The Evolutionary Snow Lichen

What's in a microbial mat left by receding snow? And what is it doing there?

Figure 1: Microbial mat left by receding snow. Mount Washington BC, Paradise Meadows (5 June 2025 8am)

Microbial mats form at the right temperature and pH in snowmelt and only last fleetingly. They consist mainly of the disorganized organic debris accumulated in the receding snow column. The patterns they form are mainly the product of bacterial organization.

The analysis of the sample of a microbial mat formed at 8am at Paradise Meadows on June 5 showed that it consisted mainly of bacteria, cyanobacteria, Chlorophycae, Fungi, yeast and some protists (*Galionella ferruginea, Chlamydomonas nivalis, Chlainomonas rubra, Trebouxia, Dolichospermum, Pseudanabaena catenata, Nematoda, Tardigrada, Amoeba (Spongomonas), Ciliophora (Frontonia).* This is consistent with what DNA analysis has shown to be found in subalpine and alpine snow. It is therefore of interest to consider that these are normal constituents of snow. It is also important to consider that these organisms were not dormant throughout the winter period. They are known to be active throughout the year and have an important function fixing carbon, year-round.

We take so many things around us for granted that we fail to appreciate just how really alive the world about us is. Perhaps nowhere is this true than in our general lack of appreciation of what snow really is. More than a winter

wonderland, snow, which is traditionally associated with winter cold, a period of dormancy and death, turns out to be a miracle of life that makes the regenerative power of spring possible, and is in fact essential to it. Snow holds the microbial elements and nutrients essential to structuring our northern terrestrial and aquatic ecosystems. This has tremendous implications for our understanding of evolution.

So what is snow? Over the last decade polar and alpine scientists have come to realize that snow is much more than just frozen water. It is a missing link in our modelling of carbon cycles. As one researcher working in the Olympic peninsula put it, snow is "a cryptic photosynthetic system." Researchers also know that in the arctic around Svalbaard ocean productivity is driven by the input of organisms associated with snow algae plunging into the ocean. Researchers refer to this as "the snow rainforest" to describe the large variety and complexity of organisms who live in the snow.

There are two things we do not normally stop to consider.

First, "snow " is a blend of mineral, elements and organic matter. It is peaty water, but not a single malt. The precipitation that falls as snow or rain is part of a global atmospheric condensation system - a distillation- which transports not just water and nucleation chemicals such as sulphur. The majority of organisms reproduce by sporulation. Pollen , fungal and bacterial spores, soot, volcanic ash and soot, and now microplastics, can remain airborne in the stratosphere for indefinite periods. (Little is really known about the fate and duration of these essential constituents of rain and snow.) These particles constitute a reservoir for ice nucleation that will contribute to the formation of rain and snow, integral to precipitation. Heavier spores of algae and eggs tardigrades are also carried in the lower atmosphere and incorporated in precipitation.

Second, snow is crystalline. Like water, it has optical properties. Therefore when snow blankets a landscape the blanket has a photic layer in the same way that a lake does. Depending on the structure of the snow, its chemistry, and the density of particulate matter in the snow and the degree of sunlight, light penetrates snow creating a photic zone between 30cms and 130cms.

As any cross-country skier can attest, in subalpine environments, below the treeline trees contribute branch and lichen debris. This adds to the bacterial, fungal, algal and also faunal material, such as insects and "worms" that can become integrated into the snow. Essentially that is not very different from what researchers have observed in the arctic and antarctic. It is just a richer complex, as should be expected from temperate ecosystems.

So then what does snow become? Polar and alpine researchers have found that the algae form a photosynthetic layer at the top of the snow. The question that arises, and which remains largely unanswered, is whether that layer forms an "organized system", or whether it is just a disorganized random assemblage of algae and fungi? Answering that depends entirely on taking an interdisciplinary approach to the data. Looking at the data from the point of view of a lichenologist, rather than as a glaciologist, a microbiologist, or a phycologist, the complex of organisms in the snow's photic zone forms an organized multi-partner symbiosis consistent with the definition of what constitutes a lichen.

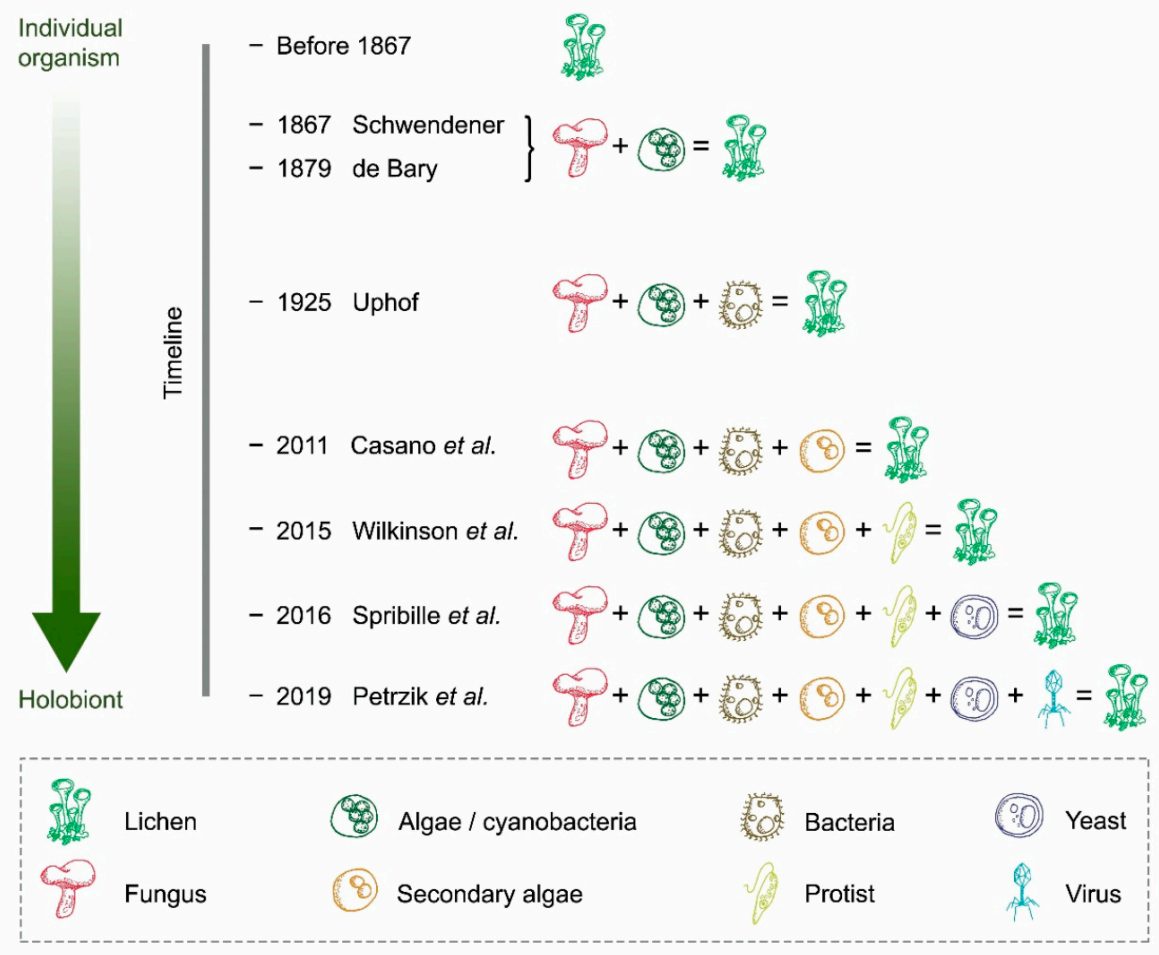

Figure 2: Evolution of our understanding of lichens and the variety of symbioses comprised in lichens. (From Lourdes Morillas et al. (2022) "Lichen as Multipartner Relationships. *Encyclopedia of Fungi)*

Lichens have long been considered to be anomalies in the world of biological taxonomy, because they are an undeniable symbiosis, different organisms living

cooperatively together, contrary to the competitive dogma of of Western science. As the late Lynn Margulis correctly postulated in the late 1960s, much to her grief and much to the establishment's outrage, life on this planet has evolved as a series of symbiosis merging archaea and bacteria. That is a simple fact we now teach in High School science today. As **Figure 2** illustrates, lichens which were originally were first thought to be plants, were discovered to be a symbiosis in 1867. In 1925 Uphof revealed that lichens were a symbiosis of at least three partners: fungi, algae, and bacteria. Since 2011, thanks to DNA analysis our understanding of what a lichen is has been radically expanded to include the additional roles of yeast, a secondary algae, protists and a virus.

In light of these discoveries, "Lichen" has had therefore to be re-defined as "a multipartner relationship," by Morillas et al. in2022.[1] The basic structure for that "multipartner relationship" remains essential to what defines a lichen. It consists of at least a bi-layer of upper fungal hypha housing algae usually forming protective barrier that produces UV protective metabolites, followed by a loose spongy medulla housing carbon and nitrogen fixing algae and cyanobacteria. If this is not directly attached to a rocky substrate, a third basal hyphal layer attaches the symbioses to a substrate.

In 2023 Caleb Schuler and Jill A. Mikucki published the results of a two-year PhD research project on Mt. Baker in *Arctic, Antarctic and Alpine Research* in a paper entitled: "Microbial ecology and activity of snow algae within a Northwest Pacific snowpack."[2] The project did a DNA analysis of the strata of the snow column at six sites. Their DNA an analysis does not identify the constituents to species, it is limited to families. While they do not seem to have realized the similarities with lichen structure and constituents, the distribution that their data reveals is in fact consistent with that of a lichen, as "a multipartner relationship."

The snow column consists of a covering layer of "water melon snow" that is *Chlamydomonas nivalis* and *Chlainomonas rubra*, green algae that produce the red pigment "astaxanthin," and some fungi. Astaxanthin is a UV-blocker. The column below consists of loosely dispersed fungal hyphae, green algae and bacteria, together with cyanobacteria, viruses, yeast and protists. The basal part of the photosynthesizing relationship consists of a hyphal bed. So the covering of populations of *Chlamydomonas nivalis* do not merely produce astaxanthin to protect themselves, as is customarily thought. Here is altruism. They serve as UV-

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[1] https://www.mdpi.com/2673-8392/2/3/96 Lourdes Morillas et al. (2022) "Lichen as Multipartner Relationships. *Encyclopedia of Fungi.*

[2] Caleb G. Schuler & Jill A. Mikucki (2023) Microbial ecology and activity of snow algae within a Pacific Northwest snowpack, Arctic, Antarctic, and Alpine Research, 55:1, 2233785, DOI: 10.1080/15230430.2023.2233785

blockers to protect the photosynthetic activity of a much more complex lichen-like symbiotic organization.

So when we look at snow, we are actually looking at a vast lichen-like template for the symbiotic organization of ecosystems and species. If this is correct, that has some interesting ramifications in how we view the evolution of life.

First it challenges an old assumption that during the last Ice Age (and all Ice Ages before that) when much of North America was covered by two kilometres of ice there was no life. First the weight of ice had to exert pressure (and pressure is heat) and create a basal layer of water which would have harboured microbial life. Second, the covering of the glacier would have had photosynthetic properties driven by microbial organisms, much as glaciologists find today. Third, when glaciers retreated 10 to 12 thousand years ago the regeneration and re-population of life, the "re-greening" of North America was not only driven by a movement of macro-organisms from the south, but by the micro-organisms present in the snow. All confirming the basic axiom of biology: "Only life begets life."

There is continuity rather than sequence in evolution, in the same way that human evolution is increasingly understood to have been a continuous merging of species rather that a series of replacements. (We are all still genetically Neanderthals, though we claim Sapienhood.)

Second, there is the problem of viewing life as separate competitive units rather than as a symbiotic continuum. Paleontologists and taxonomists have long been bedeviled by two organisms that escape all attempts at neat pigeonholing. These are *Prototaxites* and *Spongiophyton*. *Prototaxites* was once thought to be a tree - a relative of gymnosperms, but turned out to be more like a giant fungus, and now seems to belong to "an unknown branch of life". [3] More recently *Spongiophyton,* an unruly organism that seems to be neither a vascular plant nor a lichen, seems also to belong to "an unknown branch of life".[4]. That may be life itself!

What the snow lichen may suggest is that evolution is not a neat set of sequences. It is more akin to a continuous variation on a broad template of multipartner relationships. Evolution is creative on a fairly simple theme of symbiotic

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[3] https://www.smithsonianmag.com/smart-news/giant-mysterious-spires-ruled-the-earth-long-before-trees-did-what-exactly-are-these-odd-looking-fossils-13709647/

[4] Bruno Becker-Kerber et al. (2025) "The rise of lichens during the colonization of terrestrial environment," *Science.29 Oct 2025 Vol 11, Issue 44* https://www.science.org/doi/10.1126/sciadv.adw7879

variations that defy the comfort of hierarchy - and sometimes we have surprises outside the comfort of our expectations.

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