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Snow algae community on a Himalayan glacier, Glacier AX010 East Nepal : Relationship with glacier summer mass balance

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Abstract

An altitudinal change of the snow algae communitis on a Himalayan glacier, Glacier AX010 (4950 -5380 m a.s.l.), Shorong region of East Nepal, was quantitatively analyzed to clarify the relationship between the glacier algal community and glacier summer mass balance. The results were compared with that of another Himalayan Clean Type glacier, Yala glacier (Yoshimura *et al.*, 1997).

In this glacier, 5 species of snow algae including 4 species reported from Yala glacier were observed. In both glacier, the algal biomasses were in a similar level at the same altitude and decreased as the altitude increase at a similar rate.

The structure of algal community represented by the proportion of each species to the total algal biomass differed by altitude and summer mass balance estimated by stake measurement. The algal community on this glacier could be divided into the following two types : Type 1 community with 5 species highly dominated by *C. brĕbissonii* observed in the minus mass balance area from terminus to 5180 m a.s.l. and Type 2 community with 4 species dominated by the Oscillatoriacean alga observed in the plus mass balance area above 5200 m a.s.l. In community structure, Type 1 and Type 2 community corresponded to the community observed in the lower part (5100-5200 m a.s.l.) and the middle part (5200-5300 m a.s.l.) of Yala glacier, respectively. Relationship between snow algal community and summer mass balance was discussed. The results suggest that the snow algal community could be useful as an indicator of summer mass balance and equilibrium line of this type of glaciers.

1. Introduction

Though snow algae have been reported from various parts of the world and many reports were published (Kol, 1968), we still have few reports from Himalayan glaciers. However, in a Himalayan glacier (the Yala Glacier in Langtang region, Central Nepal), Kohshima (1984a, 1984b, 1987a, 1987b) found a specialized animal community consisting of cold-tolerant insects and copepods living on the glacier by feeding on algae and bacteria growing in the snow and ice ; he pointed out that the glacier is a unique freshwater ecosystem with very simple and specialized biotic community on the basis of the primary production of these algae. The study of snow algae on the glacier is important not only ecologically but also glaciologically. Snow algae on Yala glacier were also reported to play an important role in melting process of the glacier ; they accelerated glacier melting and affected glacial mass balance by forming dark-colored materials on the glacier and reducing surface albedo (Kohshima *et al.*, 1993). Moreover, as these algae were stored in glacial strata every year and ice core samples recovered from this glacier contained many layers with algae of many years ago ; the algae could be a new information source for the past environment study of this area by ice core analysis (Kohshima, 1984b). Since it is easy to sample and analyze the algae on glaciers, the algal information would be useful to the glacier studies in this region.

Recently, Yoshimura *et al.* (1997) showed that the biomass and community structure of the snow algae on Yala glacier changed with altitude reflecting altitudinal change of the algal growth conditions on the glacier. They indicated that the glacier could be divided into three zones with different types of algal community : the Lower Zone (5100-5200 m a.s.l.), the Middle Zone (5200-5300 m a.s.l.) and the Upper Zone (5300-5430 m a.s.l.), and discussed that this altitudinal zonation of snow algal community was mainly due to the difference in the effect of snow cover. Since the thickness and frequency of the snow cover on the glacier closely correlate with the mass balance at that site, their results suggest a close relationship between the snow algal community and the glacier mass balance at that point during the algal growth period (summer). However, the relationship is still unclear because our knowledge on snow algal community of Himalayan glacier is limited to that from the Yala glacier.

In this study, we made community analysis of snow algae and mass balance measurement on another Himalayan glacier in Shorong region of East Nepal, to verify the relationship between glacier algal community and summer mass balance.

2. Field description and methods

2.1. Study area

The research was carried out at the Glacier AX010 (4950-5380 m a.s.l.) in Shorong region of East Nepal (Figs. 1 and 2) during the monsoon season of 1995. Glacier AX010 is a small glacier (1.7 km in length and 0.57 km² in area) without debris cover. According to the classification of Himalayan glacier by Moribayashi and Higuchi (1977), both this glacier and Yala glacier are "Clean type glacier" (debris free type). Recently (1978-1991) the glacier has reduced 3×10^6 m³ in volume (Kadota *et al.*, 1993, Kadota *et al.*, 1997).

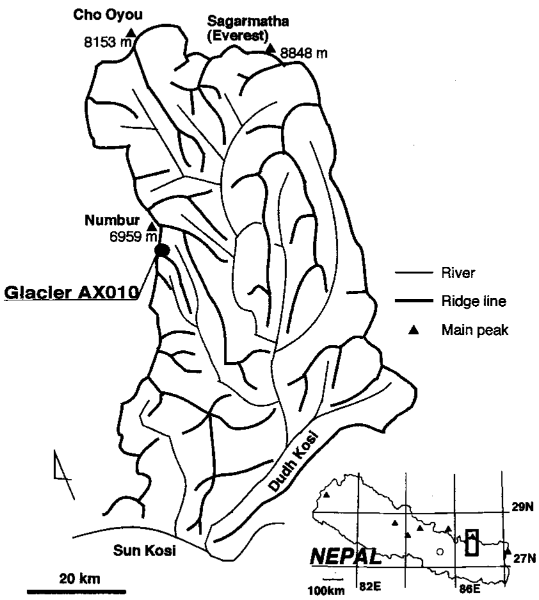

Fig. 1. Location of Glacier AX010 and Shorong region in East Nepal.

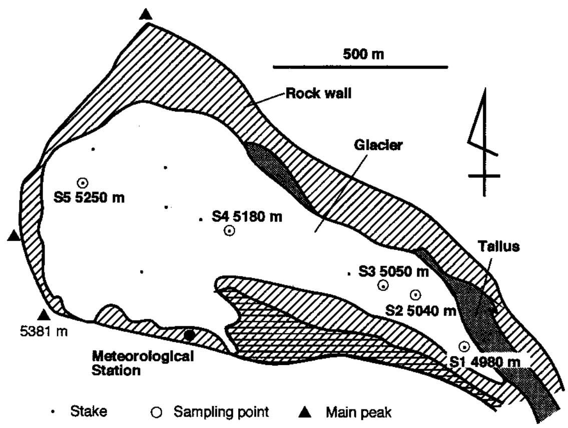

Fig. 2. A map of Glacier AX010 showing the locations of sampling points on the glacier October 1995. Dots show the locations of the stakes for mass balance study.

2.2. Sampling of the algae

A quantitative sampling of snow and ice containing snow algae was carried out at five points on the glacier (4980, 5040, 5050, 5180 and 5250 m a.s.l. respectively, S1-S5 in Fig. 2) from 3 to 7 October 1995. Since, all area of the glacier was covered with new snow during the sampling period, the surface ice with dirt (20 cm square, 2 cm in thickness) under the snow cover (30-40 cm in depth) was collected with an ice axe, and at S5 uppermost dirt snow layers (74 cm beneath the surface) were collected with a spoon. In this sampling, the area of sampled plots was measured in order to calculate the cell number per unit area. Collected samples were melted and kept in 100-mL clean polyethylene bottles and preserved as 3 % formalin solution. All the samples were transported to Japan and analyzed at the laboratory of Tokyo Institute of Technology.

2.3. Analysis of algae

In this study, the algal biomass of each sampling point was represented by the total algal volume per unit area. Cell counts and estimations of cell volume were carried out with a microscope (NIKON OPTIPHOT 2). In observation of small sized blue-green algae (1-3 μm in length) a florescence microscope was used. These small algae were only detected with florescence of chlorophyll in the florescence microscopy. Before microscopic observation, the samples were stained with 0.5 % erythrosin (0.5 mL was added to 1 mL of the sample) and ultrasonicated for 1 min. to loosen sedimented particles. Small amount of the processed sample water (2-5 microliters) was mounted on a glass microslide under a coverslip (8 X 8 mm), and the number of algae was counted. The algal density was calculated as "Cells mL^{-1} and Cells m^{-2}". Mean cell volume was estimated by measuring the size of 50-100 cells for each species at each sampling point. The total algal biomass (mL m^{-2}) was estimated to sum up each algal volume which was calculated to multiply the mean cell volume (mL) by the algal density (Cells m^{-2}). Community structure was represented by the proportion of each species to the total algal volume at each sampling point.

2.4. Mass balance measurement and estimation of ablation

Mass balance of the glacier was obtained by the stake measurement during the period from June to October, 1995. Eleven stakes were installed on the glacier at various elevations from 4980 to 5250 m a.s.l. Mass balance in water equivalent (w.e.) was estimated from the surface level change and snow or ice densities. It is assumed that the density of ice for the stakes below 5080 m a.s.l. is 870 kg m^{-3} and the density of snow for the stakes above 5080 m a.s.l. is 500 kg m^{-3}, respectively.

Ablation at each stake is estimated by the following equation which is derived from the observation on this glacier during the monsoon season of 1978 (Ageta *et al.*, 1980) ;

$$a = -1.5(T_a + 3.0)^{3.2} \qquad (1)$$

where T_a and a are an daily mean air temperature averaged for 15 days and a specific ablation during the same period. Data of air temperature used for this study was recorded at the meteorological station besides the glacier (5247 m a.s.l. ; Fig. 2) from 21 June to 3 October, 1995. Air temperature at each study site is estimated using the lapse rate of 0.006 ℃ m^{-1}, which was obtained by the field research in 1978 (Ageta *et al.*, 1980). Accumulation at each study site is obtained from the observed mass balance and the estimated ablation.

3. Results

3.1. Snow and ice algae observed on Glacier AX010

The following five species were observed (Fig. 3).

As all these species except the Chrococcacean alga were reported from Yala glacier, see Yoshimura *et al.* (1997) for precise description of these species.

List of algal species

CHLOROPHYTA

Cylindrocystis brēbissonii (31-53 μm in , 25-34 μm in width)

Mesotaenium berggrenii (15-21 μm in length, 6-12 μm in width)

Trochiscia sp. (9-18 μm in diameter)

CYANOPHYCEAE

Oscillatoriacean alga

Trichomes 1.0-1.5 μm in width, 1.5-2.0 μm in length. Cells about as long as broad. It seemed to be the same species described as Oscillatoriacean alga 1 in Yoshimura *et al.* (1997).

Chroococcacean alga (1.5-3.0 μm in diameter)

This alga could be observed only by florescence microscopy.

Some animals were also observed in this glacier. The red colored copepods (*Glaciella yalensis*) which have been reported in the Yala glacier (Kikuchi 1994) were trapped with a small net at the melt water stream at 5100 m a.s.l. Rotifers were observed in the dirt samples from the glacier surface. However the midge (*Diamesa kohshimai*) which has been reported in Yala glacier (Kohshima, 1984a) was not observed in this glacier.

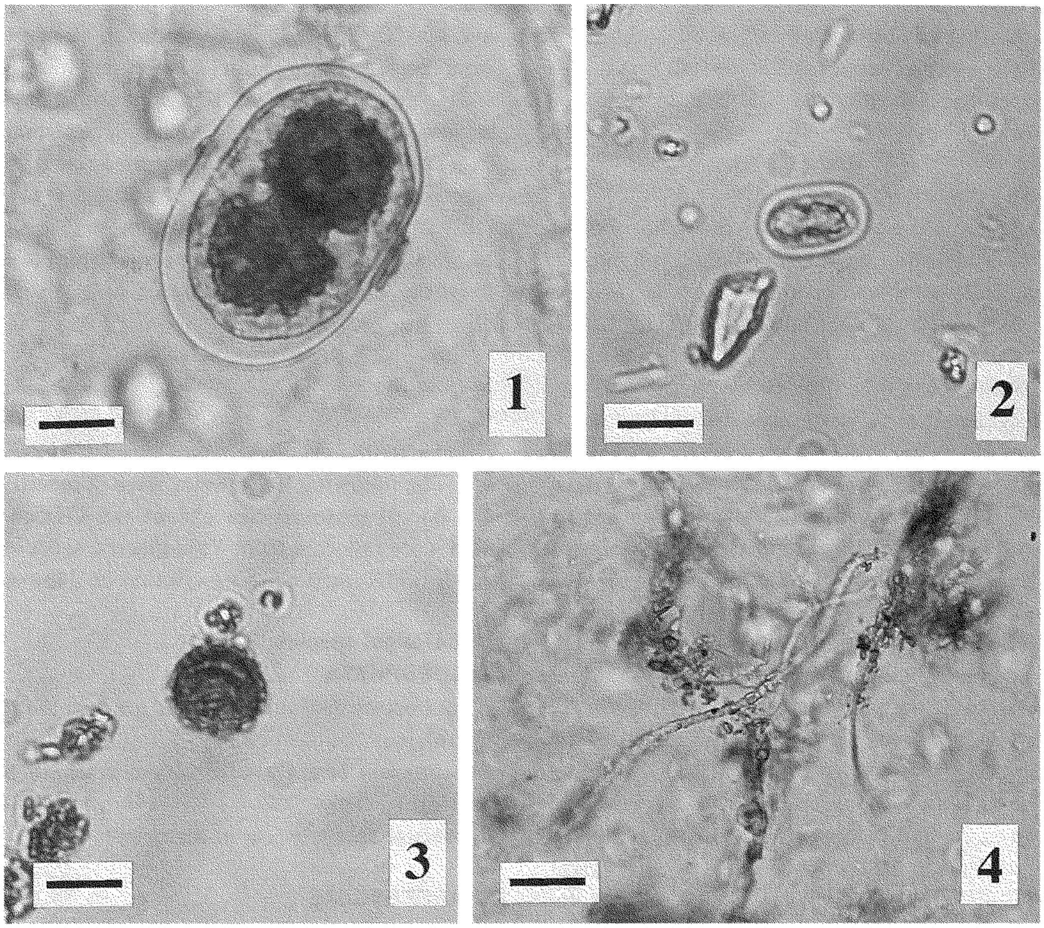

Fig. 3. Snow algae in Glacier AX010. 1 : *Cylindrocystis brěbissonii*, 2 : *Mesotaenium berggrenii*, 3 : *Trochiscia* sp., 4 : Oscillatoriacean alga. Scale bars = 10 μm.

3.2. Distribution range of each species

Figure 4 shows the distribution range of each algal species. *C. brěbissonii* only distributed in the area lower than 5200 m a.s.l. and very common in the lower part. Though other 4 species were observed at all sampling points, the Oscillatoriacean alga was very common especially in the area lower than 5200. These results well agreed with the reported distribution range of these species on Yala glacier (Yoshimura *et al*., 1997) excepting the fact that *Trochiscia* sp. was observed even in the area lower than 5200 m a.s.l. in this glacier.

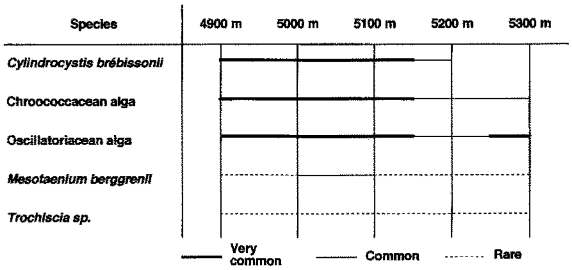

Fig. 4. Algal distribution range and relative frequency of occurrence on the glacier.

Table 1. List of collected samples, algal cell density, and algal biomass

Sample	Date	Sampling point	Altitude (m)	Sampling area (cm^2)	Condition	Cell density (10^3 cells mL^{-1})	Algal biomass (10^{-3} mL m^{-2})
1	8-Oct	S1	4980	100	Blackish cryoconite on Ice, 16 cm below surface	23082	2256
2	8-Oct	S2	5040	100	Blackish cryoconite on Ice, 23 cm below surface	7121	1288
3	8-Oct	S3	5050	156	Blackish cryoconite on Ice, 25 cm below surface	11943	1412
4	10-Oct	S4	5180	100	Blackish cryoconite on Ice, 39 cm below surface	2822	74
5	10-Oct	S5	5250	140	Blackish dirty snow, 74 cm below surface	5056	78

3.3. Biomass

Table 1 shows population sizes in cells per milliliter in each sample water and the algal biomass at each sampling point in milliliter per square meter. Figure 5 shows the change of algal biomass with altitude on this glacier. The data of Yala glacier (Yoshimura *et al.*, 1997) are also plotted in the same figure. The figure shows that, on both glaciers, the algal biomasses rapidly decreased in a similar rate as the altitude increased, and the algal biomasses at the same altitude were in a similar level.

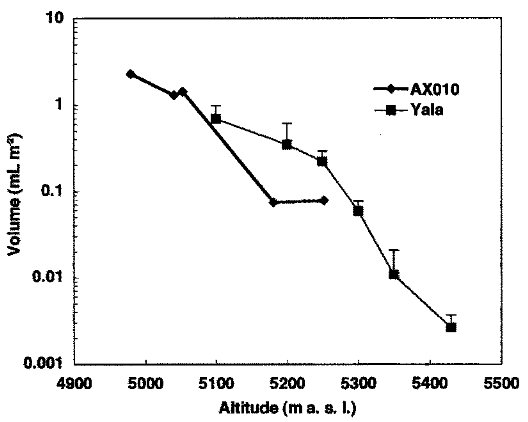

Fig. 5. Altitudinal change of algal biomass (mL m^{-2}) estimated by measuring the total algal volume.

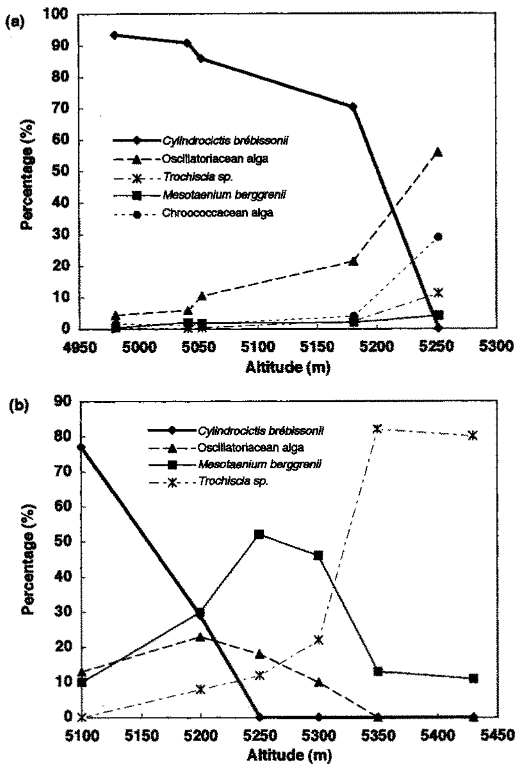

Fig. 6. Altitudinal change of community structure which was represented by the proportion of each algae to the total algal biomass (a) AX010 (b) Yala glacier (modified after Yoshimura *et al.*, 1997).

3.4. Altitudinal change of community structure

Figure 6 shows the attitudinal change of community structure which was expressed by the proportion of each species to the total algal biomass. The structure of the algal community gradually changed with altitude. For example, as the altitude increased, the ratio of *C. brēbissonii*. decreased and those of other 4 species increased.

The algal community on this glacier could be categorized into following two types :

Type 1 : the community observed at the area lower than 5200 m a.s.l. (S1–S4) that consists of 5 algal species dominated by *C. brēbissonii*. In this type, the ratio of the most dominant species (*C. brēbissonii*.) to the total algal biomass was very high (70–93 %). The Oscillatoriacean alga was the secondary dominant species (4–21 %). Rates of other 3 species were very little.

Type 2 : the community observed at the highest sampling point (S5, 5250 m a.s.l.) that consists of 4 algal species dominated by the Oscillatoriacean alga. In this type, the ratio of the most dominant species (the Oscillatoriacean alga) to the total algal biomass was not so high (56 %) and the subdominant species accounted for relatively higher percentage (Chroococcacean alga : 23 %, *Trochiscia* sp. : 11 % and *M. berggrenii* : 4 %) compared with Type 1 community. *C. brēbissonii.*, the most dominant species in Type 1 community was not observed.

3.5. Mass balance

Figure 7 shows the altitudinal distribution of the observed mass balance, the estimated ablation and accumulation during the period from June to October, 1995. The figure shows that the equilibrium line altitude during the study period was around 5230 m a.s.l. It was located between S4 and S5. Thereby the sampling points below 5230 m a.s.l. was located in the ablation zone, and only the highest sampling point (S5, 5250 m a.s.l.) was in the accumulation zone. The ablation, which is related with the meltwater supply for algae, was high at all site during the study period. Meltwater, which is 2035 mm w.e. at the lowest point, decreases to 645 mm w.e. at the highest point. Accumulation, which would be zero below 5040 m a.s.l., increases to 853 mm w.e. at the highest point (5250 m a.s.l.).

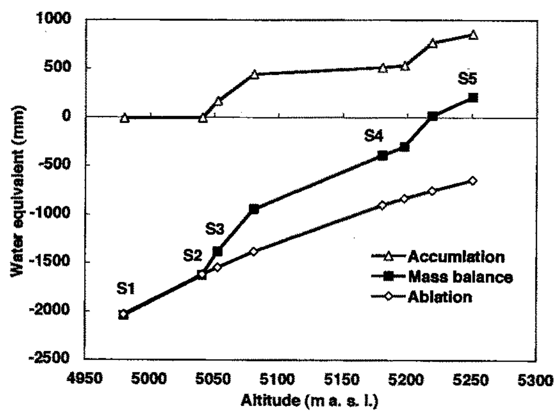

Fig. 7. Results of mass balance measurement of AX010 from June to October 1995 and the calculated accumulation and ablation.

4. Discussion

4.1. Algal flora on the Himalayan clean type glaciers

Out of 5 algal species observed in this study, 4 species (*C. brēbissonii*, *M. berggrenii*, *Trochiscia* sp. and Oscillatoriacean alga) were also reported from Yala glacier in Central Nepal (Yoshimura *et al.*, 1997). Though we still have a few information on the snow algal flora of the Himalayan glaciers, distribution of these identical species on the two glaciers in different regions suggests that they are the main member of the algal community characteristic to the Himalayan Clean Type glaciers.

4.2. Altitudinal change of algal biomass

As figure 5 shows, in both Glacier AX010 and Yala glacier, the algal biomasses rapidly decreased in a similar rate as the altitude increased, and the algal biomasses at the same altitude were in a similar level. This suggests that on both glaciers algal biomasses were controlled by the same environmental conditions. Yoshimura *et al.*, (1997) analyzed relationship between algal biomass and environmental conditions on Yala glacier and suggested that the algal biomass was mainly limited by the amount of snow cover at each altitude during summer, because light intensity available for the algal growth mainly depends on thickness and frequency of snow cover on algal habitat.

4.3. Algal community and glacier summer mass balance

Altitudinal distribution of the two types of snow algal community on Glacier AX010 corresponded to that of the mass balance during the study period (Fig. 6a and Fig. 7) ; Type 1 community was observed in the minus mass balance area (ablation zone, S1 – S4) and Type 2 community was observed in the plus mass balance area (accumulation zone, S5). The result suggests that the snow algal community was affected by the mass balance at that site.

In the study of another Himalayan Clean Type glacier (Yala glacier, Langtang region in Central Nepal), Yoshimura *et al.*, (1997) divided the glacier into three zones from the difference of the algal community (Fig. 6b) : the Lower Zone (5100–5200 m a.s.l.) with seven species dominated by *C. brēbissonii*, the Middle Zone (5200–5300 m a.s.l.) with eleven species dominated by *M. berggrenii*, and the Upper Zone (5300–5430 m a.s.l.) with four species dominated by *Trochis-*

cia sp. They reported that the most dominant species occupied the most part of the algal biomass (77-83 %) in the Lower Zone and the Upper Zone, but in the Middle Zone, the percentage of the most dominant species was not so high (30-50%) and the subdominant species accounted for relatively higher percentage.

When we compared the algal communities on both glacier (Fig. 6), Type 1 community of Glacier AX010 highly dominated by *C. brêbissonii*. clearly corresponds to the community observed in the Lower Zone of Yala glacier, and Type 2 community seemed to correspond to the community observed in the Middle Zone ; because the second dominant species in the Middle Zone of Yala glacier (the Oscillatoriacean alga 1) was the most dominant species in Type 2 community, and in both community types, the subdominant species accounted for relatively higher percentage. In Glacier AX010, however, the community that corresponds to the community observed in the Upper Zone of Yala glacier was not observed.

Yoshimura *et al.* (1997) analyzed relationship between snow algal community and environmental conditions on the glacier and suggested that this vertical zonation of the algal community type reflects the difference in summer climatic conditions with altitude, especially thickness and frequency of the snow cover on algal habitat because it drastically changes the algal growth conditions. Since the thickness and frequency of the snow cover on the glacier closely correlate with the mass balance at that point, their results also suggest the close relationship between the snow algal community and the glacier summer mass balance.

They pointed out that the algal habitats on the glacier can be divided into two types with different conditions ; "ice-environment" with ice substrate, much and stable meltwater, a long growth period, strong radiation, and relatively rich nutrient, and "snow-environment" with snow substrate, less and unstable meltwater, a short growth period, weak radiation, and relatively poor nutrients. The ice-environment and snow-environment corresponded to the Lower Zone and the Upper Zone, respectively. The Middle Zone is an unstable transition area between these two environments, in which the two types of conditions exchanged frequently. They discussed that in the stable snow-environment of the Upper Zone, a snow-environment specialist (*Trochiscia* sp.) becomes dominant in competition with generalist species that moderately competitive both in snow and ice, but in the stable ice-environment of the Lower Zone, an ice-environment specialist (*C. brêbissonii*) becomes dominant, and in the unstable condition of Middle Zone, generalist species (*M. berggrenii*) becomes dominant and opportunist species temporally survive. They explained the largest species number and the high percentage of subdominant species in the Middle Zone by the "intermediate disturbance hypothesis" (Connell, 1978) that the highest diversity is maintained at intermediate levels of disturbance. They discussed that unstable condition of the Middle Zone prevents specialists from excluding other species.

Our results on altitudinal distribution pattern of each species (Figs. 4 and 6) support their view that *C. brêbissonii* is an ice-environment specialist, *Trochiscia* sp. is a snow-environment specialist and *M. berggrenii*, is a generalist. Though *Trochiscia* sp., a snow-environment specialist only distributed in firn area above 5200 m in Yala glacier, was observed even in the area lower than 5200 m a.s.l. in Glacier AX010, it can be explained by the presence of the snow cover during the sampling period. The characteristics of Type 2 community also support their view about the altitudinal zonation of glacial algal community.

Thus our results suggest that in the Himalayan Clean Type glaciers, the community structure highly dominated by *C. brêbissonii* observed in Type 1 community of Glacier AX010 and Lower Zone community of Yala glacier is characteristic to the area with minus summer mass balance (ablation zone during the summer), and the community structure moderately dominated by generalist species (*M. berggrenii*, the Oscillatoriacean alga, etc.) with higher percentage of subdominant species observed in Type 2 community and the Middle Zone community is characteristic to the area near zero summer mass balance (around the equilibrium line during the summer). Increase of *Trochiscia* sp. at the highest sampling point on Glacier AX010 suggests that this species is a snow-environment specialist and the community structure highly dominated by this species observed in the Upper Zone of Yala glacier is characteristic to the area with plus summer mass balance (accumulation zone during the summer) in this type glaciers. These community types can be called "ablation zone type", "equilibrium zone type" and "accumulation zone type", respectively.

In Glacier AX010, the "accumulation zone type" algal community was not observed. This suggests that the mass balance was negative in almost all the area of Glacier AX010 during the algal growth period of this year. It well agreed with the result of the stake measurement (Fig. 7) and the report on the remarkable reduction of this glacier in the recent years (Kadota *et al*., 1993, Kadota *et al*., 1997) ; the terminus retreated 58 m and the thickness decreased 20-30 m. 3×10^6 m^3 in volume from 1978 to 1991.

4.4. Snow algae as an indicator of glacier summer mass balance

The results of this study and previous study (Yoshimura *et al*., 1997) suggested that the snow algal communities on the Himalayan Clean Type glaciers reflect the mass balance during the growth period at that site, and there are three types of algal community characteristic to the ablation zone, the accumulation zone and the area near the equilibrium line during the algal growth period, respectively. In other words, we can estimate the elevation of the equilibrium line during the summer by analyzing the altitudinal distribution of snow algal community on the glacier. Snow algal communities on this type of glacier can be a good indicator of summer mass balance and elevation of the equilibrium line.

Since sampling and analysis of the snow algae are easier than the usual mass balance survey that require at least two visits to the glacier for stake setting and remeasurments, the algal information would be useful to the glacier studies in this region.

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