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The impact of moisture on the albedo of lichens

Albedo measurement of a lichen board with *C. stellaris*

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This thesis is worth 60 study points

ABSTRACT

Lichens cover about 8% of the Earth's land surface. They are an important forage for reindeer, but they also have an impact on the microclimate of their surroundings. Lichens have a relatively high albedo, giving them a cooling effect compared to other vegetation. Lichens also work as an insulating layer for the surface underneath them, and are important for the thawing depth in areas with permafrost. Previous research has shown that the surface albedo of the lichens is affected by several factors such as colour and structure, sunlight, solar zenith angle, and season and time of the day. However, it is not yet clear if moisture has an impact on the albedo of lichens.

Therefore, this study focuses on the effect moisture has on the albedo of lichens, both in an idealised field study and in natural lichen heaths, and on the question if there is a difference in water absorption and drying between different lichen species. Wooden boards covered with lichens were used for the albedo measurements. One lichen board was watered, while the other board was used as the control and was kept dry. Aluminium trays with the lichen species *C. islandica, C. stellaris* and *F. nivalis* were used for the drying experiment.

Both the field study and the analysis of a natural lichen heath show that the albedo of *C. stellaris* increased with enhanced humidity. When *C. stellaris* became wet its albedo increased with 0.025. Though, it was more difficult to see a difference in albedo in natural lichen heath after a rain shower as other natural factors also affected the measurements.

Colour and structure of different lichen species can affect their ability to absorb water and their drying rate. In this study, the lichen species *C. stellaris* with thinner branches absorbed over 40% more water than the lichen species *C. islandica* and *F. nivalis* with thicker branches. *C. stellaris* also dried faster, but after some time the moisture content of all the lichen species was similar. Colour did not seem to have an impact on drying.

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Martine Øien

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1 INTRODUCTION

Global warming is one of the largest issues in the world today, and it will continue to be in the future. The Earth's temperature is estimated to increase with an average of over 1.5^{o}C, according to the RCP 4.5 scenario (Representative Concentration Pathway), over the course of this century. Since the preindustrial era, the temperature has already increased by 1.2^{o}C (Collins et al, 2013). The temperature does not increase evenly around the world as the warming is more expressed at higher latitudes than lower latitudes. For instance, the temperature rise in Arctic areas is already exceeding the global average temperature estimate (Michelsen et al., 2011; Collins et al., 2013).

The warming of the climate has influenced the treelines and forest lines (TFL) in many areas. As of 2018, the TFL are found at around 1300 m.a.s.l. in south-central Norway, while a hundred years ago the TFL in these areas were almost 90 meters lower (Bryn & Potthoff, 2018). This resent rise in TFL is partly explained by a warmer climate that facilitates for vascular plants to grow at higher altitudes (Odland et al., 2010), where mainly the dwarf birch (*Betula nana*) benefits from this in Arctic areas (Juszak et al., 2014a). The upward migration of trees and shrubs results in smaller areas of lichen, also resulting in less snow cover in the winter because the lichen heaths are replaced with higher and denser vegetation (Bryn & Potthoff, 2018). Another contributing factor to the upward migration of the TFL is the decline in use of the land by humans, mainly the reduction of grazing livestock and semi-domestic reindeer (Bryn & Potthoff, 2018). Gaare (1997) proposed that a decrease in grazing of lichens could lead to a build-up of litter and humus on the soil surface, increasing the water storage capacity of the soil underneath. The water storage can be beneficially for vascular plants, and facilitate their growth. Although grazing animals seem to have a positive effect on lichens, intensive reindeer grazing and trampling can also lead to reduced lichen abundance (Heggenes et al., 2017).

Lichens cover about 8% of the Earth's land surface (Chagnon & Boudreau, 2019). In Norway alone over 2,000 different lichen species have been reported (Bryn & Potthoff, 2018; Frisch et al., 2020). Alpine lichen species are mostly distributed in areas with harsh conditions where few other species can grow, often in areas with low temperatures during the winter and little precipitation (Sundberg et al., 1999; Michelsen et al., 2011; Odland et al., 2018). Because of the lichens' lack of roots or leaves, they are dependent on moisture in the atmosphere to receive important nutrients (Matwiejuk, 2000; Beringer et al., 2001; Joly el al., 2009; Chagnon & Boudreau, 2019).

Climate changes, as reflected by higher temperatures, more precipitation, and longer growing seasons give vascular plants the ability to grow at higher altitudes than before, causing them to outcompete lichens (Beringer et al., 2001; Michelsen et al., 2011; Chagnon & Boudreau, 2019). Lichen heaths often grow in areas with little or no competition and have therefore little resistance towards competing species (Odland et al., 2018; Aartsma et al., 2020). A reduction in the distribution of lichen heaths will reduce species richness and the biodiversity in alpine areas (Michelsen et al., 2011; Nystuen et al., 2019).

The reduction in lichen abundance is seen in both Norway and other countries with alpine and Arctic vegetation. Michelsen et al. (2011) saw an increase in species richness of vascular plants at the expense of lichen heats at Dovrefjell. These changes were caused by an increase in soil temperature. Chagnon & Boudreau (2019) found that the reason for the reduction in abundance and diversity of lichens, in favour of shrubs, in some Arctic areas was caused by the competition of light, due to the lichens' low tolerance for shading.

Lichens are an important food resource for reindeer and caribou, especially during the winter when other food sources are scarce (Kershaw, 1978; Odland et al., 2018). Though, reindeer may also graze extensively on lichens during the summer. The most important lichen for reindeer grazing is the *Cladonia* spp., which is common in Fennoscandia (Heggenes et al., 2017).

Albedo (α) is the fraction of incoming solar radiation that is reflected by a surface. Albedo is presented as a number between zero and one, where zero is total absorption, and one is total reflection of solar radiation by a surface. Albedo is determined by the ratio between outgoing shortwave radiation (K_{out}) and incoming shortwave radiation (K_{in}). Shortwave radiation is measured in W/m^2 (Oke, 1987).

$$Albedo\ (\alpha) = K_{out} / K_{in} \qquad \text{(Eq. 1.1)}$$

Different surfaces have different albedo values depending on several natural factors such as their texture and colour (Table 1.1).

Table 1.1 *Different albedo values for different natural surfaces*

Surface	**Albedo**	
Water	0.1 – 1*	(Dobos, 2003)
Arctic snow cover	0.70 – 0.90	(Zhang et al., 2019)
Earth (mean)	0.36	(Dobos, 2003)
C. stellaris (lichen)	0.36	(Skøyen, 2020)
F. nivalis (lichen)	0.34	(Skøyen, 2020)
C. islandica (lichen)	0.15	(Skøyen, 2020)
Dry dark soil	0.15 – 0.35	(Dobos, 2003)
Shrubs	0.13	(Aartsma et al., 2020)
Grassland	0.10 – 0.25	(Dobos, 2003)
Forest	0.05 – 0.20	(Dobos, 2003)

* The albedo of water depends on the zenith angle as the albedo decreases with a decreasing zenith angle (Oke, 1987).

The net radiation (Q*) is the relationship between incoming and outgoing radiation. At daytime, the net radiation can be described as

$$\text{Net radiation } (Q^*) = (K_{in} - K_{out}) + (L_{in} - L_{out}) \qquad \text{(Eq. 1.2)}$$

where L_{in} is incoming longwave radiation, and L_{out} is outgoing longwave radiation. Longwave radiation is measured in W/m^2. At night, the solar radiation is absent, so net radiation is solely determined by the difference between incoming and outgoing longwave radiation (Oke, 1987).

The resulting net radiation is often exchanged into the energy balance of the surface, either as sensible (Q_H) or latent heat (Q_E). Sensible heat is heat that is required to change the temperature of an object. Latent heat is heat that is either absorbed or released, and causes an object to change phase. When water on a surface evaporates, latent heat is required, and the surface will become cooler than its dry surroundings. When the transfer of sensible heat to or from the underlying soil (Q_G) is included, the surface energy balance can be described as (Oke, 1987):

$$Net\ radiation\ (Q^*) = Q_H + Q_E + Q_G \qquad \text{(Eq. 1.3)}$$

Most lichens have a relatively high albedo compared to shrubs and grass, making them important in cooling of the surface in alpine areas (Porada et al., 2016). The high reflection of shortwave radiation by the lichens lead to a low net radiation. The lower the albedo, the more solar energy is absorbed at the surface and transformed into thermal energy (Oke, 1987; Aartsma et al., 2020). The high albedo gives the lichens the ability to reduce the exchange of heat between the soil underneath the lichens and the atmosphere. Lichens act as an insulating layer for the ground surface (Beringer et al., 2001; Porada et al., 2016). Therefore, lichen covers affect the soil thawing depth, especially playing an important role in areas with permafrost (Beringer et al., 2001; Sundstøl & Odland, 2017). Reductions in soil thawing depth can cause a release of gases such as carbon dioxide and methane into the atmosphere, eventually leading to an increase in atmospheric heating (Bernier et al., 2011; Myers-Smith et al., 2011; Porada et al., 2016; Aartsma et al., 2020).

Surface albedo is affected by several factors, including sunlight, colour of the surface, cloud cover, solar zenith angle, season, time of day, and possibly precipitation. Clouds produce more diffuse solar radiation than direct sunlight that is easily trapped in the lichen, causing a reduction in surface albedo. The zenith angle is the sun's position relative to the vertical (called zenith) expressed in degrees (Oke, 1987). An increasing zenith angle will cause an increase in surface albedo (Peltoniemi et al., 2010; Skøyen, 2020). The lowest zenith angle the sun can have in an area is called solar noon (Oke, 1987).

The outgoing longwave radiation is depending on the surface temperature, while incoming longwave radiation is mostly affected by air temperature, air humidity and clouds. Since outgoing longwave radiation decreases with a decreasing surface temperature, a cold rain shower may lead to a decrease in the outgoing longwave radiation in lichen heaths, increasing the net radiation.

Lichens and shrubs differ in structure and colour. Aartsma et al. (2020) compared the albedo of lichen heaths and shrubs at Imingfjell in Norway, where the average albedo was measured at 0.255 for lichen-dominated plots and 0.132 for plots dominated by *Betula nana* shrubs. Shrubs have a more complex structure and a darker colour than lichens, giving them a lower albedo. Canopies in forest vegetation can trap radiation due to their branches and leaves, lowering the albedo of the surrounding vegetation (Dobos, 2003). Larger leaves and leaves with a darker colour also make the albedo decrease in vascular plants (Juszak et al., 2014b). A decrease in albedo will lead to an increase in the absorption of shortwave radiation in shrubs, increasing the sensible heat as well, causing the area around the shrubs to increase in radiation. When lichens are outcompeted by vascular plants, this change in radiation and heat fluxes will occur in the affected areas (Te Beest, 2016).

The many different lichen species vary in shape, colour, and texture. The structure of the lichen may affect the lichens' ability of water absorption and moisture storage, possibly having an impact on the albedo of the lichens (Matwiejuk, 2000). When water replaces air in the pores of soil, the light absorption of the surface tends to increase, decreasing the albedo of the soil (Gascoin et al., 2009). However, there is little research concerning water's effect of the light absorption in lichens. A study by Heggenes et al. (2017) focused on how humidity and moisture affected the elasticity of lichens. Here, lichens with a humidity between 50-100% were hardly affected by reindeer trampling, because the water increased the elasticity of the lichens. They also saw that dry lichens that were trampled experienced volume loss.

There are few studies about the albedo of lichen in general, and hardly any studies about the possible effects moisture has on the microclimate of lichen. Most of the documented studies regarding albedo of Arctic vegetation focus on vascular plants and shrubs. Some studies also include bryophytes, but lichens are fairly overlooked. Both Peter Aartsma's PhD project (2021) and Konstanse Skøyen's MSc project (2020) look at different natural factors affecting the albedo of different lichen species and some shrubs. However, they do not discuss the possible effect moisture has on lichens. This study will be an extension to their projects.

It can be difficult to study how moisture affects the albedo of lichens in lichen heaths under natural conditions due to factors such as clouds, rainfall, and homogeneity of the different lichen species. Therefore, an idealised experimental study could help to reveal the impact of moisture on lichens. This study has the aims to see:

1) How moisture can affect the albedo of the lichen species *Cladonia stellaris*
2) If different lichen species have different drying times after rainfall
3) If the effect of moisture on albedo is visible in albedo measurements of natural lichen heaths

2 METHODS

2.1 Study species

For this experimental study, the three lichen species used were *Cetraria islandica, Cladonia stellaris* and *Flavocetraria nivalis.*

2.1.1 *Cetraria islandica*

Figure 2.1 *Closeup of the lichen C. islandica*

C. islandica (Figure 2.1), also called Icelandic moss, is a dark brown lichen with thick, curly branches that can grow to a height of 15 cm (EMA, 2014; Grujičić et al., 2014). The lichen species is common in Arctic and subarctic areas, mostly in northern and eastern Europe, Siberia, and North America (EMA, 2014). It usually grows in areas with tundra and boreal forests, but can also be found in areas with more moisture (Ahti & Oksanen, 1990).

2.1.2 *Cladonia stellaris*

Figure 2.2 *Closeup of the lichen C. stellaris*

C. stellaris (Figure 2.2) is a light-coloured mat-forming lichen. *C. stellaris* is one of the most important reindeer forages during the winter (Joly et al., 2009; Odland et al., 2014; Heggenes et al., 2017). It grows mostly on soil, but can also be found on tree bases and decaying wood (Zhurbenko & Pino-Bodas, 2017). *C. stellaris* is quite dominant in northern boreal forests and forest tundra, and is a common lichen species in Fennoscandia (Ahti & Oksanen, 1990).

2.1.3 *Flavocetraria nivalis*

Figure 2.3 *Closeup of the lichen F. nivalis*

F. nivalis (Figure 2.3) is a light-coloured lichen, often with shades of green or yellow. Its structure is similar to *C. islandica*, with thick, curly branches. It is found in boreal forests and alpine areas, and is a common lichen species in Fennoscandia (Ahti & Oksanen, 1990).

During the winter, *F. nivalis* is found in areas with thin or absent snow layers as they often grow on exposed ridges (Oksanen & Virtanen, 1995; Löffler, 2007), and it is also important winter forage for reindeer (Joly et al., 2009)

2.2 Experimental design

The lichens used in this experimental study had already been collected for Skøyen's (2020) study. Samples of the different lichen species were collected at Imingfjell, a mountain area in Viken County in August and September 2018, and March 2019. The lichens had also been arranged on wooden boards to create monocultures.

The study was conducted at USN, campus Bø (59°24'N, 9°03'E) in Telemark & Vestfold county, at an elevation of approx. 80 m.a.s.l. The different measurements were obtained between August and September 2020.

2.2.1 Albedo measurements

For the albedo measurements, two wooden boards covered with lichens were used for the first part of the albedo study (Figure 2.4). They were placed out in a field without any tall trees or buildings close nearby to prevent shadows, reflection, or other disturbances. The grass around the wooden boards was cut short. The boards were round, had a diameter of 175 cm, and a 10 cm high mesh around the edges to keep the lichens in place. Crates were put underneath the lichen boards to make them levelled. The measurements took place every other day to allow the subject board to dry completely between measurements. If the weather allowed it, the boards were put outside to dry on those days. The lichen boards were put underneath a roof nearby when they were not being used to shield them from rain.

Two radiometers were used to measure the radiation balance of the lichen surface, one over each board. The same radiometers were used for the same lichen boards throughout the measuring period. The two radiometers used were CNR 4 radiometers from Kipp & Zonen. The radiometers consist of a pyranometer pair and a pyrgeometer pair, where one is facing upwards, and one is facing downwards for each pair. The pyranometer pair measures shortwave radiation, while the pyrgeometer pair measures longwave radiation (Kipp & Zonen, 2014). The radiometers were placed 20 cm over the lichen surface, giving the radiometers a measuring radius of 75 cm. The radiometers were attached to poles in the ground, where the poles went through a hole close to the edge of each board to centre the radiometers. The poles were stabilised with cords to prevent them from moving during the day, and to make sure the radiometers always were levelled and facing southwards. Data loggers, LOGBOX SE, were attached to each radiometer, recording measurements every 5 seconds (Kipp & Zonen, 2014). This data was retrieved at the end of each measuring day. The radiometers were put up at around 8:00 every morning, but only the measurements after the zenith angle was below 65^{o} were used.

Figure 2.4 *The subject board consisting of C. stellaris with a radiometer*

The albedo measurements were conducted between 31st August and 22nd September 2020, with a total of six measuring days. The time of the measurements was dependent on the zenith angle. The zenith angle becomes higher closer to fall as the elevation angle gets lower, shortening the time interval of measuring each day. A spread sheet of the elevation angles throughout the days was used to determine the start and end of the measurements each day, as well as the time of watering. Measurements started when the zenith angle was below 65^{o} in the morning and ended when the zenith angle was above 65^{o} in the afternoon. A higher zenith angle than 65^{o} can cause inaccurate measurements by the radiometers, and values above this was therefore not used. Because of the time of the year, the zenith angle was never lower than 50^{o}.

The two lichen boards were treated differently. One of the boards was used as an experimental board, also called the subject board. The lichen on this board was watered to see if moisture has an impact on the lichens' albedo. The other board was used as a control board and was kept dry throughout the experiment. The experimental board consisted of the lichen species *C. stellaris,* while the control board consisted the lichen species *F. nivalis*. Ideally, we would have used the same lichen species for both the experimental and control board. However, only the lichen collected previously in 2019 were available, as new lichen collection was not feasible due to restriction related to the COVID-19 pandemic. Unfortunately, there were only enough lichens of each species to cover one board each. *C. stellaris* and *F. nivalis* were therefore used as they have similar albedo (Table 1.1). The subject board was watered when the zenith angle was at its lowest, also called solar noon. The zenith angle at solar noon was not constant and became higher each day during the field study. The subject board was watered with a watering can 10 minutes before solar noon with 24 litres of water to mimic a 10 mm rain shower. There was no disturbance or shade to interfere with the measurements around the boards at solar noon.

One of the natural factors affecting the albedo measurements are clouds. Therefore, the cloud cover was estimated using an okta scale describing the fraction of clouds in the sky, where zero indicates a completely clear sky and eight indicates a completely cloudy sky. The cloud cover was observed every 30 minutes during measuring days by the same person to reduce bias.

2.2.2 Drying experiment with two different watering techniques

To give an estimate of how the subject lichen board was drying after being watered, an experiment using two different watering techniques was also conducted simultaneously with the albedo measurements. Here, six aluminium trays with the volume of one litre, were filled with *C. stellaris* and underwent the same treatment as the experimental lichen board (Figure 2.5). At solar noon, the trays were each watered with 450 ml of water to mimic a 10 mm rain shower. Small holes were cut in the bottom of the trays for excess water to run off. Two different watering techniques were used for the lichen trays. For three of the trays, the water was poured carefully onto the lichen, while the water was sprayed onto the three remaining trays. This was to see if there was a difference in absorption and drying of lichen between the two watering methods.

Figure 2.5 *Six aluminium trays with C. stellaris*

In order to see if there was any difference in drying of the lichens when two different watering techniques were used, moisture content was calculated using the formula:

$$Moisture\ content = \frac{(Wet\ weight - dry\ weight)}{Dry\ weight} \qquad \text{(Eq. 2.1)}$$

The moisture content of the lichen trays can be described as a fraction of how much water the lichen has absorbed compared to its original dry weight (Doran, 2013).

2.2.3 Drying experiment of three different lichen species

A second drying experiment was set up in order to assess if different lichen species have different drying times based on differences in colour and structure. This drying experiment was conducted between 8th and 22nd September, with three measuring days. Aluminium trays with the volume of one litre were used for each sample. The experiment consisted of five trays of *C. islandica*, five trays of *C. stellaris*, and three trays of *F. nivalis* (Figure 2.6). The reason for the unevenness in tray samples was due to the lack of *F. nivalis,* which had been stored at school, but were thrown away by mistake.

Figure 2.6 *Aluminium trays with lichens. On the left side: F. nivalis, centre: C. stellaris, on the right side: C. islandica.*

The trays were filled with lichens to resemble the density of the lichen species in the field. Because of the similar structure of *C. islandica* and *F. nivalis* the trays had approximately the same weight (ranged from 98 – 104 grams) at the beginning of the experiment. Even though the trays with *C. stellaris* contained the same volume of lichen as the two other species, the *C. stellaris* has a different structure and the trays were lighter (ranged from 68 – 69 grams).

The dry weight of the trays was recorded before each tray was watered with 450 ml of water and weighed again. The water was poured carefully onto the lichens, as spraying the lichens would be too time consuming due to the large number of trays. The trays were put on a wooden board to dry and were then weighed again every 30 minutes during the day. The drying period lasted between five and seven hours each day. The cloud cover was also observed every 30 minutes. The trays were put outside to dry on non-measuring days for them to be completely dry before each measuring day.

2.2.4 Field data of natural lichen heaths

To see if the effect of moisture on albedo is also visible in natural lichen heaths, Peter Aartsma's field data from Imingfjell for the summers of 2018 and 2019 were used. Imingfjell is a mountain area in southern Norway with elevation between 1100 and 1350 m.a.s.l., with low-alpine zone vegetation. Lichen heaths dominated by *Cladonia* spp., *F. nivalis* and *A. ochroleuca* were used for albedo and radiation measurements. However, these plots also contained small fractions of vascular plants. The radiometers were set up in the same way as in the idealised albedo experiment. From the data sets, days with clear rain showers were found, and albedo, longwave radiation and shortwave radiation were calculated and visualised by graphs in Excel. A weather station was used during the summer of 2019, but not for the summer of 2018. This measured, among other factors, precipitation. However, a rain gauge was used during the summer of 2018. The execution of the field work and the collection of field data is described more thoroughly by Aartsma et al. (2020, 2021).

Because the zenith angle was below 60^o between 09:00 and 18:00, only measurements during this period was used to eliminate inaccurate measurements by the radiometer. No statistical analysis was used for this part of the study.

2.3 Data analysis

2.3.1 Albedo measurements

Graphs in Excel were made to visualise potential differences in albedo between the subject board and the control board. The values for the incoming and outgoing longwave radiation were corrected using the equation:

$$Corrected\ LW = obtained\ LW + \sigma * (air\ temp + 273{,}15)^4 \qquad \text{(Eq. 2.2)}$$

where the obtained longwave radiation value was the value measured by the radiometer. The Stefan-Boltzmann constant (σ) value in SI units is $5.670 \times 10^{-8}\ W/m^2K^4$ (Oke, 1987).

The data was grouped into hourly intervals, where the highest value of each interval was used. The highest value in the hour before and in the hour after solar noon were used for the statistical test in order to limit the impact of the zenith angle. This method was used instead of the hourly average value to better eliminate cloud interference. For the statistical analysis, a paired Wilcoxon signed rank test was done in R studio. The null hypothesis stated no difference in albedo before and after solar noon. Because of the small size of the data set, we could not assume that the data was normally distributed, and therefore chose to use a non-parametric test. The value before solar noon was compared with the value after solar noon for each board on each measuring day. Thirty minutes around solar noon was excluded due to potential shading of the lichen boards and radiometers in conjunction of watering of the subject board.

2.3.2 Drying experiment of three different lichen species

To best describe the absorption of water by the lichen for this study, moisture content was calculated (Eq. 2.1), and graphs of the moisture content of each tray were made in Excel. The graphs showed the moisture content right after the lichen trays were watered, until they had dried for five hours, with a moisture content value for every 30 minutes. Exponential curves were fitted to the measurements, as the R-squared value was closest to 1 with this type of curve. The exponent-value of each graph was then used as the drying rate for each lichen tray. For the statistical analysis, a two-way ANOVA was performed in Excel. This test was used to see if there was a difference in drying time between the three different lichen species, where the null hypothesis stated no difference in drying time. The different species and different measuring days were used as factors in the statistical test. The test does not however say anything about which factor may be different from the others, only that there is a significant difference. Because the analysis included two factors, and the sample size was small, a statistical test comparing two and two species such as a non-parametric Kruskal Wallis test could not be used after the two-way ANOVA test.

3 RESULTS

3.1 Albedo measurements

3.1.1 Lichen boards

The six graphs of the albedo measurements all show an increase in albedo after watering at solar noon for the subject board. However, there was no increase in albedo before and after solar noon for the control board. Cloud interference was also visible on the graphs showing incoming shortwave radiation and albedo. The control board also had a lower albedo in general compared to the subject board. Figure 3.1 shows a day with little cloud interference (Table A1), whereas Figure 3.2 shows a day with more cloud interference (Table A2). The increase in lichen albedo for the subject board after watering is still visible despite the interference of clouds.

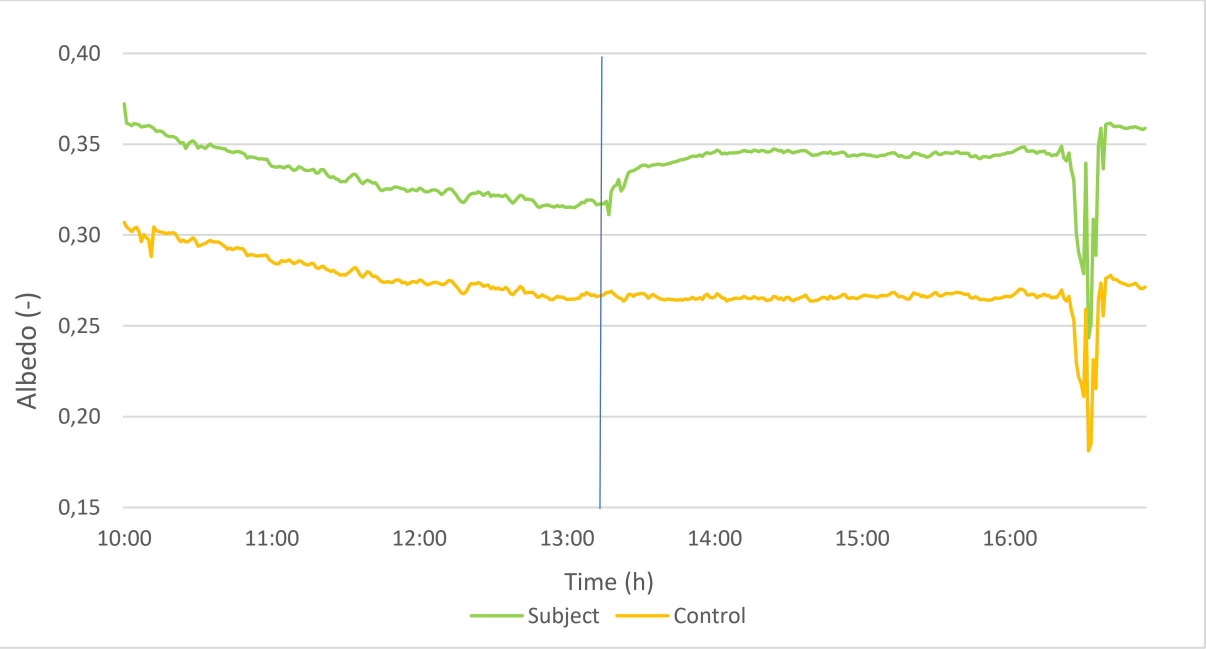


Figure 3.1 *Albedo of the subject and control board measured 31.8.20. The vertical line in the graph indicates when the subject lichen board was watered. Solar noon is at 13:25.*

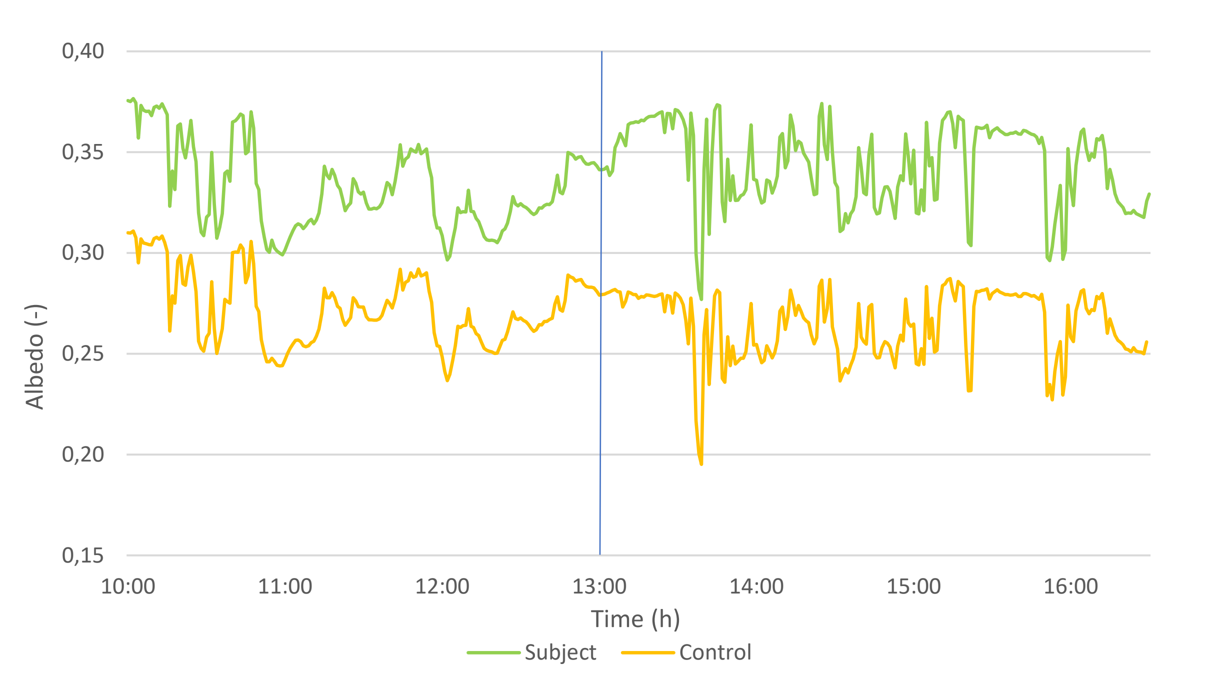


Figure 3.2 *Albedo of the subject and control board measured 8.9.20. The vertical line in the graph indicates when the subject lichen board was watered. Solar noon is at 13:20.*

The average albedo of the maximum values before watering for the subject board, *C. stellaris,* was 0.343 (σ ± 0.011, range 0.325 – 0.351). After watering, the average albedo was 0.368 (σ ± 0.013, range 0.349 – 0.379). The difference in albedo before and after watering for *C. stellaris* was 0.025. Table 3.1a shows the measured albedo values before and after watering for the subject board.

The average albedo of the maximum values before solar noon for the control board, *F. nivalis,* was 0.286 (σ ± 0.007, range 0.275 – 0.293). After solar noon, the average albedo was 0.282 (σ ± 0.008, range 0.268 – 0.290). The difference in albedo before and after solar noon for *F. nivalis* was 0.004. The albedo of *F. nivalis* was lower than the albedo of *C. stellaris* when both lichen boards were dry, with a difference of approximately 0.057. Table 3.1b shows the measured albedo values before and after solar noon for the control board. The zenith angle at solar noon increased throughout the experiment period, and the albedo of both boards also increased, as seen in Table 3.1.

Table 3.1 *Measurements of the highest albedo value one hour before and one hour after solar noon. 30 minutes around solar noon is excluded to eliminate disturbances from watering* **a)** *Albedo values from the subject board. Here the watering of the lichens occured right before solar noon.* **b)** *Albedo values from the control board.*

a)

Sample	**Albedo before SN**	**Albedo after SN**	**Difference in albedo**
1	0.325	0.347	0.022
2	0.334	0.359	0.025
3	0.348	0.373	0.025
4	0.350	0.374	0.024
5	0.351	0.379	0.028
6	0.351	0.378	0.027
Mean	0.343	0.368	0.025

b)

Sample	**Albedo before SN**	**Albedo after SN**	**Difference in albedo**
1	0.275	0.268	-0.007
2	0.281	0.277	-0.004
3	0.286	0.282	-0.004
4	0.289	0.287	-0.002
5	0.293	0.289	-0.004
6	0.292	0.290	-0.002
Mean	0.286	0.282	-0.004

When conducting the statistical analysis paired Wilcoxon signed rank test in R studio, the p-values for the subject and control board were calculated. When comparing the albedo before and after solar noon for the subject board, the p-value was 0.03125. When doing the same for the control board, the p-value was 0.03351. When the p-value is less than 0.05 there is a significant difference before and after a treatment, and the null hypothesis is therefore rejected. For the albedo measurements this means a difference in albedo before and after watering for the subject board, and before and after solar noon for the control board.

A box plot shows the difference in albedo for the subject and control board before and after solar noon (Figure A1). The box plot shows an increase in albedo after solar noon for the subject board, while for the control board there was a slight decrease in albedo. Thus, the albedo responds in opposite directions after solar noon.

The net radiation for the subject board (Figure 3.3) showed a decrease in outgoing longwave radiation after the lichen board was watered. Because of this, the net radiation for the lichen board increased even though there was also a slight increase in outgoing shortwave radiation after watering. There were no changes in net radiation for the control lichen board (Figure 3.4) before and after solar noon.

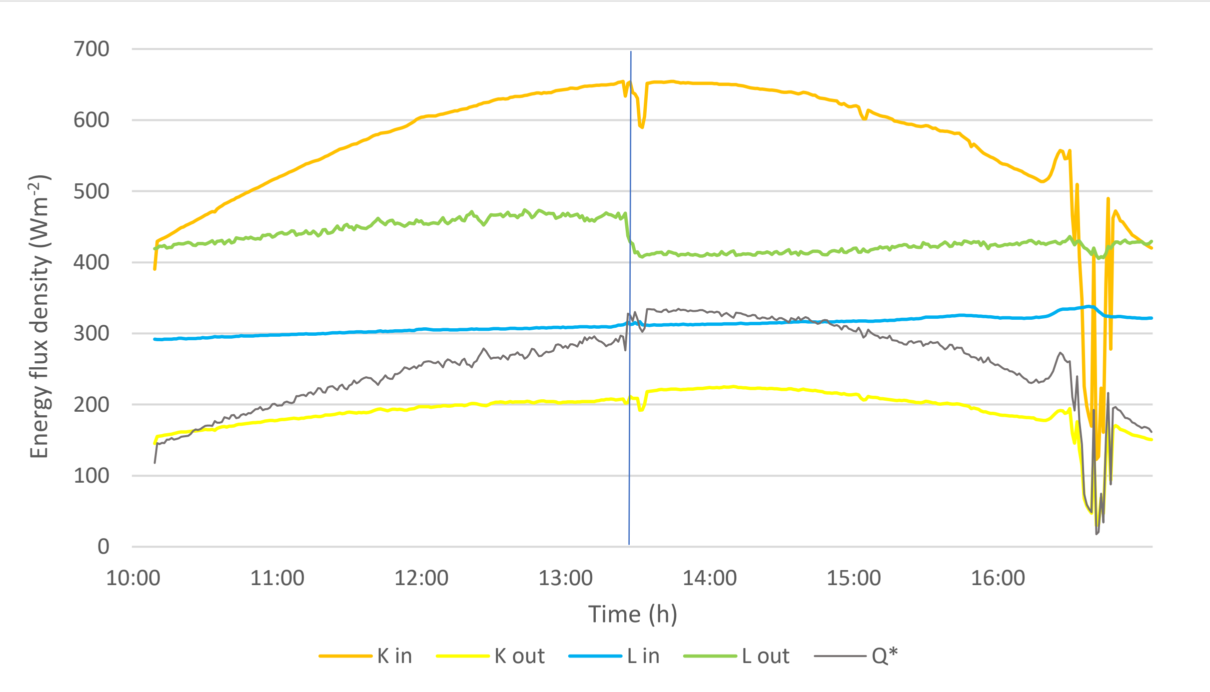


Figure 3.3 *Net radiation for the subject board measured 31.8.20. The vertical line in the graph indicates when the lichen board was watered.*

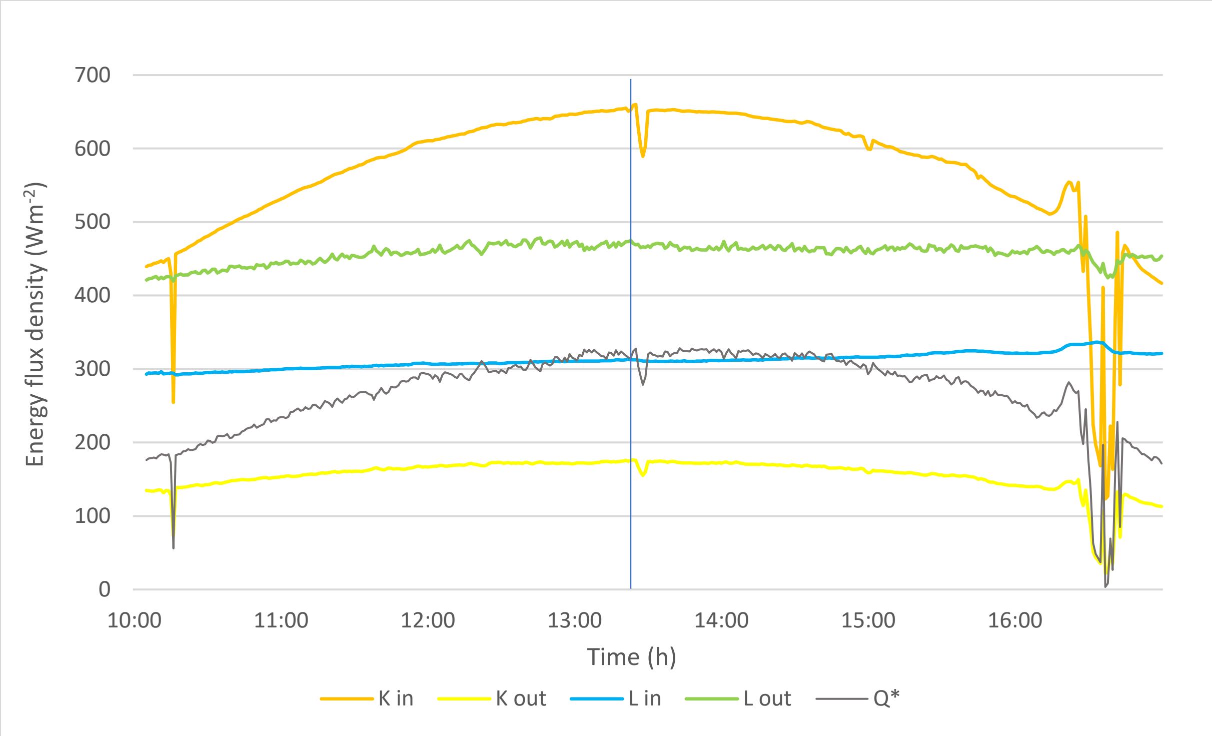


Figure 3.4 *Net radiation for the control board measured 31.8.20. The vertical line in the graph indicates solar noon.*

3.1.2 Drying experiment with two different watering techniques

The moisture content of the trays where the water was poured carefully onto the lichen was an average of 1.17 (σ ± 0.281, range 0.78 – 1.59) when weighed right after watering. After three hours of drying the average moisture content of the trays was 0.59 (σ ± 0.176, range 0.43 – 0.88). The moisture content of the trays where the water was sprayed onto the lichen was an average of 1.43 (σ ± 0.290, range 1.07 – 1.86) when weighed right after watering. After three hours of drying the average moisture content of the trays was 0.69 (σ ± 0.219, range 0.38 – 0.97).

The difference in moisture content between the two watering techniques was 0.26 right after watering, where the trays that were sprayed with water had the highest moisture content. At the end of the drying period there was a difference of 0.10 in moisture content, where the trays that had been sprayed still had the highest moisture content (Figure 3.5).

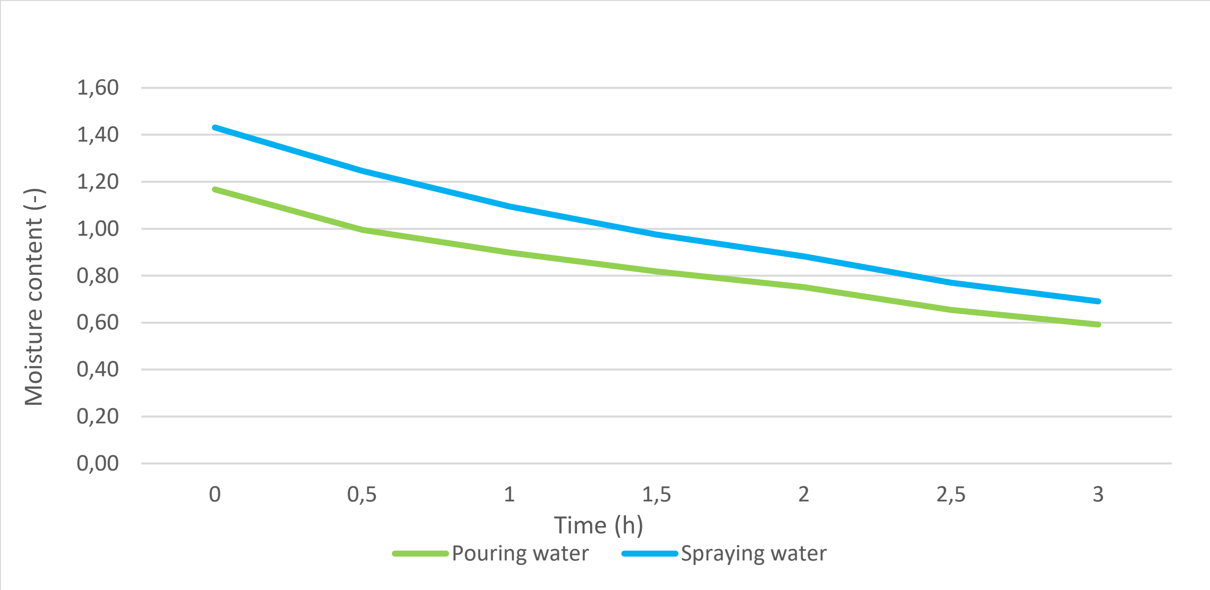


Figure 3.5 *The average moisture content of the six lichen trays measured from right after they were watered using two different watering techniques until they had been drying for three hours.*

The watering and drying of the lichen trays were done to mirror the subject board containing *C. stellaris.* When comparing the graphs from the lichen board measurements and the drying of the lichen trays, it did not seem that the albedo of the lichen board decreased even though the lichen trays became dryer. The lichen trays were lying right beside the lichen boards and do therefore have the same cloud cover.

3.2 Drying experiment of three different lichen species

A total of 39 graphs (Figure A2) showing moisture content were made from the drying experiment of *C. islandica*, *C. stellaris* and *F. nivalis*. By using the statistical test, a two-way ANOVA (Table A3), the null hypothesis was rejected, and there was a significantly difference in drying of the three species. Though, the test does not say anything about which species are different and which are more similar. The drying curves of the *C. islandica* and *F. nivalis* were similar, while the drying curves for *C. stellaris* was different from the two other species (Figure A3). The trays with the *C. stellaris* had a higher moisture content after watering, hence a higher absorption of moisture (Table 3.2). After five hours, the moisture content of the three species were similar, but because of *C. stellaris'* higher moisture content right after watering, it implies that *C. stellaris* dried faster than the two other species.

Table 3.2 *The average moisture content (MC) of the three different lichen species right after watering, and after five hours of drying.*

Species	MC after watering (-)	MC after drying (-)
C. islandica	1.00	0.46
C. stellaris	1.43	0.52
F. nivalis	0.98	0.49

3.3 Field data of natural lichen heaths

3.3.1 Field data from the summer of 2018

Since the summer of 2018 was very dry, there were only three days with a clear rainfall during daytime, July 7th, July 13^{th,} and August 6th. However, all those days showed an increase in albedo after the rain. The incoming shortwave radiation had a drop during the rain period, probably due to clouds. The outgoing shortwave radiation did also decrease during the rain period, but not as much as the incoming shortwave radiation. Because of the drop in albedo during the rain shower it is difficult to say how much the albedo of the lichen increased due to moisture compared with its dry albedo. For the first (Figure 3.6) and third day (Figure A4a) with rain the increase in albedo can be clearly seen in the graphs. However, for the second day (Figure A5a) with rain the increase is not as visible. In the morning, before the shortwave radiation was measured, there was some minor rainfall (less than 1 mm). However, the weather was humid after this, and could therefore have slowed down the drying of the lichen heaths.

When comparing the highest albedo value before the rain shower with the highest albedo value right after the rain shower, there was an increase in albedo of the lichens after the rain. For the first day (Figure 3.6) the highest albedo value right before the rain was 0.245. The highest albedo value right after the rain was 0.280, causing an increase in lichen albedo of 0.035. The duration of the 4 mm rain shower was between 12:05 and 12:30. For the second day (Figure A5a) the highest albedo value right before the rain was 0.301. The highest albedo value right after the rain was 0.321, causing an increase in lichen albedo of 0.020. As mentioned before, the difference in albedo before and after rainfall for this day was not as visible from the albedo graphs. However, when comparing exact albedo values one can see a difference before and after the rain. The duration of the 7 mm rain shower was between 11:15 and 15:30. For the third day (Figure A4a) the highest albedo value right before the rain was 0.302. The highest albedo value right after the rain was 0.332, causing an increase in lichen albedo of 0.030. The duration of the 2 mm rain shower was between 08:40 and 13:00. The average increase in lichen albedo after the rainfall for the three measured days is 0.028.

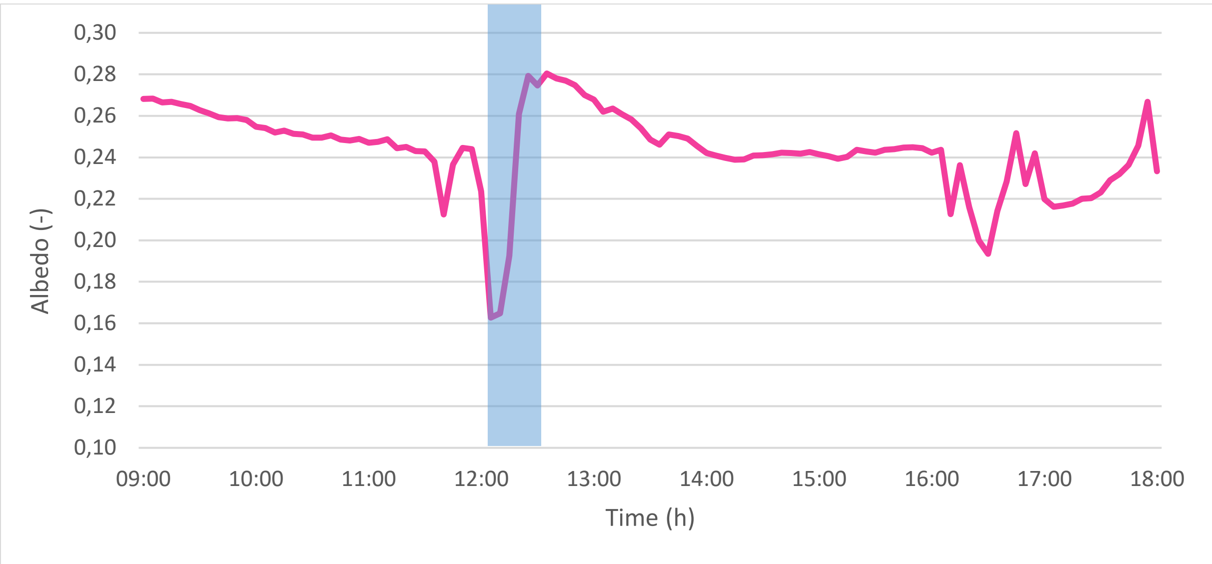


Figure 3.6 *Albedo of the lichen heaths for 13.7.18. The blue area indicates a 4 mm rain shower. This is described as the first day for the data of 2018.*

The incoming longwave radiation increase after the rain for all the three days, while the outgoing longwave radiation decreased (Figure 3.7, Figure A4b & Figure A5b). Since there was not used a weather station in 2018, the rainfall was observed by Peter Aartsma, and there are therefore no precipitation curves describing the exact rainfall at any given time. However, the rain gauge provided data of the total precipitation throughout the day.

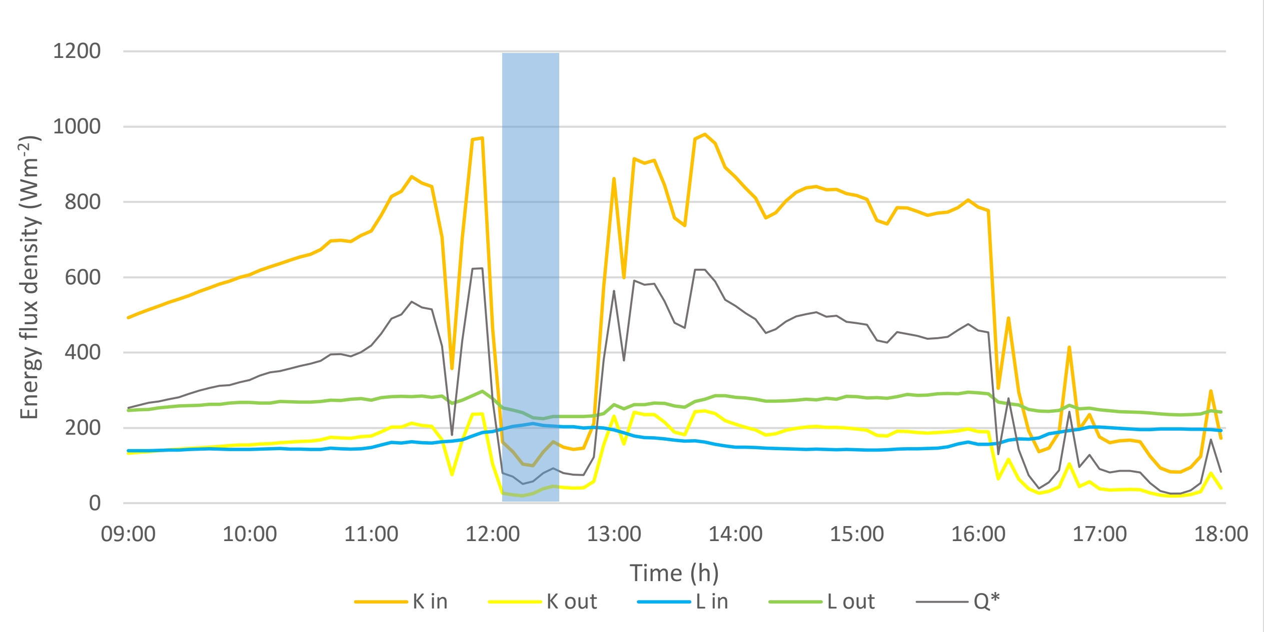


Figure 3.7 *Radiation budget of the lichen heaths for 13.7.18. The blue area indicates a 4 mm rain shower. This is described as the first day for the data of 2018.*

3.3.2 Field data from the summer of 2019

The summer of 2019 had 13 days with precipitation between the 24th of June and the 19th of August. However, only three days had a clear rain shower. For these selected days, the albedo decreased after the rain shower for the first day (July 20th), had a slight increase in albedo the second day (August 6th), and a visible increase in albedo the third day (August 12th).

For the first day (Figure 3.8) the highest albedo value right before the rain shower was 0.268. The highest albedo value during the rain period was 0.264, giving a 0.004 decrease in albedo after it started to rain. Because it continued to rain for the rest of the day there were no albedo values for the lichen after the rain shower, as the albedo and shortwave radiation was not measured after 18:00. However, the graph shows a continuous decrease in albedo throughout the day. The highest recorded albedo for this day was 0.284, measured at 10:00, which was before it started to rain. The day before, there had been a 16 mm rain shower.

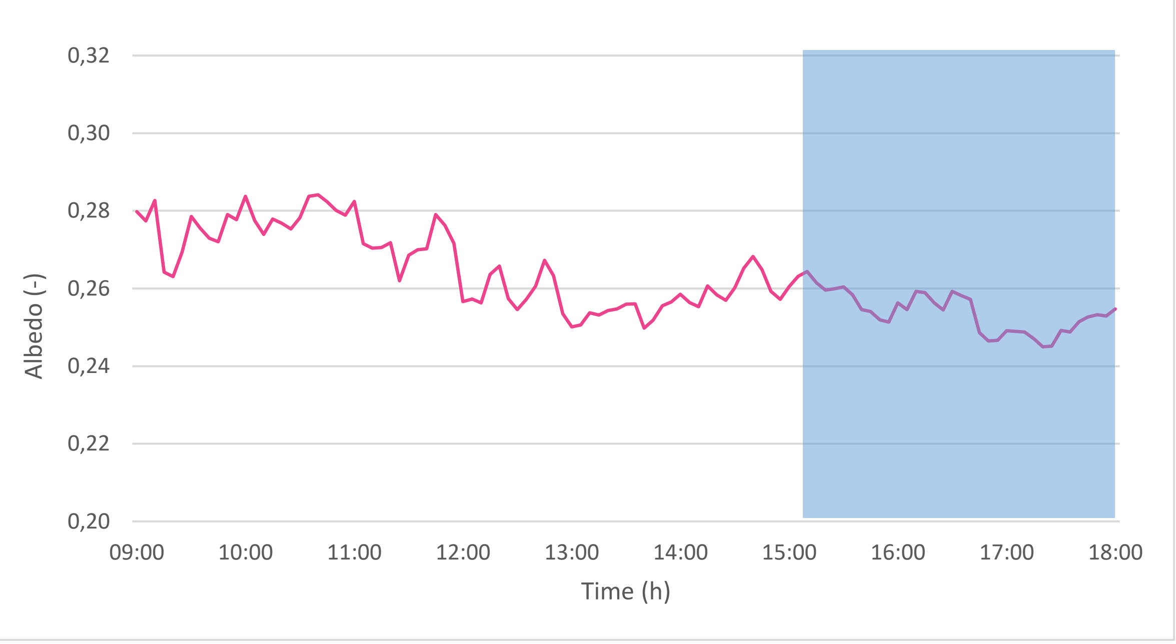


Figure 3.8 *Albedo of the lichen heaths for 20.7.19. The blue area indicates a 1.8 mm rain shower. This is described as the first day for the data of 2019.*

For the second day (Figure A6a) the highest albedo value right before the rain shower was 0.288. The highest albedo value after the rain shower was 0.318, causing an increase in lichen albedo of 0.030. Though the increase in the albedo on the graph was not as visible, the albedo values showed a great difference.

For the third day (Figure A7a) the highest albedo value before the rain shower was 0.327. The highest albedo value during the rain period was 0.340. Because it continued to rain until 20:15 there were no albedo values for the lichen after the rain shower. The lichen albedo increased with 0.013 from before the rain shower to during the rain shower. This was the day where the increase in albedo after a rain shower was most noticeable on the graph. There had also been a small rain shower of 5 mm the previous day.

The incoming and outgoing longwave radiation did not change noticeably after rainfall for any of the measuring days (Figure 3.9 and Figure A6b), with the exception of the third day where there was a small change (Figure A7b).

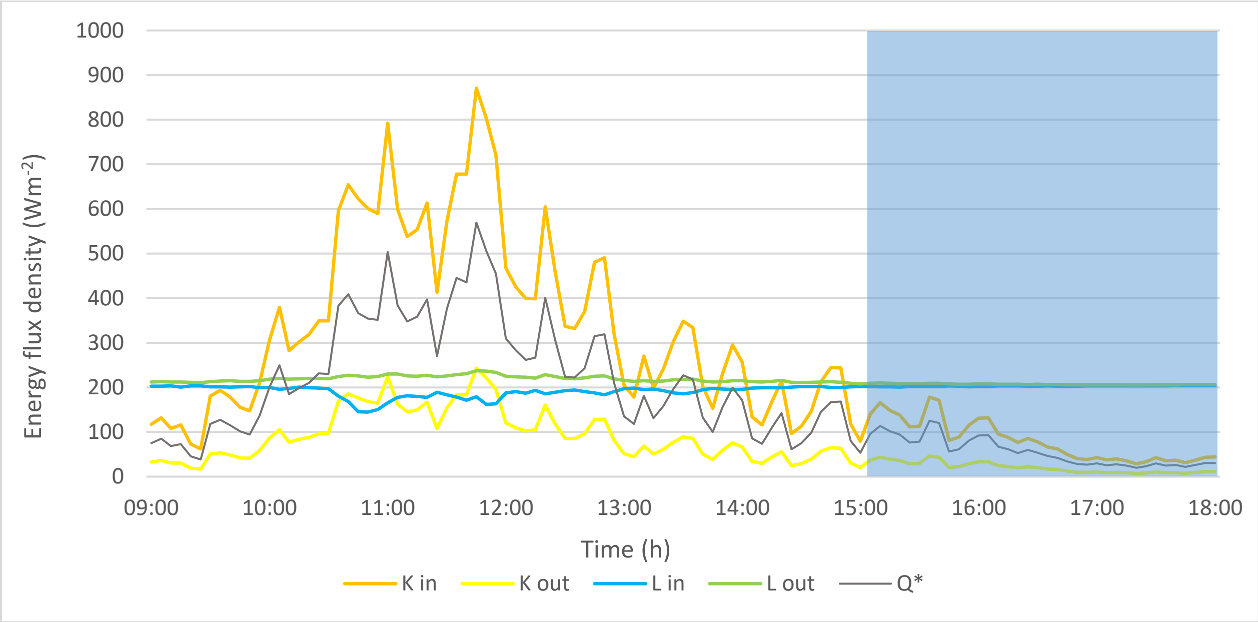


Figure 3.9 *Radiation budget of the lichen heaths for 20.7.19. The blue area indicates a 1.8 mm rain shower. This is described as the first day for the data of 2019.*

4 DISCUSSION

4.1 Albedo measurements

4.1.1 Lichen boards

Although there is a significant difference before and after solar noon for both the subject board and the control board according to the paired Wilcoxon signed rank test, it is plausible that moisture affects the albedo of lichens by increasing it. When looking at the data one can see a larger difference before and after solar noon for the subject board, than the control board (Table 3.1). The box plot (Figure A1) of the measurements before and after solar noon for both boards shows that the albedo of the subject board increased after solar noon, while the albedo of the control board decreased slightly. Again, this suggests that moisture causes the albedo of the lichen to increase. When becoming wet the *C. stellaris* did not become noticeably darker, and colour is most likely not the reason for the change in albedo. Because of the increasing zenith angle after solar noon, one would expect the albedo of the control board to increase again. However, this was not the case as the albedo decreased slightly. Nearby buildings may disrupt the solar radiation and cause reflection, which may affect the albedo of the dry control board.

Albedo measurements of the lichen boards were also conducted by Skøyen (2020). Here, the albedo of the lichen species *C. stellaris* and *F. nivalis* were almost the same, where *C. stellaris* had an albedo of 0.36 and *F. nivalis* had an albedo of 0.34 (Table 1.1). In this project however, the average albedo of *F. nivalis* before solar noon was 0.286 and after solar noon was 0.282. This is a large difference from Skøyen's measurements, even though the same lichen board was used in both projects. The albedo of *C. stellaris* in its dry state was 0.343, similar to Skøyen's measurements. There are several factors that may have caused such a difference in the albedo measurements of *F. nivalis.* Firstly, the two radiometers that were used measured the same lichen board throughout the experiment, unlike in Skøyen's project where the radiometers were switched between the lichen boards to prevent bias. Nevertheless, her measurements showed no difference between the two radiometers. Secondly, in our case, the lichen board consisting of *F. nivalis* was not covered thoroughly with lichens (Figures A8a and A8b). During storage, the lichens had dried and shrunk, leaving gaps between the lichen patches. Because of the shortage of *F. nivalis* we were not able to fill these gaps. The radiometer may therefore have measured the albedo of the wooden board underneath as well.

Since the wooden board has a different surface and colour than the lichens, it may have different properties causing it to have a different albedo than the lichens. By looking at the albedo value, we can assume that the wooden board had a lower albedo than *F. nivalis.* Aartsma et al. (2020) also found little difference in the albedo between *C. stellaris* and *F. nivalis* in their study.

For the lichen board experiment, only the species *C. stellaris* was watered to see how moisture affected the lichens' albedo. *C. stellaris* did not change colour noticeably when becoming wet. Other lichen species however may become darker when watered, as darker surfaces tend to have a lower albedo (Petzold & Rencz, 1975), and one can therefore not say if the albedo of these lichen species would increase when becoming wet as well. Rutherford et al. (2017) found an increase in the albedo of biocrust after being exposed to moisture. They assumed that cyanobacteria found on the surface of the biocrust was the reason for the change in albedo. Lichens are symbiotic associations often consisting of cyanobacteria and fungi (Rikkinen, 2013). The presence of cyanobacteria may explain the increase in albedo after watering for the lichens. Several other studies such as Guan et al. (2009), Sugathan et al. (2014) and Yang et al. (2020) described the influence of moisture on soil surfaces. All the studies showed a decrease in albedo with increasing moisture. However, this may largely be affected by the darkening of the soil when it becomes wet. There are no studies describing the relationship between albedo and moisture for lichens.

The net radiation for the subject lichen board increased after watering. This was probably due to a decrease in outgoing longwave radiation. This change in microclimate could be caused by the oasis effect, where a reduction in surface temperature of a wet surface is caused by evaporation. Evaporation requires latent heat for the water to change into water vapor, causing a decrease in sensible heat leading to a decrease in surface temperature. The oasis effect is especially seen where the surroundings of a wet surface is very dry, which was the case for the albedo measurements of the lichen boards (Oke, 1987). There was also an increase in outgoing shortwave radiation, as already implied by the increase in albedo, which may be caused by moisture, where the lichens will reflect more radiation when becoming wet. When comparing the radiation budget between the subject board and the control board, the same increase in net radiation could not be seen for the control board. The outgoing shortwave radiation and the outgoing longwave radiation for the control board did not decrease. Since the lichens used in this experiment was placed on a wooden board, and not on top of soil, the longwave and net radiation will not necessarily reflect how these parameters are affected by moisture in natural lichen heaths.

4.1.2 Cloud cover

Though, the influence of clouds on the albedo of lichens was not one of the aims for this project, the cloud cover was still observed because of their interference with incoming shortwave radiation. The cloud cover was only observed every 30 minutes and is therefore only describing the cover of clouds at that exact moment. However, the cloud cover can give an indication of the weather condition for each measuring day. Cloud cover could also be observed on the graphs showing incoming shortwave radiation due to large decreases in incoming shortwave radiation (Figure 3.2 and Table A2). For a more precise description of cloud cover, the cloud factor can be calculated. As mentioned earlier, the effect of cloud cover was not part of this project, but can be described as a possible reason to the reductions in albedo and shortwave radiation for the lichen boards.

4.1.3 Drying experiment with two different watering techniques

The purpose of this part of the project was to mirror the subject lichen board. After watering, the albedo values of the subject board remained more or less constant during the afternoon, even though it may be assumed that the lichen dried substantially, similar to the lichens in the watered trays. We assumed that the lichens in the trays had relatively the same albedo as the subject lichen board as they were watered with the same volume of water relative to their lichen volume. The albedo measurements suggested that moisture in lichen increased the lichens' albedo, and one may assume that the lichen trays had a lower albedo at the end of the day compared to right after they were watered. Though, the lichen trays were supposed to mirror the subject lichen boards, the aluminium trays were shallower than the lichen board. Therefore, the lichen board may not have dried up as fast as the trays. At the end of each measuring day, the subject lichen board was examined, and deeper within the lichens there was always observed moisture that had not evaporated. Because of this, the albedo of the subject lichen board may therefore not have been affected as much by drying compared to the lichen trays. On days with more cloud cover the lichens also seemed to dry slower, and direct sunlight may play an important part in faster drying of the lichens.

The difference in moisture content between the two watering techniques showede that the lichens absorbed more water when they were sprayed with a water bottle compared to when the water was poured gently onto them. When spraying the lichens, it seemed as they absorbed more water in their outer branches as well. They became softer and increased in size compared to the lichens where the water was poured onto them. The outer branches of these lichens were dryer and did not increase in size, believing that it was harder for the lichens to absorb water when the water flow was higher. When looking at the drying curves of the lichen trays (Figure 3.5), it seems that the drying rate is similar for both watering techniques, although the technique of spraying water may seem to dry a little faster in the beginning. Since there was more water in the outer branches for these lichens, the water may have been more accessible, hence the faster drying.

For the subject lichen board, a watering can was used and did therefore not have the same watering technique as the lichen trays, and this technique may be described as somewhere in between the two other techniques. This may potentially affect the water absorption of the lichens on the board. The reason why the watering can was not used for the lichen trays was because the diameter of the water stream was too big for the trays due to the size of the watering can. This would have caused some of the water to pour outside of the tray, or the lichens at the edges of the trays would not have been watered. Natural rain showers differ in water volume, intensity, and duration. However, the spraying technique may be closer to a natural rain shower than the pouring technique.

4.2 Drying experiment of three different lichen species

4.2.1 Difference between the lichen species

The capacity to take up water for *C. stellaris* became larger after watering compared to the two other species. Whereas there was only a difference of 0.02 in moisture content between *C. islandica* and *F. nivalis*, the difference in moisture content between these two and *C. stellaris* was 0.43-0.45. After five hours of drying, there was only a difference of 0.06 in moisture content between the three lichen species. Though, the two-way ANOVA does not specify what lichen species had a different drying rate compared to the two others, but by looking at the differences in Table 3.2 one may assume that *C. stellaris* is the lichen species that is different from the two other species, and had the highest drying rate. After some time, here five hours, is seems that the moisture content of the different lichen species evened out.

Structure and texture of the lichens can be assumed to play a role in the drying rates of the species. *C. stellaris* have thin, soft branches which seem to absorb water well. *C. islandica* and *F. nivalis* have thicker and stiffer branches and do not absorb water as well, explaining why they may have a lower moisture content right after watering. Gauslaa (2014) mentions in his study that thin lichens absorb humidity faster than thicker and more compact lichens. Colour also usually plays an important part in absorption and reflection of sunlight, where darker surfaces absorb more radiation and heat compared to lighter surfaces (Petzold & Rencz, 1975). There is a great difference in colour between *C. islandica*, a dark brown lichen, and *F. nivalis*, a light-coloured lichen. However, this does not seem to have affected the drying of the two lichen species as they have similar moisture content after drying, and the darker *C. islandica* is the lichen species that dried the most between the two. This result seems consistent with Van Zuijlen et al. (2020) who found that difference in lichen colour did not affect the soil temperature or the microclimate conditions underneath the lichen mats.

The aluminium trays used in this experiment may have affected the drying of the lichens. A study by Gul et al. (2018) showed that aluminium foil can have an albedo of up to 0.8, but it may decrease with moisture. Thus, the reflection of the aluminium trays could potentially affect the drying of the lichens compared to their natural environment. This also applies to the drying experiment with different watering techniques.

4.2.2. Relevance to the albedo experiment

When comparing the drying of the different lichen species to the albedo measurements of the lichen boards, one may assume that the outcome of the experiment could have been different if a different lichen species had been used. These measurements show that *C. stellaris* absorbed more water than the two other species. If *C. islandica*, *F. nivalis*, or even a different lichen species had been used instead, the changes in albedo after watering may have been different. It is difficult to say anything about the possible albedo of these two lichens after watering, because they both seem to absorb less water than *C. stellaris*. Even though they had similar moisture content and drying rates, the *C. islandica* is darker than *F. nivalis* and has a lower albedo in its dry state (Table 1.1), which may also have affected the albedo if this lichen species was used in the albedo experiment.

4.3 Field data of natural lichen heaths

As opposed to lichens in an idealised experimental study, it can be difficult to measure the affect moisture has on the albedo of natural lichen heaths due to the interference of many different natural factors such as precipitation. In the albedo experiment, the lichens were watered with a certain amount of water at a certain time. This is not possible to control in the field. The radiometer sensors in the field became wet during rainfall, in contrast to the idealised experiments where the sensors were kept dry during watering. When a sensor becomes wet, this partly blocks and disturbs the radiation the sensor is supposed to measure. Possibly, the sensors facing upward are more affected than the sensors facing downward. This may also have caused an increase in albedo in the field, as incoming shortwave radiation was more perturbed than the outgoing longwave radiation.

4.3.1 Field data from the summer of 2018

From the field data of 2018 it seems that the albedo of the lichen heaths increased with moisture. Even though there are only three days with a clear rain shower, the same pattern could be seen for all these days.

The albedo measurements showed that a decrease in incoming shortwave radiation occurred during the rain showers. The decrease was likely caused by the clouds, as this could also be seen in the albedo experiment on cloudy days. There was also a decrease in outgoing shortwave radiation, which may be a result of the reduction in incoming shortwave radiation. The outgoing longwave radiation decreased after the rain shower. This is probably due to the reduction in surface temperature of the lichens caused by the colder rain, as evaporation requires energy, causing the surface to cool down. The incoming longwave radiation increased during the rain shower. This, however, is different from the albedo experiment where the incoming longwave radiation was not affected by watering and did not seem to change noticeably throughout the measuring at all. One explanation to the increase in incoming longwave radiation may be clouds. For the albedo experiment, the incoming longwave radiation seemed to increase slightly with clouds, whereas the other types of radiation measured decreased. Because the lichen boards were watered “artificially”, there were not many clouds at the time of watering. In the natural lichen fields however, the rain must come from a cloudy sky. This could explain why the increase in incoming longwave radiation was only seen in the data from the natural lichen heaths, and not from the lichen boards in the albedo experiment.

The average increase in albedo before and after rainfall for the natural lichen heaths was 0.028. This is close to the average increase in albedo from the lichen board experiment, which was 0.025. Even though the amount of rain was smaller in the natural lichen fields, moisture seems to have the same effect on the albedo as it had for the lichen boards.

4.3.2 Field data from the summer of 2019

The field data from 2019 was not as consistent as the year before. The three days with clear rain showers all gave somewhat different results.

The albedo measurements for the first day did not show an increase in lichen albedo after a rain shower. Though, for this day it kept raining throughout the evening and night. The graph showing the albedo of the lichens (Figure 3.8) showed a continuous decrease in albedo during the rain shower. The reason for this may be clouds, bad weather and less sunlight following the rain. There was also a large decrease in incoming shortwave radiation (Figure 3.9) before the rain shower began, which was probably due to clouds. There had also been a 16 mm rainfall the previous day. Because of the rainfall there is a great chance that the lichens did not have time to dry before the next shower, and the albedo of the lichens was therefore not affected by the rain since the lichens were already wet. The outgoing longwave radiation decreased before the rain shower, but not as much as expected compared to the results from the albedo experiment. The low air temperature (average of 10.2^{o}C) may be the reason for this. The surface temperature of the lichens may therefore not have been reduced as much when it started to rain, hence the low decrease in outgoing longwave radiation.

The second day showed an increase in albedo after the rain shower. As well as the previous day, it also rained throughout the evening so the albedo could not be measured after the rain shower was over. During the measuring time, there was a rainfall of 1.6 mm (Figure A6a). The albedo actually started to increase 50 minutes before it started to rain, and continued to increase during the rain shower. The increase in albedo may have been caused by other factors as well. Though, it seemed that the albedo increased faster when it started to rain, indicating that moisture may have an effect on the albedo of the lichens.

The third day showed an increase in albedo after the rain shower most clearly (Figure A7a). There was first a large decrease in albedo before it started to increase, probably due to clouds, since this was also seen on the incoming shortwave radiation. Similar to the first day, it had also been raining the previous day here, but it did not seem to affect the albedo quite as much. The rain shower before the third day was also lighter than the rain shower before the first day.

4.3.3. Comparison to the albedo experiment

With near perfect conditions the natural lichen heaths seemed to experience the same increase in albedo after a rain shower as the subject lichen board in the albedo experiment did. It also seems that the albedo is affected by even smaller amounts of rain as the same increase in albedo is seen in both the field data and the albedo experiment, where the rainfall in the field was smaller than in the experiment. However, the data may not be comparable as they are measured at different times during the year, with different elevations and surroundings. The albedo experiment also lacks some natural factors such as clouds due to the rain, and unevenness in precipitation.

4.4 Methodological considerations

The albedo experiment could have had more measuring days. The measuring started in late summer until early autumn. More measuring days may have given a different result in the paired Wilcoxon signed rank test for the control board. There was also only used one type of lichen species for the subject board, and other lichens with different colours and structure may have given a different result. Though *C. stellaris* and *F. nivalis* have similar albedo, it may have been better to have the subject board and the control board consisting of the same lichen species.

The drying experiment of the different lichen species could also have had more measuring days. There was also an unevenness in species samples, where we had fewer trays of *F. nivalis*, which could possibly be an error.

Regarding the field data from the summers of 2018 and 2019 there were also few days to analyse. However, this is difficult to do something about as one cannot control the weather. During a natural rain shower, dark clouds usually appear. In the albedo experiment however, the sky was clear when the lichens were watered. As mentioned earlier, the clouds affect both the incoming shortwave radiation and the incoming longwave radiation. This was seen in the radiation measurements of the natural lichen heaths, but not in the lichen board experiment. The radiation budget given in the lichen board experiment may therefore not represent the radiation budget the lichens experience in their natural environment.

5 CONCLUSIONS

The purpose of this project was to gain a better understanding of how moisture can affect the microclimate of lichens. The conclusions for the aims of this study are:

1) **How moisture can affect the albedo of the lichen species *Cladonia stellaris***
   Moisture seems to have an impact on the albedo of the lichen species *C. stellaris*, where the albedo increases with 0.025 after watering. The changes in albedo have only been studied for this lichen species, and other lichen species may give different results.
2) **If different lichen species have different drying times after rainfall**
   Lichen species with thinner branches such as *C. stellaris* seem to absorb more water than lichen species with thicker branches such as *C. islandica* and *F. nivalis*. This resulted in a moisture content difference of approximately 0.45 after watering for *C. stellaris* compared to the two other lichen species. *C. stellaris* dries faster than the other lichen species as well, but after five hours of drying the moisture content became similar for all three species. Colour, however, does not seem to have an influence in drying as the light-coloured lichen *C. islandica* and the dark-coloured lichen *F. nivalis* had similar drying rates.
3) **If the effect of moisture on albedo is visible in albedo measurements of natural lichen heaths**
   It is difficult to see how moisture affects lichen albedo in natural lichen heaths as it is harder to have optimised conditions. For the days where the conditions were favourable for albedo measurements, there was an increase in lichen albedo after rainfall similar to the albedo increase in the lichen board measurements.

Future studies on the effect of moisture on the albedo of lichens should include different lichen species to see if structure and colour may affect the albedo as well. Both idealised field studies and studies of natural lichen heaths are competent methods for albedo measurements. But, an idealised field study makes it easier to control natural factors such as homogenous lichen mats and rainfall.

6 REFERENCES

Aartsma, P., Asplund, J., Odland, A., Reinhardt, S., & Renssen, H. (2020). Surface albedo of alpine lichen heaths and shrub vegetation. *Arctic, Antarctic, and Alpine Research*, 52(1), 312-322.

Aartsma, P., Asplund, J., Odland, A., Reinhardt, S., & Renssen, H. (2021). Microclimatic comparison of lichen heaths and shrubs: shrubification generates atmospheric heating but subsurface cooling during the growing season. *Biogeosciences*, 18, 1577-1599.

Ahti, T., & Oksanen, J. (1990) Epigeic lichen communities of taiga and tundra regions. *Vegetatio,* 86, 39-70.

Beringer, J., Lynch, A.H., Chapin III, F.S., Mack, M., & Bonan, G.B. (2001). The representation of Arctic soils in the land surface model: the importance of mosses. *Journal of climate,* 14, 3324-3335.

Bernier, P.Y., Desjardins, R.L., Karimi-Zindashty, Y., Worth, D., Beaudoin, A., Luo, Y., & Wang, S. (2011). Boreal lichen woodlands: A possible negative feedback to climate change in eastern North America. *Agricultural and Forest Meteorology*, 151, 521-528.

Bryn, A., & Potthoff, K. (2018). Elevational treeline and forest line dynamics in Norwegian mountain areas – a review. *Landscape Ecology*, 33, 1225-1245.

Chagnon, C., & Boudreau, S. (2019). Shrub canopy induces a decline in lichen abundance and diversity in Nunavik (Québec, Canada). *Arctic, Antarctic, and Alpine Research,* 51(1), 521-532.

Collins, M., Knutti, R., Arblaster, J., Dufresne, J-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W.J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver, A.J., Wehner, M.F., Allen, M.R., Andres, T., Beyerle, U., Bitz, C.M., Bony, S., & Booth, B.B.B. (2013). Long-term climate change: projections, commitments and irreversibility. In T. F. Stocker, D. Qin, G-K. Plattner, M. M. B. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013 - The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1029-1136). (Intergovernmental Panel on Climate Change). Cambridge University Press.

Dobos, E. (2003). Albedo. *Encyclopedia of Soil Science.* doi: 10.1081/E-ESS 120014334

Doran, P.M. (2013). Chapter 11 – Unit Operations. In *Bioprocess engineering principles*. (2nd edition, pp. 445-595). Elsevier Gezondheidszorg.

EMA. (2014). *Assessment report on Cetraria islandica (L.) Acharius s.l., thallus*. Retrieved from: https://www.ema.europa.eu/en/documents/herbal-report/final-assessment-report-cetraria-islandica-l-acharius-sl-thallus-first-version_en.pdf

Frisch, A., Klepsland, J., Palice, Z., Bendiksby, M., Tønsberg, T., & Holien, H. (2020). New and noteworthy lichens and lichenicolous fungi from Norway. *Graphic Scripta*, 32(1), 1-47.

Gaare, E. (1997). A hypothesis to explain lichen-*Rangifer* dynamic relationships. *Rangifer*, 17, 3-7.

Gascoin, S., Ducharne, A., Ribstein, P., Perroy, E., & Wagnon, P. (2009). Sensitivity of bare soil albedo to surface soil moisture on the moraine of the Zongo glacier (Bolivia). *Geophysical Research Letters*, 36(2). doi:10.1029/2008GL036377

Gauslaa, Y. (2014). Rain, dew, and humid air as drivers of morphology, function and spatial distribution in epiphytic lichens. *The Lichenologist*, 46(1), 1-16.

Grujičić, D., Stošić, I., Kocanić, M., Stanojković, T., Ranković, B., & Milošević-Djordjević, O. (2014). Evaluation of in vitro antioxidant, antimicrobial, genotoxic and anticancer activities of lichen *Cetraria islandica*. *Cytotechnology*, 66(5), 803-813.

Guan, X., Huang, J., Guo, N., Bi, J., & Wang, G. (2009). Variability of soil moisture and its relationship with surface albedo and soil thermal parameters over the Loess Plateau. *Advances in Atmospheric Sciences*, 26(4), 692-700.

Gul, M., Katok, Y., Muneer, T., & Ivanova, S. (2018). Enhancement of albedo for solar energy gain with particular emphasis on overcast skies. *Energies*, 11. doi:10.3390/en11112881

Heggenes, J., Odland, A., Chevalier, T., Ahlberg, J., Berg, A., Larsson, H., & Bjerktvedt, D.K. (2017). Herbivore grazing – or trampling? Thampling effects by a large ungulate in cold high-latitude ecosystems. *Ecology and Evolution*, (7), 6423-6431.

Joly, K., Jandt, R.R., & Klein, D.R. (2009). Decrease of lichens in Arctic ecosystems: the role of wildfire, caribou, reindeer, competition and climate in north-western Alaska. *Polar Research*, 28, 433-442.

Juszak, I., Eugster, W., Heijmans, M.M.P.D., & Schaepman-Strub, G. (2014a) Contrasting radiation and soil heat fluxes in Arctic shrub and wet sedge tundra. *Biogeosciences Discussions*. doi:10.5194/bg-2016-41

Juszak, I., Erb, A.M., Maximov, T.C., & Schaepman-Strub, G. (2014b) Arctic shrub effects on NDVI, summer albedo and soil shading. *Remote Sensing of Environment*, 153, 79-79.

Kershaw, K.A. (1978). The role of lichens in boreal tundra transition areas. *The Bryologist*, 81(2), 294-306.

Kipp & Zonen B.V. (2014). CNR 4 net Radiometer. Instruction Manual. Manual version: 1409. Retrieved from: https://www.kippzonen.com/Product/85/CNR4-Net-Radiometer#.YI612rUzY2x

Löffler, J. (2007). The influence of micro-climate, snow cover, and soil moisture on ecosystem functioning in high mountains. *Journal of Geographical Sciences*. doi: 10.1007/s11442-007-0003-3

Matwiejuk, A. (2000). Water content in terricolous lichens. *Acta Societatis Botanicorum Poloniae*, 69(1), 55-63.

Myers-Smith, I.H., Forbes, B.C., Wilmking, M., Hallinger, M., Lantz, T., Blok, D., Tape, K.D., Macias-Fauria, M., Sass-Klaassen, U., Lévesque, E., Boudreau, S., Ropars, P., Hermanutz, L., Trant, A., Collier, L.S., Weijers, S., Rozema, J., Rayback, S.A., Schmidt, N.M., Schaepman-Strub, G., Wipf, S., Rixen, C., Ménard, C.B., Venn, S., Goetz, S., Andreau-Hayles, L., Elmendorf, S., Ravolainen, V., Welker, J., Grogan, P., Epstein, H.E., & Hik, D.S. (2011). Shrub expansion in tundra ecosystems: dynamics, impacts and research priorities. *Environmental Research Letters*,6(4). doi:10.1088/1748-9326/6/4/045509

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

Nystuen, K.O., Sundsdal, K. Opedal, Ø.H., Holien, H., Strimbeck, G.R., & Graae, B.J. (2019). Lichens facilitate seedling recruitment in alpine heath. *Journal of Vegetation Science,* 30, 868-880.

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., Sandvik, S.M., Bjerketvedt, D.K., & Myrvold, L.L. (2014). Estimation of lichen biomass with emphasis on reindeer winter pastures at Hardangervidda, Norway. *Rangifer,* 34(1), 95-110.

Odland, A., Sundstøl, S.A., & Bjerketvedt, D.K. (2018). Alpine lichen-dominated heaths: ecology, effects of reindeer grazing, and climate change. A review. *Oecologia Montana,* 27, 30-50.

Oke, T.R. (1987). *Boundary layer climates* (2nd edition). Routledge.

Oksanen, L., & Virtanen, R. (1995). Topographic, altitudinal and regional patterns in continental and suboceanic heath vegetation of northern Fennoscandia. *Acta Botanica Fennica*, 153, 1-80.

Peltoniemi, J.I., Manninen, T., Suomalainen, J., Hakala, T., Puttonen, E., & Riihelä, A. (2010). Land surface albedos computed from BRF measurements with a study of conversion formulae. *Remote sensing,* 2, 1918-1940.

Petzold, D.E., & Rencz, A.N. (1975). The albedo of selected subarctic surfaces. *Arctic, Antarctic, and Alpine Research,* 7(4), 393-398.

Porada, P., Ekici, A., & Beer, C. (2016). Effects of bryophyte and lichen cover on permafrost soil temperature at large scale. *The Cryosphere,* 10, 2291-2315.

Rikkinen, J. (2013). Molecular studies on cyanobacterial diversity in lichen symbioses. *MycoKeys*, 6, 3-32.

Rutherford, W.A., Painter, T.H., Ferrenberg, S., Belnap, J., Okin, G.S., Flagg, C., & Reed, S.C. (2017). Albedo feedbacks to future climate via climate change impacts on dryland biocrusts. *Scientific Reports,* 7. doi: 10.1038/srep44188

Skøyen, K. (2020). *The surface albedo of three lichen species (Flavocetraria nivalis, Cladonia stellaris, Cetraria islandica) and crowberry (Empetrum nigrum), and the influence of zenith angle, clouds and aspect.* (Master's thesis). University of South-Eastern Norway

Sugathan, N., Biju, V., & Renuka., G. (2014). Influence of soil moisture content on surface albedo and soil thermal parameters at a tropical station. *Journal of Earth System Science,* 123, 1115-1128.

Sundberg, B., Ekblad, A., Näsholm, T., & Palmqvist, K. (1999), Lichen respiration in relationship to active time, temperature, nitrogen and ergosterol concentrations. *Functional Ecology,* 13, 119-125.

Sundstøl, S.A., & Odland, A. (2017). Responses of alpine vascular plants and lichens to soil temperatures. *Annales Botanici Fennici,* 54(1-3), 17-28.

Te Beest, M., Sitter, J., Ménard, C.B., & Olofsson, J. (2016). Reindeer grazing increases summer albedo by reducing shrub abundance in Arctic tundra. *Environmental Research Letters*, 11. doi:10.1088/1748-9326/aa5128

Van Zuijlen, K., Roos, R.E., Klanderud, K., Lang, S.I., & Asplund, J. (2020). Mat-forming lichens affect microclimate and litter decomposition by different mechanisms. *Fungal Ecology*, 44. doi.org/10.1016/j.funeco.2019.100905

Yang, J., Li, Z., Zhai, P., Zhao, Y., & Gao, X. (2020). The influence of soil moisture and solar altitude on surface spectral albedo in arid area. *Environmental Research Letters*, 15. doi: 10.1088/1748-9326/ab6ae2

Zhang, R., Wang, H., Qiang, F., Rasch, P.J., & Wang, X. (2019). Unraveling driving forces explaining significant reduction in satellite-inferred Arctic surface albedo since the 1980s. *PNAS*, 116(48) 23947-23953.

Zhurbenko, M., & Pino-Bodas, R. (2017). A revision of lichenicolous fungi growing on Cladonia, mainly from the northern hemisphere, with a worldwide key to the known species. *Opuscula Philolichenum*, 16, 188-266.

7 APPENDIX

Table A1 *Cloud cover from 31.8.20.*

Time	Cloud cover	Shade over lichen?
10:30	1	No
11:00	1	No
11:30	2	No
12:00	2	No
12:30	2	No
13:00	2	No
13:30	2	No
14:00	2	No
14:30	3	No
15:00	3	No
15:30	3	No
16:00	4	Yes
16:30	4	Yes
17:00	3	No

Table A2 *Cloud cover from 8.9.20.*

Time	Cloud cover	Shade over lichen?
08:30	6	Yes
09:00	3	Yes
09:30	3	Yes
10:00	4	No
10:30	3	Yes
11:00	3	Yes
11:30	4	Yes
12:00	4	Yes
12:30	4	Yes
13:00	4	No
13:30	4	Yes
14:00	4	Yes
14:30	4	Yes
15:00	4	Yes
15:30	4	No
16:00	4	No
16:30	5	Yes

Table A3 *Two-way ANOVA made in Excel of the drying experiment of three lichen species. The two factors used in this test were lichen species and measurement days.*

SUMMARY	*Quantity*	*Sum*	*Average*	*Variance*
8.9.2020	3	0,613	0,204	0,002024
	3	0,664	0,221	0,003433
	3	0,634	0,211	0,000616
	2	0,653	0,218	0,001172
	2	0,639	0,213	0,004329
10.9.2020	3	0,546	0,182	0,001039
	3	0,542	0,181	0,003605
	3	0,507	0,169	0,000439
	2	0,539	0,180	0,001697
	2	0,502	0,167	0,000950
22.9.2020	3	0,372	0,124	0,000844
	3	0,343	0,114	0,000644
	3	0,314	0,105	0,000842
	2	0,340	0,113	0,000444
	2	0,365	0,122	0,002400
C. islandica	15	2,378	0,159	0,001483
C. stellaris	15	3,106	0,207	0,002909
F. nivalis	9	2,089	0,139	0,001842

Variance analysis

Source of variance	*SK*	*fg*	*GK*	*F*	*P-value*	*F-crit*
Rows	0,07496	14	0,00535	12,1641	2,08E-08	2,064
Columns	0,03664	2	0,01832	41,6166	4,10E-09	3,340
Error	0,01232	28	0,00044			
Total	0,12392	44				

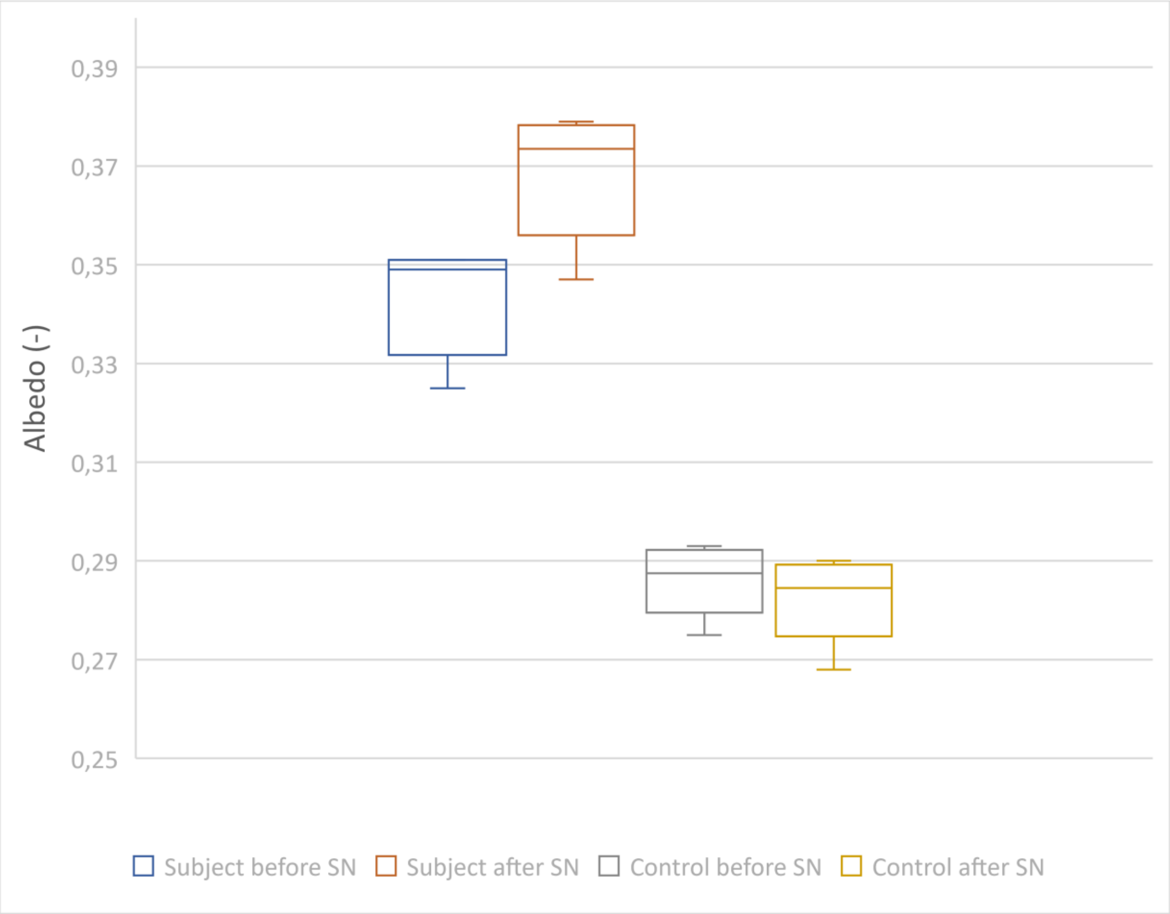
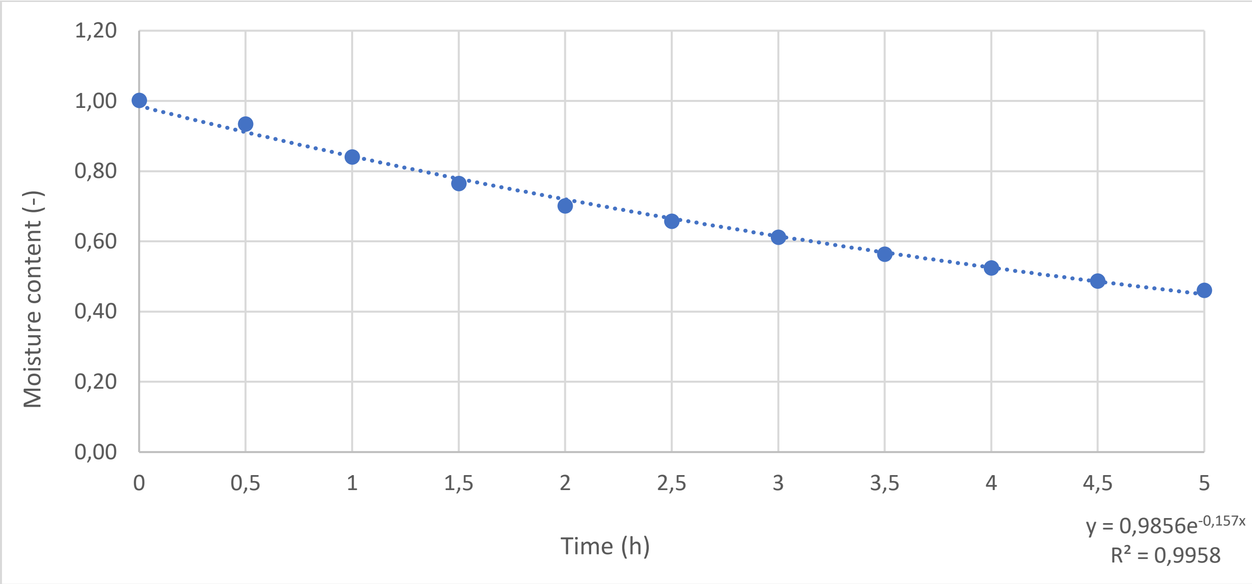
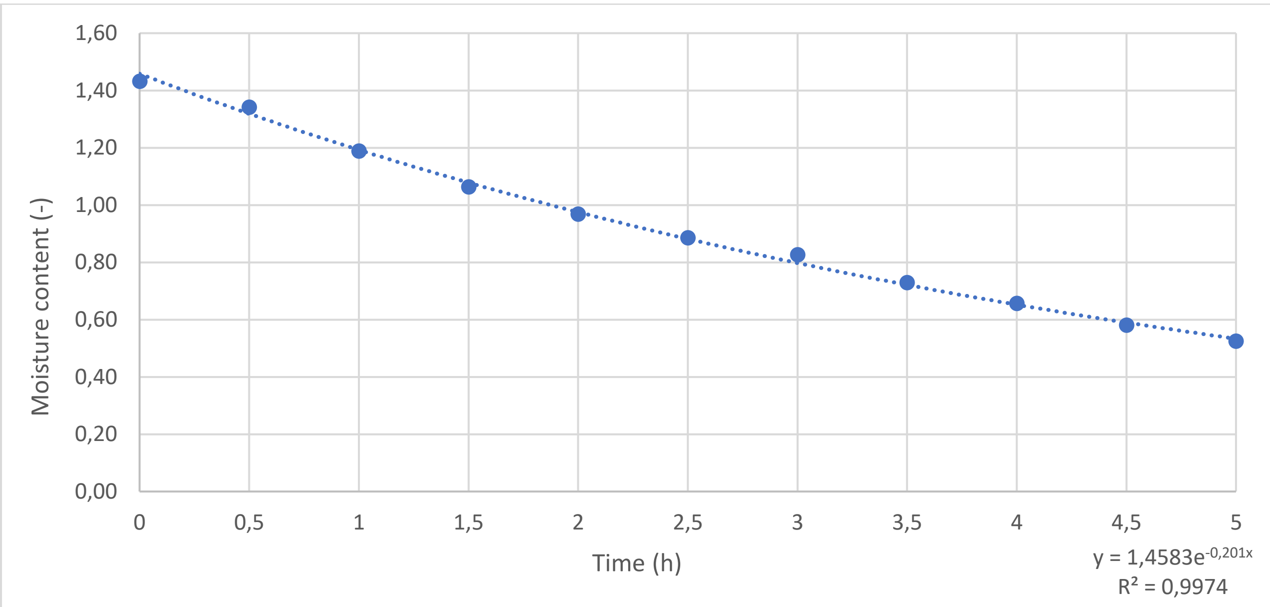


Figure A1 *Box plot of the albedo measurements of the lichen boards before and after solar noon (SN).*

a)


1,20
1,00
0,80
0,60
0,40
0,20
0,00
Moisture content (-)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Time (h)
y = 0,9856e-0,157x
R² = 0,9958

b)


1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
Moisture content (-)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Time (h)
y = 1,4583e-0,201x
R² = 0,9974

c)

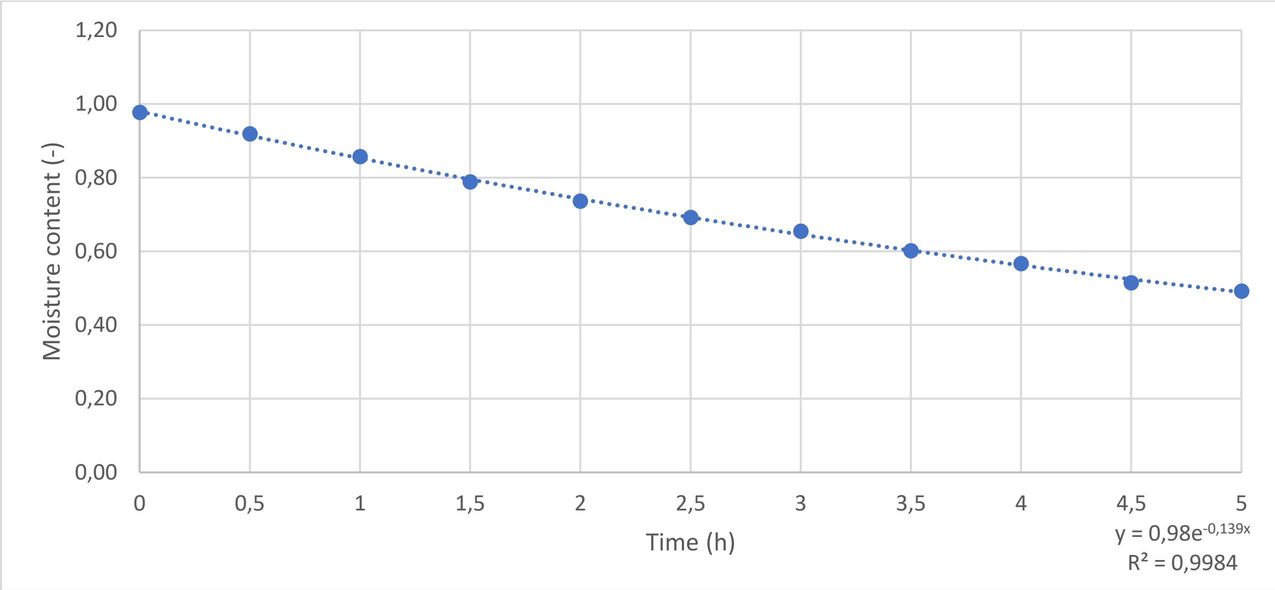


Figure A2 *Graphs showing drying rate of the different lichen species according to their decrease in moisture content a) average drying rate of C. islandica b) average drying rate of C. stellaris c) average drying rate of F. nivalis*

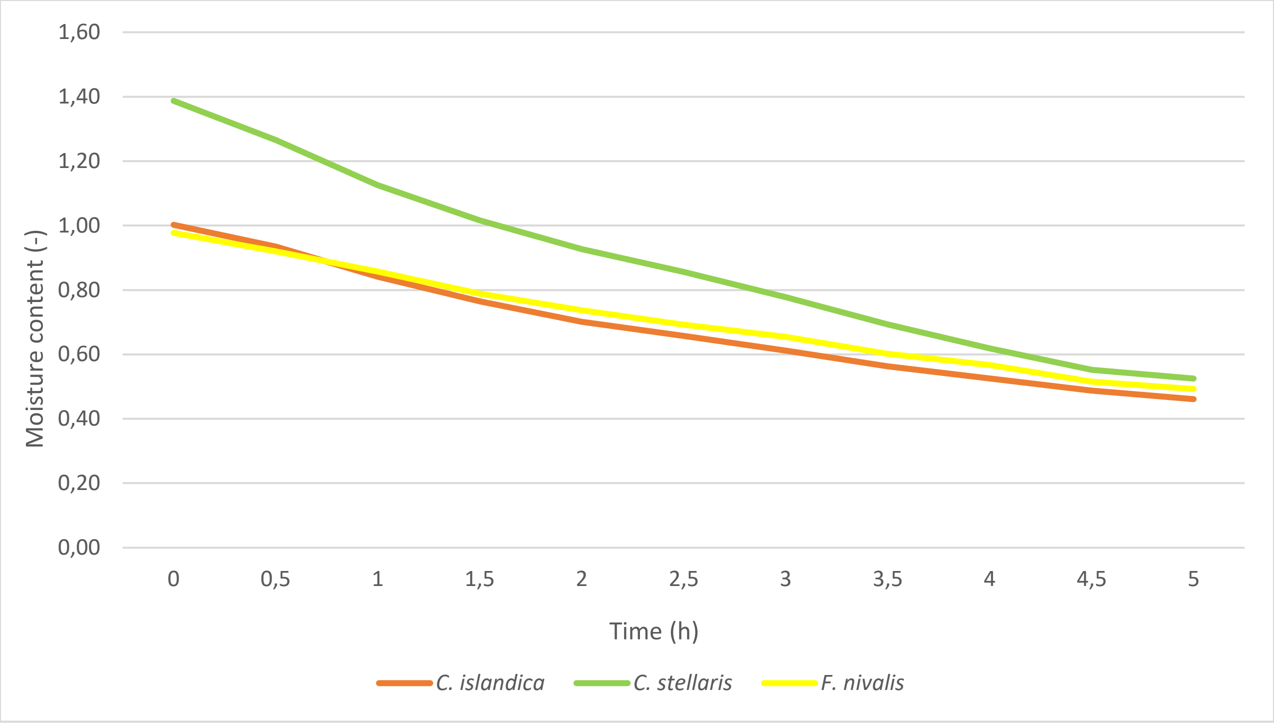


Figure A3 *The average loss in moisture content of three different lichen species measured over a drying time of five hours.*

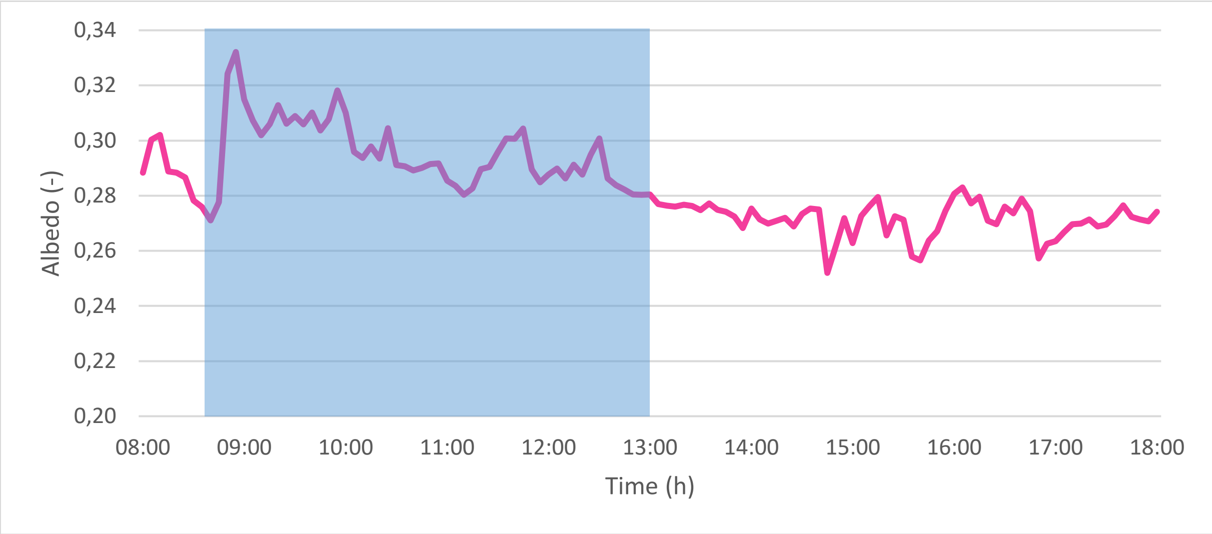


Figure A4a *Albedo of the lichen heaths for 2.8.18. The blue area indicates a 2 mm rain shower. This is described as the third day for the data of 2018. As the rain shower began at 8:40 the graph includes values from 8:00.*

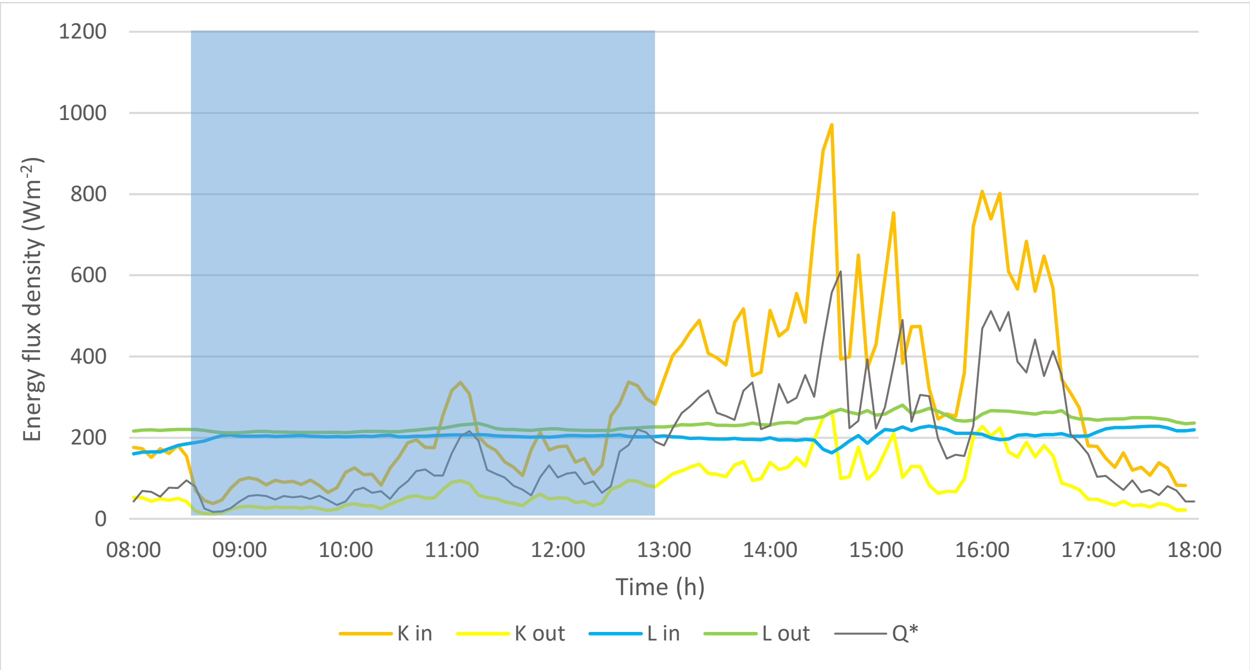


Figure A4b *Radiation budget of the lichen heaths for 2.8.18. The blue area indicates a 2 mm rain shower. This is described as the third day for the data of 2018. As the rain shower began at 8:40 the graph includes values from 8:00.*

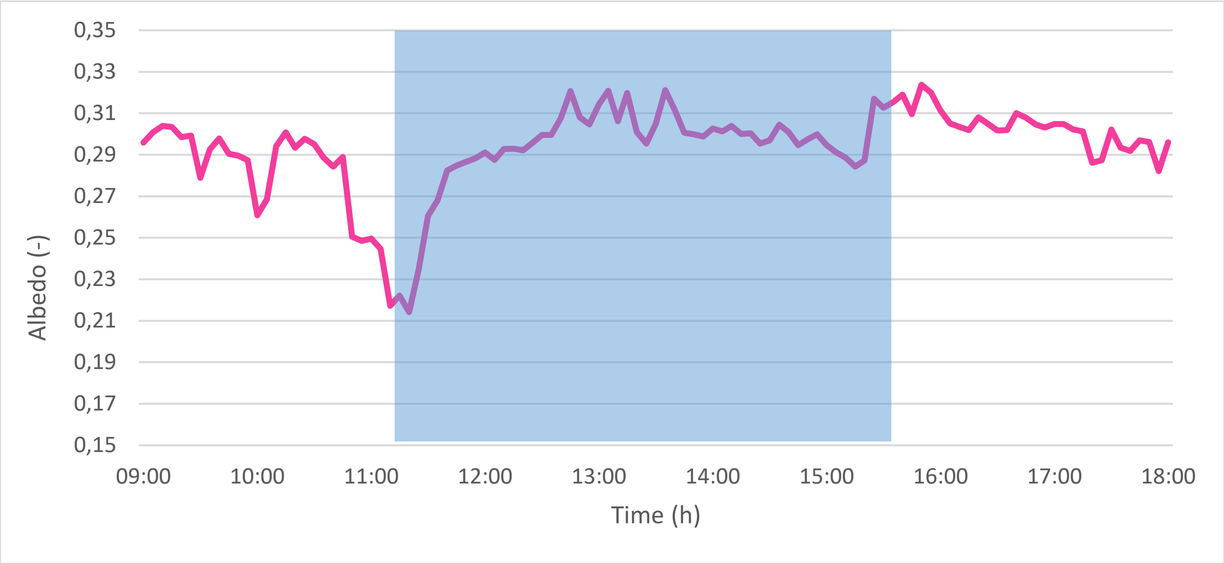


Figure A5a *Albedo of the lichen heaths for 17.7.18. The blue area indicates a 7 mm rain shower. This is described as the second day for the data of 2018.*

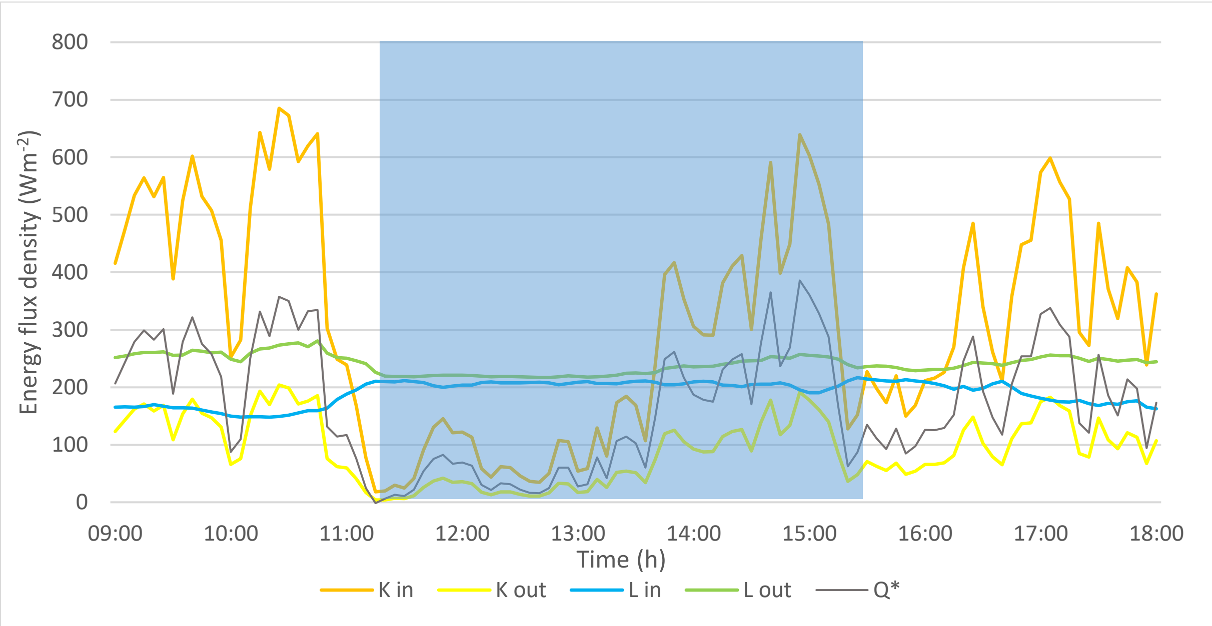


Figure A5b *Radiation budget of the lichen heaths for 17.7.18. The blue area indicates a 7 mm rain shower. This is described as the second day for the data of 2018.*

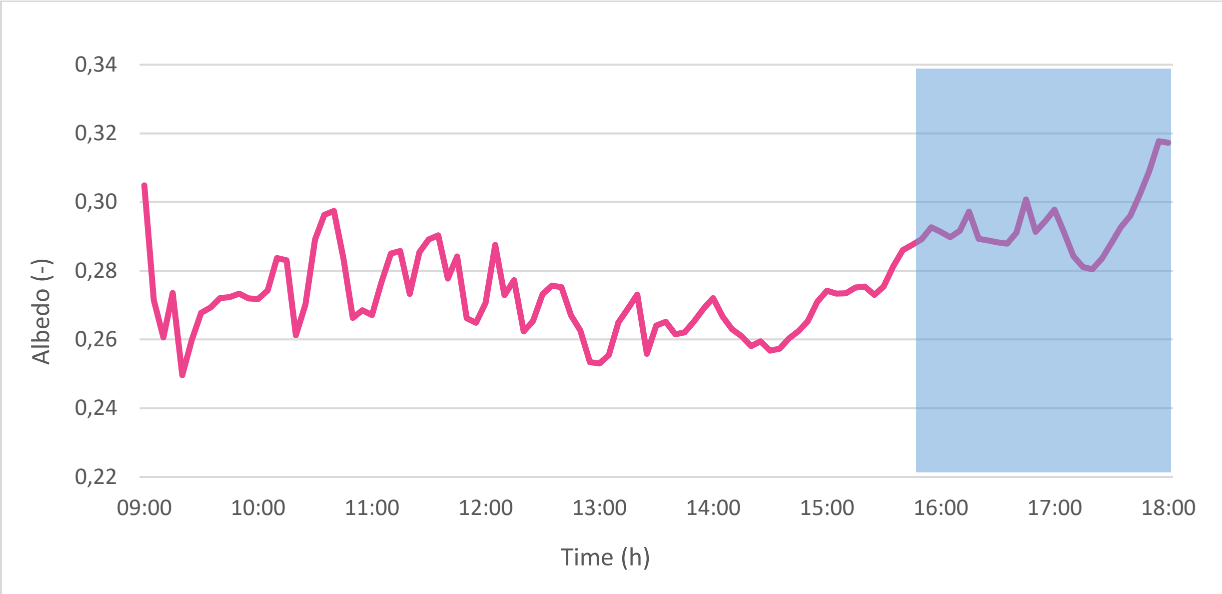


Figure A6a *Albedo of the lichen heaths for 6.8.19. The blue area indicates a 1.6 mm rain shower. This is described as the second day for the data of 2019.*

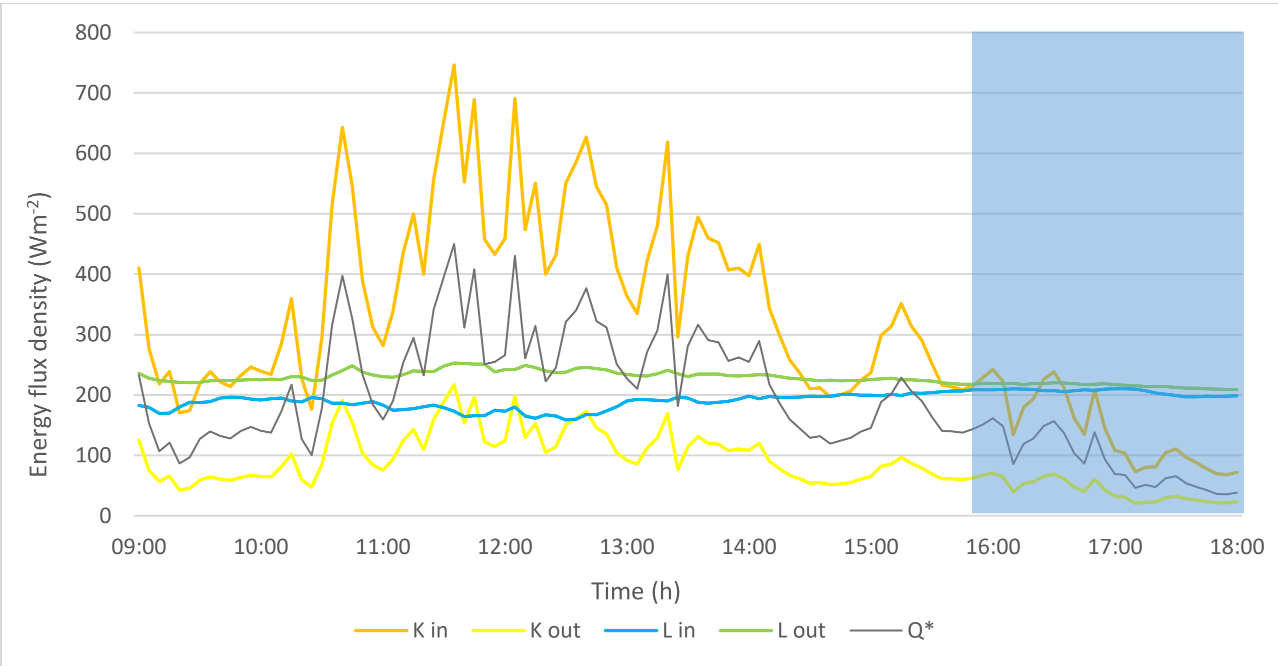


Figure A6b *Radiation budget of the lichen heaths for 6.8.19. The blue area indicates a 1.6 mm rain shower. This is described as the second day for the data of 2019.*

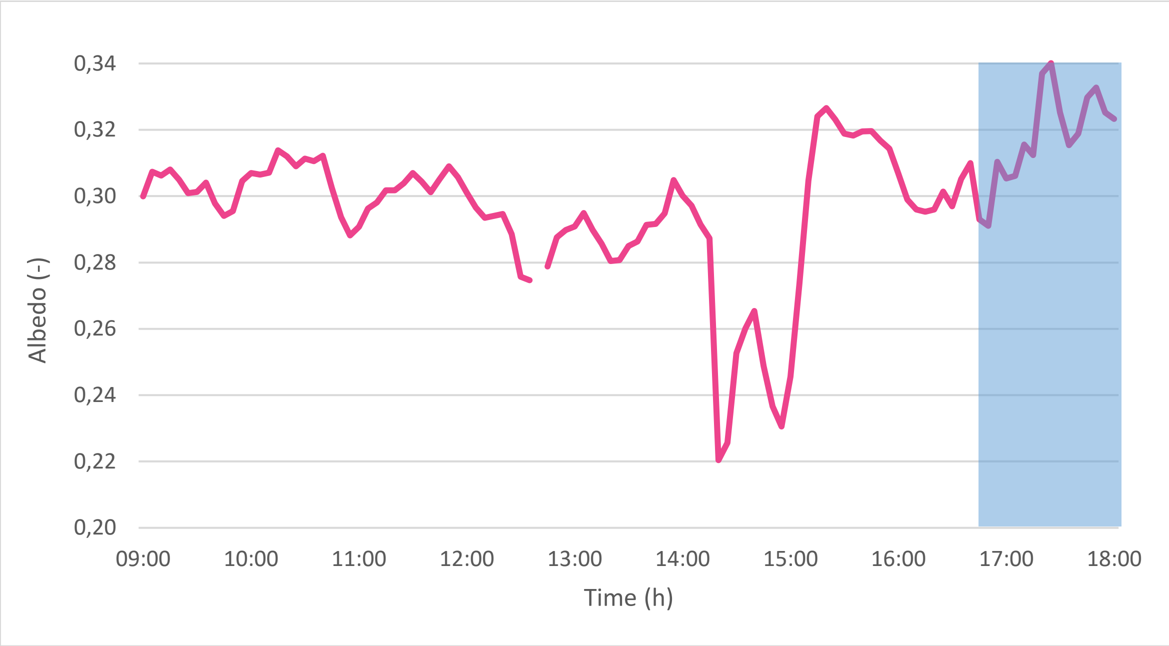


Figure A7a *Albedo of the lichen heaths for 12.8.19. The blue area indicates a 7.2 mm rain shower. This is described as the third day for the data of 2019. The hole in the graph is caused by missing data for incoming and outgoing shortwave radiation at 12:40.*

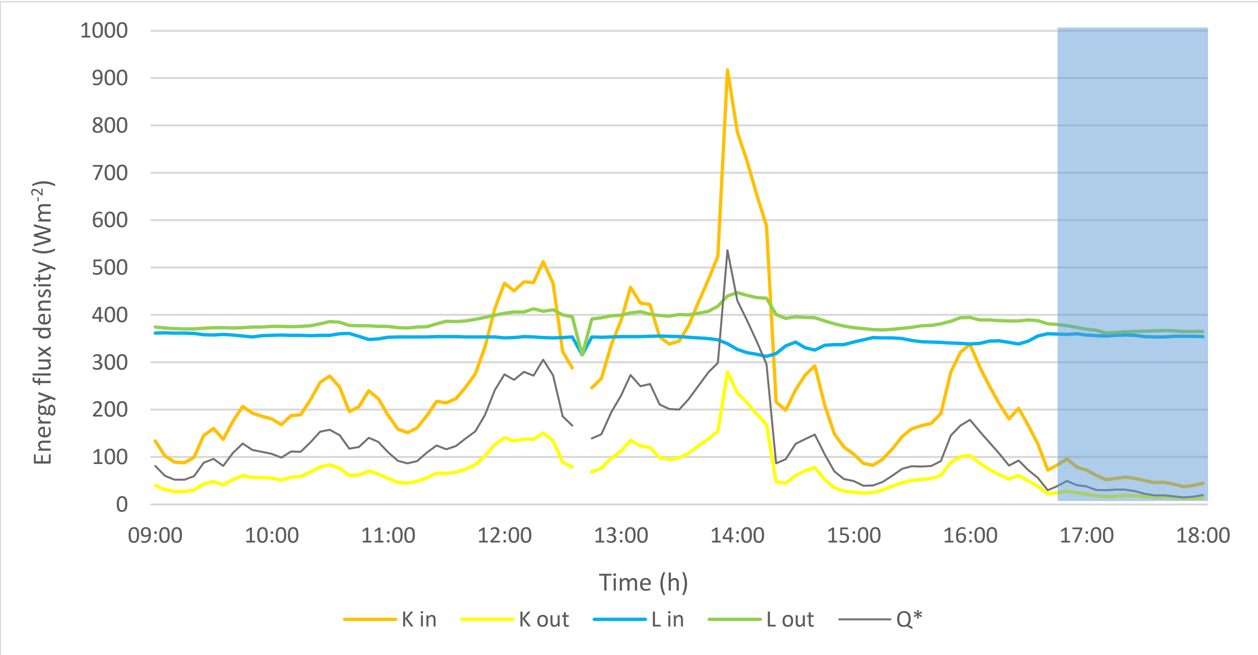


Figure A7b *Radiation budget of the lichen heaths for 12.8.19. The blue area indicates a 7.2 mm rain shower. This is described as the third day for the data of 2019. The hole in the graph is caused by missing data for incoming and outgoing shortwave radiation at 12:40.*

Figure A8a *The subject lichen board consisting of C. stellaris. The lichens were tightly packed leaving no gaps to expose the wooden board underneath.*

Figure A8b *The control lichen board consisting of F. nivalis. Gaps between the lichen patches exposed the wooden board underneath, and the darker underside of the lichens covered in soil were also exposed.*