



Future Arctic

A global initiative on bryophyte and lichen Arctic research:
from species to ecosystems



24th-26th May 2017

Forêt Montmorency

Université Laval, Québec, Canada

BIENVENUE au QUÉBEC
Bonjour à tous !

It gives us great pleasure to welcome all of you to Québec and the workshop *Future Arctic*. The objective of the workshop is to bring together world-class experts to discuss all aspects of bryophytes and lichens in Arctic research: from species to ecosystems.

The four main goals of this workshop are:

- > *Synthesize the current understanding of Arctic cryptogamic research*
- > *Emphasize the interplay between biogeochemical processes, microbes and biodiversity of cryptogams*
- > *Encourage multidisciplinary collaboration among Arctic researchers*
- > *Highlight the future research initiatives*

We have reunited over sixty colleagues, amongst established professionals, young researchers and future investigators (students and postdocs), from ten countries and twenty-eight institutions to discuss the most relevant topics on arctic research. We hope this workshop will be a fruitful and convivial experience for all of us. The organizing committee is grateful to the sponsors of the workshop: The Department of Biology, Phytology and the Faculty of Forestry (Université Laval); the Louis-Marie Herbarium (U. Laval), Center for Northern Studies (CEN), the Sentinel North and the Peatland Ecology Research Group (PERG).

We hope you enjoy the workshop and the surrounding nature at this very unique place, *La Forêt Montmorency*.

With our best wishes,
The organizing committee

Juan Carlos Villarreal
Département de Biologie
Université Laval

Line Rochefort
Département de Phytologie
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SPONSORS AND RESEARCH INSTITUTES

CENTRE FOR NORTHERN STUDIES (<http://www.cen.ulaval.ca/en/>)

The Centre for Northern Studies nordiques (CEN) is a research centre involving three academic institutions, the Université Laval, the Université du Québec à Rimouski and the Centre Eau, Terre et Environnement of the Institut national de la recherche scientifique.

CEN researchers also include professors from the Université du Québec à Trois-Rivières, Université de Sherbrooke, Université de Montréal, Université du Québec à Chicoutimi, Université du Québec à Montréal, McGill University, Concordia University and Cégep F-X Garneau.

CEN brings together over 300 researchers, students, postdoctoral fellows and professionals from diverse disciplines (biology and microbiology, geography, geology, engineering, archeology, landscape management). CEN's mission is to contribute to the sustainable development of northern regions by way of an improved understanding and prediction of environmental change. Their research focuses on northern ecosystems and geosystems, and is used to formulate adaptation strategies relevant to the North.

LOUIS-MARIE HERBARIUM – U. LAVAL (<https://www.herbier.ulaval.ca/>)

Curator: Serge Payette

The Louis-Marie Herbarium contains a collection of more than 770,000 specimens, which places it amongst the principal Canadian herbaria. The Herbarium has a mission to assure an expertise in plant identification, documenting biodiversity and finalizing *La flore du Québec*.

SENTINEL NORTH (<https://www.ulaval.ca/en/sentinel-north.html>)

In 2015, Université Laval received a \$98 million grant from the federal government's Canada First Research Excellence Fund, the largest research grant in its history. With Sentinel North, Université Laval draws on over a half-century of northern research to develop innovative tools in optics-photonics and improve our understanding of the northern environment and its impact on human beings and their health. Sentinel North provides for the establishment of an international scientific panel, new international research chairs, joint international research units, and the recruitment of world-renowned professors. Sentinel North's ambitious research program is at the core of these numerous initiatives and will encourage the development of research teams and joint projects focusing on discovery, transdisciplinarity, innovation, collaboration, national and international partnerships, and technology transfer. Sentinel North will help us monitor and prepare for changes in northern environments using state-of-the-art technologies and intervention strategies in the pursuit of sustainable health and development.

QUEBEC CENTRE FOR BIODIVERSITY SCIENCE QUÉBEC (CSBQ, <http://qcbs.ca/>)

The CSBQ network connects more than 120 researchers, 700 graduate students and postdoctoral fellows, as well as many undergraduate students and numerous national and international partners. The objective of the QCBS is to foster the emergence of an integrated biodiversity science in Québec, the general scientific principles of which will allow the discovery, study, and sustainable use of the Québec biodiversity.

PEATLAND ECOLOGY RESEARCH GROUP (<http://www.gret-perg.ulaval.ca>)

Director: Line Rochefort

The Peatland Ecology Research Group (PERG) was formed through the partnership of the university scientific community, the Canadian peat moss industry and federal and provincial agencies. Their common objective is the integrated sustainable management of Canadian peatlands. Since 1992, this research group has led many projects, dealing with, among others, the *Sphagnum* ecology and productivity, the development of restoration techniques after peat harvesting, and the hydrology, geochemistry, microbiology and fauna of natural, harvested and restored peatlands. PERG's expertise in restoration and conservation is recognized at the international level and has created a strong interest from the private sector, governments, and conservation organizations.

FORÊT MONTMORENCY (<http://www.foretmontmorency.ca/en/>)

The Montmorency Forest is the largest teaching and research forest in the world, totaling 412 km². It is open to the public and located 45 minutes north of Quebec City. The Montmorency Forest's mission is to be a welcoming environment committed to excellence in the areas of teaching, research and public education related to sustainable forest management. In order to achieve this, we aim to develop a viable sustainable forest management of timber, wildlife, water, recreation, tourism and landscape resources in a way that preserves the forest's productivity model, its regeneration capacity and its vitality. The model also ensures the maintenance of biodiversity by safeguarding the distinctive ecological features of the natural regional forest, following the principles of ecosystem management.

PROGRAM

Wednesday 24th May

- 13.00-15.15 **Visit to the herbarium Louis Marie (optional)**
Pavillon Charles E. Marchand, Université Laval
Serge Payette
- 15.30 **Departure to The Forêt Montmorency**
- 17.00-18.00 **Dinner**
- 19.00-19.15 **Welcome and opening of the workshop**
Juan Carlos Villarreal
- 19.15-20.00 **Arctic environment**
Esther Lévesque
- 20.00-20.45 **Infrastructure and mission
of the Centre for Northern Studies (CEN)**
Gilles Gauthier
- 21.00 -21.30 **Ice breaker**

Thursday 25th May

- 7.30-8.15 **Breakfast**
- 8.30-8.45 **Bryophyte explorations
on Bylot Island, Nunavut, Canada**
Line Rochefort
- 8.45-9.00 **Diversity and distribution of Arctic bryophytes**
Kristian Hassel
- 9.00-9.15 **Rare lichens on the Svalbard Archipelago**
Liudmila Konoreva
- 9.15-9.30 **The moss flora of the Arctic: the view from
the regional level based on Anabar Plateau**
Vladimir Fedosov
- 9.30-9.45 **A comparison of moss diversity in the Russian
Arctic and Premafrost Zone of Siberia**
Michael Ignatov
- 9.45-10.00 **Preliminary study on the bryophyte flora
at the southern-end of Canadian Arctic**
Imura Satoshi

- 10.00-10.30 **Coffee break**
- 10.30-10.45 **Speciation and biogeographic relatedness
in *Racomitrium lanuginosum***
Dietmar Quandt
- 10.45-11.00 **Moss-microbe consortia in polar aquatic ecosystems**
Warwick Vincent
- 11.00-11.15 **Snow penetration in bryophyte and lichen cover:
experimental observations**
Kelina Higgins
- 11.15-11.30 **Boreal bryophyte growth rate and functional
trait variation among species and environments**
Nicole Fenton
- 11.30-11.45 **The Russian study of hepatics diversity in Svalbard**
Nadezha Konstantinova
- 11.45-12.00 **Inter-annual variation in bryophyte dispersal: linking
bryophyte phenophases and weather conditions**
Marion Barbé
- 12.00-13.00 **Lunch**
- 13.00-15.00 **Excursion with Jean Faubert**
- 15.00-15.15 **Coffee break**
- 15.15-15.30 **The first DNA barcode reference library for mosses:
rbcL and trnL-F for 775 species from Canada**
Maria Kuzmina
- 15.30-15.45 **Worldwide spatio-temporal patterns of symbiotic
specificity between *Peltigera* and its *Nostoc* partners**
Nicolas Magain
- 15.45-16.00 **Population genetics of two lichen species
on talus slopes in deboullie in Northern Maine**
Bonnie Corey
- 16.00-16.15 **Where did the Arctico-Alpine mosses
survive in a frozen Europe?**
Alice Ledent

- 16.15-16.30 **Targeted enrichment of nuclear protein coding genes and their introns for inferring phylogenetic histories of bryophytes**
Bernard Goffinet
- 17.00-18.00 **Dinner**
- 18.15-18.45 **Workshop about BOLD (Barcode of Life Data management system)**
Maria Kuzmina
- 19.00-19.30 **Mission of the société québécoise de bryologie**
<http://www.societequebecoisedebryologie.org/>
Jean Faubert
- 19.30-20.30 **Round table: Establishing collaborative partnerships for student and postdoc exchange**

Friday 26th May

- 7.30-8.15 **Breakfast**
- 8.30-8.45 **Boreal endolichenic fungal community structure at local, regional, and global scales**
François Lutzoni
- 8.45-9.00 **Moss associated N-fixation in boreal Alaska: impacts of a transplant experiment under deciduous and coniferous canopies**
Mélanie Jean
- 9.00-9.15 **Do moss host phylogenetics shape microbiome composition and function?**
Lily R. Lewis
- 9.15-9.30 **Taxonomic and functional attributes of the boreal moss microbiome**
Hannah Holland-Moritz
- 9.30-9.45 **Contribution of alternative nitrogenases to nitrogen fixation in cyanolichens; implications for our understanding of high latitude N cycling and cyanolichen symbiosis**
Jean-Philippe Bellenger

- 9.45-10.00 **Determination of baseline metal contamination using foliose lichens in Eastern Canada (Québec)**
Romain Darnajoux
- 10.00-10.30 **Coffee break**
- 10.30-10.45 **Bryophyte persistence in glacial landscapes**
Catherine LaFarge
- 10.45-11.00 **Herbivores, mosses, DNA – Unravelling hidden diversity in Arctic terrestrial food webs**
Michael Stech
- 11.00-11.15 **Change in peatland bryophyte traits following long-term water level draw-down**
Eeva-Stiina Tuittila
- 11.15-11.30 **Yukon ice patches: Role of ice-entombed bryophytes in alpine environments**
Britney Miller
- 11.30-11.45 **Cryptogamic Russian Information System (CRIS) as an important source on biodiversity in Arctic**
Nadezha Konstantinova
- 11.45-12.00 **Lichen and bryophyte inventories in Québec's Arctic by Québec Governmental Agencies (1998 to present)**
Jean Gagnon
- 12.00-13.00 **Lunch**
- 13.00-13.30 **An open platform for biodiversity monitoring in Québec and the Arctic**
Quebec Centre for Biodiversity Science (CSBQ)
Dominique Gravel
- 13.30-14.45 **Round table: Future directions in Arctic research**
- 14.45-15.00 **Coffee break**
- 15.00-16.15 **Round table: Funding for Arctic research and resources available for bryologists**
- 16.30 **Closing of the workshop**

Bryophyte explorations on Bylot Island, Nunavut, Canada

Line Rochefort¹, Guy R. Brassard², Harold L.K. Whitehouse³

¹Département de phytologie and Centre for Northern Studies,
Université Laval, Québec, Canada

²Société québécoise de bryologie, Québec, Canada

³Department of Botany, Cambridge University, Cambridge, U.K.

The first bryophytes collected in the Canadian Eastern Arctic were brought back to England by the expedition under the command of John Ross in 1818, which is considered the first botanical collection ever made in the American Archipelago. A century later, four mosses were collected by the Fifth Thule Expedition 1921-1924 (Rasmussen 1937) for Bylot Island. They were in fact collected as bycatch that is moss stems were picked out of the collected phanerogamic material. George W. Scotter from Canadian Wildlife Service, Environment Canada, had the opportunity to collect bryophytes from 16 sites on Bylot Island in 1982 as part of a natural resource inventory in preparation for the designation of Simirlik National Park which includes a large part of Bylot Island. A major part of the Scotter collections was identified by Brassard and the collection deposited at the Ayre Herbarium, St John's, Newfoundland.

In 1994-95 Rochefort and Whitehouse borrowed the collection and identified all specimens that had not been packeted or determined, including all the Sphagna. During summers 1993-1995, Rochefort collected over 400 bryophyte specimens. A consolidated list of the bryophytes (124 mosses and 16 hepatics) of Bylot Island will be available at the Future Arctic event.

Diversity and distribution of Arctic bryophytes

Kristian Hassel & Tommy Prestø

NTNU University Museum, Trondheim, Norway

The Arctic zone, defined as the area north of the Arctic woodland limit, has a flora consisting of about 900 species of mosses (Bryophyta) and liverworts (Marchantiophyta). This constitutes only about 5% of the total global species diversity of bryophytes. Most of the species have wide distributions and only 10-15% are restricted to the Arctic. Environmental conditions similar to those in the Arctic can also be found in mountain areas further south, in areas otherwise dominated by a boreal or temperate environmental conditions. The vegetation of the Arctic is open and in many places dominated by bryophytes and lichens, while vascular plants are sparser. The Arctic regions have experienced large shifts in climate with glaciations and warmer periods in between. However, the Arctic has not been totally glaciated and even during the glacial maxima, refugial areas have existed. Some of these refugial areas seem to act as diversity centers in the arctic region, like the Beringian region, and has probably been a source for the colonization of other areas as the ice retreated. Here we define arctic species as species with their main distribution in the Arctic vegetation zone, but occurrences in mountainous areas further south may occur. We present a list of arctic bryophytes and make a comparison of species diversity across Arctic regions.

Rare lichens of the Svalbard archipelago

Liudmila Konoreva

Polar-Alpine Botanical Garden, Murmansk Province, Russia

Diversity of lichens has been studied by us in 12 areas of Spitsbergen in 2008-2016, including eastern coast of Grønfjorden, Pyramiden area, Trygghamna Bay, Colesbay, Prins Oscars Land (Innvika Bay), Nordvika and Kinnvika (Murchisonfjorden), Duvefjorden area, Aghardbukta, St. Jonsfjorden, Prins Karls Forland, Barentsøya. To date, about 755 species are known for the Svalbard according to the literature (Øvstedal et al., 2009, Konoreva, 2011, 2014). 280 of them are rare or only known, 23 species are included in the Red list of Svalbard (Timdal, 2015). However, many of these data are given as a result of insufficient study of the archipelago and its lichens. For example, all species which are currently considered rare can be divided into three groups.

1. Rare due to poor study of the territory, but in fact, these species are distributed widely (*Caloplaca tornøensis* H. Magn., *Rhizocarpon hochstetteri* (Körb.) Vain. etc.)
2. Rare due to the insufficient of taxonomical knowledge of this group, for example *Acarospora* A. Massal., *Caloplaca* Th. Fr., *Lecidea* Ach., *Porpidia* Körb., *Verrucaria* Ach. Some of these taxa are very difficult to determine reliably, as well as to find them on the field.
3. Red-listed species are not necessarily rare, but always threatened. For example, in Svalbard there are lichens which are food for the reindeer: *Cladonia arbuscula* s.l. (EN), *C. mitis* Sandst. (NT) *Flavocetraria cucullata* (Bellardi) Karnefelt & Thell (NT), *F. nivalis* (L.) Karnefelt & A. Thell (NT). These are included in red list of Svalbard (Timdal, 2015). There is a species that cannot be associated with any group cited previously, *Sarcosagium campestre* (Fr.) Poetsch & Schiederm. It is really rare in Svalbard because its main area belongs to the more humid regions (UK, Central Europe), and in Svalbard it occurs in very specific conditions. We studied distribution, ecology and rarity a number of such lichen species in Svalbard. The identification of species among listed groups and their mapping allow to save the lichen diversity in Arctic communities.

The moss flora of Arctic: the view from the regional level based on Anabar Plateau

Vladimir E. Fedosov

Lomonosov Moscow State University, Moscow, Russia

Patterns of the Arctic and Subarctic moss flora differentiation have been considered on 3 levels: ecotope - landscape - region, two former based on our data from the Anabar Plateau (Subarctic Siberia), and the latter with a circumpolar scope. Data on distribution of saxicolous mosses through a wide range of bedrocks was involved as well. Multivariate analyses show a significant correlation between presence of moss families and geographic elements with acidity, estimated by the ecological scales (for the ecotopes) and Ca and SiO₂ content in rocks (based on direct measurements). Moss floras of 9 considered landscapes groups were considered due to rock composition. On the regional level rates of the same families show a correlation with average annual temperature and annual precipitation. Thus, their distribution is affected by the complex geochemical/climatic gradients with two polar groups - (1) oceanic/acidophilic/oligotrophic/Subarctic (more thermophilic) and (2) continental/basi-(calciphilic/eutrophic/Arctic (less thermophilic) that can be delineated based on the data analyzed. Their separation is especially sharp in basal clades of mosses, since based on their ecology and geography/patterns of diversity most of them can be attributed either to oceanic/acidophilic (*Takakiaceae*, *Sphagnaceae*, *Oedipodiaceae*, *Andreaeaceae*, *Polytrichaceae*, *Tetraphidaceae*, as well as *Rhabdoweisiaceae*, *Grimmiaceae*

subfam. *Racomitrioideae*, *Ditrichaceae* s.str., *Mielichhoferiaceae*, *Pseudoleskeaceae*) or to continental/calciphilic (*Andreaeobryaceae*, groups with double-opposite peristomes - *Funariaceae*, *Encalyptaceae*, *Timmiaceae*, and double haplolepidous peristomes - *Catoscopiaceae*, *Pseudoditrichaceae*, as well as *Flexitrichaceae*, *Distichiaceae*, *Pottiaceae*, *Bryaceae*, *Pseudoleskeellaceae*) elements. Recent diversification and expansion in these elements alternated due to Quaternary climatic oscillations. In several cases contrasting ecological preferences and geographic patterns indicate problematic points in taxonomy, which were recently confirmed and resolved using molecular-phylogenetic approaches. Distribution and diversity of these groups delineate rather humid "oceanic" and rather xeric continental areas, with most Arctic and Subarctic endemics and sub-endemics being concentrated in the latter. Arctic moss flora lacks strict endemics and is weakly delimited from subarctic ones, gradually becoming poorer northward, though in typically Arctic ecotopes calciphilic and eutrophic species dominate, while in typical subarctic - rather oligotrophic acidophilic. High Arctic is rather clearly delimited due to disproportionate depauperization of the moss flora, disappearance of the genus *Sphagnum* and dominance of pioneer moss groups.

A comparison of moss diversity in the Russian Arctic and permafrost zone of Siberia

Michael S. Ignatov

Lomonosov Moscow State University, Moscow, Russia

There are two extensive areas in Russia, which are referred to cold biomes. One is an Arctic (1,250,000 km²), forestless area along the coast of the Arctic Ocean, therefore it includes islands. The other is the permafrost zone (ca. 5,000,000 km²), this territory underlies frozen grounds with the temperatures from -1 to -12°C. The permafrost zone is quite xeric, which however does not preclude the forest to grow using the water from the melt permafrost. The forest is formed mostly by *Larix*, with the dominance of the mosses *Rhytidium*, *Aulacomnium*, *Tomentypnum* and *Hylocomium*. The moss flora of Arctic is relatively poor and lacks much distinctiveness, while the moss flora of the permafrost zone is highly diverse, includes endemic (*Myrinia rotundifolia*, *Platydictya acuminata*), and subendemic species (*Brachythecium boreale*, *B. jacuticum*, *Scouleria pulcherrima*, *S. rschewinii*, *Grimmia jacutica*). The permafrost zone is rich in isolated populations representing disjunctions with the North American Arctic (*Andraeobryum macrosporum*), the temperate East Asia (*Struckia enervis*, *Philonotis falcata*, *Hyrogonium gregarium*, *Anomobryum nitidum*), and highly disjunctive xeric species (*Hilpertia velenovskyi*, *Pterygoneuron kozlovii*, *Tortella densa*). It seems that the permafrost zone area has not been changed strongly since the Pleistocene, thus representing a time machine for the study of the flora that occurred in a considerable part of the northern Eurasia during the last glacial period.

Preliminary study on the bryophyte flora at the southern-end of Canadian Arctic

Imura Satoshi

National Institute of Polar Research, Tokyo, Japan

The Arctic region research project, called ArCS (Arctic Challenge for Sustainability), is a Japanese national flagship project funded by the Ministry of Education, Culture, Sports, Science and Technology. The National Institute of Polar Research (NIPR), Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Hokkaido University are playing the key roles in this project, and are carrying it out for approximately four-and-a-half years from September 2015 to March 2020. This project aims to elucidate the changes in the climate and environment, clarify their effects on human society, and provide accurate projections and environmental assessments for internal and external stakeholders so that they can make appropriate decisions on the sustainable development of the Arctic region. Under the big umbrella of ArCS, we launched a subtheme “Response and biodiversity status of the Arctic ecosystems under environmental change (<http://www.arcs-pro.jp/en/project/collaborated/06.html>)”. Preliminary field surveys of this subtheme were carried out at Kuujjuarapik, Canada, from 11th to 14th in August 2016, to clarify the biodiversity of bryophytes in the Arctic tundra ecosystem. About 100 samples of bryophytes and lichens were collected and identified. In this meeting, preliminary results of the bryophyte flora of the southern-end of Canadian Arctic will be reported.

Hyperspectral remote sensing and UAV applications at the Mer Bleue Arctic Surrogate Simulation Site (CANCELED)

J. Pablo Arroyo-Mora¹, George Leblanc¹, Margaret Kalacska², Raymond Soffer¹, Gabriela Ifimov¹, Oliver Lucanus³

¹National Research Council of Canada Flight Research Laboratory, Ottawa, Canada

²Department of Geography, McGill University, Montréal, Canada

³Below Water Inc. Rigaud, Canada

Here we present a summary of novel hyperspectral remote sensing and UAV applications at the Mer Bleue Arctic Surrogate Simulation Site, located at the eastern boundary of the City of Ottawa, Ontario, Canada. Mer Bleue is a protected ombrotrophic bog (i.e. rain feed ecosystem) with a hummock-hollow-lawn microtopography, poor fen sections and beaver ponds at the margin. Vegetation types at Mer Bleue encompass mosses (e.g. *Sphagnum capillifolium*, *S. angustifolium*, and *S. fallax*), shrubs (e.g. *Chamaedaphne calyculata*, *Kalmia angustifolia* and *Rhododendron groenlandicum*), herbs (e.g. *Eriophorum vaginatum*) and trees (e.g. *Betula populifolia*, *Larix laricina*, *Picea mariana* and *Pinus strobus*). Although Mer Bleue has a long-term research history based on in-situ observations, remotely sensed data provides the only possible approach for collecting surface data across a range of different spatial scales (from few meters to kilometers). Our research at Mer Bleue uses a bottom-up approach that integrates in-situ plot field spectroscopy data (e.g. vegetation physiognomies mapping), UAV Structure from Motion (SfM) photogrammetry (e.g. microtopographic characterization) and airborne imagery (e.g. vegetation phenological patterns). This data integration allowed testing the utility of the recently launched satellite Sentinel-2 (European Space Agency) for mapping a short phenological cycle at Mer Bleue between April and June 2016. We believe that Future Arctic research would greatly benefit from the remote sensing based methodological approaches we have developed and therefore, it would enhance the understanding of Arctic ecosystems under climate change.

Moss-microbe consortia in polar aquatic ecosystems

Warwick Vincent & Connie Lovejoy

Department of Biology, Université Laval, Québec, Canada

Centre d'études nordiques & Québec Océan, Québec, Canada

The close association and assumed mutualism between mosses and the cyanobacterium *Nostoc* has been known since at least the 1860's. Since the advent of the molecular era, knowledge and appreciation of the diversity of microbes associated with mosses has expanded greatly. The term bryosphere was proposed in 2010 (Lindo and Gonzales, *Ecosystems* 13:61) to bring attention to the belowground detrital activity of moss beds and the aboveground compliment of cyanobacteria and associated microorganisms, fungi and small metazoans. Mosses dominate many northern landscapes and these microbial associations contribute to both carbon and nitrogen cycling in vast regions of the Subarctic and Arctic. In contrast to the large literature on semi-aquatic mosses, true aquatic mosses are relatively understudied, which may in part be due to their relative inaccessibility to researchers. For example, the moss microbe consortia in perennially ice-covered lakes have been largely invisible to microbial ecologists. Aquatic mosses living in a permanently wet state require a novel suite of adaptations compared to more terrestrial mosses and we speculate that their bryosphere including their microbiomes will differ as well. In our presentation, we will outline knowledge gaps, and suggest research questions and potential sites for future research in this emerging field.

Snow penetration in bryophyte and lichen cover: experimental observations

Kellina Higgings

Société québécoise de bryologie, Québec, Canada

While rain generally percolates through vegetation to reach the ground or evaporates, snow can accumulate on vegetation. In winter, tree branches can be covered in snow and shrubs trap snow in their branches. Little has been documented regarding how bryophytes and lichens intercept snow as explored in the present study. Specimens of feather mosses and *Cladonia* spp. were collected in northern Ontario at the southern limit of the boreal forest. The samples of depths around 5cm were placed in flat circular containers of 20cm of diameter. These were left outside during snowfall events. Snow penetration into the branches was observed and differences were found by species. While small, the observed differences could influence the thermal regime and photosynthetic capacity of cryptogam mats beneath shallow snow layers, which is particularly important in the Arctic where the thermal regime is tied to permafrost and the snow-free growing season is so short.

Boreal bryophyte growth rate and functional trait variation among species and environments

Nicole J. Fenton, Morgane Higelin, Yves Bergeron

Université du Québec en Abitibi-Témiscamingue,
Rouyn-Noranda, Canada

Large boreal bryophyte species make up a continuous layer over the mineral or organic soil in many ecosystems, such as coniferous forests or peatlands. Consequently, this continuous bryophyte layer influences many ecosystem processes such as the water cycle, nutrient cycles, and soil freeze-thaw cycles. While the role of bryophytes in these systems is increasingly being included in research projects, few researchers examine the characteristics and functional traits of bryophyte species and how they influence ecosystem processes. Furthermore, bryophytes are notoriously morphologically plastic at both the shoot and colony level, and these environmentally driven variations might influence ecosystem processes. Here we synthesis research in contrasting forest environments that measured inter- and intra- species growth rates and functional traits of several dominant forest floor bryophytes. Growth in length and mass were measured over two growing seasons for *Pleurozium schreberi*, *Sphagnum capillifolium* and *S. russowii* and while growth in length differed little among species or environments, growth in mass was significantly different among species and between the two habitats for the two sphagna. Functional traits (colony density, water absorption, and insolation) varied among species, between forest environments (all species collectively) and for a specific species in contrasting environments. These results suggest that differences in growth form (mass) at the shoot and colony level (represented by density) result in different functional trait values that in turn will influence ecosystem processes in these forests. While inter-species variability is not unexpected considering the different growth forms of the species considered, the intra-species variation is significant and will affect ecosystem processes. This underlines the need for further research on bryophyte ecology in boreal and arctic environments in order to understand and predict future functioning.

The Russian study of hepatics diversity in Svalbard

Nadezha Konstantinova & Anatoliy Savchenko

Polar-Alpine Botanical Garden-Institute of the Kola SCI Center RAS, Murmansk Province, Russia

The results of the study of bryophytes in Svalbard were summarized at the end of the 20th century in a comprehensive publication by A. Frisvoll (Frisvoll & Elvebak, 1996). It was a good starting point for our study of hepatics of Svalbard which we started in 2004 and which we are currently pursuing. Based on compiled map of localities of rare hepatics in Svalbard, we determined areas that have never been studied and concentrated our efforts on these areas taking into account geology and geomorphology. In total, we collected ca. 2500 specimens in 17 different areas including 5 remote and inaccessible areas in Nordauslandet. As a result, 24 new species of hepatics were recorded or confirmed for Svalbard. New data on distribution in Svalbard of many species were obtained. A number of species that were considered rare and very rare in Svalbard were shown to occur sporadically and were even abundant in some areas, while some previously reported to be widespread in Svalbard species were not collected or collected in single plots. It should be stressed that many of collected specimens are not identified yet. Basically, it's because identification of arctic liverworts is extremely difficult because of specific and quite unusual appearance, growth forms and color of species. Apart from the publication of new findings for Svalbard the annotated lists of species were published by us for the north coast of Murchison fjorden and Grónfjord area and the lists of species for Barentsøya and Prins Karls Forland are in preparation. Since 2016 we started working in collaboration with Norwegian University of Science and Technology on the project "Mapping bryophytes on Svalbard as the basis for monitoring and conservation".

Inter-annual variation in bryophyte dispersal: linking bryophyte phenophases and weather conditions

Marion Barbé, Nicole J. Fenton, Yves Bergeron
Université du Québec en Abitibi-Témiscamingue,
Rouyn-Noranda, Canada

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In the current context of global changes that modify species distribution ranges, it is urgent to identify climate variables that impact species dispersal patterns. We investigated patterns of propagule release (sexual and asexual dispersal organelles) of boreal bryophyte communities in response to weather. We present the first community-level study that also examines the impact of weather on the different phases of bryophyte phenology. Aerial bryophyte propagule rain was trapped during summer and fall 2013 and during spring and fall 2014, and climatic variables were collated for the years 2012, 2013 and 2014. The phases of the phenology and the weather variables one season to two years preceding the propagule release and that may influenced on it were identified. Propagule release varies with weather conditions at the time of dispersal (i.e., direct weather effects) but is also associated with weather during the winter and summer one year preceding dispersal, which presumably influences survival, growth and fertilization of the mother plant as well as vegetative organelle and sporophyte development. We suggest that propagule release is related to weather conditions occurring from one to several seasons upstream, and especially on humidity, temperature and winter length. Using an original method we provide new insights about bryophyte dispersal dynamics in response to climate, together with proposing alternative hypotheses to weather conditions to explain bryophyte dispersal patterns.

The first DNA barcode reference library for mosses: *rbcL* and *trnL-F* for 775 species of Bryophyta from Canada

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Mosses (*Bryophyta*) are sensitive indicators of environmental quality and change. However, their subtle morphology often makes species determinations challenging, even for specialists. By contrast, once a comprehensive, accurate reference DNA barcode reference library is available, DNA barcoding will enable the rapid identification of mosses. Mosses were not a key group in driving selection of the standard DNA barcodes (*rbcL*, *matK*) for land plants. Difficulties in the recovery of *matK* from mosses required the search for a replacement marker. The plastid-encoded marker *trnL-F*, a widely-adopted marker for mosses due to its universality and high variability, is a promising second DNA barcode for mosses. We tested sequence recovery and species resolution with *rbcL* and *trnL-F* for 775 Canadian moss species (57 families, 20 orders), about three quarters of the Canadian flora. Samples of nearly 2000 specimens from the herbarium at the Canadian Museum of Nature were analyzed at the Center for Biodiversity Genomics. Standard protocols recovered *rbcL* from 94% of the species and *trnL-F* from 98%. A maximum likelihood phylogeny

using these markers suggested the polyphyly of some families (e.g. *Rhabdowesiaceae*, *Dicranaceae*). The complementing resolution power for *rbcL* and *trnL-F*, although varied among orders (Sphagnales 32%, Splachnales 100%), allowed the discrimination of about 60% of the species examined and all of the genera. The barcode data revealed 15 cases of deep intraspecific variation, suggesting the presence of cryptic species. About 5% of the specimens were re-identified after reexaminations provoked by the barcode results. Extension of taxonomic representation in the barcode library will increase opportunities to critically examine the alpha and beta taxonomy of Canadian mosses while improving the quality of identifications on herbarium specimens. The current reference sequence library is ready for use in the identification of bulk moss samples gathered in ecological surveys, for eDNA detection and as a baseline resource for the molecular identification of Canadian mosses.

Speciation and biogeographic relatedness in *Racomitrium lanuginosum*

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Phylogenetic analyses of recent radiations and population genetic analyses of mosses are usually hampered by low evolutionary rates of DNA sequence markers. ISSRs, AFLP, or RAPD markers in most cases could not overcome this problem due to still low resolution or methodological problems. Latest advances in sequencing techniques now offer promising alternatives, such as genome wide single nucleotide polymorphism (SNP) data from reduced-representation methods like restriction-site associated DNA sequencing (RADseq, Baird et al. 2008) or genotyping-by-sequencing (GBS, Elshire et al. 2011). GBS is a low-cost, simple, highly multiplexed system for multi-locus SNP discovery. It allows a targeted investigation of the under-methylated, i.e. low- and single-copy parts of plant genomes, by choosing a methylation-sensitive enzyme (Elshire et al. 2011). The method is so powerful that even introgression and hybridization can be detected (Eaton & Ree 2013). *Racomitrium* is an emblematic moss genus due to (at first sight) easily recognizable species such as *R. lanuginosum* (Hedw.) Brid. This species is widely distributed (Holarctic, scattered occurrences throughout the Southern Hemisphere)

and covers huge areas in arctic tundra areas, e.g. in Iceland. Species delimitations of *R. lanuginosum* and closely related species from the Southern Hemisphere (*R. geronticum*, *R. patagonicum*, *R. pruinosum*) are not yet clear. Besides, own preliminary analyses of ITS sequences indicate complex biogeographic patterns of genotypes with the *R. lanuginosum* complex. However, ITS alone does not provide enough resolution for rigorous biogeographic analyses and other DNA markers are even less variable. Therefore, we applied GBS to a representative worldwide sampling of specimens of the *R. lanuginosum* complex, which seems to be a powerful and cost-efficient tool to analyze patterns of intraspecific genetic variation. With these data, we aim to a) unravel biogeographic patterns of genotypes and identify centers of genotype diversity in the *Racomitrium lanuginosum* species complex and b) resolve the taxonomy and redefine the morphological characters traditionally used to identify the taxa within the *Racomitrium lanuginosum* complex based on molecular data.

World-wide spatio-temporal patterns of symbiotic specificity between *Peltigera* and its *Nostoc* partners

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Variation in specificity among symbiotic partners is key to a comprehensive understanding of the evolution of symbiotic systems. Specificity of mutualistically interacting partners, based on a world-wide sampling of all known species of a monophyletic group for one of the symbiotic partners, has rarely been studied. We assessed the level of inter-partner specificity between the cosmopolitan lichen-forming genus *Peltigera* (mycobiont), and its cyanobacterial partner *Nostoc* (cyanobiont), based on phylogenetic species delimitations and validations for both partners. We found a broad spectrum of specificity for both partners, ranging from strict specialists to broad generalists. However, in general, mycobionts are more specialized than cyanobionts by associating mostly with one or few *Nostoc* phylogroups, whereas cyanobionts associate most frequently with several *Peltigera* species. Our results support the hypothesis that specialization of mycobionts to one or few cyanobionts is acquired through time and favored in geographic areas where partners have been co-established for long periods of time. We detected higher genetic diversity and higher diversification rates in clades of *Peltigera*

species with lower degrees of specialization. We found that *Peltigera* species specialized on a single *Nostoc* phylogroup have narrower geographical distributions compared to generalist species that are associated with different cyanobionts in different geographic areas or with cosmopolitan cyanobionts. We also studied the patterns of associations along a North-South (58 to 48° N) and an East-West (64 to 73° W) transect across the boreal forest in Québec, where we found that at this scale most *Peltigera* species were highly specialized on one of two abundant *Nostoc* phylogroups, which were both associated with several *Peltigera* species. The diversity of *Peltigera* species is lower in the southernmost localities (<51 °N) then more or less constant along the transects despite a relatively high turnover of species in the North-South transect, whereas there is a higher diversity of *Nostoc* phylogroups in the northernmost localities (>56° N). The *Nostoc* phylogroups are more widespread than their *Peltigera* partner species along these transects, suggesting a higher sensitivity to abiotic factor by the mycobiont. Spatial distance alone is not a good predictor of variation in partnerships.

Population genetics of two lichen species on talus slopes in Deboullie in Northern Maine

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There are five rock glaciers at the base of talus slopes in the Deboullie Public Reserved Lands in the North Maine Woods that maintain subterranean ice year-round. Thick mats of lichens and mosses are found in some areas on the talus boulders. Lichen samples were collected along elevation transects on each glacier to ask the question of whether there is more genetic variation in lichen populations along the slope within a rock glacier or between rock glaciers. DNA was extracted from 'individuals' of two species, *Cladonia stygia* and *C. stellaris*. The ITS region of the fungal partner was amplified by PCR and sequenced. Variable length polymorphisms were found in both species with some individuals carrying an insertion of 228/234 bp (*C. stellaris*/*C. stygia*) in the 18S region which is a likely Group I intron. Haplotype analysis revealed high population genetic diversity with 11 *C. stellaris* and 10 *C. stygia* haplotypes identified and a phylogenetic network was estimated by the TCS program. Individuals with the same haplotype were found on more than one glacier and at varying heights within a glacier suggesting that gene flow is occurring both within and between rock glaciers.

Where did Arctico-Alpine mosses survive in a frozen Europe? Insights from a multispecies coalescent analysis

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Arctico-Alpine species in Europe exhibit a strikingly disjunct distribution between Fennoscandia and the high mountain ranges of the South. During the cold stages of the Pleistocene, these areas were covered almost entirely with a continuous ice shield. Two hypotheses were formulated to explain the survival of organisms in Arctico-Alpine ranges during the ice-ages: the "nunatak" hypothesis, that suggests *in situ* survival in micro-refugia within the ice shield, and the *tabula rasa* hypothesis, that proposes the total eradication of populations and subsequent recolonization from refugia outside the main glaciated area. These hypotheses are tested here using the Arctico-Alpine bryophyte flora as a model. We used species distribution models to generate prior information on extant and LGM distribution ranges in an Approximate Bayesian Computation framework. More precisely, we compared the observed patterns of genetic structure and diversity across a wide population sampling of Arctico-Alpine species in Europe with those expected under competing scenarios of the *tabula rasa* vs the *in situ* survival hypotheses. Our results are not consistent with the idea that Arctico-Alpine bryophyte flora was assembled by recolonization from non-glaciated lowland areas and instead point to *in situ* survival, in line with recent evidence for the ability of frozen moss gametophytes to regenerate after periods of thousands of years. The low dispersal capacities that Arctico-Alpine species displayed during the last glacial-interglacial cycle raises the question of their persistence in a warming environment.

Targeted enrichment of nuclear protein coding genes and their introns for inferring phylogenetic histories of bryophytes

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Nuclear loci, central to integrating coalescence theory in phylogenetic reconstructions, and essential to test organellar genome based hypotheses, have typically been undersampled in bryological studies. Recent methodological advances in sampling loci across the genome have provided large data sets but these may suffer from uneven trait recovery, and hence various degrees of missing data. We have adopted a strategy targeting specific loci, namely putative single copy nuclear loci, during the preparation of genomic libraries for high-throughput sequencing. We sampled 150 loci for 140 exemplars of all but one order of mosses and 800 loci for nearly 100 species of *Funariaceae*, and for close to 300 species from many genera of the *Hyphnanae* and of the grade subtending it within the *Bryidae*. Raw reads are processed using the recently developed bioinformatics pipeline HybPiper (Johnson et al. 2016), and screened for evidence of paralogous copies, a necessity considering the frequency of autopolyploidy within morphospecies and whole genome duplications during the evolution history of mosses. Furthermore, the pipeline was enhanced to also recover sequences of introns present in these genes. We have complemented these data with sequences for all

organellar protein coding genes, targeted using the same hybridization technique. We demonstrate that enrichment is highly efficient across the moss tree of life for organellar loci, and for nuclear loci, with for the latter, locus recovery decreasing with phylogenetic distance of the target taxon to the taxon used to develop the original baits used for the DNA hybridization. Within the *Funariaceae* and *Hyphnanae*, the percentage of missing data is small and cases of extensive paralogy (i.e., duplication) within specific lineages rare. The data obtained provide an opportunity to test for the role in hybridization in the diversification of the focal lineages and the effect of incomplete lineage sorting on the phylogenetic reconstruction. The recovery on intron sequences provides data partitions that are more variable than the coding regions, and hence suitable perhaps for infraspecific phylogenetic reconstructions. DNA suitable for targeted enrichment was obtained from herbarium specimens, and in the case of some pleurocarps, from even a single stem. The method promises to be applicable to a broad range of taxa and questions in bryology and for assessing the diversity and history of the Arctic bryoflora.

Mission of the société québécoise de bryologie

Jean Faubert

Société québécoise de bryologie, Québec, Canada

The société québécoise de bryologie is a not-for-profit organization incorporated under the Québec Companies Act. It is administered by a Board of Directors, and managed by an Executive Committee. The organization's goal is to promote scientific activities in the field of bryology by fostering research and dissemination of knowledge about bryophyte species.

More precisely, the société québécoise de bryologie has given itself the following mandates:

- > to publish the Flore des bryophytes du Québec-Labrador;
- > to create a database allowing online release and updating of information on the taxonomy and distribution of Québec and Labrador bryophytes;
- > to channel the foreseeable benefits of the publication of the Flore des bryophytes du Québec-Labrador;
- > to facilitate the establishment of new projects dealing with bryophytes;
- > to seek solutions to the shortage of publication channels for floristic papers in bryology.

Boreal endolichenic fungal community structure at local, regional, and global scales

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Lichen thalli contain abundant and diverse fungal communities that are phylogenetically distinct from the lichen mycobiont and lichenicolous fungi. These endolichenic fungi occur within thalli in close association with the photobiont. Like their close relatives, plant endophytes, endolichenic fungi cause no apparent symptoms. Here a collection of >11,000 cultures in conjunction with next-generation sequencing (NGS) from the same host tissues was used to examine endolichenic communities in (a) multiple years at one boreal forest site; (b) nine equidistant sites across a 1300 km transect from the southernmost to northernmost extent of boreal forest in Québec; and (c) seven sites distributed along the entire circumboreal belt. This study reveals previously unexplored temporal stability of endolichenic communities in a focal boreal site. Despite relatively similar biotic and abiotic conditions along a consistent circumboreal latitudinal band, the abundance, diversity, and composition of endolichenic fungal communities differed as a function of geographic location. Across the north-south extent of boreal forest in Québec, communities were largely structured by host. Overall, culture-based and NGS methods yield different richness estimates but complementary ecological patterns. Ongoing work will incorporate network analyses with fungal and bacterial symbionts and examine biotic and abiotic factors important for structuring endolichenic communities.

Moss associated N-fixation in boreal Alaska: impacts of a transplant experiment under deciduous and coniferous canopies

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In boreal forests, mosses and their associated nitrogen-fixing (N) microbes are important sources of N inputs, and are potentially important in regulating ecosystem productivity. Mosses dominate the understory of coniferous forests, while deciduous stands support a lower moss abundance, likely because of leaf litter inputs. We aim to quantify the impacts of canopy composition and deciduous leaf litter on N-fixation associated with two mosses (*Hylocomium splendens* and *Pleurozium schreberi*) using a field-based experiment near Fairbanks, Alaska. In 2012, we established 30 study plots in paper birch (*Betula neoalaskana*) and black spruce (*Picea mariana*) stands. *Hylocomium* dominated moss cores (n=90) were randomly transplanted from spruce stands into the plots and assigned to a treatment: birch leaf litter exclusion, litter addition, and ambient litter deposition. We identified 30 procedural controls (natural *Hylocomium* patches). We measured moss growth (1200 individuals) and environmental covariates (e.g. temperature, moisture) annually. In 2015, we measured N-fixation rates using stable isotope labelling ($^{15}\text{N}_2$). Our preliminary results suggest that naturally-occurring and transplanted mosses in birch stands, and mosses with experimental and ambient leaf litter inputs presented lower N-fixation than the others. A leaf litter cover of 60% eliminated N-fixation and significantly reduced moss growth. Results from this study give us insights in the functioning of the moss-microbe association and factors affecting it. Understanding N-cycling in boreal forests is important in a context of changing forest composition towards a more deciduous-dominated landscape, as leaf litter impacts on moss may have cascading impacts on forest structure and composition.

Do moss host phylogenetics shape microbiome composition and function?

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Bryophytes and their associated microbes are critical components of carbon (C) and nitrogen (N) cycling in arctic tundra and boreal forest ecosystems. Mosses account for approximately half of the net primary productivity in these biomes, and moss-associated microbes are the major source of biologically fixed N into these nitrogen-limited ecosystems. The extent to which climate change will perturb the ecosystem C and N dynamics critically depends upon how the moss-microbiome assemblages respond to new temperature and precipitation regimes. Here we evaluate the roles of environmental factors as opposed to moss host genotype in shaping moss-microbiome community assembly and function. We collected eleven moss species, representing seven genera and one leafy liverwort from multiple sites near Fairbanks and Toolik Lake, Alaska. We used stable isotope incubations to estimate the rates of nitrogen and methane fixation in individual samples, 16S amplicon sequencing and shotgun metagenomic analyses to survey the community of bacteria hosted on each sample, and sequence capture to generate a moss phylogeny. Microbiomes from different moss species and sites fixed variable quantities of N and C. We found high relative abundances of members of novel bacterial phyla as well as a high diversity of putative N₂-fixing bacteria. Furthermore, we identified large numbers of nifH sequences from these metagenomes, including many from poorly described lineages. We are currently developing approaches to link biogeochemical processes to specific bacterial communities to understand the role of moss phylogeny in shaping microbiome function, and the potential for climate change to influence the function of the moss-microbiome.

Taxonomic and functional attributes of the boreal moss microbiome

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Boreal forests represent an enormous global carbon (C) sink storing nearly as much C per hectare as tropical rainforests. Mosses in these systems are regulators of C accumulation accounting for 20-50% of above-ground net primary productivity while also serving as the primary source of biologically fixed nitrogen (N) through their close association with microbial N-fixers. These microbial communities play a key role in regulating production and availability of N in these N-limited environments yet it remains unclear how variation in microbial communities across moss species and sites may translate into functional differences in N-fixing potential. Therefore, we examined seven common boreal moss species in each of three boreal forest sites outside of Fairbanks, Alaska. We used 16S rDNA marker gene sequencing to compare microbial community composition across host species and measured N-fixation rates through ¹⁵N isotopic enrichment. We also used metagenomics to assemble the genomes of several abundant bacteria from those communities to analyze the genetic N-fixing potential in the microbial communities and to better understand the functional potential of the most abundant microbes. We find that host species rather than site structures moss microbial communities and that mosses host a diverse pool of potential N-fixers in addition to the well-studied cyanobacterial groups. We furthermore find that boreal mosses harbor high abundances of diverse and poorly studied lineages of bacteria. Here we present results of the microbial community comparisons as well as the genomes of several of the most abundant of these lineages and discuss their potential functional role on the mosses.

Contribution of alternative nitrogenases to nitrogen fixation in cyanolichens; implications for our understanding of high latitude N cycling and cyanolichen symbiosis

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Cyanolichens from the genus *Peltigera* are abundant in high latitude ecosystems where they are key contributors to the nitrogen (N) cycle through dinitrogen fixation. This reaction is catalyzed by the enzyme nitrogenase (Nase) harbored by their cyanobionts. While Nases exist as three isoenzymes: the molybdenum (Mo) Nase, the vanadium (V) Nase and the iron (Fe) Nase, only the Mo-Nase is thought to have ecological relevance in unmanaged ecosystems. However, genetic and biogeochemical evidences tend to question this assumption for peltigerelean cyanolichens. In this study, we used genetic, metallomics, and isotopic characterization methods to investigate the importance of alternative N fixation in thalli of the tri-membered *Peltigera aphthosa* collected from several areas of the northern hemisphere (Canada, Sweden and Russia). We report that V-Nase genes are present, that the V homeostasis in *P. aphthosa* demonstrates all the characteristics of a metal of critical importance to N fixation, and that its acquisition by *P. aphthosa* is controlled by the Mo available to the cyanobiont. We also show that alternative Nase activity in *P. aphthosa* may account for as much as half of the total Nase activity. These results highlight the importance of alternative N fixation in boreal cyanolichens, with strong implication for the N cycle in high latitude ecosystems. We will briefly discuss (i) how these results impact our conception of N fixation and the reliability of current N input estimates in cyanolichen on other N₂ fixing biomes, (ii) to what extent these results might apply to other boreal N₂ fixing biomes (i.e., bryophytes), and (iii) how the alternative nitrogenase V-Nase affects cyanolichen symbiosis establishment and function.

Determination of baseline metal contamination using foliose lichens in Eastern Canada (Québec)

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Our work aims at defining background levels for metal contamination in boreal lichens over non-urbanized areas of Eastern Canada (Québec). Concentration of 18 elements (Na, Mg, Al, P, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Cd, and Pb) was determined in four species of foliose cyanolichens, *Nephroma arcticum*, *Peltigera aphthosa* s.l., *P. neopolydactyla* s.l. and *P. scabrosa* s.l., along two transects spanning the boreal biome in northern Québec up to the tree limit (51.234° to 57.834° N and 68.990° to 59.146° W). Our results indicate that most of the studied area is characterized by a low concentration of most elements, similar to background levels found by other studies in pristine areas throughout the world (The Alps, Antarctica). However, the southernmost sites show higher levels of metal exposure. These lichen populations characterized mostly by low metal background across a large part of the northeastern Canada, can be used to address additional questions on metal acquisition and homeostasis in unaltered lichens. This study established an elemental baseline for future bio-monitoring surveys on metal pollution in sub-polar ecosystems, including northern Québec where an industrial expansion is expected as part of the province governmental project "Plan Nord".

Bryophyte persistence in glacial landscapes

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Permafrost environments harbour unique archives of past environments spanning millennia with some having Tertiary origins. These deposits have traditionally been used for paleoenvironmental reconstruction at a given site. These deposits not only document the vegetation history through time and provide organic substrate for successional species once thawed, they also form critical biological reservoirs.

At 82° N on Ellesmere Island, Nunavut exceptionally thick deposits were sampled in 1983 and resampled in 2007. Growth chamber assays on subsamples of frozen field samples that were hydrated, sealed, and placed in culture indicate the temporal scale of diaspore regeneration from the frozen state (cryobiosis) that has been 14C dated between 2300-7430 cal YR BP. Results and implications will be discussed.

Change in peatland bryophyte traits following long-term water level draw-down

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Biogeochemical cycles of ecosystems are tightly linked to vegetation composition via the plant traits. In northern peatlands where bryophytes, especially *Sphagnum* species are major players, their trait composition regulates carbon sink function. Predicted climate change is likely to alter hydrology and consequently lead to change in bryophyte vegetation. However, this dynamic response is poorly known and lacking from peatland ecosystem models. We studied the impact of water level draw-down on the bryophyte vegetation composition and the composition of bryophyte traits using a long term experiment Finland. It has a mesotrophic fen, an oligotrophic fen and a bog site that all have three plots: a natural, a water level draw-down treatment conducted in 2001/2002 and a plot drained for forestry in 1961. For the composition we estimated the cover of bryophyte species altogether from 300 relevés. For trait measurements we selected species based on their dominance. The biggest difference in species composition was found between other treatments and forestry drained treatment where forest mosses such as *Polytrichum commune*, *Dicranum* ssp and *Sphagnum russowii* had colonized the sites. Water level draw-down had favored lawn species such as *Sphagnum rubellum* and *balticum*, and small species that benefit on disturbance such as hepatics and *S. tenellum*. Species adapted to wettest surfaces, *Limprichtia intermedia*, *Scorpidium scorpioides*, *S. riparium* and *S. cuspidatum* were found only in control plots. Based on the response to exposure bryophytes formed three groups according to their traits. Bryophytes in open bog plots were characterized by species adapted to prevent evaporation with dense growth habit. Species in shaded sites with tall vascular species were typically green and had low moisture storage capacity. Species in open fens had large capitulum with high water holding capacity and loose growth forms. The groups will be used in development of ecosystem model with dynamic vegetation.

Herbivores, mosses, DNA – Unravelling hidden diversity in Arctic terrestrial food webs

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Despite their low nutrition value, mosses are foraged by both mammals and migratory birds in the Arctic, probably because of their high biomass and availability within the tundra vegetation. Barnacle goose (*Branta leucopsis*) and Pink-footed goose (*Anser brachyrhynchus*) breed in large numbers around the Greenland Sea (Greenland, Iceland, Svalbard) during Arctic summer. Both goose species were described to prefer vascular plants, but switch to a diet richer in mosses when the preferred food plants are not available. Microscopic analysis of plant fragments in herbivore droppings indicated that geese fed substantially on mosses, especially pleurocarps such as *Calliergon richardsonii*, at least during some stages of their stay in the Arctic. However, it remains to be tested how the diet composition differs between individuals and between both goose species. Gaining more detailed insights is important to assess the impact on the tundra vegetation of the substantial increase of goose populations in the circumpolar Arctic in the past 50 years. To facilitate identification of diet components, we applied a DNA metabarcoding approach. We used next generation (Ion Torrent) sequencing of plastid *psbA-trnH* and nuclear ribosomal ITS to compare (i) the diet of Barnacle goose populations from East Greenland, Jan Mayen, West Spitsbergen, and eastern Svalbard (Edgeøya), and (ii) diet compositions of Barnacle and Pink-footed goose in Edgeøya. First results for Barnacle goose show that the diet in the first three areas is mainly composed of vascular plants in different compositions. Analyses of the samples from Edgeøya is ongoing. In addition, we carried out a microscopic analysis of different sets of Barnacle goose droppings from West Spitsbergen, including a time series from the same locality as well as individual goslings, females (nests), and non-breeders, which showed different proportions of mosses from low (nests) to high (non-breeders).

Yukon ice patches: role of ice-entombed bryophytes in alpine environments

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Yukon alpine glacial ice patches are rapidly disappearing, exhuming 8000-year-old (BP) plant populations preserved in pristine condition. A major component of the ice patch flora are bryophytes, which are critical to alpine ecosystems. However, relative to diverse archaeological work, they remained uninvestigated. Bryophytes have the incredible ability to generate a new organism from any viable cell (totipotency), allowing them to persist through extreme conditions. The regeneration of formerly ice-entombed vegetation would indicate that ice patches function as reservoirs of genetic diversity in alpine ecosystems. Subfossil tissue was collected along the margin (<1m) of the Mount Granger and Mount Gladstone ice patches (August 2015 and July 2016, respectively), submitted for 14C dating, and cultured in greenhouse assays to show the regeneration capacity that could be expected *in situ* under global warming. Plants were sampled within 40m of the ice margin to document the extant diversity, and the plant succession with ice margin retreat. Non-metric multidimensional scaling (NMDS) was used to determine the successional gradient and if the plant modern composition is analogous to the ancient communities. Cultured subfossil samples showed remarkable regrowth of propagules (spores and plant tissue), emphasizing the viability of ancient ice patch vegetation. NMDS analysis demonstrated a clear successional pattern that is closely associated with the subfossil species composition. These results reveal a cyclical role of bryophytes from exhumed assemblages that contribute to the establishment, revegetation, and maintenance of diversity in alpine ecosystems.

Cryptogamic Russian Information System (CRIS) as an important source on biodiversity in Arctic

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Cryptogamic Russian Information System (CRIS) was created in order to accumulate data on distribution, ecology, taxonomy of bryophytes, lichens, fungi and cyanoprokaryota. It is based mainly on data labels of specimens preserved in the herbarium of Polar-Alpine Botanical Garden-Institute (KPABG) of Kola Science Center of the Russian Academy of Sciences (KSC RAS) but it includes as well data labels from the herbarium of Botanical Garden-Institute of Far East Branch of the RAS as well as collections of Institute of the Industrial Ecology Problems of the North of KSC RAS (INEP). Currently, data labels of ca. 75,265 specimens are incorporated in CRIS including 62,288 records of bryophytes, 11,091 of lichens, 582 of fungi and 1,304 records of cyanoprokaryota. CRIS focuses mainly on diversity of the previously mentioned groups in Murmansk Province and Svalbard but includes as well data from other Arctic regions of Russia (Polar and Northern Urals, Taymyr Peninsula, etc.) and hepatics of Far East of Russia. Apart from data label, CRIS includes literature sources, data of DNA sequences and pictures of species that are linked to the specimen record. Approximately 1,807 original photos of cyanoprokaryota, 1,400 photos of lichens, 30 of fungi and 15 of bryophytes are incorporated at present in the CRIS to this day. About half of records include coordinates measured with GPS. Some of these data were transferred to GBIF. However, many old records are without coordinates. The most important task to be done is to assign coordinates for the old records based on a specimen labels and adding recently identified collections from different regions.

Lichen and bryophyte inventories in Québec's Arctic by Québec Governmental Agencies (1998 to present)

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Several floristic inventories (vascular plants, lichens and bryophytes) have been carried out in Québec's Arctic since 1998. Such inventories were first carried out as part of the knowledge acquisition process for the creation of national parks in Nunavik (Québec Arctic). Beginning in 2011, biodiversity inventories were also carried out on large portions of northern Québec as part of Plan Nord, a Québec Government initiative for the development of the north with a knowledge acquisition component. A synthesis of the results of this work is presented here. These have allowed developing a better knowledge of the distribution and the ecology of lichens and bryophytes of the studied territory. They also allowed the addition of over a hundred species for Québec, mainly crustose lichens, some of which represent species new to science. More than 25,000 specimens of lichens and bryophytes were collected during these inventories and are available for research. Some specimens have been used for molecular biology or taxonomical work (genera *Peltigera*, *Stereocaulon*, *Leptogium*).

An open platform for biodiversity monitoring in Québec and the Arctic

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Performing biodiversity assessments in Québec and the Arctic is a major challenge because of the extent and diversity of territory to cover. A global strategy, directed by a consortium of scientists, partners and governments, has to be put in place. Collaboration, data sharing and coordination of future monitoring efforts offer several advantages such as cost reduction, establishing reference datasets, transparency and accessibility. The project of The Québec Observatory of Ecosystems is the result of a consensus between several actors in biodiversity science, including Ouranos, the Ministère du Développement durable, de l'Environnement et de la Lutte contre les Changements climatiques, the ministère de la Forêt de la Faune et des Parcs, and Hydro-Québec, along with researchers regrouped under the different FRQNT strategic networks concerned by biodiversity.

The Observatory has for mission to 1) Create a unique portal that will facilitate collection, integration and diffusion of biodiversity information; 2) Represent a neutral reference on biodiversity issues for Québec; 3) Support training and development of expertise for biodiversity monitoring; 4) Develop and support provincial capacity for monitoring and predictions of biodiversity changes; 5) Establish linkages to national and international initiatives in biodiversity monitoring. This mission will be filled by activities such as the development of a cyber-infrastructure for data archiving, sharing and processing, coordination of sampling campaigns and regular publication of biodiversity assessments.

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