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Does the moss *Racomitrium lanuginosum* form mires in Iceland?

Muodostaako kalliotierasammal soita Islannissa?

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In Iceland, moss *Racomitrium lanuginosum* is the pioneer species covering lava rock surfaces. The growing moss forms thick mats of living moss and dead organic matter of up to 40 cm over the rocks, and the annual thickening rate of the mat can be almost 2 mm in favourable conditions. These ecosystems are usually called Racomitrium heaths. However, as *R. lanuginosum* also grows in peatlands (e.g., in blanket peats in British Isles), the question arises, could the *R. lanuginosum* covered heaths in Iceland be defined as peatlands, i.e., ecosystems where organic matter, peat, is actively being formed by wetland plants? In this essay we discuss the ecology and distribution of *Racomitrium lanuginosum*, in order to answer whether the term peatland is relevant in the context of Icelandic Racomitrium heaths.

Introduction

In Iceland there are large and vast rocky areas covered in Woolly Fringe-Moss *Racomitrium lanuginosum* (Hedw.) Brid. The rock beneath the moss has formulated from volcanic eruptions. Each eruption starts a new cycle of primary succession, as the fresh lava rock has no vegetation on it to begin with.

On our field course to Iceland, we visited one of such rocky plains on the Eldhraun lava field, where we were asked the question, does the *Racomitrium* moss growing on such rocks form peat. This was an interesting question to toss around, as it seemed that a layer of partly decomposed organic matter had formed underneath the *R. lanuginosum* growing on the lava field. The moss layer consisting of both growing moss and dead moss parts also seemed to get quite thick. Relevance of the question was further enhanced by the fact that in Scotland there are blanket bogs where *R. lanuginosum* is one of the formers of peat (Lindsay et al. 1988).

To answer such a question, one must discuss what peat is, and what are peatlands exactly. In this essay our intention is to take this question seriously and argue whether the term peatland is relevant in the context of Icelandic *Racomitrium* fields. On our dive into the ecology of *Racomitrium* and the basics of peatland formulation we hope to give a conclusive answer to the question "Does *Racomitrium* moss growing on lava rock formulate peat and therefore peatlands?".

The ecology of the moss *Racomitrium lanuginosum*

Mosses are an essential part of arctic and subarctic flora (Longton 1982; Jägerbrand et al. 2011). They can survive in harsh climatic conditions where temperature is low and the growing season short. In addition to this, they can grow in places with low nutrient availability. Mosses are also the main formulants of peat in many mire ecosystems. Our interest is in one specific species of moss, *R. lanuginosum*, as it forms thick moss mats on volcanic land and other suitable soil (Longton 1982, 1988; Bjarnason 1991).

Racomitrium lanuginosum is a very widespread species around the globe, as it can be found on all continents (Tallis 1958; Ochyra & Bednarek-Ochyra 2007). However, it is most abundant in the northern hemisphere in maritime areas (Tallis 1958). The geographical distribution of *R. lanuginosum* is governed by air humidity, rainfall, and temperature (Tallis 1958), while the occurrence within a given region is enhanced by increasing latitude and oceanity of the climate and decreasing competition by higher plants (Tallis 1958; Kallio & Heinonen 1973). The moss tufts may desiccate if relative humidity is below 95% (Tallis 1964). Thus, areas with ample rain, low clouds and frequent fog are ideal for *R. lanuginosum* (Tallis 1958). The optimum temperature for net photosynthesis has been observed to be 5 °C (Kallio & Heinonen 1973) or 8–10 °C (Tallis 1959) and for elongation growth 12–13 °C (Tallis 1964). The moss dominated vegetation type becomes more prominent at higher elevations. In the Thingvallavatn area, southwestern Iceland, mosses, mostly *Racomitrium* spp., were observed to grow in harsh conditions at 700–800 m (Thorsteinsson & Arnalds 1992), which is at the limit of continuous plant cover in Iceland (Thorsteinsson et al. 1971). Iceland had the greatest moss cover and thickness on measured *R. lanuginosum* heath plots when compared to Norway, Faroes, and the United Kingdom, where *R. lanuginosum* also forms thick moss mats. However, shoot decomposition and biomass turnover were greater at the UK sites (Armitage et al. 2012).

R. lanuginosum prefers a combination of high humidity and dry growing surface. Distribution of *R. lanuginosum* is also controlled by high water table, as its respiration rate is lowered as water content rises above 400% of dry weight (Tallis 1959, 1964). Flora of North America describes *R. lanuginosum* as a moss that grows on dry, exposed areas, mostly with high light intensity (Ochyra & Bednarek-Ochyra 2007). It is further described to grow on acidic or seldom calciferous soil and rocks, boulders, cliffs, ledges, scree and in fellfields, polar tundra and tundra-like barrens in mountains, hummocks in peatland and moorland and over raw earth of bog margins. The porous volcanic soil found in Iceland also suits the species (Longton 1982, 1988; Bjarnason 1991). In Iceland *R. lanuginosum* moss cover is a common sight, playing an important role in the primary succession of lava fields and other types of rocks (Vilmundardóttir et al. 2018).

R. lanuginosum can form vast moss mats as a part of primary or secondary succession (Bjarnason 1991; Thorsteinsson & Arnalds 1992), or in higher altitudes where vascular plants can not grow (Thorsteinsson & Arnalds 1992). The moss mat thickens as the moss grows continuously upwards. The annual thickening rate of the mat can be 1.6–1.7 mm on lava in favourable conditions (Vilmundardóttir et al. 2018). The average moss thickness varies between regions but for Iceland, Armitage et al. (2012) measured 8.6 cm and Vilmundardóttir et al. (2018) 13.7 cm. The maximum thickness is reached after 300–700 years (Vilmundardóttir et al. 2018). Tallis (1959) and Bjarnason (1991) suggest that *R. lanuginosum* can in some conditions reach a thickness of even 30–40 cm. *R. lanuginosum* can fully cover a lava field in 24 years (Vilmundardóttir et al. 2018) and it can dominate landscape for centuries.

The Eldhraun lava field that our group visited was formed by the Laki eruption that lasted from 1783 to 1784 (Guilbaud et al. 2005) (Figs. 1, 2).

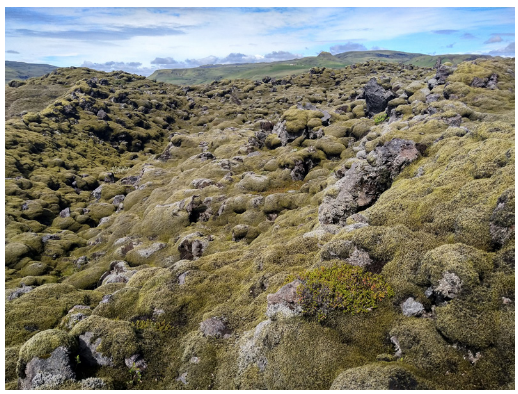

Fig. 1. *Racomitrium lanuginosum* has formed a dense mat on The Eldhraun Lava Field on the southern coast of Iceland. Photo: Jaana Kulmala.

Kuva 1. Kalliotierasammal (Racomitrium lanuginosum) muodostaa tiivistä sammalmattoa laavakivien päälle Eldhraun laavakentällä Etelä-Islannissa.

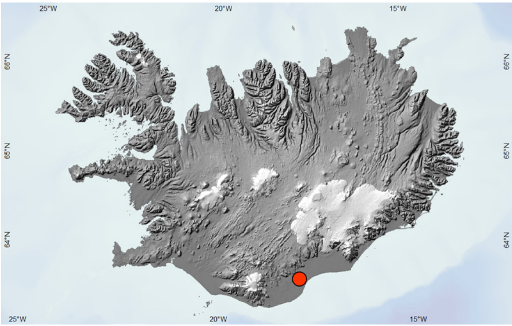

Fig. 2. The location of the Eldhraun lava field within Iceland. Map based on data from: https://gatt.lmi.is/geonetwork/srv/eng/catalog.search#/metadata/6dc71751-5fbe-4464-9743-231700e09e48

Kuva 2. Eldhraun laavakentän sijainti.

The age of the moss cover is therefore almost 250 years, and it represents the second stage of succession on lava according to succession stages by Vilmundardóttir et al. (2018). They identified four stages of succession on the lava flows of Hekla volcano in south Iceland, which were 1) initial colonization and cover coalescence of *R. lanuginosum* and *Stereocaulon* spp. (lavas <70 years of age), 2) secondary colonization – *R. lanuginosum* dominance (170−700 years), 3) vascular plant dominance (>600 years), which includes birch woodland, Iceland's climax ecosystem, and 4) highland conditions/retrogression by tephra deposition (70−860 years).

The *R. lanuginosum* moss mats we observed are a distinct habitat type called *Racomitrium* heath. Besides just Iceland, it is a common vegetation type in also other maritime parts of the Arctic (Tallis 1958). The Icelandic *R. lanuginosum* heaths on lava are recognized by the European Nature Information System (EUNIS) as their completely own habitat type (European Environment Agency 2012a). In the EUNIS classification they fall under the category "Moss and lichen dominated mountain summits, ridges and exposed slopes" as a subcategory "Icelandic lava flow moss heath".

In the EUNIS fact sheet the *R. lanuginosum* heaths are described as habitats where *R. lanuginosum* forms thick mantles that cover very large surfaces over all parts of the relief, engulfing asperities, bridging gaps, draping protruding rocks with large cushions, or else, in less evolved complexes, forming preferentially in the depressions and concavities where some organic matter accumulates.

Racomitrium lanuginosum bogs of the United Kingdom

In the British Isles, *R. lanuginosum* is found in different environments and varying altitudes (Tallis 1958). In high altitudes, such as fellfields and exposed mountain tops with shattered rock waste, it forms *R. lanuginosum* heaths. In the EUNIS classification these heaths belong to a habitat type called "Oroboreal *Carex bigelowii-Racomitrium* moss-heaths" (European Environment Agency 2012b). This habitat type can be found also in Iceland along with the habitat type "Icelandic lava flow moss heaths".

In low altitudes *R. lanuginosum* is found in lowland calcareous grassland, dry-stone walls, patterned blanket mires with *Cladonia* spp. and in the vicinity of eroded, such as grazed or burned peat (Tallis 1995; Ellis & Tallis 2003). Since *R. lanuginosum* seems intolerant to permanently high water table (Tallis 1959), on mire sites it grows on tall hummocks, peat mounds, ridges and gully sides as suitable environments (Tallis 1995). *R. lanuginosum* can still grow on a wide range of water table depths (Tallis 1995). For example, in the patterned mire of Silver Flowe in southern Scotland, *R. lanuginosum* was found 2–60 cm above the water table (Ratcliffe & Walker 1958).

Ellis and Tallis (2003) described different scenarios where *R. lanuginosum* grows on British blanket bogs both due to disturbance and naturally. According to them *R. lanuginosum* is mostly associated with tall hummock growth, and disturbances that have lowered the water table of the mires, such as drainage. In disturbed conditions *R. lanuginosum* may also occur in the succession process turning blanket mires into heaths. Blanket mires and heaths in the United Kingdom are formed both naturally and culturally (Moore et al. 1984).

In addition to disturbances, Ellis and Tallis (2003) suggest that *R. lanuginosum* occurs during periods of climate change from dryer conditions towards increased humidity. After a period of dry climate, when the climatic humidity rises, *R. lanuginosum* appears to the mire surface. When the humidity increases such that water table rises as well, the abundance of *Sphagna* increases and the abundance of *R. lanuginosum* decreases. Palaeo-ecological evidence that Ellis and Tallis (2003) gathered suggests that development of blanket bogs has met both drier and wetter climatic conditions. In their peat samples, layers of *R. lanuginosum* and *Sphagna* alternate, and *R. lanuginosum* is most abundant during conditions of lower water table but high climatic humidity. This suggests that in addition to conditions of disturbances, *R. lanuginosum* is also a natural peat-forming component in the blanket mires, and part of their natural cycles.

In addition to water table and humidity, other occurrence regulating factors on *R. lanuginosum* growth on mire are low growing speed of 5 to 15 mm/year and the moss's susceptibility to competition (Tallis 1958, 1959).

The British blanket mire is nationally and internationally recognized as an important habitat that faces threats from other land uses (Lindsay 1995). In the United Kingdom they are threatened mostly due to heavy sheep grazing and nitrogen deposition (Welch et al. 2005; Armitage et al. 2012).

Could the *Racomitrium lanuginosum* heaths of Iceland be defined as peatlands?

Peat is incompletely decomposed organic matter that accumulates in places where decomposition is low. The most important reason for peat accumulation is retarded decay due to water saturation (Clymo 1983). One way to characterize peat is by its organic matter content. Depending on the definition, the required amount of organic matter varies from 20% to 80% (Rydin et al. 2013). We did not find numbers from the literature on the organic content of the not fully decomposed *R. lanuginosum*, but its organic content should most certainly remain above 20%. In terms of the required organic content, it would be fair to call the partly decomposed litter of *R. lanuginosum* as peat.

The process of peat accumulation can be distinguished into terrestrialisation, where peat forms in open water, and paludification, where peat accumulation starts directly over a formerly dry mineral soil. If *R. lanuginosum* residue matter were to be determined as peat, the latter would be the case of its growth, as the moss layer formulates on top of a former lava rock.

A mire refers to a peatland where peat is actively being formed. Other types of peatlands are for example drained peatlands, where peat is still the basis of the soil, but no peat accumulation is

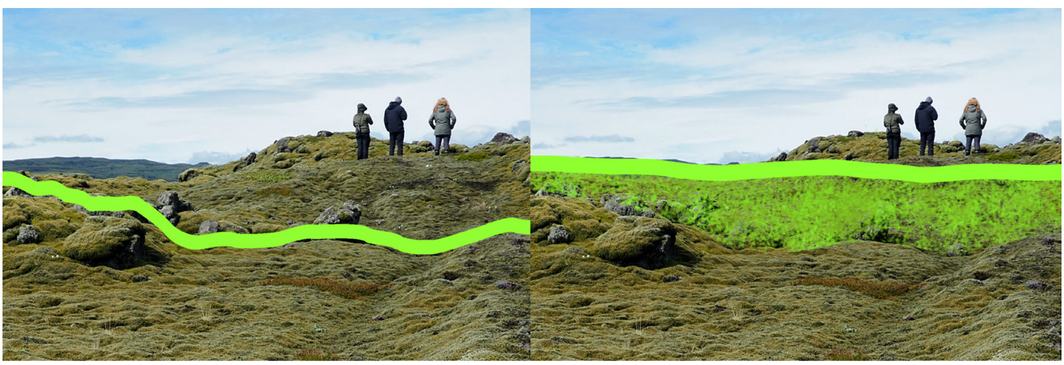

Fig. 3. Illustration of an imaginary situation, where *R. lanuginosum* would fill up depressions in the landscape and form fens. Photo by Anna Isotalo, edited by Johanna Tuviala.

Kuva 3. Graafinen kuvaus kuvitellusta tilanteesta, jossa kalliotierasammal peittäisi painaumat ja muodostaisi suoekosysteemin laavakivien päälle.

left. The concept of mire is therefore more relevant in the case of *R. lanuginosum*, as no drainage or other disturbances had occurred to stop the process of succession on the Eldhraun lava field.

Mires can further be divided into bogs and fens. Bogs, also known as ombrogenous mires, are higher than their surrounding landscapes and receive water only from precipitation, whereas fens are flat or concave mires where usually water flows to the area from surfaces.

In our *R. lanuginosum* context the topography of the mossy heaths is vastly hilly and slopy. There are some concaves in the landscape that could potentially gather water and fill up with organic matter (Fig. 3). If such would take place with the *R. lanuginosum*, the definition of fen could be considered. Such accumulation due to high moisture would be a very usual case of peat accumulation and form a typical mire. Yet it is the case that *R. lanuginosum* prefers dry growing surfaces, and the highest tufts of the moss reach the thickness of 30–40 centimeters (Tallis 1959; Bjarnason 1991). Therefore, as concaves do not seem to be filled up by *R. lanuginosum*, but rather quite evenly thick layer of the moss formulate on slopes as do in concaves, the term fen would not suit to describe the growth of *R. lanuginosum*.

As told earlier, in Scotland *R. lanuginosum* forms peat on the blanket bogs. According to Lindsay et al. (1988), blanket mires require four climatic conditions for their formation: 1) annual precipitation of at least 1000 mm, 2) on average more than 160 annual rainy days a year, 3) the average temperature of the warmest month of the year is below 15 degrees Celsius, and 4) the monthly changes in temperature are relatively low. According to the website Weather and Climate, all of these conditions apply in the South Icelandic village of Kirkjubæjarklaustur, located right next to the Eldhraun lava field (World Weather & Climate Information 2022). Therefore, the climatic conditions would allow formation of such mires in Iceland as well.

Yet, the ecology of *R. lanuginosum* in the blanket bogs is such that it is not the only formulant of peat, but rather a component of the mire cycle. Blanket bogs can form thick layers of peat, whereas with *R. lanuginosum* the limitation of thickness is 30–40 cm. It seems therefore that a sustaining and developing blanket bog ecosystem would climatically be possible in Iceland as well but would require other mire species as well to form.

Last, it seems that definitions of mires and peat formulation are tightly linked to water. For example, Ivanov (1981) wrote that peat accumulation only takes place when the water table is over the long term just under, at or just above, the ground surface. When the water table is too low, plant remains decay too rapidly because of abundant oxygen, whereas when it is too high, plant production is hampered by insufficient provision of oxygen and carbon dioxide to the submerged parts.

R. lanuginosum is usually found 2–60 cm above water table. It does not elevate the water level surface as it grows and prefers dry growing surface. This is therefore the most important limitation why we concluded that *R. lanuginosum* by itself is not able to form peat or a mire. It seems more consistent to define peat formation and therefore peatlands by the accumulation of organic matter due to high water table, as otherwise various ecosystems could be defined as mires with a very thin peat layer.

It further seems that if the succession process were given enough time, the *R. lanuginosum* heaths of Iceland would eventually develop into birch woodlands instead of peat bogs (Vilmundardóttir et al. 2018). The organic matter that accumulates may then be used up by the growing vascular plants, and form eventually a type of mineral soil. This does not, of course, define whether the mats of *R. lanuginosum* are mires right now. It still suggests that we are not dealing with early mire development stages.

Conclusions

The *R. lanuginosum* heaths have been defined to be heaths for a reason. Mires are usually defined by high water table, which is not a condition found on the *R. lanuginosum* heaths. The moss mat grows more due to climatic humidity rather than high water table, and high water table would even prohibit the growth of *R. lanuginosum* which prefers dry growing surface.

For a Finnish forest sciences student, the concept of heath is somewhat new. In Finland heaths are endangered habitat types located mainly in coastal areas. The Finnish heaths are also mainly formed due to cultural usage, and fully natural heaths are rare (Lehtomaa et al. 2018).

Finnish peatlands are mostly formed by either *Sphagnum* peat or *Carex* peat. *R. lanuginosum* is not known to formulate peat in Finnish conditions similarly as it has for example in Scotland. In the British blanket bogs *R. lanuginosum* forms peat both naturally and due to cultural usage of the mires. As the growth of *R. lanuginosum* in the British blanket bogs is often a sign of degradation and succession towards a heath ecosystem, differentiation between heaths and bogs may sometimes be difficult. Such questions are not as abundant in the Finnish mire classification system.

In the United Kingdom the classification is mainly done using Braun-Blanquet classification systems, but most likely a relevant way to distinguish mires from heaths is also the height of their water table. This is also the main reason we distinguish the Icelandic lava flow heaths to be heaths instead of mires.

It was a welcome thought experiment to stress test basic concepts of mire formation in a habitat type completely new to us, as such broadening of views also enhances our understanding of our own local Finnish mires.

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Tiivistelmä

Kalliotierasammal (*Racomitrium lanuginosum*) on sammallaji, joka on levinnyt ympäri maailmaa, mutta runsaimmin sitä esiintyy pohjoisella pallonpuoliskolla pohjoisilla ja mereisillä alueilla. Näissä se voi karulla kasvualustalla vähäisen kilpailun olosuhteissa muodostaa laajoja jopa 30-40 cm paksuja sammalmattoja. Tällaisia kalliotierasammalvaltaisia elinympäristöjä kutsutaan englanniksi termillä “Racomitrium heath”, joka on tässä yhteydessä käännetty suomeksi kalliotierasammalnummeksi.
Kalliotierasammalella on Islannissa tärkeä rooli tulivuorenpurkausten jälkeisten laavakenttien ensivaiheen sukkessiossa, ja kalliotierasammalnummet voivatkin hallita purkausten jälkeistä maisemaa vuosisatojen ajan. Vierailimme Islannin kenttäkurssillamme Eldhraunin laavakentän kalliotierasammalnummella, jossa viimeisestä tulivuorenpurkauksesta on kulunut noin 250 vuotta. Laavakentillä keskustelimme yhdessä ryhmänä siitä, voisiko laavakivillä kasvavan sammalen ajatella muodostavan turvetta. Kysymys oli kiinnostava siitä syystä, että laavakiven päällä kasvava sammalkerros oli paksu ja elävän pintakerroksen alapuolella oli kerros osittain maatunutta sammalmateriaalia - turpeen kaltaista orgaanista ainetta. Lisäksi pohdimme, että jos ajattelisimme sammalen alapuolisen orgaanisen aineksen olevan turvetta, tekisikö se samassa kalliotierasammalnummista soita.
Päätimme lähestyä laavakentillä ilmoille heitettyä kysymystä tutkimalla kirjallisuutta sen osalta, mikä on turpeen määritelmä, ja voisiko huonosti maatunutta kalliotierasammalta määritellä turpeeksi. Kysymys tuntui kirjallisuuskatsauksen arvoiselta erityisesti siitä syystä, että kalliotierasammalta kasvaa myös Britannian peittosoilla. Selvitimme siten katsauksessamme turpeen ja soiden määritelmien lisäksi sitä millaisissa ekologisissa olosuhteissa kalliotierasammal viihtyy, ja millainen turpeentekijä se Britannian peittosoilla on.
Tulimme katsauksessamme päätelmään, että kalliotierasammal ei yksinään pysty muodostamaan turvetta tai soita, koska se suosii kuivia kasvualustoja. Peittosoillakin se viihtyy selvästi vedenpinnan yläpuolella ja hyötyy suon kuivumista aiheuttavista häiriöistä. Kalliotierasammal ei siis nosta vedenpintaa tai viihdy vedenkyllästämiä olosuhteissa, jotka estävät hajoamisen. Totesimme, että tärkein määrittävä tekijä niin turpeelle kuin suollekin ei ole vain jollekin paikalle kertyneen kuolleen kasvimassan paksuus ja orgaanisuusaste, vaan vesi.