden, the second highest mountain in Scandinavia. The sampled species include several high alpine taxa known as members of well-established alpine lichen communities but only few pioneer species indicating that the investigated rocks had already been ice-free for a long time. The local flora is compared to that reported from Scandinavia's highest mountain, Galdhøpiggen, by the late Gunnar Degelius in the 1940s. With the continuing melting of the local ice cap on the summit of Glittertinden, biota will face profoundly changed environmental conditions with much additional substrate ready to be colonized in the near future.

Key words: biodiversity, climate change, global warming, high-alpine/nival vegetation belt, Jotunheimen, lichenized fungi, lichenicolous fungi, Scandinavia

Introduction

Changes in species diversity on mountain tops due to global warming is also a topic in Scandinavia, not only with emphasis on vascular plants (e.g., Klanderud & Birks 2003; Odland et al. 2010; Grindrud 2019), but also for lichenized fungi (e.g., Michelsen et al. 2011). These changes do not always go into the same direction. Whereas vascular plants often profit from raising temperatures affecting the belt close to their upper growth limit (e.g., Kullman 2002), less competitive terricolous lichens may suffer severely by conditions favoring shrubs, grasses and herbs (e.g., Klanderud & Totland 2005, 2008; Klanderud 2008; Alatalo et al. 2017; Vanneste et al. 2017). Changes in saxicolous communities may take place too, although they have rarely been documented so far.

As the summit ice cap of the Glittertind (Note: -en as suffix is the definite article in Norwegian, therefore the Glittertind or Glittertinden) is melting and a colonization of the boulders of the summit blockfield by lichens is likely to start in the near future, it may be of interest to document which lichen species were already on that mountain top at times when the summit ice cap was still prominent and the only places where lichens could grow were situated in a narrow rim near the upper edge of the N-facing rock walls and some low outcrops somewhat W of the summit.

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The Scandes and the Jotunheimen area

Mountain Glittertinden is situated in the southern part of the Scandinavian Mountains or Scandes, in a mountain region named Jotunheimen where the highest summits of Norway and even Scandinavia are concentrated (Reusch 1903; Machaček 1908; Strøm 1948; Lidmar-Bergström et al. 2000, 2013; Grabherr et al. 2003; Dierßen 2004; Ebert 2009).

Jotunheimen covers an area of approximately 3,500 km^2 and attained its arctic-alpine landscape character with its numerous high peaks, plateaus and trough valleys, glaciers and permanent snowfields, moraines, screes and blockfields during the Quaternary, mainly in the Weichselian Late Glacial (LG) with the lowering and melting of the Fennoscandian ice sheet and a simultaneous uplift of the terrain (Vorren & Mangerud 2008; Fredin et al. 2013).

In Norway, there are 3 mountains higher than 2,400 m and some 20 mountains higher than 2,300 m, all of them situated in the wider Jotunheimen area including Hurrungane. (The 23 highest mountains in Norway are all located in Jotunheimen and Hurrungane). The spectacular landscape of Jotunheimen was first explored to some extent by B.M. Keilhau and C.P.B. Boeck as late as 1820, who approached the mountains from the east side (compare Hestmark 2020). The first documented access of the summit of Glittertinden dates back to the mid-19th century (14 VII 1841 by Harald Nicolai Storm Wergeland and Hans Sletten, fide Burchardt 1948).

For a long time, Glittertinden, situated in the NE of Jotunheimen, was regarded as the highest peak in Norway and even Scandinavia. However, there is hardly another mountain in Europe the height of which has been corrected so often. The reason is the peculiar geomorphology of the summit, namely the presence of an ice cap. Early measurements of the mountain's height were made on the top of this ice cap and varied with the thickness of the ice. Since the second half of the 20th century with the onset of more rapid global warming, the ice cap became considerably thinner over the years by partial melting in the summer months and the height was corrected in a number of steps. In various historical encyclopedias and maps, the author noticed summit heights starting from 2,481 m (e.g., Jotunheimen 1: 250 000, Kristiania 1917), to 2,474, 2,472, 2,470 (e.g., Jotunheimen 1: 250 000, ?Oslo 1951/1960), 2,465, 2,464, and 2,460 m s. m. Apart from changes in reference heights, these changes are mainly caused by the ongoing thinning of the ice cap on the summit. Currently, the ice cap on the Glittertind has almost completely melted and the most recent and final height correction was made to 2,452 m elev., which is the elevation of the highest point of rock beneath resp. at the upper = northern edge of the summit glacier cap, measured by L.M. Andreassen and coworkers in 2020 (see Noreng Trøn & Lusæter 2020; Melvold & Andreassen 2021). This measurement makes Glittertinden the second highest mountain in Norway (in Scandinavia) behind Galdhøpiggen (2,469 m), a mountain situated some 13 km WSW on the opposite western side of Visdalen (e.g., http://www.nfo2000m.no/). Interestingly, Jørgensen (1932) had already given the height of Glittertinden with "modern" 2,451 m s. m., a figure he had received from Norges Geografiske Opmåling who was preparing new maps for the area.

Geomorphology of the upper part of Glittertinden and our study sites

The shape of the mountain is characterized by gently to moderately inclined south-eastern and south-western slopes. The southern slope of Glittertinden, equally moderately inclined in the uppermost part, is getting abruptly steeper further down (ice-free, but with long lying snow fields) and shows there the shape of a small cirque descending towards the Steinbuvatnet cirque lakes. The northern slope of Glittertinden descending towards the two tongues of the Grotbreen glacier (recently also spelled Grotbrean) is extremely steep, partly even vertical. The summit of Glittertinden is connected to a somewhat lower ridge with a slight incline orientated W to E (Fig. 1).

An ice cap, gently inclined on all sides except the very steep north side, covers the summit area (Fig. 2). Its shape is fairly asymmetric, larger on the E-side, due to frequent local snow transported by westerly winds. The formation of such an ice- or firn cap needs two preconditions: gentle uppermost slopes ("rounded summits") and an elevation high enough to be above the climatic snowline. This summit type is known to occur both in the Scandes in Southern Norway and the European Alps with Mt. Blanc being the most prominent example (Manley 1955). Ice- or firn-caps on lower summits may have existed during the Last Glacial Maximum (LGM) and the early, but they have already melted off either during the Bølling–Allerød interstadial or in the early Holocene when temperatures rose rather abruptly to almost recent levels (Mangerud et al. 2016; Naughton et al. 2023).

Below the ice the summit area, the little inclined ridge towards the W and the uppermost part of the markedly inclined ridge towards the E are covered, as far as

Figure 1. Glittertind: Rock walls exposed to the N and summit from the west in the background; in the far back the connection between Gråsubreen and Grotbreen at that time still prominent. Photo taken from approximately the place where the trail coming up from Steindalen reaches the rim and the summit becomes visible for the first time (photo J. Hafellner, 23 VIII 1984).

Figure 2. Glittertind in summer 1984: strongly asymmetric summit with gentle western and southern slope, a very steep N-facing rock wall, and the author after the collecting stop on the summit and now heading towards Visdalen. The lichens reported here have been collected on outcrops on the upper rim of the rock wall. Note the partly ice-free blockfield in the foreground. (photo A. Ochsenhofer, 23 VIII 1984).

discernable at the edge of the ice cap, by an autochthonous blockfield (Nesje et al. 1988; Nesje & Dahl 1990; Winkler et al. 2021; Matthews & Nesje 2023). In 1984, this blockfield was still mostly buried and preserved by the cold-based ice cap (Fig. 2). In recent years, the ice cap diminished considerably both in size and thickness (e.g., Melvold & Andreassen 2021). Blockfields on summits and ridges at high elevation are regarded to be indicators of periglacial conditions during the period of their formation and the lack of displacement in the time after (Rea 2013; Ballantyne 2018; Winkler et al. 2021). They are the product of weathering of bedrock and frost sorting under cold conditions during the Quaternary leaving a regolith cover (Ballantyne 2010).

On the other hand, the summit area lacks other glacial landforms (Sollid & Sørbel 1994) including those taken as indicators of the presence of moving glacier ice in the past, such as polished rock surfaces or rock striae (also own observations in the field). These landscape features fit the hypothesis that, during the LGM, eastern Jotunheimen with the Gittertind was situated close to the ice divide, a zone with little ice movement (Vorren & Mangrud 2008).

Similar to other high mountains in Jotunheimen, the Glittertind down to approximately 2,000 m s. m. is in the zone of continuous mountain permafrost (King 1983, 1986; Harris & Cook 1986; Ødegård et al. 1988, 1992, 1999; King & Åkerman 1993; Etzelmüller et al. 1998, 2001a, b, 2003; Isaksen et al. 2002; Hauck et al. 2004; Etzelmüller & Hagen 2005; Gisnås 2011; Gisnås et al. 2013, 2017; Westermann et al. 2013; Hipp et al. 2014; Winkler et al. 2021; Hallang et al. 2022a, b; Czekirda et al. 2023), probably permanently present throughout the Holocene (Lilleøren et al. 2012). The N-facing rockwall is likely to be in the zone of continuous permafrost down to significantly less than 2,000 m elev. (Magnin et al. 2019).

Etzelmüller & Frauenfelder (2009) discuss in some detail the relation between precipitation (continentality), temperature, glacier equilibrium line altitude (ELA), and permafrost: the lower the annual precipitation (higher continentality) the colder (higher elevation) a site must be in order to reach the ELA. This means for southern Norway, that at a mean annual precipitation (MAP) of approximately 1,000 mm (as in the Glittertind area, compare Grindrud 2019) the mean annual air temperature (MAAT) must be approximately –6°C or lower/colder (i.e., in the belt of continuous mountain permafrost) to reach ELA.

However, ongoing degradation of mountain permafrost, namely at its lower limits in response to rising air and ground temperatures, is also observed in southern Norway (Isaksen et al. 2007, 2011; Hovden 2022) and will possibly affect also the summit of Glittertinden in the future if warming continues as expected (Hanssen-Bauer et al. 2015, 2017).

During the LGM, the Jotunheimen mountains were buried beneath an ice sheet that rose to a height of approximately 2,000 m above sea level (Nesje et al. 1988, 1994; Nesje & Dahl 1990). Summits above this height may have protruded as nunataks (Wilson 2009), but may have been covered by individual cold based ice caps depending on the geomorphology and indicated by the preservation of autochthonous blockfields. Therefore, also the mountain top of Glittertinden can be assumed to be situated above the LG ice sheet. At least the upper part of the steep northern rock wall is likely to have been ice-free since for a long time and has probably been a nunatak at least since the Weichselian LG, whereas the summit itself due to its geomorphological features may have been buried under a local ice cap. Goehring et al. (2008) had already published rock exposure data for Blåhø (1,617 m elev.) NE of Jotunheimen discussed the vertical extend of the LGM

Fennoscandian Ice Sheet (FIS) and the indicator value of blockfields. For the mountains not far N of Jotunheimen, it was shown that blockfield formation at high elevation has been favored by severe periglacial conditions during a LG stadial some 19 ka b. p. (Marr et al. 2018).

Geology of Jotunheimen

An important part of the Scandes belongs geologically to the Caledonides, an orogen formed out of Proterozoic/Precambrian material during the Caledonian folding (e.g., McKerrow et al. 2000; Fossen et al. 2008). The major part of this orogenesis which took place in a number of widely scattered more or less simultaneous collision events during the Palaeozoic period. The plates taking part in this orogenesis are now situated in the Northern Hemisphere, namely in the Holarctic region and constitute an important part of the present time boreal mountain region (Nagy & Grabherr 2009).

The geological history of the Caledonides in Norway during the Palaeozoic period is characterized by long periods of ultrahigh-pressure metamorphism and three partly overlapping phases of subduction directed towards the W (e.g., Andersen 1998; Corfu et al. 2014) and connected to a nappe formation. One of these is a Precambrian basement nappe complex of largely magmatic rocks of mafic to felsic composition, the 'Jotun Nappe Complex' (Kruse & Stünitz 1999; Lundmark et al. 2007).

The uplift of these bedrocks to the mountains of Jotunheimen is however a geologically young event, probably two-phased during the Cenozoic (Lidmar-Bergström et al. 2000, 2013; Lidmar-Bergström & Näslund 2002; Vorren & Mangerud 2008; Vorren et al. 2008). Therefore, Glittertinden can be called a mountain of old rocks with young shape.

In the area E of Visdalen (with Glittertinden), W of Visdalen (with Galdhöpiggen) and N of the Tyin-Gjende Fault (approximate position indicated by Gjende Lake) the dominating rock types are pyroxene gneisses with lenses of ultramafites (Battey & McRitchie 1973, 1975; Piper & Poppleton 1990). The geological map of the area offered at the web site of NGU (https://geo.ngu.no/kart/berggrunn_mobil/) shows that the summit area of Glittertinden is situated within a polygon with the signature of orthopyroxene-gneiss with some ultramafic lenses nearby. The substrate of our saxicolous samples is of these hard, dense rock types.

Climatical conditions on the summit of Glittertinden

There is no meteorological station on the summit of Glittertinden. Therefore, the climatological data circumscribing roughly the ecological conditions with which biota have to cope there must be extrapolated from measurements nearby or other data serving as proxies. A summary of the climate with its regional variations in Jotunheimen has recently been presented by Winkler et al. (2021). A sketch of the climate in the Galdhöpiggen area is given by Matthews et al. (2018). The closest meteorological station is on Juvvasshøe (1894 m elev.), operating since 1999 and situated ~10.3 km WNW of Glittertinden.

According to data presented by Winkler et al. (2021) on Juvvasshøe, the calculated mean of the mean annual air temperature (MAAT) for the normal period 1960–1990 is −4.6°C.

Green & Harding (1980) dealt with the altitudinal gradients of air temperature in southern Norway. If the diagram for MAAT variation with elevation in SW Norway published there, which ends at approximately 2,000 m elev., is extrapolated – under the premise of a linear decrease – MAAT at 2,450 m (i.e., on the summit of Glittertinden) should be about −8°C. This is fairly in accordance with another dataset. Ødegård et al. (1992) estimated for Juvflye (a NE exposed slope S of Juvvasshøe) the MAAT to be −2.6°C at 1500 m and −6.4°C at 2,200 m a. elev. If the calculated temperature lapse rate of ~0.6°C per 100 m rise in elevation is applied to the Glittertind area nearby, a MAAT of about −7.9°C can be suggested at 2,450 m (i.e., the height on the summit of Glittertinden).

The temperatures during the growing season are also of interest. Manley (1955) estimated that MAT_{JJAS} on summit level in NE Jotunheimen is approximately −2°C. On Juvvasshøe, the calculated mean of MAT_{Jul} for the normal period 1960–1990 is 3.9°C. From calculations presented by Odland (2009), MAT_{Jul} for Jotunheimen at 2,450 m elev. can be extrapolated. It should have been about 1.3°C in this period. Since 1990, also in Jotunheimen, a continuous trend of warming is observed, accumulating in the meanwhile to >1°C warmer seasonal and annual temperatures (Grindrud 2019).

The second climatological key factor is precipitation which shows a strong west–east gradient across southern Norway lowering towards the E. On the mountain Fannaråki (2,062 m elev., ~38 km SW of Glittertinden), the mean annual precipitation (MAP) for the normal period 1960–1990 is 1,200 mm (Winkler et al. 2021). In NE Jotunheimen at higher elevations, it should be about 800–1000 mm (e.g., Østrem et al. 1988). Above 1,300 m practically all winter precipitation falls as snow (e.g., Dyrrdal 2010; Isaksen et al. 2011). Snow depth on local scale varies by elevation, wind and land surface, and has therefore a strong influence on the temperature-precipitation equilibrium-line altitude (Lie et al. 2003). In the last decades on the summit of Glittertinden, summer temperatures (amount of snow melt) were too high or winter precipitation was too low (amount of snow accumulation) for an equilibrium explaining the thinning of the ice cap. Anyway, on the summit of Glittertinden biota have to cope with harsh environmental conditions.

Vascular plants at high altitudes of Glittertinden and on other high summits in Jotunheimen – observed changes in time of global warming

The nomenclature of altitudinal belts in Scandinavia differs from that in Central Europe (Dahl 1986). What is called the "nival belt" – its lower limit is approximately the snowline – together with its subnival ecotone in the European Alps (e.g., Braun-Blanquet 1954; Reisigl & Pitschmann 1958), in Scandinavia is called “high-alpine belt” (e.g., Du Rietz 1925; Nordhagen 1943), with “upper oroarctic zone” as a synonym (Ahti et al. 1968; Dahl 1975). This belt is the zone where consolidated plant communities disappear, vascular plants may occur as more or less open mosaics or isolated individuals up to their ecophysiological limit and cryptogams dominate at least in number of species. In northeastern Jotunheimen the lower limit of the high-alpine belt is drawn at 1,600–1,800 m a.s.l., depending on the slope exposure (Matthews et al. 2018). Cold-adapted vascular plant species referred to the high-alpine element, such as *Ranunculus glacialis*, *Campanula uniflora*, *Erigeron uniflorus*, *Sagina nivalis*, *Luzula arctica*, or *Poa flexuosa* are limited by maximum summer temperatures of +22°C or lower (Dahl 1998).

So far there are no vascular plants growing on the summit of Glittertinden. The mountain is apparently too high and vascular plants have not managed to grow under environmental conditions prevalent on the summit.

A sound basis for our knowledge about the diversity of vascular plants and their horizontal and altitudinal distribution on Glittertinden and other mountains in Jotunheimen has been laid by Jørgensen (1932). Jørgensen climbed Glittertinden in summer 1931 and noted the local diversity of vascular plants along a transect with 20 localities with an altitudinal range of 1,500–2,120 m s. m. He reported 2 species of flowering plants (*Ranunculus glacialis*, syn. *Beckwithia glacialis* and *Poa laxa* [ssp. *flexuosa*], syn. *Poa flexuosa*) from 2,100–2,120 m elev. and an additional two species (*Luzula confusa*, *Salix herbacea*) from an altitudinal range between 2,000 and 2,060 m elev. Comparable fieldwork has been performed twice in more recent times in order to document possible changes in presence and range shifts. Both Klanderud (2000) and Grindrud (2019) documented the changes on 23 summits including Glittertinden in Jotunheimen since Jørgensen’s baseline study. After the first restudy, Klanderud & Birks (2003) interpreted the data accumulated by Klanderud (2000) and concluded, that for cold-adapted species an increasing abundance at higher elevation, but not a substantial upwards migration or enrichment of the flora at its uppermost limit could be documented. On occasion of the second restudy, Grindrud (2019) has documented only the presence of *Ranunculus glacialis* above of 2,100 m s. m., whereas in the range 2,001 to 2,100 m s. m. he additionally found *Poa flexuosa*, *Luzula confusa*, *Salix herbacea*, *Trisetum spicatum*, *Gnaphalium supinum* (syn. *Omalotheca supina*), and *Saxifraga tenuis*. In the meanwhile, *Ranunculus glacialis* was able to establish first individuals far up on the eastern ridge at approximately 2,300 m s. m documented by A. Breili in 2021 (https://artskart.artsdatabanken.no).

Odland & Birks (1999) interpret some of Jørgensen’s distributional data accumulated in 1930–1931 (Jørgensen 1932). As Jørgensen’s highest records of 5 species of vascular plants were from above of 2,300 m on the upper slopes of Galdhøpiggen, they calculate a “climatic vascular plant limit” in Jotunheimen corresponding to a mean July temperature of ~2.2°C in that area of the southern Scandes. And, based on a record of *Ranunculus glacialis*, the vascular plant limit in Jotunheimen is seen at 2,370 m elev. (Birks 2021).

Previous lichenological research in Jotunheimen

More intensive lichenological field work in Jotunheimen apparently started relatively late, in the first half of the 20th century. Other than the at that time already well studied Dovre(fjell) (N of Jotunheimen), the “Lichen flora of Norway” (Lynge 1921) still reports only a single species for Jotunheimen (*Stereocaulon paschale*). The first important lichen collections from high grounds in the area were those by the botanist R. Jørgensen, who had climbed a number of mountains in Jotunheimen investigating the altitudinal distribution of vascular plants and other biota.

There is no indication that apart from the author other people have collected lichens on the summit of Glittertinden. However, there is evidence that the Glittertinden massif (but not the summit) has been visited by other lichenologists in the past, although traces in the lichenological literature are few. Evidently, Rolf Santesson has studied the lichen flora on the eastern slopes of Glittertinden in 1963. One of his collections, a specimen of *Polysporina subfuscescens* originating from boulders in a moraine of Gråsubreen (1950 m s. m.) was reported by Knudsen & Kocourkova (2008). Some other specimens can be traced in NLD2 database (https://nhm2.uio.no/botanisk/nxd/lav/nld_e.htm) and the herbarium databases of the Museum of Evolution, Uppsala University (http://webdev.its.uu.se/evomus/botanik/home.php). Furthermore, R. Santesson determined the following six lichen species which had established on a boulder buried in ice of an ice-cored moraine in front of Gråsubreen: *Umbilicaria hyperborea*, *Pseudephebe pubecens Tremolecia atrata*, *Rhizocarpon geographicum*, *Rhizocarpon badioatrum*, and *Porpidia melinodes* (Østrem 1965). From the same boulder the moss *Andreaea blytii* was sampled and used for ^{14}C dating giving an age of 720 ± 170 C years.

Our own previously published records from Glittertinden were limited to the lichenicolous taxa *Carbonea aggregantula* (host: *Lecanora polytropa*) and *Nigropuncta rugulosa* (host: *Bellemerea cinereorufescens*) (Hafellner 1993), as well as *Endococcus verrucosus* (host: *Aspicilia grisea*) (Hafellner 1994). Furthermore, Kukwa (2011) has recorded *Ochrolechia frigida* based on one of our collections from the summit.

The NLD2 database currently contains only 3 datasets referring to high-altitude localities on Glittertinden including duplicates of two specimens listed below:

Carbonea vorticosa: Hafellner 14615 (O-L-99506).

Lecidea lapicida: Hafellner 14463, confirm. R. Haugan, 2011 (O-L-18119).

Umbilicaria proboscidea: Glittertind, [UTM(WGS84): MP 754-783 352-354 (M711: 1618 III)], Alt.: ~2,200 m, Naken steinblokk nær snøen, 1969.07.10, Høiland, K. (O-L-33123).

Some further datasets can be extracted for the digitized herbarium holdings of the Museum of Evolution, Uppsala

University altogether about 10 specimens, most of them collected by the late R. Santesson in 1963 on the SE slopes in the area surrounding the glacier Gråsubreen and one duplicate of one of our own collections from the summit (*Nigropuncta rugulosa* on *Bellemerea cinereorufescens* [Note: The host was not indicated on this duplicate]).

A search in GBIF database (https://www.gbif.org) with term "Glittertind" among occurrences brings up a list of 347 entries, the majority (~300) refer to vascular plants, but also 25 fungal species with the majority lichenized. Most of the specimens traced in various herbaria participating in GBIF originate from localities on the slopes of Glittertinden. Those from the summit refer to duplicates the author sent to UPS several years ago.

Jørgensen, who had climbed Glittertinden and had documented the altitudinal distribution of vascular plants on that mountain (Jørgensen 1932, see above), did not record any lichens from one of the localities he studied on the way up to the summit of Glittertinden.

The summit of Norway's highest mountain, Galdhøpiggen, has been visited at least three times by botanists collecting lichens (1931 by R. Jørgensen, 1947 by G. Degelius, 2012 by R. Haugan). R. Jørgensen got the lichens that he had collected on the summit of Galdhøpiggen determined by Lynge, who identified altogether 13 species among the material. An additional four species were recorded from sites in an altitudinal range between 2,300 and 2,400 m. Jørgensen (1932: 122–123) published all these data in his monograph of the altitudinal limits of plant life in Jotunheimen. Degelius (1948) combined Jørgensen's data with the results of his own collections into a list of 38 species including two lecideoid lichens described as new by H. Magnusson (*Lecidea altissima*, *L. ludificans*; see also table 1, right column). The types of these two species have among others been restudied by Jørgensen & Nordin (2009). The authors confirmed them as distinct species. With the generic concepts of today, *Lecidea ludificans* should be kept in *Lecidea*, whereas *Lecidea altissima* constitutes a species of *Miriquidica* (compare Haugan et al. 2013) and not of the *Lecidea elata*-group as supposed by Jørgensen & Nordin (2009). In recent times (2012), R. Haugan has revisited the type locality and he confirmed that *Miriquidica altissima* is still present on the summit of Galdhøpiggen (see Amundsen 2014, NLD2). Some *Rhizocarpon* species from Galdhøpiggen have been reported partly under synonyms by Runemark (1956), including three taxa from the summit area (*Rhizocarpon geographicum* ssp. *diabasicum*, *R. norvegicum*, and *R. inarense*).

Apart from the altitudinal distribution data of lichens on Galdhøpiggen, Jørgensen (1932) reports some lichens from other summits in Jotunheimen with elevations exceeding 2,000 m, e.g., *Alectoria ochroleuca*, *Umbilicaria rigida* and *Stereocaulon denudatum* from Besshø (2,257 m), *Umbilicaria rigida*, *Pseudephebe pubescens* and *Solorina saccata* from Knutshulstind (2,200 m), and *Umbilicaria vellea* from Svartdalspiggen (2,143 m).

The most thorough investigation on the saxicolous lichens of southern Norway including some lower summits and ridges of mid elevation (all below 1,900 m) in Jotunheimen is the community-approach by Creveld (1981). Other lichenological contributions from sites at elevations below 2,000 m came from Østhagen (1975) and Clauzade & Roux (1975). Hestmark et al. (2004a, b, 2005, 2007) performed population studies on some macrolichens in mid-elevated glacier forefields in the same area. Lichenologial data for high grounds in Jotunheimen are also included in vegetation surveys. The most important and one including numerous lichen records is the monographic treatment of Nordhagen (1943). Extensive fieldwork has also been performed in the surroundings of Juvasshytta (N of Galdhøpiggen). Data of the recorded species in that area are accessible via the Norwegian Lichen Database 2.

Some scattered records of lichens can be traced in studies of the succession in the vegetation established in glacier forefields (e.g., Matthews 1979a, b; Foskett 1998), but most of these records are likely to exist only as names in vegetation surveys and it will be difficult to find specimens in the event that a confirmation of one of the mentioned species would be desirable.

Furthermore, there are a number of studies from Jotunheimen in which the exposure age of rock surfaces was estimated by use of lichenometric data. As in other parts of the world, lichenometry turned out to be useful for dating events that happened not too long ago. Therefore, lichenometry was mainly applied to boulders in moraines deposited in the youngest Holocene, e.g., in Little Ice Age (LIA) moraines, but also as a control test for other relative dating methods (e.g., Matthews 1973, 1974, 1975, 1977; Ballantyne & Matthews 1982; Erikstad & Sollid 1986; Cook-Talbot 1991; McEwen et al. 2020).

A search in the NLD2 database with the locality term "Jotunheimen" brings up about 120 hits/specimens of about 50 species, most of them from localities at lower altitudes and only about two dozen hits/specimens (of less than 20 species) from sites above 2,000 m elev. several of these from the summit area of Galdhöpiggen (Tab. 1).

Furthermore, it is worth mentioning that several arctic-alpine lichen species reported from high mountains in Jotunheimen are included in the last version of the Norwegian Red List. They are regarded as being trapped on high summits and hardly have the possibility to disperse to other ecosystems, hence are endangered due to strict niche limitations (Haugan et al. 2021). For instance, *Miriquidica altissima* and *Lecanora orbicularis* turn up in the Red List database (https://artsdatabanken.no/lister/rodlisteforarter/2021/). An earlier record from the W-side of Glittertinden at about 1,950 m s. m. is founded on one of the author's collections (Hafellner 12503 in GZU) gathered in 1984 during our ascent to the summit.

Lichenological research on high mountains in Norway with special emphasis on mountain groups in the surroundings of Jotunheimen

The knowledge about lichen diversity on other high mountains in Southern Norway is quite different among the mountain groups. For a first overview, Fries (1871,

1874) and Lynge (1921) can be consulted. More modern floras (e.g., Krog et al. 1994) do not contain sufficiently precise data.

For a comparison with the local lichen floras found on the high peaks in Jotunheimen, we concentrate on mountain systems in the surroundings of Jotunheimen, namely the mountain-groups Dovre(fjell), Rondane and Hardangervidda.

Dovrefjell is a mountain-group N of Jotunheimen (partly in prov. Møre og Romsdal, Innlandet, Trøndelag) with Snøhetta (2286 m elev.) being the highest mountain of Norway outside Jotunheimen. As a curiosity, it is worth mentioning that for some time in the past due to its subjective height difference to its foreland because of its more isolated position Snøhetta was regarded to be the highest mountain of Norway. There are many species records for the Dovre(fjell) group in the classical treatment of the Nordic lichen flora by Fries (1871, 1874), but most lacking more precise data. For the summit of Snøhetta, visited at least twice by lichenologists, a local lichen flora can be compiled. In 1925 on occasion of an excursion across Scandinavia, this peak was visited by the Swiss lichenologist E. Frey, who reported 27 taxa occurring up to the mountain top, including the saxicolous *Umbilicaria virginis*, *U. cylindrica* with 2 varieties, *U.* cf. *vellea*, *U. hyperborea*, *U. nylanderiana*, *U. proboscidea*, *U. rigida*, *U. decussata*, *U. torrefacta*, *Melanelia stygia*, *Pseudephebe pubescens*, *Brodoa* cf. *oroarctica*, *Ophioparma ventosa*, *Sporastatia polyspora*, *S. testudinea*, *Lecanora polytropa*, *Rhizocarpon alpicola*, *R. badioatrum*, *R. geographicum*, *Lecidea auriculata*, *L. lapicida*, and *L. lapicida* var. *pantherina* (Frey 1927). Additional species were reported from lower elevations. The macrolichens of the area were studied in detail by Schei (1984), who had also climbed Snøhetta where she collected in the summit area (her locality 27) 19 species, including the saxicolous *Melanelia commixta*, *M. hepatizon*, *Brodoa oroarctica*, *Allantoparmelia alpicola*, *Parmelia omphalodes*, *P. saxatilis*, *Pseudephebe minuscula*, *P. pubescens*, *Sphaerophorus globosus*, *Umbilicaria arctica*, *U. cylindrica*, *U. hyperborea*, *U. proboscidea*, *U. rigida*, and *U. torrefacta*. Another early lichenological contribution listing a number of alpine species exclusively for Dovrefjell is authored by Vrang (1934), but locality information is missing. More data on lichen species recorded from Snøhetta are accessible via the Norwegian Lichen Database 2. And it was in the Dovrefjell area, where the effect of rising temperatures on high altitude ground vegetation was thoroughly investigated first in Norway (Michelsen et al. 2009; Vanneste 2016; Vanneste et al. 2017).

Rondane is a mountain group situated NE of Jotunheimen (prov. Oppland and Hedmark, now Innlandet) with Rondslottet (2,178 m elev.) being the highest summit. Dahl (1956) lists records of a greater number of lichen species, predominantly macrolichens, from above 2,000 m s. m. in Rondane, including a few restricted to the high-alpine belt (e.g., *Umbilicaria virginis*).

Hardangervidda is a medium high plateau S of Jotunheimen (Hordaland, now Vestland) of which Sandfloegga (1,721 m elev.) rises as the highest mountain. An excellent baseline study for Hårteigen, another summit rising from Hardangervidda plateau, was published by Havaas (1928). Unfortunately, only the vascular plant flora has been reinvestigated by Odland (2012). Hertel (1975) studied the alpine lichen flora in the surroundings of Finse at the northern edge of Hardangervidda including some mid-elevation mountain tops of which only the most interesting findings have been included in the cited publication. Further lichenological contributions from the plateau came from Havaas (1903), Frey (1927), and Sparrius et al. (2007). Sparrius et al. (2006) recorded numerous species from some mid-elevated mountain summits scattered over Southern Norway.

Data on the presence or regional distribution of lichens on mountain regions in southern Norway are occasionally included in monographic vegetation surveys beyond a regional scope (e.g., Gjaerevoll 1956) and of course, scattered records can be traced in the taxonomic literature (e.g., Runemark 1956; Timdal 1983, 1984; Tønsberg 1992) and floristic contributions (e.g., Timdal 1982, 1992; Haugan 1990). But this gets out of the scope of this introduction.

Material and methods

Field work

In late summer 1984, we had approached the mountain top of Glittertinden in a lengthy one-day hike from the west side starting from our base camp close to Spiterstulen in Visdalen. At that time, the summit of Glittertinden was still covered by an ice cap approximately 10–15 m thick (Fig. 1, 2) and for collecting equipment for ice mountaineering (rope, crampons, ice axe, ice screws) was necessary to be able to safely reach the upper rim of the subvertical rock walls on the north side.

The author sampled the local lichen flora at two sites. Locality 1 was situated on the upper edge of the rock falls exposed to the north towards the upper end of Grotbreen at the lower N edge of the ice cap directly below the highest point of the ice cap at that time. The searchable surface area was only a few square meters. The time spent collecting was approximately one hour, which should give an impression of how complete the sampled set of species might be. Locality 2 was a low elongated outcrop and some large boulders nearby, situated on the gently inclined ridge W of the summit, which in summer 1984 was found partly by a thin layer of snow from last winter. The time spent for collecting was approximately half an hour.

The investigated localities (Text as given on the labels, but translated from the original German); [added and/or corrected data in square brackets]

Norwegen, Oppland [now Innlandet]: Kommune Lom, Jotunheimen

1: Summit of Glittertind, inaccessible, N-facing rock walls, [61°39′04″N / 08°33′26″E], 2,469 m elev. [vere ~2,450 m elev.!] a) rock heads, gneiss b) on bryophytes and/or plant debris over soil in fissures, 23 VIII 1984, leg. J. Hafellner & A. Ochsenhofer

2: Summit of Glittertind, low outcrops W of the highest point on the gently inclined SW-side, [61°39′01″N / 08°33′09″E], ~2,440 m elev. [vere c. 2420 m elev.!)], on boulders and low outcrops (gneiss) with lenses of ultramafic rock, 23 VIII 1984, leg. J. Hafellner & A. Ochsenhofer

Laboratory work

In treating the samples, the commonly used procedures have been applied. External morphology was studied with a dissecting microscope (WILD M3, 6.4–40×). Anatomical studies of the thallus and the ascomata were carried out under the light microscope (Leitz Biomed, 100–1000×). Sectioning was performed by hand, but squash preparations were also used. Amyloid reactions in hymenia were observed using Lugol's reagent (MERCK 9261). Where necessary, secondary chemistry of crystallized lichen substances was investigated by TLC (Culberson & Ammann 1979). For determining the specimens, mainly the keys of Clauzade & Roux (1985), Wirth (1995), Smith et al. (2009) and its former editions were used. The nomenclature follows the checklist of Fennoscandia (Westberg et al. 2021) except some recent changes. Abbreviations for institutional herbaria follow Holmgren et al. (1990), continued and updated as electronic database hosted at New York Botanical Garden (https://sweetgum.nybg.org/science/ih/).

Specimens of all collected species are deposited in GZU (Herbarium of the Institute of Biology, Karl-Franzens-University, Graz).

Results

Altogether 44 taxa (41 species, 3 infraspecific taxa) of lichens and 5 species of lichenicolous fungi were sampled in two nearby localities, both above 2,400 m elev. in the summit area of Glittertinden (Table 1).

On site 1, species dominated which regularly occur in alpine silicicolous communities close to climax communities throughout Europe (Frey 1927; Klement 1955; Creveld 1981). The various lichen species grow in mosaics leaving little bare rock in between. Only a few terricolous lichens were found probably due to lack of sufficient substrate. On site 2, among others, a few species were found which indicate a high content of metal ions in the siliceous substrate (Purvis & Halls 1996).

The lichen diversity is hence similar to that documented for Galdhøpiggen (51 lichenized taxa) although it can be assumed that fairly different surface areas were searched for lichens on both summits. Of the total diversity, about one third of the taxa (25) occur on both summits and approximately one third were found on only one of the summits (19 + 5 lichenicolous fungi on Glittertinden, 26 + 2 lichenicolous fungi on Galdhøpiggen).

Similar to other high mountains in the Holarctic, in the nival belt, the overwhelming majority of the species is lichenized with coccal green algae (e.g., Scheidegger 2021) and fertile species dominate.

Discussion

The lichen flora

The relatively high diversity of saxicolous lichen species including several taxa regarded as characteristic for silicicolous communities close to climax with preference for the alpine to nival belt (e.g., *Sporastatia testudinea*, *S. polyspora*, *Bellemerea alpina*) on the one hand, and on the other hand, according to the author's field observations, the rarity of pioneer species at the study sites (e.g., rarity of *Bellemerea subsorediza*, practical lack of juvenile thalli of *Rhizocarpon geographicum* agg. and/or *Umbilicaria* spec. on rock surface otherwise bare of lichens, no *Trapeliaceae*) makes it likely that the investigated rock surfaces have already been ice-free for a long time.

The match of only about one third of species common to both high summits indicates that the accumulated data are still fragmentary. An extension of investigations both in studied area and spent collection time most likely would increase the number of species considerably. Furthermore, a stronger inclusion of ultramafic rocks in surveys of the local lichen diversity could increase the number of recorded species because such rock types show fairly different lichen species compositions including several chalcophilous and even calcicolous species.

The exposure time of substrate

There are numerous publications dealing with the extent of the Fennoscandian Ice Sheet (FIS) at various stages of the Pleistocene and also for aspects of the deglaciation after the LGM. It would be beyond the scope to discuss this subject in detail. However, one aspect is of special interest, namely when the high summits of Jotunheimen became ice-free, opening herewith the opportunity for the establishment of lichens on newly exposed substrate. And what happened during the Little Ice Age (LIA) – long after the melt-down of the FIS – to the local glaciers?

During the Weichselian LGM, the position of Jotunheimen was in or close to the ice culmination zone of the FIS and herewith close to the ice divide with little ice movement conserving possibly already existing autochthonous blockfields (e.g., Hole & Bergersen 1981; Mangerud et al. 2011; Patton et al. 2016, 2017). The Weichselian FIS covered most of Scandinavia until the Younger Dryas stadial (YD), a final cold period marking the end of the Weichselian LG (Mangerud et al. 2011). Both during the LGM and the YD, Jotunheimen was situated in a zone of cold based ice (Lane et al. 2020).

During the Weichselian LG, a thin multi-domed ice-sheet existed in Central Norway, creating large areas of LG nunataks and an ice-free plateau (Paus et al. 2006, 2011, 2015; Patton et al. 2017) already suitable for lichen colonization (Dahl 1946). This thin FIS lasted during the YD (Dahl et al. 1997). The FIS melted and transformed into a net of local glaciers during the early Holocene (Preboreal) at the latest, about 10 ka ago (Bjune 2005; Stroeven et al. 2016; Hughes et al. 2016; Patton et al. 2017). During the Holocene climate, the extent of glaciers varied considerably (Matthews & Dresser 2008).

Table 1. Lichen records from the summits of the two highest mountains in Norway. Glittertinden column: this study, recorded taxa in **bold**; Galdhøpiggen column: data from Jørgensen 1932 and Degelius 1948[1)], NLD2[2)], Runemark 1956[3)], only taxa determined to species included, NLD2 searched on 21 Apr. 2023
The (5-digit numbers in brackets) are collection numbers of the author. The material is deposited in GZU. Duplicates of some collections marked by an asterisk (*) have been sent to herbarium O and/or UPS. Synonyms used by Degelius in (brackets) if different from accepted name.

Taxon	Glittertinden	Galdhøpiggen
Alectoria ochroleuca (Hoffm.) A. Massal.	–	+[1)], +[2)]
Allantoparmelia alpicola (Th.Fr.) Essl.	1a (14452)	+[1)] (sub *Parmelia a.*), +[2)]
Aspicilia grisea Arnold	1a (14432), 2 (83919)	–
Bellemerea alpina (Sommerf.) Clauzade & Cl.Roux	1a (14428)	–
Bellemerea cinereorufescens (Ach.) Clauzade & Cl.Roux	1a (14440, under the name of its parasite *Nigropuncta rugulosa*)	–
Bellemerea subsorediza (Lynge) R. Sant.	1a (14442), 2 (14618, 83920)	–
Brodoa intestiniformis (Vill.) Goward	–	+[1)] (sub *Parmelia i.*)
Brodoa oroarctica (Krog) Goward	1a (14453)	+[2)]
Bryocaulon divergens (Ach.) Kärnefelt	–	+[1)] (sub *Cornicularia d.*)
Bryonora curvescens (Mudd) Poelt	–	+[2)]
Calvitimela armeniaca (DC.) Hafellner	1a (14443)	–
Calvitimela melaleuca (Sommerf.) M.P. Andreev	–	+[1)] (sub *Lecidea arctogena* f. *rubroreagens*)
Carbonea vorticosa (Flörke) Hertel	2 (14615*)	+[1)] (sub *Lecidea v.*)
Cetrariella commixta (Nyl.) A. Thell & Kärnefelt	–	+[1)] (sub *Cetraria c.*)
Foveolaria nivalis (L.) S. Chesnokov et al.	1b (14447)	+[1)] (sub *Cetraria n.*), +[2)]
Gowardia nigricans (Ach.) Halonen et al.	1b (14435)	–
Japewia tornoensis (Nyl.) Tønsberg	1b (14429) admixture: *Pseudephebe pubescens*	–
Lecanora formosa (Bagl. & Carestia) Knoph & Leuckert	1a (14439)	+[2)]
Lecanora handelii J. Steiner	2 (83921)	–
Lecanora leptacina Sommerf.	–	+[1)], +[2)]
Lecanora polytropa (Ehrh. ex Hoffm.) Rabenh.	1a (14423), 2 (14611)	+[1)]
Lecidea atrobrunnea (Ramond ex Lam. & DC.) Schaer.	2 (14610, 83922)	+[2)]
Lecidea diducens Nyl.	–	+[1)] (sub *Lecidea auriculata* var. *d.*)
Lecidea ecrustacea (Anzi ex Arnold) Arnold	–	+[1)] (sub *Lecidea lapicida* f. *e.*)
Lecidea lapicida (Ach.) Ach. var. ***lapicida***	1a (14463*, 14464, 14471), 2 (14616)	+[2)]
Lecidea lapicida var. ***pantherina*** Ach.	1a (14462, 14468, 14474)	–
Lecidea ludificans H. Magn.	–	+[1)] (locus classicus!)
Lecidea praenubila Nyl.	–	+[2)]
Lecidea promiscens Nyl.	2 (14614)	–
Lecidea swartzioidea Nyl.	1a (14458, 14472, 14473)	–
Lepraria neglecta (Nyl.) Lettau	1b (14449)	–
Melanelia hepatizon (Ach.) A. Thell	1a (14427)	–
Miriquidica altissima (H. Magn.) Haugan & Timdal ined.	–	+[1)] (sub *Lecidea a.*, locus classicus!), +[2)]
Miriquidica lulensis (Hellb.) Hertel & Rambold	–	+[1)] (sub *Lecidea l.*)
Miriquidica garovaglii (Schaer.) Hertel & Rambold	2 (83923)	+[2)]
Miriquidica liljenstroemii (Du Rietz) R. Sant.	–	+[2)]
Miriquidica nigroleprosa (Vain.) Hertel & Rambold	1a (14437)	–
Ochrolechia frigida (Sw.) Lynge (det. M. Kukwa)	1b (14426)	–
Parmelia omphalodes (L.) Ach.	1b (as admixture in specimen of *Sphaerophorus fragilis*)	+[1)], +[2)]
Protoparmelia badia (Hoffm.) Hafellner	1a (14438)	–
Pseudephebe minuscula (Nyl. ex Arnold) Brodo & D. Hawksw.	2 (83925)	+[1)] (sub *Alectoria m.*)
Pseudephebe pubescens (L.) M. Choisy	1a (14424, 14445)	+[1)] (sub *Alectoria p.*), +[2)]
Psorinia conglomerata (Ach.) Gotth.Schneid.	–	+[2)]
Rhizocarpon copelandii (Körb.) Th.Fr.	–	+[2)]
Rhizocarpon geographicum (L.) DC. ssp. *geographicum*	1a (14475)	+[1)]
Rhizocarpon geographicum ssp. *diabasicum* (Räsänen) Poelt & Vězda	–	+[3)] (sub *R. lindsayanum* ssp. *d.*)
Rhizocarpon geographicum ssp. ***frigidum*** (Räsänen) Hertel	1a (14467)	+[3)] (sub *R. lindsayanum* ssp. *f.*)
Rhizocarpon glaucescens (Th.Fr.) Zahlbr.	–	+[1)]
Rhizocarpon inarense (Vain.) Vain.	1a (14466)	+[1)] (sub *R. chionophilum*)
Rhizocarpon jemtlandicum (Malme) Malme	–	+[1)]

Table 1. Continued.

Taxon	Glittertinden	Galdhøpiggen
Rhizocarpon norvegicum Räsänen	2 (83924)	+3)
Rhizocarpon polycarpum (Hepp) Th.Fr.	1a (14469, 14470)	–
Rhizocarpon subgeminatum Eitner	–	+1) (sub *R. phalerosporum*)
Sphaerophorus fragilis (L.) Pers.	1b (14446) admixtures: *Pseudephebe pubescens*, *Parmelia omphalodes*, *Brodoa oroarctica*	+2) [close to summit]
Sporastatia polyspora (Nyl.) Grummann	1a (14434)	+1) (sub *S. cinerea* var. *scandinavica*), +2) [close to summit]
Sporastatia testudinea (Ach.) A. Massal.	1a (14441), 2 (14612) admixtures: *Tremolecia atrata*, *Rhizocarpon norvegicum*	+1), +2)
Stereocaulon vesuvianum Pers.	–	+1) (sub *S. denudatum* var. *pulvinatum*)
Thamnolia vermicularis (Sw.) Schaer.	–	+1)
Tremolecia atrata (Ach.) Hertel	2 (14619, 83926)	+1) (sub *Lecidea dicksonii*)
Umbilicaria aprina Nyl.	–	+1)
Umbilicaria cylindrica (L.) Delise ex Duby var. *cylindrica*	1a (14436), 2 (14617, 83927)	+1), +2)
Umbilicaria cylindrica var. ***tornata*** (Ach.) Nyl.	1a (14433)	–
Umbilicaria decussata (Vill.) Zahlbr.	2 (83928)	+1)
Umbilicaria havaasii Llano	–	+1) (sub *U. fuliginosa*)
Umbilicaria hyperborea (Ach.) Hoffm.	–	+1), +2)
Umbilicaria proboscidea (L.) Schrad.	1a (14444)	+1), +2)
Umbilicaria rigida (Du Rietz) Frey	1a (14448)	+1), +2)
Umbilicaria torrefacta (Leightf.) Schrad.	1a (14431)	+1)
Umbilicaria virginis Schaer.	1a (14430)	+2)
Xanthoria elegans (Link) Th.Fr.	–	+1) (sub *Caloplaca e.*), +2)
Non-lichenized lichenicolous fungi		
Carbonea aggregantula (Nyl.) Hertel on *Lecanora polytropa*	1a (14476)	–
Endococcus verrucosus Hafellner on *Aspicilia grisea*	1a (14460)	–
«*Leptosphaeria* spec.» on *Tremolecia atrata*	–	+1)
Muellerella pygmaea (Körb.) D. Hawksw. coll. on *Lecanora polytropa*	1a (14479)	–
Nigropuncta rugulosa D. Hawksw. on *Bellemerea cinereorufescens*	1a (14440)*, (14476, as admixture in specimen of *Carbonea aggregantula*), 2 (14620)	–
Polycoccum sporastatiae (Anzi) Arnold on *Sporastatia testudinea*	1a (41914)	–
Stigmidium conspurcans (Th.Fr.) Triebel & R. Sant. on *Psora rubiformis*	–	+1) (sub *Pharcidia dispersa* f. *hygrophila*)

Matthews et al. (2000) argued that in the period of 7,900–5,300 cal. y BP there were no glaciers in central Jotunheimen. The onset of neoglaciation in a cooling phase afterwards culminated in a neoglacial maximum during the LIA about 250–270 a BP (= around 1,750 BC) (Matthews 1974, 1975, 1977, 2005). In Jotunheimen, the climatic deterioration during the LIA only led to larger and thicker local glaciers, but large areas of the slopes, ridges and summits remained unglaciated and hence remained under periglacial conditions. Since the LIA culmination the glaciers in Jotunheimen lost about one third of their area and length (Baumann et al. 2009; Winkler et al. 2021).

Therefore, as far as the exposed time of bedrock at the upper edge of the N-facing rock walls of Glittertinden is concerned, it is very likely that lichens had at least about 10 ka years, i.e., since the early Holocene to reach the locality and to establish successfully. More than 30 species managed to do so, followed by some lichenicolous parasymbionts, a further indicator for long-time colonizations under healthy environmental conditions (Lawrey & Diederich 2003).

The influence of climate change on flora and vegetation – studies in Norway with emphasis on those using lichen data

Climate change in historical and recent times leads to an increase of the number of species on mountain summits. This is so far documented for vascular plants for a number of peaks including Piz Linard in Switzerland, the classical site for comparative field observations of vascular plant diversity on a summit over more than one century (Heer 1884; Braun-Blanquet 1957; Pauli et al. 2003; Wipf et al. 2013). The precondition to document changes in diversity over periods of time is the availability of a first dataset. This can be a historical flora (e.g., Stöckli et al. 2012), but if such a flora is not available, specimens deposited in herbaria may be an alternative. However, as many herbaria are not yet digitized, access to label data may be difficult.

Changes in the altitudinal distribution of vascular plants under the influence of climate change have also been studied in Norway, namely in the mountainous southern part of the country (e.g., Lye 1973; Høitomt & Olsen 2010; Odland 2010, 2012; Odland et al. 2010, 2015, 2018), including Jotunheimen (Jørgensen 1932; Dahl & Hygen 1951; Klanderud 2000; Klanderud & Birks 2003; Grindrud 2019).

But climate change does not always lead to an enrichment of summit floras. Cold-adapted species in particular may get stressed when their habitats start to transform under the influence of changing environmental conditions (e.g., Engler et al. 2011; Rixen et al. 2014; Vanneste 2016; Rixen & Wipf 2017; Vanneste et al. 2017).

Gottfried et al. (2012) put together the data of many local studies and reported a transformation of vegetation on summits due to raising temperatures throughout Europe.

Studies including data on lichens focusing on the terricolous vegetation of summits in the low-alpine to mid-alpine altitudinal belts in the Dovrefjell area showed that terricolous lichens suffer with a decrease of cover, namely as a result of the increasing performance of dwarf shrubs and graminoids (e.g., Michelsen et al. 2009, 2011; Vanneste 2016; Vanneste et al. 2017). Some macrolichen species (e.g., *Thamnolia vermicularis*, *Bryocaulon divergens*) however, were found to be able to increase their cover in the investigated plots during the observation period of 15 years.

Nothing is known about the influence of rising temperature on possible changes in the diversity of saxicolous lichens dwelling in the high-alpine (nival) belt, neither in Central Europe nor in Scandinavia. Only in Antarctica the effect of climate change on saxicolous lichens has so far been studied in some detail (e.g., Sancho et al. 2019) and changes in growth rates of saxicolous lichens are also reported from high elevation sites in the Himalaya range (Bisht et al. 2019).

Practical problems include the slow growth of most of the species, in particular crustose ones, and the long period of time needed for an initial establishment of lichens. Even at lower altitudes in the foreland of glaciers in Jotunheimen, it was observed and calculated, that a period of about 20 years is necessary for the colonization of newly exposed rock surfaces by initial stages of species of *Rhizocarpon* subgen. *Rhizocarpon* (Matthews 2005; Matthews & Vater 2015; Matthews et al. 2020). Therefore, in most cases it will be out of the physical capability of single researchers to perform comparative studies on high alpine peaks during their active time. This underlines the importance of baseline studies providing data for comparative studies in the future. Considerable changes can be expected on Glittertinden. After the melting of the ice cap uncovering larger parts of the blockfield, a superficial weathering process of the freshly exposed rock surfaces will start which, after several years, will make the boulders suitable for an initial colonization by saxicolous lichens. Small patches of soil possibly appearing here and there in between the boulders will be the first microsites where additional species of alpine lichens might manage to settle.

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References

Ahti, T., Hämet-Ahti, L. & Jalas, J. 1968. Vegetation zones and their sections in northwestern Europe. *Annales Botanici Fennici* 5: 169–211.

Alatalo, J. M., Jägerbrand, A. K., Chen, S. & Molau, U. 2017. Responses of lichen communities to 18 years of natural and experimental warming. *Annals of Botany* 120: 159–170.

Amundsen, B. 2014. The lichen that only likes Galdhøpiggen. The lichen species Altissima [sic!] has never been found anywhere else than the summit of Norway's highest mountain – Galdhøpiggen. https://sciencenorway.no/biodiversity-endangered-species-forskningno/the-lichen-that-only-likes-galdhopiggen/1406189, (visited 7 VIII 2020, 7 III 2023).

Andersen, T. B. 1998. Extensional tectonics in the Caledonides of southern Norway, an overview. *Tectonophysics* 285: 333–351.

Ballantyne, C. K. 2010. A general model of autochthonous blockfield evolution. *Permafrost and Periglacial Processes* 21: 289–300.

Ballantyne, C. K. 2018. *Periglacial geomorphology*. Hoboken, Chichester: John Wiley & Sons, 472 pp.

Ballantyne, C. K. & Matthews, J. A. 1982. The development of sorted circles on recently deglaciated terrain, Jotunheimen, Norway. *Arctic and Alpine Research* 14: 341–354.

Battey, M. H. & McRitchie, W. D. 1973. A geological traverse across the pyroxenegranulites of Jotunheimen in the Norwegian Caledonides. *Norsk Geologisk Tidsskrift* 53: 237–265.

Battey, M. H. & McRitchie, W. D. 1975. The petrology of the pyroxene-granulite facies rocks of Jotunheimen, Norway. *Norsk Geologisk Tidsskrift* 55: 1–49.

Baumann, S., Winkler, S. & Andreassen, L. M. 2009. Mapping glaciers in Jotunheimen, South-Norway, during the "Little Ice Age" maximum. *The Cryosphere* 3: 231–243.

Birks, H. J. B. 2021. High-elevation limits and the ecology of high-elevation vascular plants: legacies from Alexander von Humboldt. *Frontiers of Biogeography* 2021, 13.3, e53226, [18 pp.]

Bisht, K., Upadhyay, S. & Joshi, Y. 2019. Higher growth rates of saxicolous lichens in alpine regions of Western Himalaya – A consequence of warming climate? *ENVIS Bulletin Himalayan Ecology* 27: 69–72.

Bjune, A. E. 2005. Holocene vegetation history and tree-line changes on a north–south transect crossing major climate gradients in southern Norway – evidence from pollen and plant macrofossils in lake sediments. *Review of Palaeobotany and Palynology* 133: 249–275.

Braun-Blanquet, J. 1954. La végétation alpine et nivale des Alpes françaises. *SIGMA Communication* 125: 1–72.

Braun-Blanquet, J. 1957. Ein Jahrhundert Florenwandel am Piz Linard (3414 m). *Bulletin du Jardin Botanique de l'État á Bruxelles* 27: 221–232.

Burchardt, D. B. 1948. Fjell i Norge over 2000 m o. h. Norwegian mountains over 2000 metres high. Altitudes, locations, and first ascents. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography* 12: 201–235.

Clauzade, G. & Roux, C. 1975. Lichens récoltés par Jean Amic en Norvège et en Grande-Bretagne. *Bulletin de* la *Société Linnéenne de Provence* 28: 53–63.

Clauzade, G. & Roux, C. 1985. Likenoj de okcidenta Europo. Ilustrita determinlibro. *Bulletin de la Société Botanique du Centre-Ouest, Nouvelle Série, Numéro Spécia*l 7: 1–893.

Cook-Talbot, J. D. 1991. Sorted circles, relative-age dating and palaeoenvironmental reconstruction in an alpine periglacial environment, eastern Jotunheimen, Norway: lichenometric and weathering-based approaches. *The Holocene* 1: 128–141.

Creveld, M. 1981. Epilithic lichen communities in the alpine zone of Southern Norway. *Bibliotheca Lichenologica* 17: 1–288, tab.

Corfu, F., Andersen, T. B. & Gasser, D. 2014. The Scandinavian Caledonides: main features, conceptual advances and critical questions. In: Corfu, F., Gasser, D. & Chew, D. M. (eds), *New perspectives on the Caledonides of Scandinavia and related areas*. Geological Society, London, Special Publications 390(1): 9–43.

Culberson, C. F. & Ammann, K. 1979. Standardmethode zur Dünnschichtchromatographie von Flechtensubstanzen. *Herzogia* 5: 1–24.

Czekirda, J., Etzelmüller, B., Westermann, S., Isaksen, K. & Magnin, F. 2023. Post Little Ice Age rock wall permafrost evolution in Norway. *The Cryosphere* 17: 2725–2754.

Dahl, E. 1946. On different types of unglaciated areas during the Ice Ages and their significance to phytogeography. *New Phytologist* 45: 225–242.

Dahl, E. 1956. Rondane. Mountain vegetation in south Norway and its relation to the environment. *Skrifter Utgitt av Det Norske Videnskaps-Akademi i Oslo*, I. *Matematisk–Naturvidenskapelig Klasse* 3: 1–374, map. (Lichens p. 353–362)

Dahl, E. 1975. Flora and plant sociology in Fennoscandian tundra areas. In: Wielgolaski, F. E. (ed.), *Fennoscandian tundra ecosystems*. Part 1: *Plants and microorganisms*, pp. 62–67. Berlin, Heidelberg, New York: Springer.

Dahl, E. 1986. Zonation in arctic and alpine tundra and fjellfield ecobiomes. In: Polunin, N. (ed.), *Ecosystem theory and application*, pp. 35–62. Chichester, New York: Wiley.

Dahl, E. 1998. *The phytogeography of Northern Europe* (*British Isles*, *Fennoscandia and adjacent areas*). Cambridge, New York, Melbourne: Cambridge University Press.

Dahl, E. & Hygen, G. 1951. Nye høidegrenser på Surtningssuen i Jotunheimen. *Blyttia* 9: 106–110.

Dahl, S. O., Nesje, A. & Øvstedal, J. 1997. Cirque glaciers as morphological evidence for a thin Younger Dryas ice sheet in east-central southern Norway. *Boreas* 26: 161–180.

Degelius, G. N. 1948. Lichenologiska anteckningar fran en resa i sodra Norge. *Botaniska Notiser* 1948: 137–156.

Dierßen, K. 2004. West-Norwegen. In: Burga, C. A., Klötzli, F. & Grabherr, G. (eds), *Gebirge der Erde*. *Landschaft*, *Klima*, *Pflanzenwelt*. pp. 115–123, 477–478. Stuttgart: Ulmer.

Du Rietz, G. E. 1925. Die regionale Gliederung der skandinavischen Vegetation *Svenska Växtsociologiska Sällskapets Handlingar* 8: 1–60, tab.

Dyrrdal, A. V. 2010. Analysis of past snow conditions in Norway – Time periods 1931–60, 1961–90 and 1979–2008. *MET report* No. 10/2010: 32 pp.

Ebert, K. 2009. Terminology of long-term geomorphology: a Scandinavian perspective. *Progress in Physical Geography* 33(2): 163–182.

Engler, R., Randin, C. F., Thuiller, W., Dullinger, S., Zimmermann, N. E., Araujo, M. B., Pearman, P. B., Le Lay, G., Piedallu, C., Albert, C. H., Choler, P., Coldea, G., De Lamo, X., Dirnböck, T., Gégout, J.-C., Gómez-García, D., Grytnes, J.-A., Heegaard, E., Høistad, F., Nogués–Bravo, D., Normand, S., Puşcaş, M., Sebastià, M.-T., Stanisci, A., Theurillat, J.-P., Trivedi, M. R., Vittoz, P. & Guisan, A. 2011. 21st century climate change threatens mountain flora unequally across Europe. *Global Change Biology* 17: 2330–2341 + suppl.

Erikstad, L. & Sollid, J. L. 1986. Neoglaciation in South Norway using lichenometric methods. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography* 40: 85–105.

Etzelmüller, B. & Frauenfelder, R. 2009. Factors controlling the distribution of mountain permafrost in the northern Hemisphere and their influence on sediment transfer. *Arctic*, *Antarctic*, *and Alpine Research* 41: 48–58.

Etzelmüller, B. & Hagen, J. O. 2005. Glacier-permafrost interaction in Arctic and alpine mountain environments with examples from southern Norway and Svalbard. In: Harris, C. & Murton, J. B. (eds), *Cryospheric systems*: *glaciers and permafrost*, pp. 11–27. London: Geological Society, Special Publication 242.

Etzelmüller, B., Berthling, I. & Sollid, J. L. 1998. The distribution of permafrost in Southern Norway; a GIS approach. In: Lewkowicz, A. G. & Allard, M. (eds), *Seventh International Conference on Permafrost*, *Proceedings*, *Collection Nordicana* 57: 251–257. Québec: Centre d'Etudes Nordiques, Universite Laval.

Etzelmüller, B., Hoelzle, M., Heggem, E. S. F., Isaksen, K., Mittaz, C., Vonder Mühll, D., Ødegård, R. S., Haeberli, W. & Sollid, J. L. 2001a. Mapping and modelling the occurrence and distribution of mountain permafrost. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography* 55: 186–194.

Etzelmüller, B., Ødegård, R. S., Berthling, I. & Sollid, J. L. 2001b. Terrain parameters and remote sensing data in the analysis of permafrost distribution and periglacial processes: Principles and examples from Southern Norway. *Permafrost and Periglacial Processes* 12: 79–92.

Etzelmüller, B., Berthling, I. & Sollid, J. L. 2003. Aspects and concepts on the geomorphological significance of Holocene permafrost in southern Norway. *Geomorphology* 52: 87–104.

Foskett, J. I. J. 1998. *The nature and significance* of *microtopographic effects on vegetation succession on selected glacier forelands*, *Jotunheimen and Jostedalen*, *Norway*. ?London: University of Greenwich. Doctoral thesis.

Fossen, H., Pedersen, R. B., Bergh, S. & Andresen, A. 2008. Creation of a mountain chain. The building up of the Caledonides: About 500–405 million years. In: Ramberg, I. B., Bryhni, I., Nøttvedt, A. & Rangsnes, K. (eds), *The making of a land*. *Geology of Norway*. Chapter 6: 178–229. Trondheim: Norsk Geologisk Forening.

Fredin, O., Bergstrøm, B., Eilertsen, R., Hansen, L., Longva, O., Nesje, A. & Sveian, H. 2013. Glacial landforms and Quaternary landscape development in Norway. In Olsen, L., Fredin, O. & Olesen, O. (eds), *Quaternary Geology of Norway*. Geological Survey of Norway Special Publication 13: 5–25.

Frey, E. 1927. Bemerkungen über die Flechtenvegetation Skandinaviens, verglichen mit denjenigen der Alpen. In: Rübel, E. (ed.), Ergebnisse der internationalen pflanzengeographischen Exkursion durch Schweden und Norwegen 1925. *Veröffentlichungen des Geobotanischen Institutes Rübel in Zürich* 4: 210–259.

Fries, T. M. 1871. *Lichenographia scandinavica sive dispositio lichenum in Dania*, *Suecia*, *Norvegia*, *Fennia*, *Lapponia rossica hactenus collectorum*. Vol. 1, Pars prima: [I]–324. Upsaliae: E. Berling.

Fries, T. M. 1874. *Lichenographia scandinavica sive dispositio lichenum* in *Dania*, *Suecia*, *Norvegia*, *Fennia*, *Lapponia rossica hactenus collectorum*. Vol. 1, Pars secunda: 325–639. Upsaliae: E. Berling.

Gisnås, K. 2011. *Modelling of permafrost in Norway using two equilibrium models*. Oslo: University of Oslo. Master thesis.

Gisnås, K., Etzelmüller, B., Farbrot, H., Schuler, T. V. & Westermann, S. 2013. CryoGRID 1.0: Permafrost distribution in Norway estimated by a spatial numerical model. *Permafrost and Periglacial Processes* 24: 2–19.

Gisnås, K., Etzelmüller, B., Lussana, C., Hjort, J., Sannel, A. B. K., Isaksen, K., Westermann, S., Kuhry, P., Christiansen, H. H., Frampton, A. & Åkerman, J. 2017. Permafrost Map for Norway, Sweden and Finland. *Permafrost and Periglacial Processes* 28: 359–378.

Gjærevoll, O. 1956. The plant communities of the Scandinavian alpine snow-beds. *Skrifter Utgitt av Det Norske Videnskaps-Akademi i Oslo*, I. *Matematisk–Naturvidenskapelig Klasse* 1956(1): 1–405. Appendix: Index to species, p. 1–13.

Goehring, B. M., Brook, E. J., Linge, H., Raisbeck, G. M. & Yiou, F. 2008. Beryllium-10 exposure ages of erratic boulders in southern Norway and implications for the history of the Fennoscandian Ice Sheet. *Quaternary Science Reviews* 27: 320–336.

Gottfried, M., Pauli, H., Futschik, A., Akhalkatsi, M., Barančok, P., Alonso, J. L. B., Coldea, G., Dick, J., Erschbamer, B. & Kazakis, G. 2012. Continent-wide response of mountain vegetation to climate change. *Nature Climate Change* 2: 111–115.

Grabherr, G., Nagy, L. & Thompson, D. B. A. 2003. An outline of Europe's alpine areas. In: Nagy, L., Grabherr, G., Körner, C. & Thompson, D. B. A. (eds), *Alpine biodiversity in Europe*, p. 3–12. Berlin, Heidelberg: Springer. (Ecological Studies 167).

Green, F. H. W. & Harding, R. J. 1980. The altitudinal gradients of air temperature in Southern Norway. *Geografiska Annaler*, *Series A*, *Physical Geography*, 62: 29–36.

Grindrud, E. T. 2019. *Changes in species richness and altitudinal distribution of vascular plants in Jotunheimen*, *Norway*. Ås: Norges miljø- og biovitenskapelige universitet. master thesis.

Hafellner, J. 1993. Über Funde von lichenicolen Pilzen und Flechten im südlichen Norwegen. *Herzogia* 9: 749–768.

Hafellner, J. 1994. Beiträge zu einem Prodromus der lichenicolen Pilze Österreichs und angrenzender Gebiete I. Einige neue oder seltene Arten. *Herzogia* 10: 1–28.

Hallang, H., Los, S. O. & Hiemstra, J. F. 2022a. Permafrost, thermal conditions and vegetation patterns since the mid-20th century: A remote sensing approach applied to Jotunheimen, Norway. *Progress in Physical Geography* 46: 716–736.

Hallang, H., Froyd, C. A., Hiemstra, J. F. & Los, S. O. 2022b. Tree line shifts, changing vegetation assemblages and permafrost dynamics on Galdhøpiggen (Jotunheimen, Norway) over the past ~4400 years. *The Holocene* 32: 308–320.

Hanssen-Bauer, I., Førland, E. J., Haddeland, I., Hisdal, H., Mayer, S., Nesje, A., Nilsen, J. E. Ø., Sandven, S., Sandø, A. B., Sorteberg, A. & Ådlandsvik, B. 2015. Klima i Norge 2100. *Kunnskapsgrunnlag for klimatilpasning oppdatert* i 2015. NCCS Report No. 2/2015. 2. Opplag.

Hanssen-Bauer, I., Førland, E. J., Haddeland, I., Hisdal, H., Lawrence, D., Mayer, S., Nesje, A., Nilsen, J. E. Ø., Sandven, S., Sandø, A. B., Sorteberg, A. & Ådlandsvik, B. 2017. *Climate in Norway 2100 – a knowledge base for climate adaptation*. NCCS Report No. 1/2017.

Harris, C. & Cook, J. D. 1986. The detection of high altitude permafrost in Jotunheimen, Norway using seismic refraction techniques: An assessment. *Arctic and Alpine Research* 18: 19–26.

Hauck, C., Isaksen, K., Vonder Mühll, D. & Sollid, J. L. 2004. Geophysical surveys designed to delineate the altitudinal limit of mountain permafrost: an example from Jotunheimen, Norway. *Permafrost and Periglacial Processes* 15: 191–205.

Haugan, R. 1990. *Rhizocarpon dinothetes* new to Scandinavia. – *Graphis Scripta* 3: 25.

Haugan, R., Bendiksby, M., Rui, S. & Timdal, E. 2013. *Molecular phylogeny and taxonomy of the lichen genus Miriquidica* (*Ascomycota, Lecanoraceae*). Pdf of poster. https://doi.org/10.13140/2.1.4281.0886

Haugan, R., Holien, H., Hovind, A. A., Ihlen, P. G. & Timdal, E. 2021. Artsgruppeomtale lav ('Lichenes'). In: *Norsk rødliste for arter 2021*. https://artsdatabanken.no/lister/rodlisteforarter/2021/

Havaas, J. 1903. Om vegetationen paa Hardangervidden. *Bergens Museums Aarbog* 1902(5): 1–19.

Havaas, J. ("Havås") 1928. Om vegetasjonen på toppen av Hårteigen. *Bergens Museums Årbok* 1927 *Naturvidenskabelig Rekke* 3: 1–15.

Hertel, H. 1975. Über einige gesteinsbewohnende Krustenflechten aus der Umgebung von Finse (Norwegen, Hordaland). *Mitteilungen der Botanischen Staatssammlung München* 12: 113–152.

Hestmark, G. 2020. Apostlenes gjerninger: Keilhau og Boeck «oppdager» Jotunfjeldene. *GEO* 23(4): 16–21.

Hestmark, G., Skogesal, O. & Skullerud, O. 2004a. Growth, reproduction, and population structure in four alpine lichens during 240 years of primary colonization. *Canadian Journal of Botany* 82: 1356–1362.

Hestmark, G., Skogesal, O. & Skullerud, O. 2004b. Growth in the alpine saxicolous lichens *Allantoparmelia alpicola* and *Melanelia stygia*. *Nova Hedwigia* 78: 301–309.

Hestmark, G., Skogesal, O. & Skullerud, Ø. 2005. Growth, population density and population structure of *Cetraria nivalis* during 240 years of primary colonization. *The Lichenologist* 37: 535–541.

Hestmark, G., Skogesal, O. & Skullerud, Ø. 2007. Early recruitment equals long-term relative abundance in an alpine saxicolous lichen guild. *Mycologia* 99: 207–214.

Hipp, T., Etzelmüller, B. & Westermann, S. 2014. Permafrost in alpine rock faces from Jotunheimen and Hurrungane, Southern Norway. *Permafrost and Periglacial Processes* 25: 1–13.

Høitomt, T. & Olsen, S. L. 2010. Nye høydegrenser for en rekke karplanter i Norge. *Blyttia* 68: 75–80.

Hole, J. & Bergersen, O. F. 1981. Weichselian till stratigraphy and ice movements in Ottadalen, central south Norway. *Norsk Geologisk Tidsskrift* 61: 25–33.

Holmgren, P. K., Holmgren, N. H. & Barnett, L. C. (eds) 1990. *Index herbariorum. Part I. The herbaria of the world. 8th edition*. Bronx, New York: New York Botanical Garden for the International Association for Plant Taxonomy (Regnum Vegetabile 120).

Hovden, E. T. 2022. *Steinsprangfare i permafrostmiljø i Jotunheimen*. *Klimaendringene sin påvirkning* for *fjellsporten*. Oslo: Universitetet i Oslo. Master thesis.

Hughes, A. L. C., Gyllencreutz, R., Lohne, Ø. S., Mangerud, J. & Svendsen, J. I. 2016. The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1. *Boreas* 45: 1–45.

Isaksen, K., C. Hauck, E. Gudevang, R. S. Odegard & Sollid, J. L. 2002. Mountain permafrost distribution in Dovrefjell and Jotunheimen, southern Norway, based on BTS and DC resistivity tomography data. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography* 56: 122–136.

Isaksen, K., Sollid, J. L., Holmlund, P. & Harris, C. 2007. Recent warming of mountain permafrost in Svalbard and Scandinavia. *Journal of Geophysical Research* 112, F02S04, [11 pp.]

Isaksen, K., Ødegård, R. S., Etzelmüller, B., Hilbich, C., Hauck, C., Farbrot, H., Eiken, T., Hygen, H. O. & Hipp, T. 2011. Degrading mountain permafrost in southern Norway: Spatial and temporal variability of mean ground temperatures, 1999–2009. *Permafrost and Periglacial Processes* 22: 361–377.

Jørgensen, P. M. & Nordin, A. 2009. Lichens in Scandinavia known mainly from Norwegian type specimens. *Graphis Scripta* 21: 1–20.

Jørgensen, R. 1932. *Karplantenes høidegrenser* i *Jotunheimen*. Oslo: Brøgger. (Reprint out of *Nyt Magazin for Naturvitenskaberne* 72: 1–128, map. 1933).

King, L. 1983. High mountain permafrost in Scandinavia. Permafrost, Fourth International Conference, July 17–22, 1983, Fairbanks, Proceedings, pp. 612–617. Washington: National Academy Press.

King, L. 1986. Zonation and ecology of high mountain permafrost in Scandinavia. *Geografiska Annaler*: *Series A*, *Physical Geography* 68: 131–139.

King, L. & Åkerman, J. 1993. Mountain permafrost in Europe. In: *Permafrost*. *Sixth International Conference*. *July* 5–9, 1993, *Beijing*. *Proceedings* Vol. 2: 1022–1027. Wushan, Guangzhou: South China University of Technology Press.

Klanderud, K. 2000. *Recent changes in the altitudinal distribution of vascular plants in Jotunheimen*, *central south Norway*. Bergen: University of Bergen. Cand. Sci. thesis, 104 pp. [publication not seen, data pages sent by the author, results summarized in Klanderud & Birks 2003, data also included in Grindrud 2019)

Klanderud, K. 2008. Species-specific responses of an alpine plant community under simulated environmental change. *Journal of Vegetation Science* 19: 363–372.

Klanderud, K. & Birks, H. J. B. 2003. Recent increases in species richness and shifts in altitudinal distributions of Norwegian mountain plants. *The Holocene* 13(1): 1–6.

Klanderud, K. & Totland, Ø. 2005. Simulated climate change altered dominance hierarchies and diversity of an alpine biodiversity hotspot. *Ecology* 86: 2047–2054.

Klanderud, K. & Totland, Ø. 2008. Diversity-stability relationships of an alpine plant community under simulated environmental change. *Arctic*, *Antarctic*, *and Alpine Research* 40(4): 679–684.

Klement, O. 1955. Prodromus der mitteleuropäischen Flechtengesellschaften. *Feddes Repertorium Specierum Novarum Regni Vegetabilis*, *Beiheft* 135: 5–194.

Knudsen, K. & Kocourková, J. 2008. A study of lichenicolous species of Polysporina (*Acarosporaceae*). *Mycotaxon* 105: 149–164.

Krog, H., Østhagen, H. & Tønsberg, T. 1994. *Lavflora*. *Norske busk- og bladlav*. Oslo: Universitetsforlaget. 368 pp.

Kruse, R. & Stünitz, H. 1999. Deformation mechanisms and phase distribution in mafic high-temperature mylonites from the Jotun Nappe, southern Norway. *Tectonophysics* 303: 223–249.

Kukwa, M. 2011. *The lichen genus Ochrolechia in Europe*. Gdánsk: Fundacja Rozwoju Uniwersytetu Gdánskiego. 309 pp.

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

Lane, T. P., Paasche, Ø., Kvisvik, B., Adamson, K. R., Rodés, Á., Patton, H., Gomez, N., Gheorghiu, D., Bakke, J. & Hubbard, A. 2020. Elevation changes of the Fennoscandian Ice Sheet interior during the last deglaciation. *Geophysical Research Letters* 47, e2020GL088796 [10 pp.]

Lawrey, J. D. & Diederich, P. 2003. Lichenicolous fungi: Interactions, evolution, and biodiversity. *The Bryologist* 106: 80–120.

Lidmar-Bergström, K. & Näslund, J. O. 2002. Landforms and uplift in Scandinavia. In: Doré, A. G., Cartwright, J. A, Stoker, M. S., Turner, J. R & White, N. (eds), *Exhumation of the North Atlantic Margin*: *Timing*, *mechanisms and implications for petroleum exploration*. Geological Society, London, Special Publications 196: 103–116.

Lidmar-Bergström, K., Ollier, C. D. & Sulebak, J. R. 2000. Landforms and uplift history of southern Norway. *Global and Planetary Change* 24: 211–231.

Lidmar-Bergström, K., Bonow, J. M. & Japsen, P. 2013. Stratigraphic Landscape Analysis and geomorphological paradigms: Scandinavia as an example of Phanerozoic uplift and subsidence. *Global and Planetary Change* 100: 153–171

Lie, Ø., Dahl, S. O. & Nesje, A. 2003. A theoretical approach to glacier equilibrium-line altitudes using meteorological data and glacier mass-balance records from southern Norway. *The Holocene* 13: 365–372.

Lilleøren, K. S., Etzelmüller, B., Schuler, T. V., Ginås, K. & Humlum, O. 2012. The relative age of permafrost – estimation of Holocene permafrost limits in Norway. *Global and Planetary Change* 92–93: 209–223.

Lundmark, A. M., Corfu, F., Spurgin, S. & Selbekk, R. S. 2007. Proterozoic evolution and provenance of the high-grade Jotun Nappe Complex, SW Norway: U–Pb geochronology. *Precambrian Research* 159: 133–154.

Lye, K. A. 1973. The vascular plants on alpine peaks at Filefjell, south Norway. *Norwegian Journal of Botany* 20: 51–55.

Lynge, B. 1921. Studies on the lichen flora of Norway. *Skrifter Utgit av Videnskapsselskapet i Kristiania*, I. *Matematisk–Naturvidenskapelig Klasse*, 1921, 1. Bind, no. 7: 1–252.

Machaček, F. 1908. Geomorphologische Studien aus dem norwegischen Hochgebirge [Geomorphologic studies from the Norwegian high mountain area]. *Abhandlungen der K.-K. Geographischen Gesellschaft in Wien* 7(2): 1–58, tab.

Magnin, F., Etzelmüller, B., Westermann, S., Isaksen, K., Hilger, P. & Hermanns, R. L. 2019. Permafrost distribution in steep rock slopes in Norway: measurements, statistical modelling and implications for geomorphological processes. *Earth Surface Dynamics* 7: 1019–1040.

Mangerud, J., Gyllencreutz, R., Lohne, Ø. & Svendsen, J. I. 2011. Glacial history of Norway. In: Ehlers, J., Gibbard, P. L. & Hughes, P. D. (eds), *Quaternary glaciations – extent and chronology*: *a closer look*. Developments in Quaternary Science 15: 279–298. Amsterdam: Elsevier.

Mangerud, J., Aarseth, I., Hughes, A. L. C., Lohne, Ø. S., Skår, K., Sønstegaard, E. & Svendsen, J. I. 2016. A major re-growth of the Scandinavian Ice Sheet in western Norway during Allerød-Younger Dryas. *Quaternary Science Reviews* 132: 175–205.

Manley, G. 1955. On the occurrence of ice domes and permanently snow-covered summits. *Journal of Glaciology* 2(17): 453–456.

Marr, P., Winkler, S. & Löffler, J. 2018. Investigations on blockfields and related landforms at Blåhø (Southern Norway) using Schmidt-hammer exposure-age dating: palaeoclimatic and morphodynamic implications. *Geografiska Annaler*: *Series A*, *Physical Geography* 100(3): 285–306.

Matthews, J. A. 1973. Lichen growth on an active medial moraine, Jotunheimen, Norway. *Journal of Glaciology* 12(65): 305–313.

Matthews, J. A. 1974. Families of lichenometric dating curves from the Storbreen gletschervorfeld, Jotunheimen, Norway. *Norsk Geografisk Tidskrift – Norwegian Journal of Geography* 28: 215–235.

Matthews, J. A. 1975. Experiments on the reproducibility and reliability of lichenometric dates, Storbreen gletschervorfeld, Jotunheimen, Norway. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography* 29: 97–109.

Matthews, J. A. 1977. A lichenometric test of the 1750 end moraine hypothesis. Storbreen gletschervorfeld. Jotunheimen, Norway. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography* 31: 129–136.

Matthews, J. A. 1979a. The vegetation of the Storbreen Gletschervorfeld, Jotunheimen, Norway. I. Introduction and approaches involving classification. *Journal of Biogeography* 6(1): 17–47.

Matthews, J. A. 1979b. The vegetation of the Storbreen glacier foreland, Jotunheimen, Norway, II. Approaches involving ordination and general conclusions. *Journal of Biogeography* 6: 133–167.

Matthews, J. A. 2005. 'Little Ice Age' glacier variations in Jotunheimen, southern Norway: a study in regionally controlled lichenometric dating of recessional moraines with implications for climate and lichen growth rates. *The Holocene* 15(1): 1–19.

Matthews, J. A. & Dresser, P. Q. 2008. Holocene glacier variation chronology of the Smørstabbtindan massif, Jotunheimen, southern Norway, and the recognition of century- to millennial-scale European Neoglacial events. *The Holocene* 18: 181–201.

Matthews, J. A. & Nesje, A. 2023 (?2022). Scandinavia. In: Oliva, M., Nývlt, D. & Fernández-Fernández, J. M. (eds), *Periglacial landscapes of Europe*, pp. 365–426. Cham: Springer.

Matthews, J. A. & Vater, A. E. 2015. Pioneer zone geo-ecological change: observations from a chronosequence on the Storbreen glacier foreland, Jotunheimen, southern Norway. *Catena* 135: 219–230.

Matthews, J. A., Dahl, S. O., Nesje, A., Berrisford, M. S. & Andersson, C. 2000. Holocene glacier variations in central Jotunheimen, southern Norway based on distal glaciolacustrine sediment cores. *Quaternary Science Reviews* 19: 1625–1647.

Matthews, J. A., Hill, J. L., Winkler, S., Owen, G. & Vater, A. E. 2018. Autosuccession in alpine vegetation: Testing the concept on an altitudinal bioclimatic gradient, Jotunheimen, southern Norway. *Catena* 170: 169–182.

Matthews, J. A., Haselberger, S., Hill, J. L., Owen, G., Winkler, S., Hiemstra, J. F. & Hallang, H. 2020. Snow-avalanche boulder fans in Jotunheimen, southern Norway: Schmidt-hammer exposure-age dating, geomorphometrics, dynamics and evolution. *Geografiska Annaler*: *Series A*, *Physical Geography*, 102(2): 118–140.

McEwen, L. J., Matthews, J. A. & Owen, G. 2020. Development of a Holocene glacier-fed alluvial fan based on calibrated- and relative age dating techniques: the Illåe fan, Jotunheimen, Norway. *Geomorphology* 363 (2020) 107200. [15 pp.]

McKerrow, W. S., Mac Niocaill, C. & Dewey, J. F. 2000. The Caledonian Orogeny redefined. *Journal of the Geological Society*, *London* 157: 1149–1154.

Melvold, K. & Andreassen, L. M. 2021. Glittertinden. In: Kjøllmoen, B. (ed.), *Glaciological investigations in Norway 2020*. *NVE Rapport* 31/2021: 85–89. Oslo: Norwegian Water Resources and Energy Directorate.

Michelsen, O., Holten, J. I. & Syverhuset, A. O. 2009. Kartlegging av fjellflora for å studere effekter av klimaendringer – foreløpige resultater fra en undersøkelse på Dovrefjell. [An analysis of alpine flora to investigate effects of climate change – preliminary results from a study in Dovre mountain region]. *Blyttia* 67(1): 50–67.

Michelsen, O., Syverhuset, A. O., Pedersen, B. & Holten, J. I. 2011. The impact of climate change on recent vegetation changes on Dovrefjell, Norway. *Diversity* 2011(3): 91–111.

Nagy, L. & Grabherr, G. 2009. *The biology of alpine habitats*. Oxford: Oxford University Press.

Naughton, F., Sánchez Goñi, M. F. & Toucanne, S. 2023 (?2022). Quaternary climate variability and periglacial dynamics. In: Oliva, M., Nývlt, D. & Fernández-Fernández, J. M. (eds), *Periglacial landscapes of Europe*, pp. 7–35. Cham: Springer.

Nesje, A. & Dahl, S. O. 1990. Autochthonous blockfields in southern Norway: implications for the geometry, thickness and isostatic loading of the Late Weichselian Scandinavian ice sheet. *Journal of Quaternary Science* 5: 225–234.

Nesje, A., Dahl, S. O., Anda, E., Rye, N., 1988. Block fields in southern Norway: Significance for the Late Weichselian ice sheet. *Norsk Geologisk Tidsskrift* 68: 149–169.

Nesje, A., McCarroll, D. & Dahl, S. O. 1994. Degree of rock surface weathering as an indicator of ice-sheet thickness along an east-west transect across southern Norway. *Journal of Quaternary Science* 9(4): 337–347.

Nordhagen, R 1943. Sikilsdalen og Norges fjellbeiter. En plantesosiologisk monografi. *Bergens Museums Skrifter* 22: 1–607.

Noreng Trøn, M. I. & Lusæter, E. 2020. Skulle finne høgda på Glittertind – vart overraska over det dei oppdaga. https://www.nrk.no/innlandet/skulle-male-hogda-pa-glittertind-og-fant-ut-at-breen-pa-toppen-snart-er-borte-1.15169507 (visited 7. III. 2023)

Odland, A. 2009. Interpretation of altitudinal gradients in south central Norway based on vascular plants as environmental indicators. *Ecological Indicators* 9: 409–421.

Odland, A. 2010. Importance of mountain height and latitude for the altitudinal distribution limits of vascular plants in Scandinavia: are the mountains high enough? *Fennia* 188(2): 149–162.

Odland, A. 2012. Karplantefloraen på Hårteigen, Hardangervidda. Endringer fra 1877 til 2010. *Blyttia* 70(1): 52–61.

Odland, A. & Birks, H. J. B. 1999. The altitudinal gradient of vascular plant richness in Aurland, western Norway. *Ecography* 22: 548–566.

Odland, A., Høitomt, T. & Olsen, S. L. 2010. Increasing vascular plant richness on 13 high mountain summits in Southern Norway since the early 1970s. *Arctic*, *Antarctic*, *and Alpine Research* 42(4): 458–470.

Odland, A., Reinhardt, S. & Pedersen, A. 2015. Differences in richness of vascular plants, mosses, and liverworts in southern Norwegian alpine vegetation. *Plant Ecology* & *Diversity* 8(1): 37–47.

Odland, A., Høitomt, T. & Olsen, S. L. 2018. Variasjon i karplantemangfold i de øvre delene av 20 fjell-topper i Sør-Norge. *Blyttia* 76(1): 17–31.

Ødegård, R., Liestøl, O. & Sollid, J. L. 1988. Periglacial forms related to terrain parameters in Jotunheimen, southern Norway. In: Senneset, K. (ed.), *Permafrost*, *Fifth International Conference*, *August* 2–5, 1988, *Trondheim*. *Proceedings* vol. 3: 55–61. Trondheim: Tapir Publishers.

Ødegård, R. S., Sollid, J. L. & Liestøl, O. 1992. Ground temperature measurements in mountain permafrost, Jotunheimen, southern Norway. *Permafrost and Periglacial Processes* 3: 231–234.

Ødegård, R. S., Isaksen, K., Mastervik, M., Billdal, L., Engler, M. & Sollid, J. 1999. Comparison of BTS and Landsat TM data from Jotunheimen, southern Norway. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography* 53(4): 226–233.

Østhagen, H. 1975. Makrolavfloraen i Ovre Heimdalen, Jotunheimen. The macrolichens of Ovre Heimdalen, Jotunheimen, central South Norway. *Blyttia* 33(2): 83–87.

Østrem, G. 1965. Problems of dating ice-cored moraines. *Geografiska Annaler*. *Series A*, *Physical Geography* 47(1): 1–38.

Østrem, G., Selvig, K. D. & Tandberg, K. 1988. Atlas over breer i Sør-Norge [Atlas of glaciers in south Norway]. *Meddelelse fra Hydrologisk Avdeling* 61: A-1–A-68, B-1–B-180. Oslo: Norges Vassdrags-og Energiverk Vassdragsdirektoratet.

Patton, H., Hubbard, A., Andreassen, K., Winsborrow, M. & Stroeven, A. P. 2016. The build-up, configuration, and dynamical sensitivity of the Eurasian ice-sheet complex to Late Weichselian climatic and oceanic forcing. *Quaternary Science Reviews* 153: 97–121.

Patton, H., Hubbard, A., Andreassen, K., Auriac, A., Whitehouse, P. L., Stroeven, A. P., Shackleton, C., Winsborrow, M., Heyman, J. & Hall, A. M. 2017. Deglaciation of the Eurasian ice sheet complex. *Quaternary Science Reviews* 169: 148–172.

Pauli, H., Gottfried, M. & Grabherr, G. 2003. The Piz Linard (3411 m), the Grisons, Switzerland – Europe's oldest mountain vegetation study site. In: Nagy, L., Grabherr, G., Körner, C. & Thompson, D. B. A. (eds), Alpine *biodiversity in Europe*. *Ecological Studies* 167: 443–448. Berlin, Heidelberg: Springer.

Paus, A., Velle, G., Larsen, J., Nesje, A. & Lie, Ø. 2006. Lateglacial nunataks in central Scandinavia: Biostratigraphical evidence for ice thickness from Lake Flåfattjønn, Tynset, Norway. *Quaternary Science Reviews* 25: 1228–1246.

Paus, A., Velle, G. & Berge, J. 2011. The Lateglacial and early Holocene vegetation and environment in the Dovre mountains, central Norway, as signalled in two Lateglacial nunatak lakes. *Quaternary Science Reviews* 30: 1780–1796.

Paus, A., Boessenkool, S., Brochmann, C., Epp, L. S., Fabel, D., Haflidason, H. & Linge, H. 2015. Lake Store Finnsjøen–a key for understanding Lateglacial/early Holocene vegetation and ice sheet dynamics in the central Scandes Mountains. *Quaternary Science Reviews* 121: 36–51.

Piper, J. D. A. & Poppleton, T. J. 1990. A palaeomagnetic study of the Basal Gneiss Region and Jotun Nappe Complex, central-southem Scandinavian Caledonides. *Geophysical Journal International* 101: 591–612.

Purvis, O. W. & Halls, C. 1996. A review of lichens in metal-enriched environments. *The Lichenologist* 28(6): 571–601.

Rea, B. R. 2013. Blockfields (Felsenmeer). In: Elias, S. A. (ed.), *The Encyclopedia of Quaternary Science*, Vol. 3: 523–534. Amsterdam: Elsevier.

Reisigl, H. & Pitschmann, H. 1958. Obere Grenzen von Flora und Vegetation in der Nivalstufe der zentralen Ötztaler Alpen (Tirol). *Vegetatio* 8(2): 93–129.

Reusch, H. 1903. Betrachtungen über das Relief von Norwegen. *Geographische Zeitschrift* 9(8): 425–435.

Rixen, C. & Wipf, S. 2017. Non-equilibrium in alpine plant assemblages: Shifts in Europe's summit floras. In: Catalan, J., Ninot, J. M. & Aniz, M. M. (eds), *High mountain conservation in a changing world*. *Advances in Global Change Research* 62: 285–303.

Rixen, C., Wipf, S., Frei, E. & Stöckli, V. 2014. Faster, higher, more? Past, present and future dynamics of alpine and arctic flora under climate change. *Alpine Botany* 124: 77–79.

Runemark, H. 1956. Studies in *Rhizocarpon* II. Distribution and ecology of the yellow species in Europe. *Opera Botanica* 2(2): 1–150.

Sancho, L. G., Pintado, A. & Green, T. G. A. 2019. Antarctic studies show lichens to be excellent biomonitors of climate change. *Diversity* 11(3): 42 [14 p.].

Schei, A. J. S. 1984. Makrolavfloraen i Dovrefjell nasjonalpark. The Macrolichens of Dovrefjell National Park. *Gunneria* 50: 1–117.

Scheidegger, C. 2021. High alpine lichens. In: Büdel, B. & Friedl, T. (eds), *Life at rock surfaces*: *Challenged by extreme light*, *temperature and hydration fluctuations*, pp. 161–173. Berlin, Boston: Walter de Gruyter.

Smith, C. W., Aptroot, A., Coppins, B. J., Fletcher, A., Gilbert, O. L., James, P. W. & Wolseley, P. A. (eds), 2009. *The lichens of Great Britain and Ireland*. London: British Lichen Society, Department of Botany, The Natural History Museum.

Sollid, J. L. & Sørbel, L. 1994. Distribution of glacial landforms in southern Norway in relation to the thermal regime of the last continental ice sheet. *Geografiska Annaler*: *Series A*, *Physical Geography* 76(1–2): 25–35.

Sparrius, L. B. Spier, J. L., Breuss, O. & Vervoort, M. 2006. Korstmossen van het BLWG-zomerkamp in Noorwegen in 2002. *Buxbaumiella* 75: 26–33.

Sparrius, L., Spier, L., Breuss, O. & Vervoort, M. 2007. Contribution to the lichen flora of the Hardangervidda mountain plateau and adjacent areas, Norway. *Graphis Scripta* 19(2): 53–55.

Stöckli, V., Wipf, S., Nilsson, C. & Rixen, C. 2012. Using historical plant surveys to track biodiversity on mountain summits. *Plant Ecology & Diversity* 4(for 2011): 415–425.

Strøm, K. M. 1948. The geomorphology of Norway. *The Geographical Journal* 112(1–3): 19–23.

Stroeven, A. P. Hättestrand, C., Kleman, J., Heyman, J., Fabel, D., Fredin, O., Goodfellow, B. W., Harbor, J. M., Jansen, J. D., Olsen, L., Caffee, M. W., Fink, D., Lundqvist, J., Rosqvist, G. C., Strömberg, B. & Jansson, K. N. 2016. Deglaciation of Fennoscandia. *Quaternary Science Reviews* 147: 91–121.

Timdal, E. 1982. Bidrag til Norges lavflora. Contributions to the lichen flora of Norway. *Blyttia* 40: 179–185.

Timdal, E. 1983. The genus *Squamarina* in Scandinavia. *The Lichenologist* 15: 169–179.

Timdal, E. 1984. *Acarospora intricata* and *A*. *wahlenbergii* (*Acarosporaceae*) in Scandinavia. *Nordic Journal of Botany* 4: 541–543.

Timdal, E. 1992. The distribution of *Mycobilimbia fissuriseda*. *Graphis Scripta* 3: 115–117.

Tønsberg, T. 1992. The sorediate and isidiate, corticolous, crustose lichens in Norway. *Sommerfeltia* 14: 1–331.

Vanneste, T. 2016. *Climate change and alpine vegetation shifts on mountaintop summits in Norway*. Gent: University of Gent. Master thesis. http://lib.ugent.be/fulltxt/RUG01/002/275/112/RUG01-002275112_2016_0001_AC.pdf

Vanneste, T., Michelsen, O., Graae, B. J., Kyrkjeeide, M. O., Holien, H., Hassel, K., Lindmo, S., Kapás, R. E. & De Frenne, P. 2017. Impact of climate change on alpine vegetation of mountain summits in Norway. *Ecological Research* 32: 579–593 + suppl.

Vorren, T. O. & Mangerud, J. 2008. Glaciations come and go. Quaternary to Holocene (Pleistocene): 2,6 Ma–11,500 years ago. In: Ramberg, I. B., Bryhni, I., Nøttvedt, A. & Rangsnes, K. (eds), *The making of a land*. *Geology* o*f Norway*. Chapter 15: 480–532. Trondheim: Norsk Geologisk Forening.

Vorren, T. O., Mangerud, J., Blikra, J., Nesje, A. & Sveian, H. 2008. The emergence of modern Norway. The last 11,500 years – the Holocene. In: Ramberg, I. B., Bryhni, I., Nøttvedt, A. & Rangsnes, K. (eds), *The making of a land*. *Geology of Norway*. Chapter 16: 534–558. Trondheim: Norsk Geologisk Forening.

Vrang, E. P. 1934. Bidrag till kännedomen om Dovres lavflora. *Det Kongelige Norske Videnskabers Selskab Forhandlinger* 7: 8–10.

Westberg, M., Moberg, R., Myrdal, M., Nordin, A. & Ekman, S. 2021. *Santesson's checklist of Fennoscandian lichen-forming and lichenicolous fungi*. – Uppsala: Uppsala University, Museum of Evolution.

Westermann, S., Schuler, T. V., Gisnås, K. & Etzelmüller, B. 2013. Transient thermal modeling of permafrost conditions in Southern Norway. *The Cryosphere* 7: 719–739.

Wilson, P. 2009. Storurdi: A Late Holocene rock-slope failure (sturzstrom) in the Jotunheimen, Southern Norway. *Geografiska Annaler*: *Series A*, *Physical Geography* 91(1): 47–58.

Winkler, S., Donner, A. & Tintrup gen. Suntrup, A. 2021 (?2020). Periglacial landforms in Jotunheimen, central southern Norway, and their altitudinal distribution. In: Beylich, A. A. (ed.), *Landscapes and landforms of Norway*, pp. 169–202. Cham: Springer.

Wipf, S., Stöckli, V., Herz, K. & Rixen, C. 2013. The oldest monitoring site of the Alps revisited: accelerated increase in plant species richness on Piz Linard summit since 1835. *Plant Ecology & Diversity* 6(3–4): 447–455.

Wirth, V. 1995. *Flechtenflora. Bestimmung und ökologische Kennzeichnung der Flechten Südwestdeutschlands und angrenzender Gebiete*. 2. Aufl. Stuttgart: Ulmer Verlag.