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Snow algal communities on glaciers in the Suntar-Khayata Mountain Range in eastern Siberia, Russia

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A B S T R A C T

Snow and ice algal communities were investigated on four glaciers in the Suntar-Khayata Mountain Range in eastern Siberia in Russia over three melting seasons from 2012 to 2014. Two taxa of green algae and five taxa of cyanobacteria were observed on the glaciers. The algal community was dominated by green algae: *Ancylonema nordenskioldii* in the lower bare ice area and *Chloromonas* sp. in the upper snow area. The total algal bio-volume showed altitudinal variation, ranging from 0.03 to 4.0 mL m^{-2}, and was greatest in the middle of the glaciers. The altitudinal variations in the algal community were similar on all studied glaciers, suggesting that they are typical in this region. Observations over the three years revealed that there was no significant change in the community structure, but a significant change in the total biomass. Since the mean summer air temperature was significantly higher in 2012 when algal biomass was greater, the difference in algal biomass among the years is probably due to the duration of surface melting. The community structure on the studied glaciers is similar to those on glaciers in Arctic and sub-Arctic regions.

1. Introduction

Snow and ice algae are photosynthetic microbes growing on snow and ice, and they have been reported on glaciers, snow fields, and sea ice in many parts of the world. They appear on glaciers during the melting season since they need liquid water for their growth. Their community is usually composed of green algae and cyanobacteria, but occasionally of diatoms and charophytes in some regions (e.g., Daily, 1961; Watanabe, 1982). They play an important role as primary producers in glacier ecosystems (Hodson et al., 2008; Anesio et al., 2009), and they and their products sustain heterotrophic organisms living on glaciers, such as bacteria, tardigrades, rotifers, midges, stoneflies, collembolans, and ice worms (e.g., Kohshima, 1987; Aitchison, 2001; Hoham and Duval, 2001; Murakami et al., 2015).

Since algal cells in snow and ice can efficiently absorb solar radiation, they can affect the melting of snow and ice (e.g., Takeuchi et al., 2015). Blooms of algae can change the color of snow or ice to green, red, brown, or black since the algal cells are usually filled with light-absorbing pigments. For example, the melting snow surface often appears to be red due to the red-pigmented algal cells of *Chlamydomonas nivalis* or *Chloromonas* sp. (e.g., Hoham and Mullet, 1977; Kol and Eurola, 1974; Takeuchi et al., 2006; Lutz et al., 2015). Glacial ice surfaces in Svalbard and Greenland are often patchily colored blown or grey due to the dark-reddish algal cells of *Ancylonema nordenskioldii* (Remias et al., 2012; Yallop et al., 2012; Lutz et al., 2014). These snow or ice surfaces with algae can absorb more solar radiation due to their lower reflectivity, and thus melt faster than surfaces without algae (e.g., Takeuchi et al., 2001a; Takeuchi, 2009). Filamentous cyanobacteria, which often grow on ice surfaces, also have a large effect on surface albedo because they can entangle with mineral and organic particles and form dark-colored aggregates called cryoconite granules (e.g., Takeuchi et al.,

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2001b). The granules are particularly abundant on Asian mountain glaciers, and have been reported to substantially accelerate ice melting compared to a clean surface on a Himalayan glacier (Kohshima et al., 1993). Thus, spatial and geographical variations in these snow and ice algae are important in evaluating their impact on glacier melting.

Algal communities on glaciers usually vary with altitude. During the melting season, the lower part of glaciers has a bare ice surface and is dominated by algae that are ice environment specialists, which prefer the conditions on ice for their growth (Yoshimura et al., 1997). In contrast, the upper part of glaciers has a snow surface and is dominated by the algae of snow environment specialists. The area around the snow line, which is the border between snow and bare ice areas on glaciers, is dominated by generalist algae. The total algal biomass also varies with altitude on glaciers. It generally decreases as altitude increases on Asian glaciers, but reaches a maximum in the middle of Arctic and sub-Arctic glaciers (e.g., Yoshimura et al., 1997; Takeuchi, 2001). The factors affecting these altitudinal changes in algal communities have been explained by altitudinal gradients in snow cover frequency, solar radiation, and the amount of running meltwater on the surface (e.g., Yoshimura et al., 1997).

Algal communities also vary around the world (e.g., Takeuchi et al., 2006). For example, algal communities on the bare ice surface of glaciers are usually dominated by filamentous cyanobacteria in central Asia (e.g., Takeuchi and Li, 2008; Takeuchi et al., 2010), but by green algae in Arctic and sub-Arctic regions including Alaska, Greenland, and the Altai Mountains (Takeuchi et al., 2006). The geographical variation suggests that the effect of algae on the surface albedo of glaciers differs among the regions, and the variations are probably caused by the physical and chemical characteristics of glaciers in each region, and by the limited extent of algal dispersal.

Recent climate warming has substantially affected the physical and chemical conditions on glaciers, which possibly affect snow algal communities and their geographical distribution on glaciers. For example, climate warming can extend the duration of melting on glaciers, causing more algal growth. It might also affect atmospheric circulation, changing the nutrient supply via aerial deposition on glaciers. These environmental changes possibly affect algal growth on glaciers and the geographical extent of the algal communities.

Eastern Siberia is a glacierized mountainous area in the Arctic and sub-Arctic regions. There are many glaciers in mountain ranges of the region such as the Suntar-Khayata, Cherskiy, and Kodar Mountain Ranges. Some of the glaciers have been glaciologically studied since the 1950s, but there is a lack of information on the snow and ice algal community on glaciers in this region. Furthermore, a rise of mean annual and summer temperature has been reported in Suntar-Khayata region during the past 40 years (e.g. Takahashi et al., 2011; Chapin et al., 2005). Descriptions of the algal community in the region could support our understanding of the biogeography of snow and ice algae over the circum-Arctic area and are important for evaluating the impacts of climate change on glacier ecosystems in the Arctic.

In this paper, we aim to describe for the first time the snow and ice algal communities on four glaciers in the Suntar-Khayata Mountain Range in eastern Siberia in Russia. We collected samples of surface snow and ice from sites at different elevations on four glaciers and showed the spatial variation in the algal community. We also collected the samples over three melting seasons from 2012 to 2014 and showed the inter-annual variability in the algal community. Results are compared with those of other Arctic and Asian regions and their spatial and annual variations are discussed along with the physical and chemical conditions of the glaciers.

2. Study site and methods

The investigation was carried out on four glaciers in the Suntar-Khayata region in eastern Siberia. This region is located in a mountain range from 62°N to 63°N and from 140°22′E to 142°E (Fig. 1). The area was mostly vegetated with boreal forest or tundra below approximately 1900 m a.s.l., and with epilithic lichen communities around glaciers. This mountain region consists of two catchments: the Indigirka River and south-oriented drainages. The former drains into the Arctic Ocean and the latter drains into the Sea of Okhotsk. A total of 195 glaciers with a combined area of 163 km^2 have been listed in this mountain range. The total area has been reduced by 20.8% since 1945, and the average rate of loss is 0.75 km^2 per year (Ananicheva et al., 2006). Glaciers in this range can be grouped into three main massifs: the northern massifs, the central massifs, and the southern massifs. The southern massifs are closer to the Sea of Okhotsk and therefore more influenced by the Okhotsk air mass than the northern massifs, and its glaciers are retreating faster (Takahashi et al., 2011). We selected four glaciers: Glaciers No. 31, 29, 32, and 33, for this study in the central massifs. The field investigations were carried out on these glaciers from July 2 to September 3 in 2012, from July 29 to August 24 in 2013, and from July 30 to August 10 in 2014. We accessed this area by a helicopter in 2012 and 2013 and by an off-road vehicle in 2014 from the city of Yakutsk, located approximately 500 km west of the region. On the way to the area, several forest fires were observed, as were many longicorn beetles, which may have been burnt out from the forests and were observed on glaciers in 2012 and 2013.

The mass balance of Glacier No. 31 has been monitored since the 1950s. The first glaciological and meteorological observations on the glacier were conducted during the International Geophysical Year (IGY, 1957–58) by Russian researchers. Then, the glacier was resurveyed in 2001 and in 2004/2005 by Russian/Japanese joint research groups. According to these studies, this glacier retreated by approximately 200 m in length from 1959 to 2001 (Yamada et al., 2002). Snow fall mainly occurs from April to September. The equilibrium line was located at approximately 2300 m a.s.l. in 2009 (Takahashi et al., 2011).

Glaciers No. 31, 29, and 32 face the northwest, with areas of 3.20, 4.05, and 4.25 km^2 and lengths of 3.85, 4.50, and 4.90 km, respectively. Glacier No. 33 faces southeast, with an area of 2.00 km^2 and a length of 2.30 km (Koreisha, 1963). The highest peak in this area is approximately 2960 m a.s.l. All of the glaciers terminated at approximately 2030 m a.s.l. The surfaces of the glaciers were mostly debris-free bare ice or snow. Dark-colored cryoconite was observed in cryoconite holes and on the bare ice surface of the glaciers, and it appeared to be more abundant in the middle part of the glaciers. Sections of red colored snow and ice were also observed in the middle parts of Glacier No. 29 (around 2370 m a.s.l.) and No. 31 (around 2390 m a.s.l.).

Collections of surface ice or snow were carried out at a total of 20 sites on the four glaciers. We collected samples at six sites ranging in altitude from 2120 to 2540 m a.s.l. (A1–A6: Fig. 1). on Glacier No. 31; five sites on Glacier No. 29 (B1–B5 from 2100 to 2509 m a.s.l.), four sites on Glacier No. 32 (C1–C4 from 2184 to 2463 m a.s.l.), and five sites on Glacier No. 33 (D1–D5 from 2325 to 2496 m a.s.l.). The sites where we collected samples in each year are listed in Table 1. When we collected samples, the snow line in 2012 was located between A5 and A6, B4 and B5, and D4 and D5, and above C4 on Glaciers No. 31, 29, 33, and 32, respectively, while it was located above all of the study sites in 2013 and 2014. In order to know whether snow and ice algae can survive the winter under the snow cover, we collected the ice surface below the snow cover at the upper snow site (D5 of Glacier No. 33) in 2012. The snow depth was 18 cm at the site.