LICHENS IN HIGH ARCTIC ECOSYSTEMS:

Recommended research directions for assessing diversity and function near the Canadian High Arctic Research Station, Cambridge Bay, Nunavut

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Abstract

Lichens are an important component of Arctic terrestrial ecosystems. An assessment by lichen researchers with polar and alpine experience has confirmed the dominant presence of lichens in and around Ikaluktutiak (Cambridge Bay). Three main lichen communities were found: (1) lichens growing among higher plants in wetter areas, (2) lichens growing on rocks and stones in drier sites, and (3) lichens forming soil crusts. To further enhance knowledge of lichens near Cambridge Bay, efforts should be directed towards identifying lichen species in the vicinity of the Canadian High Arctic Research Station (CHARS) and developing methods to assist non-experts with identification. Setting up a Herbarium at the CHARS campus and building a DNA barcode library will facilitate the use of molecular identification techniques. Determining growth rates of lichens will allow surface dating (e.g., age determination of archaeological sites) as well as the monitoring of environmental changes. Local lichen communities should be described and factors controlling their position on the landscape determined. Chlorophyll fluorescence techniques will allow non-contact determination of the length of active period, and timing of activity during the year. This, together with studies on photosynthesis, will allow performance of key species to be made, the influences of major environmental factors to be determined, and the carbon contribution to the communities to be calculated. Collectively, these data will assist in predicting the effects of climate change for High Arctic ecosystems. The location and excellent facilities of CHARS are ideal to underpin these studies and fill a major knowledge gap about tundra ecosystems in Arctic Canada.

Résumé

Les lichens sont une composante importante des écosystèmes terrestres de l'Arctique. Une évaluation réalisée par des chercheurs spécialisés en lichens ayant de l'expérience en milieu polaire et alpin a confirmé la présence dominante de lichens à Ikaluktutiak (Cambridge Bay) et dans les environs. Trois principales communautés de lichens ont été découvertes : (1) les

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lichens poussant parmi les plantes supérieures dans les zones plus humides, (2) les lichens poussant sur des roches et des pierres dans des sites plus secs, (3) les lichens formant des croûtes de sol. Afin d'améliorer davantage les connaissances sur les lichens près de Cambridge Bay, des efforts devraient être déployés pour identifier les espèces de lichens à proximité de la Station canadienne de recherche dans l'Extrême-Arctique (SCREA) et élaborer des méthodes pour aider les non-spécialistes à les identifier. La mise en place d'un herbier sur le campus de la SCREA et la construction d'une bibliothèque de codes à barres de l'ADN faciliteront l'utilisation de techniques d'identification moléculaire. La détermination des taux de croissance des lichens permettra la datation des surfaces (p. ex. détermination de l'âge des sites archéologiques) ainsi que la surveillance des changements environnementaux. Les communautés locales de lichens devraient être décrites, tandis que les facteurs contrôlant leur position dans le paysage devraient être déterminés. Les techniques de fluorescence chlorophyllienne permettront de déterminer sans contact la durée de la période active et le moment de l'activité au cours de l'année. Cela, ainsi que des études sur la photosynthèse, permettront de réaliser des avancées sur les principales espèces, de déterminer les influences des principaux facteurs environnementaux et de calculer la contribution du carbone aux communautés. Collectivement, ces données aideront à prévoir les effets des changements climatiques sur les écosystèmes de l'Extrême-Arctique. L'emplacement et les excellentes installations de la SCREA sont idéaux pour soutenir ces études et combler une importante lacune dans les connaissances sur les écosystèmes de la toundra dans l'Arctique canadien.

Introduction

Lichens are an important component of High Arctic terrestrial ecosystems and provide a valuable food source for caribou, muskox and Arctic hare (Edwards et al. 1960, Thomas et al. 1994). Lichens are a unique complex of two types of organisms, an alga and a fungus, growing together in a symbiotic relationship; they require liquid water (rain, meltwater) to grow. Lichens are very common around the hamlet of Ikaluktutiak (Cambridge Bay) and are often the dominant vegetation type. They also have a potentially high diversity in the vicinity of Cambridge Bay owing to low precipitation levels (< 140 mm with 50% as summer rain) and limited competition with other vegetation types such as trees and shrubs. However, very little is known of their diversity in the High Arctic owing to difficulties in identification as well as access to study sites.

Recognized international lichen researchers were invited by Polar Knowledge Canada to provide an initial assessment of lichen communities near Cambridge Bay. The invitees all had extensive experience in Antarctic, alpine, and Arctic environments and have previously conducted research on the taxonomy, ecophysiology, growth, and ecology of lichens. As part of this present report, the researchers were tasked with providing recommendations to improve knowledge of lichen diversity and function in the Canadian Arctic.

Present situation: The Canadian High Arctic Research Station (CHARS) is expected to be fully operational in 2019 with an ongoing research program. Its primary objective is to "mobilize Arctic science and technology" and become "a world-class monitoring site that will act as a *hub* for CAMPNet (Canadian Arctic Monitoring and Prediction)." Towards this objective, CHARS has established an Experimental and Reference Area in which detailed research is possible on marine, freshwater and terrestrial ecosystems (CHARS 2015). Another key objective is to support the effective stewardship of Canada's Arctic lands, waters, and resources. A mechanism to achieve this will be to "identify and target international and national partnership opportunities" (CHARS 2015). CHARS has recognized that, at present, little is known of the lichens in the vicinity of Cambridge Bay. However, recent research has focused on vegetation description and classification of higher plants using satellite technology and ground-truthing (CHARS 2015, Meidinger et al. 2015, McLennan et al. 2018). This is a highly appropriate approach for the region in which surface travel can be challenging, particularly in summer.

A feature of High Arctic vegetation is the large proportion of mosses and lichens, the latter particularly in drier sites, although little has been published for the Cambridge Bay region. One paper exists on lichens (Thomson and Weber, 1992), which lists 103 species, and another on bryophytes (Persson and Holmen, 1961), which lists 56 species (7 Hepaticae *liverworts*, 0 Sphagnales and 49 Bryales, *true mosses*). The low number of Hepaticae and absence of Sphagnales provide an indication of the extreme conditions (low temperatures and low

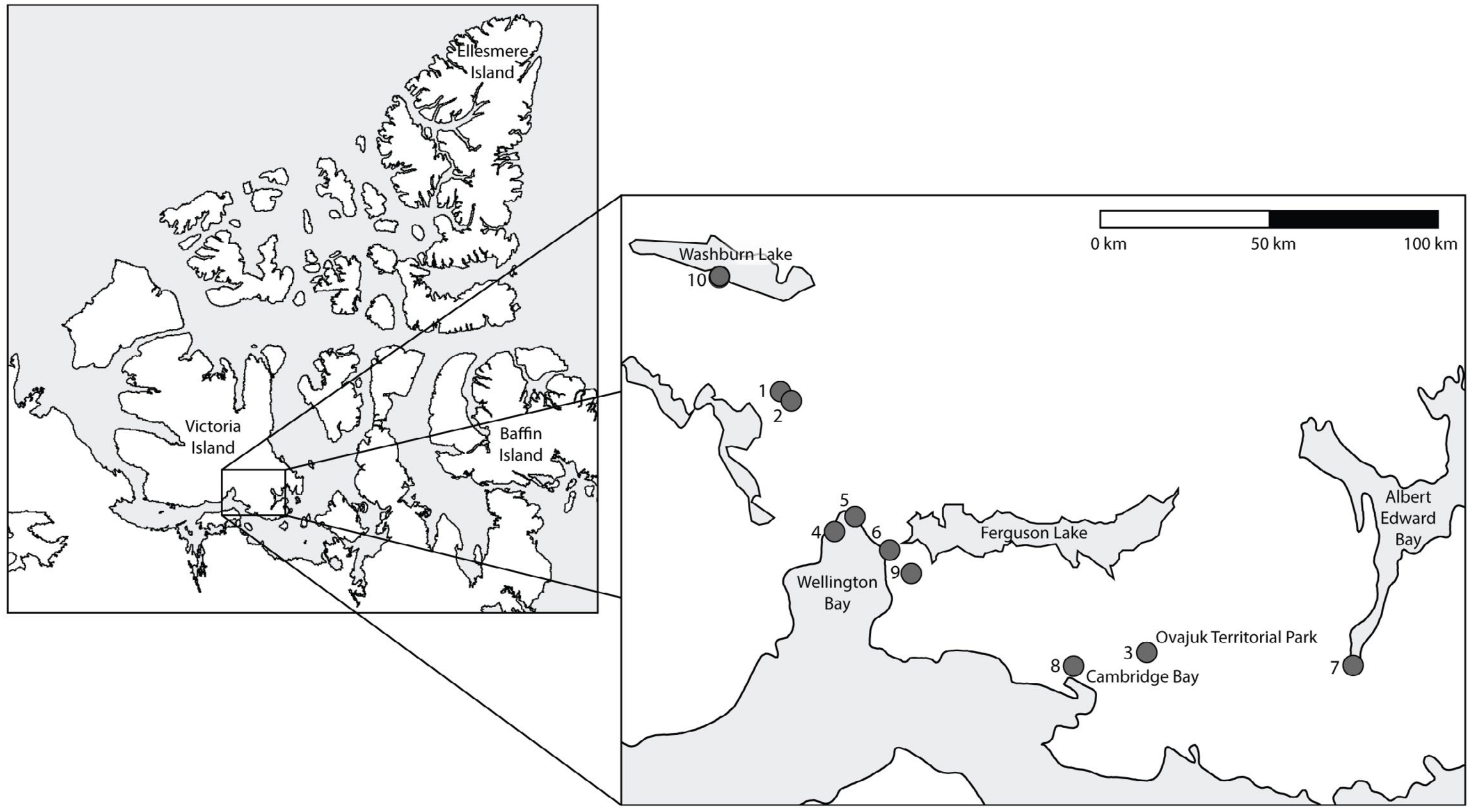

Figure 1: Study area and sampling sites visited in the vicinity of Cambridge Bay. Site numbers correspond to Table 1.

rainfall) of the Cambridge Bay climate. However, species identification for both taxonomic groups can be problematic for researchers who have not specialized in these groups. Research into bryophytes is currently underway (J. Doubt, Canadian Museum of Nature; C. La Farge, University of Alberta). When it is considered that the two published studies were the result of brief (less-than-two-day) visits to Cambridge Bay, it is reasonable to assume that future in-depth collecting will greatly increase the number of species of both bryophytes and lichens.

The objective of this current work is to visit a range of sites in the vicinity of CHARS to collect lichen samples for identification, make an initial (non-quantitative) assessment of the main lichen communities and suggest possibilities for future research. Ongoing work will involve collaborations with existing national and international experts as well as with local communities. A primary aim will be to build the required knowledge and research skills at CHARS and in the north more generally. This will be done in conjunction with northerners so that the outputs of existing investments can be further enhanced.

Fieldwork

The fieldwork was undertaken from 14 July 2018 to 2 August 2018 using helicopter or ground support for sites within about 250 km of Cambridge Bay. Visits were made to sites in the vicinity of the CHARS campus (Cambridge Bay) and more widely in southern Victoria Island, particularly around Wellington Bay (Fig. 1). A full list of sampling sites and GPS locations is provided in Table 1. In all cases, site visits lasted from one to two hours with qualitative sampling carried out.

All samples were returned to the CHARS campus, where duplicates were made where identification in home laboratories was necessary. More than 200 lichen samples were collected and are in the process of being formally identified.

Table 1: Sampling sites visited during the study, including site names and GPS coordinates.

Site No.	Date	Site Name	Latitude	Longitude
1	7/21/2018	Southern Victoria Island Site 1	69.77871	-107.04295
2	7/21/2018	Southern Victoria Island Site 2	69.75728	-106.96758
3	7/21/2018	Ovajuk (Mt Pelly)	69.16298	-104.57033
4	7/23/2018	Wellington Bay Site 1	69.45022	-106.65907
5	7/23/2018	Wellington Bay Site 2	69.4864	-106.52231
6	23/7/18 & 27/7/18	Wellington Bay Site 3 Ekaluktok (Ferguson Lake outflow)	69.40802	-106.28632
7	7/24/2018	Albert Edward Bay	69.11751	-103.20293
8	7/25/2018	Ekaluktutiak (Cambridge Bay)	69.13356	-105.05821
9	7/27/2018	Ovayoalok (Ridge south of Ferguson Lake)	69.35333	-106.13998
10	7/28/2018	Washburn Lake	70.04475	-107.48449

Preliminary observations of lichen communities near CHARS

Lichens were the dominant vegetation type in most areas around Cambridge Bay, and especially so in the rock-dominated landscapes. They also contributed to biological soil crusts, which occur in areas where soil formation has started. Algal and lichen communities were also located under transparent rocks (quartz) in a greenhouse-like environment (termed *hypoliths*). Our preliminary investigations suggest three main types of vegetation communities: (1) Vascular plants intermixed with lichens dominated by fruticose Arctic-alpine species (*Gowardia nigricans, Bryoria nitidula, Cetraria islandica, Cetraria aculeata, Flavocetraria nivalis, Thamnolia vermicularis, Vulpicida tilesii, Evernia perfragilis*), with a few mosses restricted to the most humid sites (Fig. 2a, 2b).

In this community type, lichen biomass is substantial, and is likely in a dynamic, competitive balance with vascular plants and sensitive to any environmental (e.g., climate) changes; (2) Lichen vegetation densely covering rocks and boulders, and also including extensive areas of small stones (often around 100–200 mm across and around 20–30 mm thick) and small pebbles (Fig. 3a, 3b).

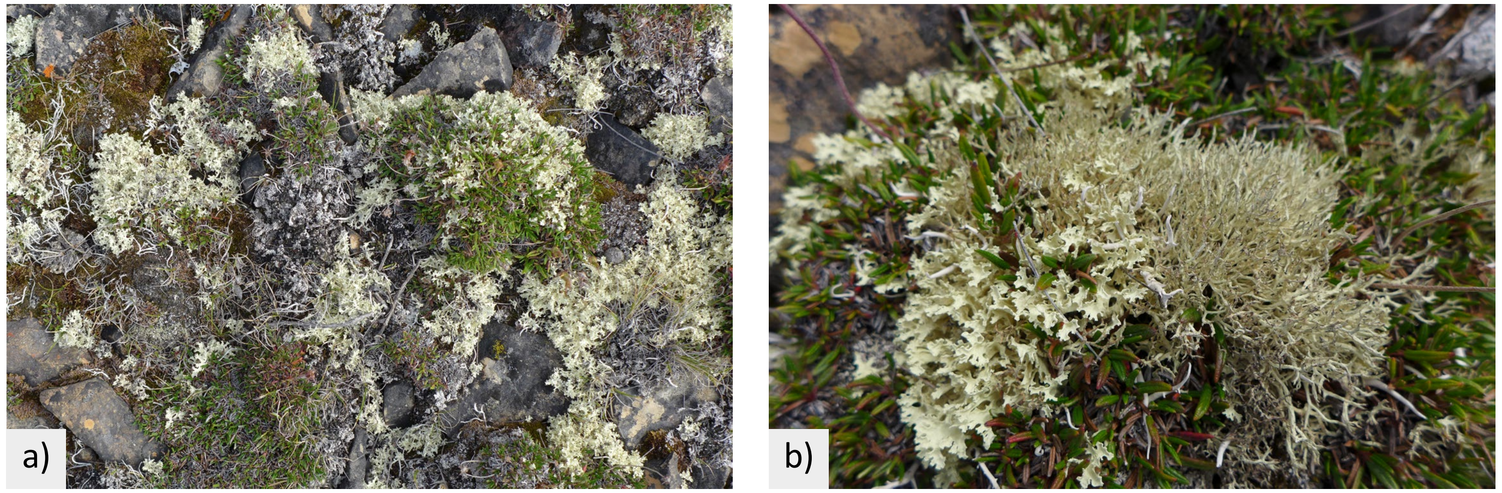

Figure 2: (a) Mixed vascular plant and lichen community; the most common lichens are of the fruticose form (like little trees), which can reach the light and compete with the leaves of the higher vascular plants and (b) The fruticose lichens Flavocetraria nivalis *(L.) Kärnefelt and Thell (left side) and* Evernia perfragilis *Llano (right side) and between both,* Thamnolia vermicularis *(Sw.) Ach. ex Schaerer, which are all commonly found among the vascular plants.*

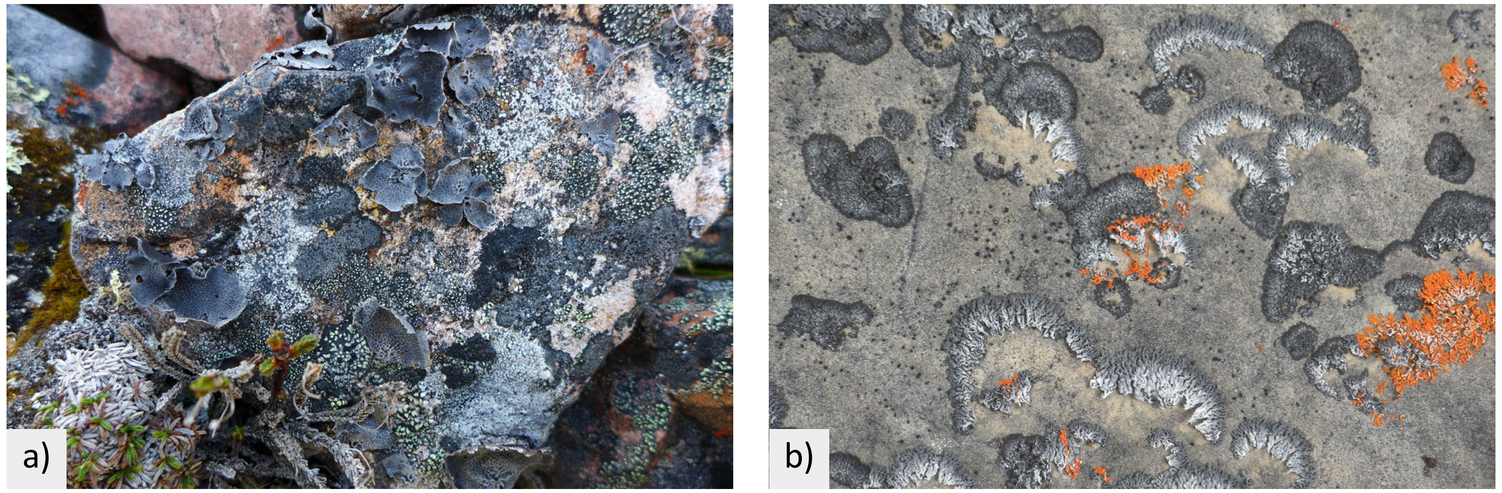

*Figure 3: (a) An epilithic lichen community (*Physcia spec., Rusavskia elegans*), which provides excellent possibilities for growth studies and (b) Rich lichen community dominated by leaf-like* Umbilicaria *species and various crustose thalli, including the lichen most studied for growth rates,* Rhizocarpon geographicum*.*

Bipolar species such as *Rhizocarpon geographicum, Rhizoplaca melanophthalma, Sporastatia testudinea, and Umbilicaria decussata* were frequently found in high abundance. In many cases, this vegetation was similar to that occurring in some areas of the southern polar Transantarctic Mountains (Green et al. 2011), offering an interesting opportunity for bipolar ecological and taxonomical comparisons; and (3) Biocrust, made up of crustose lichens (*Cladonia* sp., *Fulgensia bracteata, Ochrolechia sp., Ochrolechia frigida, Pertusaria af. dactylina, Pertusaria* af. *panyrga, Psora decipiens*), mosses and probably cyanobacteria (Fig. 4a, 4b).

This biocrust shows similarities with those from all around the world, both in polar and arid regions. Biocrust communities are not common in more humid Arctic regions such as the Svalbard Archipelago, Iceland, and Northern Scandinavia. The extensive presence of biocrusts in some areas of the southern shore of Victoria Island opens interesting research opportunities to integrate the Arctic into the international effort to understand these unique systems.

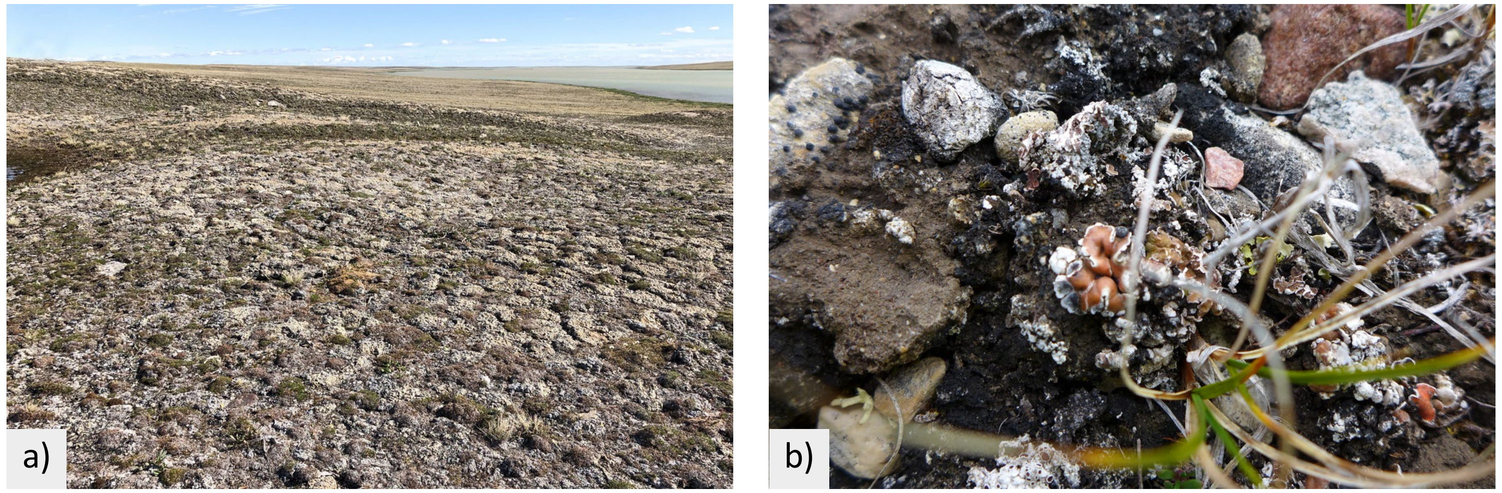

Figure 4: (a) Soil-crust lichens growing over a humid surface first created by the higher plants. Again, fruticose (tree-like) lichens are easier to see, but other crustose lichens actually grow on the soil surface and (b) Soil-crust lichen species Psora decipiens*), which is cosmopolitan, including desert areas in Spain and the United States. Such lichens have recently been found to show complex adaptations to local climate.*

Proposed research themes

A) Biodiversity, identifying the lichens:

The role of lichens in High Arctic food webs cannot be determined unless the species present can be accurately and easily identified. The first accurate identifications require suitable experts. However, a system should be developed that is also user-friendly to non-experts. We recommend the following actions: (1) encourage field surveys with targeted collection of lichens; (2) capture local information from elders regarding species presence, especially with regard to snow occurrence and persistence; (3) support visits by recognized experts to undertake further collecting and also to make identifications at CHARS as well as produce simple guides to the more obvious lichens; (4) initiate DNA barcoding of identified samples so that accurate determinations by non-experts are possible; and (5) develop a properly curated herbarium for all samples, including a DNA reference collection, at CHARS.

B) Ecology of lichens:

Lichens are a major component of the local vegetation communities. However, no readily accessible or published information exists at present. One consequence is that the spectacular lichen communities around Cambridge Bay do not get the research attention required. At present, research tends to occur in Alaska and Svalbard, likely due to the ready access to sites and facilities. The recent establishment of the CHARS campus offers enhanced access to nearby field sites as well as excellent on-site laboratory facilities. In order to make further progress, community descriptions are needed with rapid, targeted publication. Vegetation research (mostly vascular plant) has been carried out over recent years through satellite mapping and ground-truthing measurements (e.g., McLennan et al. 2018). This provides an excellent opportunity to progress lichen ecology and is needed to monitor responses to changes in climate (see subsection D below). However, detailed descriptions of dedicated research sites (e.g., within the CHARS Experimental and Reference Area) are needed to provide clear information on both vascular and non-vascular (lichens, mosses) plants, in conjunction with the existing vegetation classification program, to reveal special features of the region. This work must appear in the primary scientific literature to be of use to international researchers.

C) Landscape-level descriptions:

Vascular plant and lichen communities are determined by soil moisture in summer and snow cover in winter, with limited snow cover or winter exposure causing more arid conditions where lichens can dominate (CHARS 2015). Long-lying snow deters lichens whilst occasional cover with melt will favour them. Information on snow cover and duration will certainly exist within the local community and efforts should be made to obtain this valuable local knowledge.

D) Ecophysiology — understanding how lichens work:

There is currently no information on the ecophysiology of lichens and vascular plants in the vicinity of Cambridge Bay. Even in the research assessment by CHARS (CHARS 2015), the estimates for phytomass and net annual production come from a paper with information from Siberia. Most northern hemisphere research on tundra systems has been based in Alaska and, more recently, Svalbard. The latter has a climate that is very different to that of Cambridge Bay and the Nunavut region. The development of suitable systems to measure photosynthesis in both the laboratory and field is essential. Suitable growth chambers already exist in the laboratories at CHARS such that "over winter" studies are also possible. The satellite-based remote sensing and mapping of vegetation will also benefit, if actual productivity and related parameters such as chlorophyll content, biomass, and major nutrients can be determined and linked to the standard spectral coefficients. Suggested research themes are as follows:

1) *Photosynthetic performance of key species, lichens and vascular plants*. Portable equipment can be used to allow measurements in the field and in the laboratory at CHARS.

2) *Annual activity patterns of lichens*. Lichens and bryophytes are only active when hydrated (poikilohydric). Antarctic and alpine research has shown that activity patterns can vary considerably from that expected based on the general climate. Accordingly, actual activity patterns are best determined using "non-contact" chlorophyll fluorescence systems. Such systems have been extensively trialed in Antarctica and alpine sites. Because key environmental factors (light, temperature, relative humidity) are also recorded, the assembled database can reveal the main factors controlling performance as well as provide key data to develop models for predicting community change.

3) *Global comparisons*. Some lichen species have been investigated across large latitudinal gradients (e.g., *Cetraria aculeata* from the Antarctic to Europe), and evidence of adaptation has often been found. The main aim is to establish CHARS as a suitable site for global comparisons that are relevant to overarching themes such as climate change.

4) *Monitoring change*. The greening of the Arctic is an established process (Fauchald et al. 2017), and CHARS has decided that monitoring will be a key function of the new research station. Lichens are effective organisms to track climate-related changes, and the best method is the establishment of monitoring sites. Lichenometry is the study of lichen growth rates, and sites need to be established where lichen thalli are photographed each year and their growth rates determined. Once the growth rates have been established, they can then be used to assist other research areas such as dating exposed surfaces, providing insights on surface stability and corroborating archaeological data. Some sites show almost complete lichen cover. However, it is not known how long it takes to achieve this coverage. Rates of recovery can be established by experimentally disturbing sites and then monitoring the recovery. The monitoring of long-term change is best carried out by establishing sites that have been accurately mapped, or at least photographed, and then repeating the mapping at set intervals. In the case of lichens, such sites are small, approximately one metre square, and can be easily set up at multiple locations. Seasonal acclimation measurements of CO_2 exchange through the summer period will reveal whether the plants respond to the rapidly changing conditions.

5) *Soil metagenomics.* Plants and lichens interact with and change the soil microbiota, and such changes can be rapid. Metagenomics (or environmental genomics) can be defined as "the application of modern genomics technique without the need for isolation and laboratory cultivation of individual species." Metagenomics can provide valuable insights into the functional ecology of environmental communities such as in soils. DNA sequencing can also be used more broadly to identify species present in a body of water, debris filtered from the air, or samples of soil. This can establish the range of invasive species as well as endangered species, and track seasonal populations. We aim to obtain information on soil diversity and on changes in that biodiversity through the seasons at Cambridge Bay. This will be achieved by regular soil sampling, starting in April 2019, with molecular analysis in late 2019 and early 2020. The actual sample preparation and interpretation can be done at CHARS with the DNA sequencing undertaken at a suitable Canadian facility.

Community considerations

Country foods such as Arctic hare, caribou, and muskox are known to eat lichens. Lichens are very common around Ikaluktutiak (Cambridge Bay), even the dominant vegetation in some places. However, very little is known about their diversity and abundance, as they can be difficult to identify. An assessment by international researchers visiting the CHARS campus in July/August 2018 provided several suggestions. In particular, emphasis should be given to getting as many lichens identified and named as possible. Local lichen communities need to be described with input from local people (e.g., elders), as this will provide an important historical context regarding the possible presence or absence of different species. Simple identification systems such as guide books and DNA barcoding methods will then allow non-specialists to identify species more easily and allow for community-based monitoring. The DNA-based methods will also allow assessment of which species are important in the diets of country foods. The abundance of lichens and their annual contribution to the ecosystem productivity needs to be determined, as this is relevant to predicting effects of climate change. As vegetation shifts with changing climate, certain vegetation types might outcompete lichens and replace them in the local area. Overall, CHARS is in an excellent location to undertake lichen research.

Conclusions

CHARS is well situated to become a centre of research on High Arctic terrestrial biology and contribute to a better understanding of the stability and resilience of the local landscape. Emphasis should be given to identifying as many lichen species as possible and setting up systems (e.g., DNA barcoding) that will allow non-specialists to identify them more easily. Monitoring programs that allow growth rates to be determined could be used to establish the ages of rock surfaces or detect changes in climate. Local lichen communities need to be described with input from local people (e.g., elders) to assess how communities may have changed over time and how snow cover might influence the occurrence of lichen communities. The actual biomass of lichens present and their annual contribution to ecosystem productivity also need to be determined, as this is relevant to predicting effects of climate change.

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