Available online at www.sciencedirect.com

ScienceDirect

Polar Science 8 (2014) 397–412

http://ees.elsevier.com/polar/

Effects of substrate differences on water availability for Arctic lichens during the snow-free summers in the High Arctic glacier foreland

Takeshi Inoue [a,*], Sakae Kudoh [a,b], Masaki Uchida [a,b], Yukiko Tanabe [a,c], Masakane Inoue [d], Hiroshi Kanda [a]

[a] *National Institute of Polar Research, 10-3 Midori-cho, Tachikawa-shi, Tokyo 190-8518, Japan*
[b] *Department of Polar Science (Sokendai-NIPR), The Graduate University for Advanced Studies, 10-3 Midori-cho, Tachikawa-shi, Tokyo 190-8518, Japan*
[c] *Institute for Advanced Study, Waseda University, 1-6-1, Nishi Waseda, Shinjuku-ku, Tokyo 169-8050, Japan*
[d] *Faculty of Education and Human Studies, Akita University, 1-1 Tegata-Gakuenmachi, Akita-shi, Akita 010-8502, Japan*

Received 17 December 2013; revised 1 August 2014; accepted 18 September 2014
Available online 7 October 2014

Abstract

We used observational and experimental analyses to investigate the photosynthetic activity and water relationships of five lichen species attached to different substrates in a glacier foreland in the High Arctic, Ny-Ålesund, Svalbard (79°N) during the snow-free season in 2009 and 2010. After the rains ceased, lichens and their attached substrates quickly dried, whereas photosynthetic activity in the lichens decreased gradually. The *in situ* photosynthetic activity was estimated based on the relative electron transportation rate (rETR) in four fruticose lichens: *Cetrariella delisei*, *Flavocetraria nivalis*, *Cladonia arbuscula* ssp. *mitis*, and *Cladonia pleurota*. The rETR approached zero around noon, although the crustose lichen *Ochrolechia frigida* grown on biological soil crust (BSC) could acquire water from the BSC and retain its WC to perform positive photosynthesis. The light-rETR relationship curves of the five well-watered lichens were characterized into two types: shade-adapted with photoinhibition for the fruticose lichens, and light-adapted with no photoinhibition for *O. frigida*. The maximum rETR was expected to occur when they could acquire water from the surrounding air or from substrates during the desiccation period. Our results suggest that different species of Arctic lichens have different water availabilities due to their substrates and/or morphological characteristics, which affect their photosynthetic active periods during the summer.

Keywords: Lichen; High Arctic; Water availability; Substrate; Photosynthetic activity

1. Introduction

Lichens are symbiotic photoautotrophs that can grow in extreme environments, such as deserts, and high alpine, and polar regions, where they often dominate and play an important role in carbon fluxes

* Corresponding author. Tel.: +81 42 512 0765; fax: +81 42 528 3492.
E-mail address: inotake@nipr.ac.jp (T. Inoue).

http://dx.doi.org/10.1016/j.polar.2014.09.003
1873-9652/

(Ahmadjian, 1995; Kappen, 2000). Bare ground was exposed after the retreat of glaciers in the glacier forelands of the High Arctic, which a diversity of lichens and some mosses colonized during the early successional stage to become typical pioneer flora of the foreland (Brattbakk, 1986; Elvebakk and Hertel, 1996; Hodkinson et al., 2003).

Some lichens living in the polar region can carry out photosynthesis and respiration under frozen conditions (Kappen et al., 1996; Pannewitz et al., 2003). However, low solar elevation and snow cover further decrease the availability of solar radiation during the cold season in the High Arctic regions. Thus, photosynthetic production by lichens in the High Arctic regions is thought to occur mainly during the short snow-free summer. However, photosynthesis in the summer is sometimes limited due to low water availability, which occurs mainly in the desiccation period after rain (Longton, 1988; Uchida et al., 2006).

Lichens are poikilohydric organisms and the water content (WC) of their thalli is strongly dependent on the general water status of their surroundings (Walter, 1973; Green and Lange, 1995). Several laboratory and field studies have indicated that photosynthetic activity was highly enhanced when the WC of thalli was increased by the supply of liquid water from rain or fog, whereas it rapidly decreased when the supplies were stopped (Lange, 2003; Reiter et al., 2008). Photosynthesis of green algal lichens is affected by rain, mist, dewfall, and high humidity (above 90%), whereas photosynthesis of cyanobacterial lichens is affected only by rain (Lange et al., 2001). Lichens are thought to photosynthesize in High Arctic environments due to several morphological and distributional adaptations that combat desiccation; e.g., the acquisition of water from humid air (Lange and Kilian, 1985; Reiter et al., 2008) or substrate moisture (Harris, 1971). However, studies on the different water availabilities for various lichen species and their *in situ* photosynthesis under ambient conditions are still needed to evaluate the photosynthetic performance and ecological success of lichens in the High Arctic (Kappen, 2000).

In the present study, we used field observations and experimental analyses to investigate the photosynthetic activity based on different water availability for five lichens attached to different substrates during the snow-free season in the High Arctic glacier foreland.

2. Materials and methods

2.1. Study site

Field studies were carried out on the glacier foreland of Austre Brøggerbreen (78°55′N, 11°50′E), 2 km southwest of Ny-Ålesund in the Svalbard archipelago (Fig. 1) on 8–17 August 2009 and 15–22 July 2010. From 2001 to 2008, the annual mean air temperature in this area was 4.2 °C, the mean annual precipitation was 433 mm, and the snow-free period was about 2 months (July–August) (Uchida et al., 2010). The rainfall at the study site during the snow-free season from 2007 to 2011 occurred on average at 4.6-day intervals (Inoue, 2013), and humidity decreased after intermittent rainfall (Fig. 2; Maturilli et al., 2013). The samples were collected from an area where the target lichens dominated, according to previous studies of the glacier foreland (Brattbakk, 1986; Inoue et al., 2011).

2.2. Lichen species used

We selected five lichen species that are distributed throughout the glacier foreland in Ny-Ålesund area, and are also common in the Arctic (Elvebakk and Hertel, 1996). The characteristics of the lichen species are as follows.

(1) *Cetrariella delisei* (Bory ex Schaer.) Kärnef. & Thell: fruticose lichen mainly growing on vascular plant litter and moss litter, sometimes on biological soil crust (BSC) and gravel. Densely distributed throughout the area.
(2) *Flavocetraria nivalis* (L.) Kärnef. & Thell.: fruticose lichen growing on vascular plant litter. Distributed in patches throughout the area.
(3) *Cladonia arbuscula* ssp. *mitis* (Sandst.) Ruoss.: fruticose lichen growing on moss litter. Distributed in patches throughout the area.
(4) *Cladonia pleurota* (Flörke) Schaer.: fruticose lichen growing on BSC. Distributed in patches throughout the area.
(5) *Ochrolechia frigida* (Sw.) Lynge.: crustose lichen mainly growing on BSC, sometimes vascular plant litter, moss litter, and gravel. Densely distributed throughout the area.

All species are composed of a green algae photobiont. In the study area, the fruticose lichen *C. delisei* and the crustose lichen *O. frigida* have low substrate specificity, and the other three fruticose species have high substrate specificity. To confirm identification, morphology was observed using a stereomicroscope