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Snow Algae and Other Microbes in Several Alpine Areas in New England

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ABSTRACT

Snow algae and other microorganisms are reported from green and orange snowpacks from New England during spring 1992 and 1993. Sites sampled include Mt Katahdin and Sunday River Ski Area, Maine; Ashland, Hawley, Mt Greylock and Wachusett Mtn Ski Area, Massachusetts; Monadnock Mtn and Mt Washington, New Hampshire; and Jay Peak Ski Area, Killington Ski Area, Mt Mansfield and Stowe Ski Area, Vermont. Dominant snow algae belong to the green algal flagellate, *Chloromonas*. Other microbes include snow fungi, bacteria, ciliated protozoa, nematodes, rotifers and tardigrades. Laboratory cultures reveal several species of yellow-green algae and green algae not previously reported from snow in eastern North America. Two species of *Chloromonas* are newly discovered snow microbes, and one appears to be restricted to ski slopes. The distribution and diversity of snow microbes in eastern North America is greater than previously realized. New England isolates of *Chloromonas* will be used in laboratory studies to further our understanding of snow algal reproductive strategies and physiological ecology.

INTRODUCTION

On the North American continent, snow algae and other microorganisms have been reported mostly from western regions in alpine areas from northern Mexico to Alaska and from high latitudes in Alaska and Canada (Garric 1965, Kol 1968, Thomas 1972, Hoham and Blinn 1979, Wharton and Vinyard 1983, Hoham 1989). Prior to this report, snow microbes were known in eastern North America from the Laurentian Mountains, Québec; Mt Washington, New Hampshire; and the Adirondack Mountains, Tughill Plateau and Central New York Plateau, New York (Hoham 1987, Hoham *et al.* 1989). Duval (1993) gave a preliminary account on some of our 1992 sites from Maine, New Hampshire and Vermont.

At previous snow conferences, presentations have been given on the interactions between snow microbiology, physics and chemistry (Hoham 1987, 1989, Hoham *et al.* 1989, Hoham 1992). It is the intention here to present information on the distribution of snow microbes from several new sites in the alpine areas of New England. Future research in this region will attempt to correlate physical and chemical parameters with microbial activity.

MATERIALS AND METHODS

Surface snow and vertical cuts through melting snowpacks were examined for the presence of snow algae of concentrated population during April and May 1992 and 1993. Algae and other microorganisms were collected using scoops, knife blades or finger-tips inserted in inverted sterile Whirl-pak bags. These samples were transferred to sterile Whirl-pak bags that were stored in a cooler packed with snow to keep all samples at 0°C for transport to the laboratory.

Elevations of the collections were determined using U.S. Geological Topographical Maps. Microbes were identified in the laboratory using Zeiss phase-contrast microscopy. Maximum microbe populations were tabulated in cells ml^{-1} with hemacytometers according to Guillard (1973) at the 95% confidence level with 400 cells counted for ±10% accuracy. Conductivity was measured in samples at 4°C in the laboratory with the Hach Mini conductivity meter, model 17250, Cole-Parmer field conductivity meter, model 1481-50, and the Markson bench top ElectroMark Analyzer.

Samples were streaked onto M-1 agar plates (Hoham *et al.* 1979) using sterile technique in a Lab-Conco laminar flow chamber situated in a dust-free room. Cultures were examined for identifications and routinely subcultured for obtaining bacteria-free strains of algae for future research in mating experiments and physiological ecology. All isolates are maintained at 4°C in a Percival CTR-66 walk-in growth chamber equipped with enamel shelving, GE 40W plant-aquarium fluorescent lamps, GE 7.5W clear indicator incandescent bulbs, a photoperiod of 16 h light:8 h dark, and an irradiation level of 40-50 μEm^{-2} sec^{-1}.

RESULTS

Snow algae and other microorganisms were found on Mt Katahdin and Sunday River Ski Area, Maine; Ashland, Hawley, Mt Greylock and Wachusett Mtn Ski Area, Massachusetts; Monadnock Mtn and Mt Washington, New Hampshire; and Jay Peak Ski Area, Killington Ski Area, Mt Mansfield and Stowe Ski Area, Vermont. Elevations of collections and maximum populations of snow algae were recorded from these sites (Fig. 1; Table 1).

Collections containing microbes were made from

Table 1. 1992-1993 Collection data of snow microbes from New England and previously known sites from region.

New England site	*Elevation [meters (feet)]*	*Maximum snow algal population (cells ml^{-1})*
MAINE:		
1) Mt Katahdin	1130-1160 (3700-3800)	4.30×10^4
2) Sunday River Ski Area	550 (1800)	not determined
MASSACHUSETTS:		
1) Ashland (Berkshire Hills)	500 (1650)	2.40×10^5
2) Hawley (Berkshire Hills)	550 (1800)	3.90×10^4
3) Mt Greylock	915- 945 (3000-3100)	3.02×10^5
4) Wachusett Mtn Ski Area	490- 565 (1600-1850)	8.61×10^5
NEW HAMPSHIRE:		
1) Monadnock Mtn	825 (2700)	not determined
2) Mt Washington	1160-1175 (3800-3850)	5.50×10^4
VERMONT:		
1) Jay Peak Ski Area	825-1010 (2700-3300)	1.21×10^5
2) Killington Ski Area	1070 (3500)	8.50×10^4
3) Mt Mansfield	1130-1160 (3700-3800)	1.31×10^5
4) Stowe Ski Area	640- 760 (2100-2500)	9.20×10^4
Previously known sites from region		
NEW YORK:		
1) Georgetown, E. Hill Ravine	580 (1900)	not determined
2) Marble Mtn	1140 (3750)	not determined
3) Mt Marcy	960-1100 (3150-3600)	not determined
4) Whetstone Gulf State Park	380 (1250)	not determined
5) Whiteface Mtn	1175-1340 (3850-4400)	2.73×10^5
QUÉBEC:		
1) Laurentian Mtns:		
a) Lac À ĹEpaule region	620- 630 (2030-2070)	not determined
b) Lac LaFlamme region	770- 780 (2530-2570)	2.13×10^5

490 m at Wachusett Mtn Ski Area to 1175 m at Mt Washington, and the maximum population of algae found was 8.61 X 10^5 cells ml^{-1} at Wachusett Mtn Ski Area.

The microbes found in this study included algae, fungi, bacteria, protozoa and small invertebrates from field collections; the green alga, *Chloromonas*, was the dominant algal microbe (Table 2). *Chloromonas* sp.-A, an unnamed asexual species, was found in 9 of the 12 sites coloring the snow green (Fig. 2), *C. brevispina* in 4 of the 12 sites causing green to orange snow (Fig. 3), and two new species designated as *Chloromonas* sp.-B and *Chloromonas* sp.-C were found in 5 sites (Fig. 4). *Chloromonas* sp.-A was found at all sites except Sunday River Ski Area, Mt Greylock, and Stowe Ski Area. *Chloromonas brevispina* was found at Mt Katahdin, Mt Washington, Jay Peak Ski Area and Mt Mansfield. *Chloromonas* sp.-B was found in 4 sites coloring the snow salmon-orange on ski slopes (Sunday River Ski Area, Wachusett Mtn Ski Area, Killington and Stowe Ski Areas), and *Chloromonas* sp.-C was found only on Mt Greylock, also coloring the snow salmon-orange. The golden alga, *Chromulina chionophilia*, was found only at Wachusett Mtn Ski Area (Fig. 5), and there was no coloration of snow caused by this alga. The snow fungi, *Chionaster nivalis* and *Selenotila nivalis*, were found together on surface snow at 4 of the 12 sites (Mt Washington, Jay Peak Ski Area, Mt Mansfield, and Stowe Ski Area), and *Selenotila nivalis* was located at a 5th site, Wachusett Mtn Ski Area (Fig. 6). Other fungi included yeasts, flagellates and filamentous forms. Bacteria, protozoa (amoebae, ciliates and flagellates) and small invertebrates (nematodes, rotifers and tardigrades) were also collected in snow. Amoebae, ciliates, rotifers and tardigrades were observed feeding on the snow algae. Bacterial types were not determined or quantified.

Several algae appeared in laboratory cultures that were not seen in field collections. These included green algae (*Apatococcus* from tree bark, *Chodatia tetralantoidea*, a rare snow alga, *Klebsormidium* from soil or streams, *Stichococcus* spp. from air or soil, and *Trebouxia* spp. from lichens) and yellow-green algae (*Monodus* and *Chlorocloster* from air or soil) (Table 2).

In Table 3, two simple communities are presented. The one from Mt Washington, New Hampshire, shows populations sizes of two snow algae and a

Table 2. List of microbes from collection sites in New England and region.

1) *Chionaster nivalis*, snow fungus, (NH, NY, Qu, Vt)
2) *Chloromonas brevispina*, green alga, (Me, NH, NY, Qu, Vt)
3) *Chloromonas* sp.-A, green alga, (Me, Ma, NH, NY, Qu, Vt)
4) *Chloromonas* spp. (PREVIOUSLY UNKNOWN GREEN ALGAL MICROBES)
    a) *Chloromonas* sp.-B, from ski slopes only, (Ma, Me, Vt)
    b) *Chloromonas* sp.-C, Mt Greylock only, (Ma)
    c) *Chloromonas* sp.-D, Whetstone Gulf St. Pk. only, (NY)
    d) *Chloromonas* sp.-E, Georgetown Hill Ravine only, (NY)
5) *Chromulina chionophilia*, golden alga, (Ma, NY)
6) *Notosolenus*, colorless euglenoid, (NY, Qu)
7) *Selenotila nivalis*, snow fungus, (MA, NH, NY, Qu, Vt)
8) Other microbes and small forms from original collections:
    a) bacteria (types not determined)
    b) fungi (filamentous forms, flagellates, yeasts)
    c) protozoa (amoebae, ciliates, flagellates)
    d) small invertebrates (nematodes, rotifers, tardigrades)
    e) other invertebrates (insects, arachnids)
9) Other algae from laboratory cultures:
    a) *Apatococcus* (green alga from tree bark)
    b) *Chodatia tetralantoidea* (rare green snow alga)
    c) *Klebsormidium*, (green alga from soil)
    d) *Monodus/Chlorocloster* spp. (yellow-green algae from air/soil)
    e) *Stichococcus* spp. (green algae from air/soil)
    f) *Trebouxia* spp. (green algae from lichens)

snow fungus, and the second community from Stowe Ski Area, Vermont, shows a snow alga, snow fungus, and a ciliated protozoan. In both communities, the conductivity readings were lower in samples containing microbes than in adjacent control samples without microbes. The number of bacteria were too difficult to determine because particulates in all samples made it impossible to clearly view the bacteria.

DISCUSSION

At the time of active growth, snow microbes occupy extreme conditions of low temperature, high acidity, high irradiation levels and minimal nutrients, and they are subjected to drought after the snowpack has melted (Hoham 1992). Similar extremes were reported from cryoconite holes on glaciers (Wharton *et al.* 1985). It is because of this extreme environment and the possibility that similar environments may exist on the planet Mars (or have existed in the past) that snow and ice microbes are one of four life systems on Earth being considered by NASA as analogs for life on early and present day Mars (Wharton *et al.* 1989, Rothschild 1990).

The algae appear in the snow from the germination of resting spores at the snow-soil interface during the time of snow melt (Hoham 1980, Jones 1991, Hoham 1992). Changes in the phases of life cycles of several snow algae appear to be related to nitrogen depletion (Czygan 1970, Hoham *et al.* 1989, Jones 1991, Hoham 1992, Bidigare *et al.* 1993), and there is a correlation between nitrogen depletion and photoprotection in some species (Czygan 1970, Hoham 1992, Bidigare *et al.* 1993). Nutrient depletion by snow algae may be correlated with a drop in conductivity readings (Table 3), and similar correlations were reported in snow from the Adirondack Mtns, New York, and Laurentian Mtns, Québec (Hoham *et al.* 1989).

Distributions of snow algae and other microbes

This is the first extensive report on snow algae in

Table 3. Snow community structure.

Snow microbe collection 662, Mt Washington, New Hampshire (25 May 1992)

Microbe	*Population (cells ml^{-1})*
1) *Chloromonas brevispina* (snow alga)	4.48 X 10^4
2) *Chloromonas* sp.-A (snow alga)	1.01 X 10^4
3) *Selenotila nivalis* (snow fungus)	1.10 X 10^2

Collection Number	*Conductivity (µmhos cm^{-1} @ 4°C)*
662 (sample with microbes)	10.6
664 (control)	33.0

Snow microbe collection 648, Stowe ski area, Vermont (16 May 1992)

Microbe	*Population (cells ml^{-1})*
1) *Chloromonas* sp.-B (new ski slope snow alga)	9.19 X 10^4
2) *Chionaster nivalis* (snow fungus)	5.99 X 10^4
3) ciliated protozoa	1.80 X 10^3

Collection Number	*Conductivity (µmhos cm^{-1} @ 4°C)*
646 (control)	11.1
647 (control)	21.5
648 (sample with microbes)	6.0

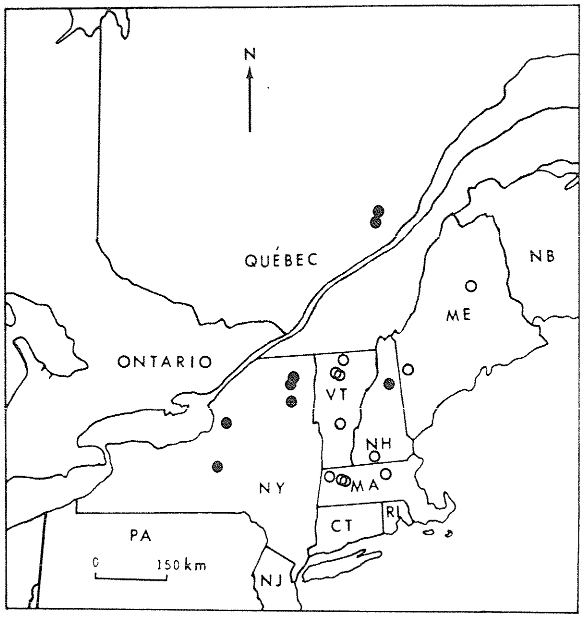

Figure 1. Snow microbes: new distribution sites in New England (open circles) and previous sites from region (closed circles).

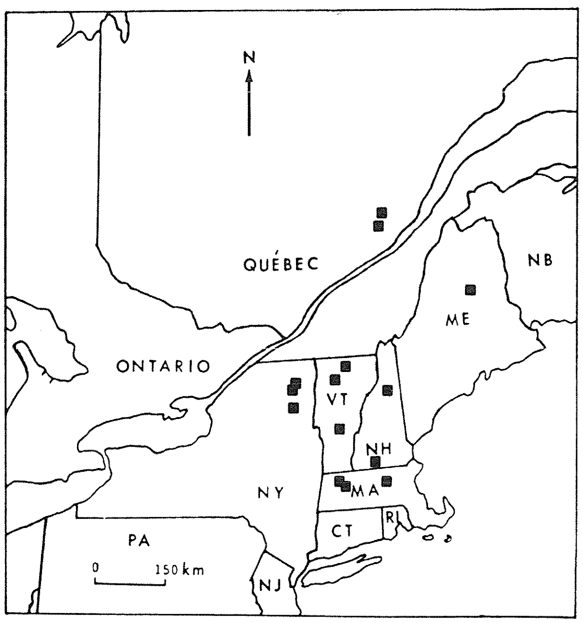

Figure 2. Distribution sites of **Chloromonas** *sp.-A in New England and surrounding region (closed squares).*

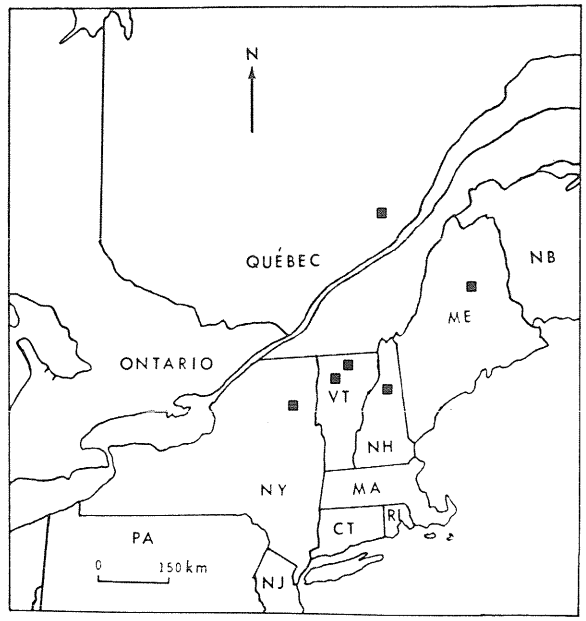

Figure 3. Distribution sites of **Chloromonas brevispina** *in New England and surrounding region (closed squares).*

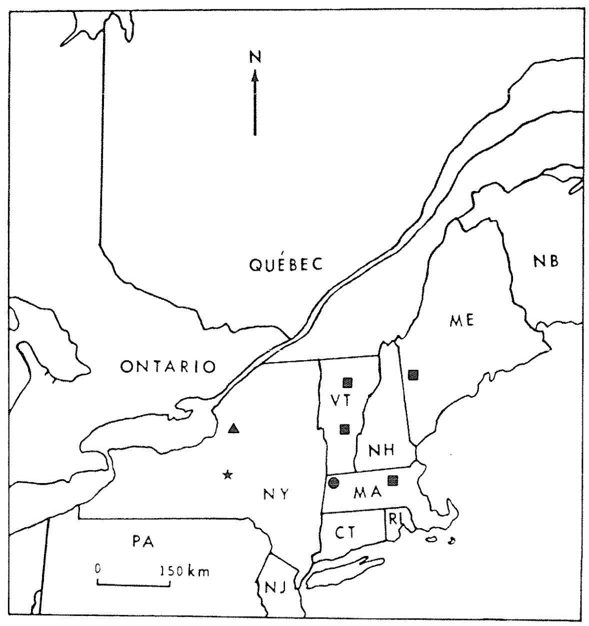

Figure 4. Distribution sites of new species of **Chloromonas** *in New England and surrounding region (***Chloromonas** *sp.-B, squares;* **Chloromonas** *sp.-C, circle;* **Chloromonas** *sp.-D, triangle;* **Chloromonas** *sp.-E, star).*

eastern North America, and prior accounts include those of Hoham 1987, Hoham *et al.* 1989 and Duval 1993 (Table 1, Figs 1-6). Snow algae are widely distributed on the North American continent including reports from the American Southwest (Hoham and Blinn 1979), northern Mexico and California (Thomas 1972), the Pacific Northwest of the U.S. (Garric 1965) and western U.S., Canada and Alaska (Kol 1968, Wharton and Vinyard 1983, Hoham 1989). Handfield *et al.* (1993) summarized

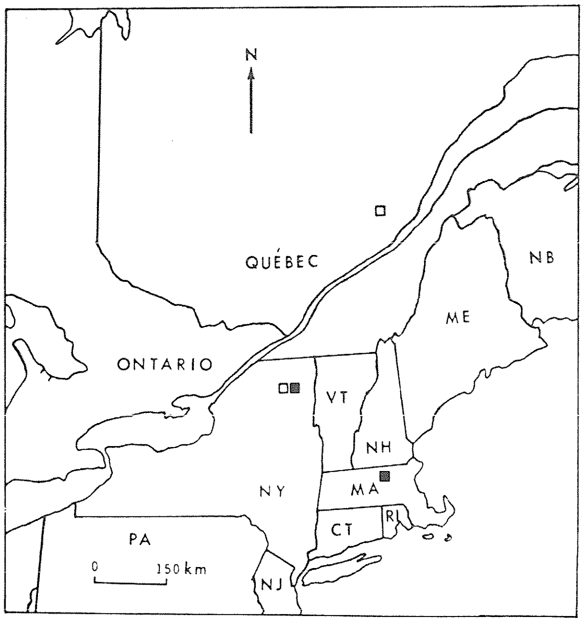

Figure 5. Distribution sites of **Chromulina chionophilia** *(closed squares) and* **Notosolenus** *(open squares) in New England and surrounding region.*

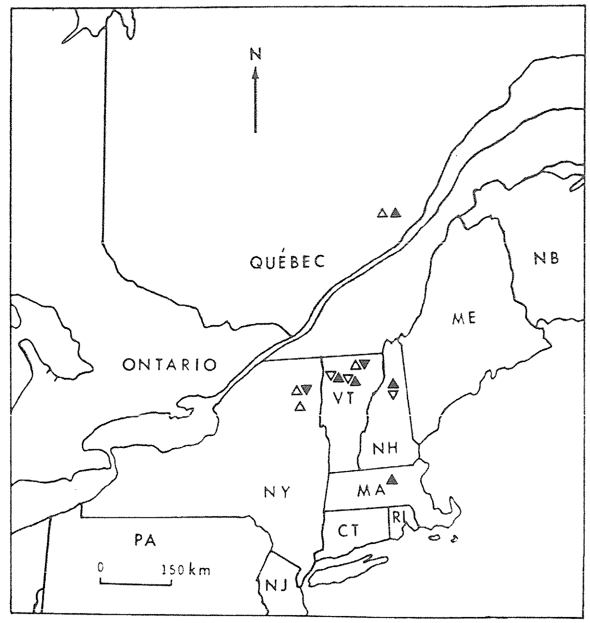

Figure 6. Distribution sites of **Chionaster nivalis** *(open triangles) and* **Selenotila nivalis** *(closed triangles) in New England and surrounding region.*

the microflora on Ellesmere Island, Canada, emphasizing the bacteria and fungi.

A variety of snow microbes are found in New England, New York and Québec snow (Table 2), but the most prominent ones are the green algae that belong to the Division Chlorophyta. In western North America, widely distributed red snow is caused by the green alga, *Chlamydomonas nivalis* (Hoham 1992); however, this species and red snow are absent from the sample sites reported here. Most green snow in this region is caused by the green alga, *Chloromonas* sp.-A, the most widely distributed snow algal microbe from New England and surrounding areas (Fig. 2). *Chloromonas* sp.-A will be discussed more extensively in a separate manuscript and a species name will be given to this taxon at that time. Some green snow may be attributed to *Chloromonas brevispina* (Fig. 3) and to *Chloromonas polyptera* which was absent from the New England sites and is known only from the Laurentian Mtns, Québec. These two species of *Chloromonas* are well distributed in western North American snowfields (Hoham *et al.* 1979, 1983) and from snow in other parts of the world (Kol 1968). Orange snow in this region is attributed to resting spores of the green algae, *C. brevispina* and two other species of *Chloromonas*, designated as *Chloromonas* sp.-B and *Chloromonas* sp.-C (Figs. 3-4). Species names cannot be given to these two new species until the biflagellate stage is isolated into culture for further study, and this applies to two additional new species of *Chloromonas* from New York, *Chloromonas* sp.-D and *Chloromonas* sp.-E (Fig. 4).

Most species of the snow alga, *Chloromonas*, are associated with the alpine and boreal forests. In this study, *Chloromonas* sp.-A and *C. brevispina* are associated with coniferous trees, and the latter species was found in similar habitats in western North America (Hoham *et al.* 1979). *Chloromonas* sp.-B is currently known only from manufactured snow on ski slopes. This *Chloromonas* inhabits snow with a greater snow density than is found for other species of *Chloromonas*, and it may or may not be associated with tree canopies. This species also has the maximum snow algal population of 8.61×10^5 cells ml^{-1} reported thus far from eastern North America at Wachusett Mtn Ski Area, Massachusetts (Table 1). It is suggested here that this species may be distributed from one ski slope to another on skis. Resting spores of this species have a gelatinous matrix to which other microbes such as bacteria and fungi adhere (It is not known if there is a symbiotic association between these microbes). This same jelly-like material would easily allow these cells to stick to skis and survive through the summer and autumn adhering to skis stored indoors at room temperature. During the next ski season, these cells could be removed when in contact with new snow and inoculate a new ski slope or similar area. Even though this hypothesis has not been tested, the explanation warrants serious consideration to explain its distribution on four disjunct ski slopes (Fig. 4). Additional samples in other ski areas and elsewhere may help resolve this question.

The golden alga, *Chromulina chionophilia*, was found only at Wachusett Mtn Ski Area in New England (Fig. 5), and it was reported previously from the region at Whiteface Mtn, New York (Hoham 1987, Hoham *et al.* 1989). This alga is usually associated with coniferous trees (Hoham and Blinn 1979), but this does not appear to be the case at Wachusett Mtn, Massachusetts. Since Wachusett Mtn supported the maximum population of snow algae found in this study (Table 1), and this was the only New England site with *Chromulina*, the concentration of nutrients in snow at Wachusett Mtn should be investigated and compared to other snow sites in the study area. The colorless euglenoid alga, *Notosolenus*, was not found in New England, but it is known from Whiteface Mtn, New York, and the Laurentian Mtns, Québec (Fig. 5) (Hoham *et al.* 1989). This heterotrophic alga was reported from snow in the American Southwest only under coniferous tree canopies (Hoham and Blinn 1979).

The snow fungi, *Chionaster* and *Selenotila*, were found in surface snow of residual snowbanks. These fungi do not appear to enter into any type of symbiotic associations with the algae, but probably receive their required external carbon from them (Hoham *et al.* 1989). These fungi are reported from several New England sites (Fig. 6), and *Chionaster* was reported previously from the Adirondack Mtns, N.Y., and from the Laurentian Mtns, Québec (Hoham *et al.* 1989). These are the first reports of *Selenotila* from eastern North America including those from outside of New England (Fig. 6), although Hoham (1989) reported previously that this fungus appeared to be absent from eastern North America.

Snow ecology and a food web

The interactions between the snow algae and the other microbes found in snow are parts of simple communities (Table 3). However, under certain situations, more complex food webs may occur that involve higher plants and animals in addition to the microbes (Snow Ecology Working Group Workshop, 1993, Québec City, unpubl.). Snow algae are consumed by protozoa (ciliates and amoebae), rotifers, tardigrades and insects (collembola). Insects such as collembola may feed on fungi, and arachnids (spiders) feed on the collembola and other insects (Aitchison 1989). Small subnivean mammals such as shrews feed on spiders (Aitchison 1989), and shrews and other subnivean mammals may be consumed by weasels that burrow through the snow seeking their prey. Higher plants provide food for subnivean shrews, voles and gophers and for supranivean grazers. Animals such as snowshoe hares, deer and caribou contribute to the nutrient dynamics of snow through their waste materials (Jones 1991), and these wastes may contribute to the patchiness of snow chemistry (Snow Ecology Working Group Workshop, 1993, Québec City, unpubl.). The patchy snow chemistry may relate to the patchy distribution of some snow algae, particularly for those species requiring higher nutrients. Heterotrophs, decomposers and detritivores enter the food web at every level, and these may include bacteria, fungi, some algae and some invertebrates. In addition, contaminants in snow may include lichen pieces and algae from tree bark, air and soil (Table 2), as well as coniferous litter and dust particles. These contaminants are important in those snow ecosystems or communities where they are prevalent.

Laboratory cultures and mating experiments

Laboratory cultures revealed a number of algal microbes not reported from original snow samples (Table 2). The green alga, *Chodatia tetralantoidea*, appeared in cultures from Killington Ski Area, Vermont, and it was reported previously as a growth form of the green alga, *Raphidonema nivale*, in a laboratory culture from Washington state (Hoham 1973). These are the only records of this species from North America, but the same alga is more widely distributed in European snow (Kol 1968). The yellow-green algae, *Monodus* and *Chlorocloster*, have not been reported from snow previously; however, they appeared in cultures in this study and in previous studies from western North America (Hoham, unpubl.).

The first bacteria-free isolate of *Chloromonas* sp.-A from New England snow, strain 654C from Jay Peak Ski Area, Vermont, was obtained in May 1993. During June 1993, it was established that strains 593A and 593C from Québec are normal + and - mating strains that produce resting zygotes (zygospores); these are the first normal mating strains of *Chloromonas* isolated from eastern North America. Until mature zygospores are obtained in laboratory culture in the cross between strains 593A and 593C, it will not be possible at this time to designate the species of *Chloromonas* to which these strains belong. Hoham (1992) suggested that these isolates of *Chloromonas* from Québec and New York were different strains of *Chloromonas polyptera*. During Summer 1993, the two normal Québec mating strains (593A and 593C) were crossed with the New England strain 654C, three Adirondack Mtn, New York, strains and four White Mtn, Arizona, strains of *Chloromonas* modifying the mating procedures of Hoshaw (1961). The New York and Arizona strains were mated against one another previously and all mating configurations were abnormal (Hoham 1992). Resting zygotes did not develop, and mating configurations of any type were very rare (Hoham 1992). These mating experiments using the Québec + and - strains (593A and 593C), and the mating experiments from summers 1988, 1991 and 1993, conclusively show that all Adirondack Mtn, New York, White Mtn, Arizona and Jay Pk., Vermont strains of *Chloromonas* are asexual and belong to *Chloromonas* sp.-A, and none of these isolates appear to belong to *Chloromonas polyptera* as suggested by Hoham (1992). These mating experiments are assisting with our understanding of what appears to be a most complex taxonomic problem within the genus, *Chloromonas*, which is widely distributed in North America and elsewhere.

Future research in snow microbiology and snow ecology

The Snow Ecology Working Group (SEWG) held a workshop from June 2-7, 1993, in Québec City, Canada, just prior to the 50th Eastern Snow Conference. This workshop on snow ecology has provided the necessary incentive for a future international meeting in snow ecology. For the first time, those of us involved in snow chemistry, physics, microbiology, macrobiology and global snow cover interrelated and discussed numerous aspects of the snow ecosystem. Also encouraging in the microbiological field was the presence of two graduate students at the 50th Eastern Snow Conference who are studying snow and ice bacteria, a very neglected area of snow microbiology. These students are Martin Handfield, Laval University, Québec City, and Paul Brooks, University of Colorado, Boulder.

Future research in snow microbiology in eastern North America should include additional collecting areas to give a more comprehensive distribution pattern. It is likely that snow microbes will be found in northern New Brunswick, the Gaspé Peninsula and northern Québec and Labrador, Canada. Handfield *et al.* (1993) have contributed recently in their discovery of bacteria and fungi from Ellesmere Island, Canada. In the United States, further collection sites should include the southern Adirondack Mtns and Finger Lakes region, New York, as well as the mid-southern Appalachian Mtns from Pennsylvania to North Carolina and Tennessee.

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