RECENT DISCOVERIES OF SNOW ALGAE IN UPSTATE NEW YORK AND QUÉBEC PROVINCE AND PRELIMINARY REPORTS ON RELATED SNOW CHEMISTRY

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ABSTRACT

Snow algae are well known from western North America, but recent discoveries have been made in eastern North America from the Adirondack Mountains, New York (1972), Central New York Highlands (1977), Tughill Plateau, New York (1988) and Laurentian Mountains, Québec (1988). The most causative agent is the green alga, Chloromonas (Division Chlorophyta), which colors the snow green and sometimes orange. More than one species is involved. Indications are that acid rain may be selecting for increased acid tolerance in snow algae in the Adirondacks. Metabolism of nutrients by snow algae and related effects on snow chemistry are reported from the Adirondack and Laurentian Mountains. Changes in pH, conductivity, SO_4^{--}, NO_3^-, NH_4^+ and K^+ were noted. Other microorganisms in the snow ecosystem may also affect snow chemistry.

Introduction: In western North America, snow algae have been reported from alpine environments from northern Mexico to Alaska and from high latitudes of Alaska and Canada (Kol 1968, Thomas 1972). Red snow is characteristic of open exposures such as those found above timberline at Mt Rainier National Park, Washington. The red snow caused by the green alga, Chlamydomonas nivalis, is frequently found following watermelt lines which occur in the snow during summer months. Orange snow, caused by species of the green alga, Chloromonas, occur mostly in snowbanks receiving partial shade.

Orange snow is particularly noteworthy of residual snowbanks in alpine areas of central and southern Arizona in April and May (Hoham & Blinn 1979). The most widely distributed snow algae in the west are those species of Chloromonas and Chlamydomonas which cause green-colored snow in residual snowbanks which receive full or partial shade or in layers of snow that are several centimeters below the snowbank surface. Green snow may harvest populations of algae reaching 5 X 10^5 to 1 X 10^6 cells mL^{-1} in western North American snowbanks (Hoham 1975, 1989b, Hoham et al. 1979, 1983). These dense populations are usually found in horizontal layers below the snowbank surface.

In northeastern United States and eastern Canada, snow algae have been discovered only recently from alpine areas. They have been reported from the Adirondack Mountains, New York (1972), Central New York Highlands (1977), Tughill Plateau, New York (1988) and Laurentian Mountains, Québec (1988). In eastern snows, the most causative agent is the green alga, Chloromonas (Division Chlorophyta), which colors the snow green and rarely orange. More than one species of Chloromonas is involved. The discoveries in the Central New York Highlands and Tughill Plateau were found in April in deep ravines on northeast facing slopes, and the snowbanks were protected by a mixture of deciduous trees and shrubs and conifers. The algae reported from the Adirondack and Laurentian Mountains were found in April and May in residual snowbanks near conifers (fir and spruce) and some deciduous plants such as alder and birch. The maximum populations of snow algae in eastern North America found to date (2-3 X 10^5 cells mL^{-1}) are about one-half to one-fourth those known from western North America (Hoham 1989b).

The Appearance and Development of Algae in Snow: Algae first appear in snow during the melt which occurs during Spring of Summer depending on elevation and latitude (Hoham 1975, 1980). In residual snowbanks, resting spores of snow algae underlying the snow on the soil surface germinate when snow contains a liquid meltwater, light penetrates through the snowbank from top surface to snow-soil interface, and there are nutrients and gases available in the snowpack to support algal growth and development (Hoham 1987, 1989a). Only a small concentration of light is probably needed at the snow-soil interface for the germination process to proceed when resting spores release algal cells with flagella into the snowpack (Curl et al. 1972). These cells swim in the liquid meltwater in the snowpack to position themselves in different layers below the surface. The germination events and developmental stages in the life cycle of the snow algae are followed using core samples taken at different depths below the surface, examining core samples in situ with a field microscope for presence of algae and type of algal cell found, preserving and fixing samples from different depths with Lugol's solution (Prescott 1978), and examining fixed samples later in the laboratory using Nomarski and phase optics. When residual snowbanks melt, the resting spore in the snow algal life cycle remains on the soil or debris over the soil where they remain fixed in place until the above events repeat themselves one year later. Thus the resting spore is exposed to drought, increased light intensity, and high temperature during summer months, In autumn, these same resting spores are exposed to numerous freezes and eventually they are covered over with new snow during late autumn and winter. The germination process repeats itself the following spring or summer at the time of snowmelt. Snow algal populations remain relatively fixed in position in the same snowpacks year after year which allows for long term studies of the same species (Hoham 1980).

Acid Precipitation and its Effects on Snow Algae: Bacterial-free strains of the green snow alga, Chloromonas, from the Adirondack Mtns, N.Y., were compared to those from the White Mtns, Arizona, for pH optima (Hoham & Mohn 1985). The Adirondack strains showed optimum growth over a pH range from 4.0-5.0, whereas the Arizona strains showed an optimum growth in a pH range from 4.5-5.0. Growth was measured using cell counts, cell measurements and absorbance at 440 nm. This study suggested that acid precipitation so prevalent in eastern North America may be selecting for more acidic strains of snow algae in the Adirondacks.

Snow Algae and Snow Chemistry in Eastern North America: The green snow in the Adirondacks of Upstate New York and the Laurentians of Québec is caused by an unidentified species of *Chloromonas*. The Adirondack snow populations were first reported in 1972 (Hoham 1987) and the Laurentian populations were discovered for the first time in May 1988 (Hoham, Jones & Germain, unpubl.) The eastern snow algal species is very closely related to the western North American snow alga, *Chloromonas polyptera*, and through further studies it may be found that all of these populations are part of the same species complex.

In a preliminary investigation, snow samples collected in May 1987 from 1265 m and 1341 m on Whiteface Mtn, New York, were analyzed to see if snow algae might be affecting snow chemistry. Two samples were collected from each site, one containing the Adirondack *Chloromonas* and an adjacent control sample lacking the algae. The samples were analyzed at Syracuse University in the laboratory of Dr Charlie Driscoll by his technician, Chris Yatsko. In both sites, the pH was more basic in samples containing algae (5.87 vs 5.63 at 1341 m; 5.17 vs 4.98 at 1265 m). Since the collections were made in mid to late afternoon, these differences may relate to CO_2 consumption during photosynthesis in samples containing algae. Also at both elevations, conductivity was lower in samples containing algae implying that nutrients were being metabolized (13.1 vs 19.5 µmhos at 1341 m; 9.6 vs 16.4 µmhos at 1265 m). Nutrients analyzed included SiO_2, Cl^-, SO_4^{--}, NO_3^-, NH_4^+, Na^+, K^+, Ca^{++} and Mg^{++}. Particularly noteworthy were drops in concentrations of NO_3^- and K^+ in samples containing algae (5.3 vs 9.7 µeq at 1341 m and 8.0 vs 10.8 µeq at 1265 m for NO_3^-; 40.6 vs 77.4 µeq at 1341 m and 29.7 vs 63.7 µeq at 1265 m for K^+).

Similar preliminary investigations of the effects of snow algae on snow chemistry were done in the Laurentian Mountains, Québec, in May 1988 from samples collected at 777 m on the north shore of Lake Laflamme (Hoham, Jones & Germain, unpubl.). Two samples were taken on May 9 and three samples on May 17. As reported for the Adirondacks, pH was more basic and conductivity was lower in Laurentian Mountain samples containing algae. Concentrations of SO_4^{--}, NO_3^- and NH_4^+ were lower in samples containing algae compared to control samples lacking algae. On May 9, NO_3^- concentrations were not detected in samples containing algae, but were present in two of the three samples containing algae from May 17. These observations correlate with a shift in the phases of the life cycle of *Chloromonas* from the active vegetative phase (biflagellate cell) with greater NO_3^- utilization (May 9) to the sexually-produced resting stage (thick-walled dormant cell without flagella) with less NO_3^- uptake (May 17). Concentrations of K^+ in Laurentian snow did not correlate with data collected from the Adirondacks. These preliminary studies indicate that more careful attention needs to focus on the biological interaction between snow microorganisms and snow chemistry. Too often, snow chemists have examined snow chemistry in the snowpack only at the time of early snowmelt. These reports should create interest between snow chemists and snow biologists to investigate the interaction between snow algae and snow chemistry from the time of early snow melt till the complete disappearance of the snowpack. Other investigations are needed in the near future in addition to those reported here.

Other Microorganisms in the Snow Ecosystem in Eastern North America: Other organisms should be mentioned to give a more complete picture of the snow ecosystem. Two algae not mentioned previously are the golden alga, *Chromulina chionophilia*, and the colorless euglenoid, *Notosolenus*. The location site of the golden alga is usually in snowbanks associated with coniferous trees (Hoham & Blinn 1979), and the implication is that the coniferous canopy probably supplies critical nutrients for this alga's growth. This alga has been found on Whiteface Mtn, N.Y. (Hoham 1987). Notosolenus is the only colorless non-photosynthetic alga known from snow (Hoham & Blinn 1979). Its presence is usually sparse in number, but it is found only in snow located directly under tree canopies (Hoham & Blinn 1979). All euglenoids studied under laboratory conditions require vitamin B_{12}, and in addition, many require vitamin B_1 (Leedale 1967). This implies that snowbanks directly underneath coniferous tree canopies must supply enough vitamins for the growth of this colorless alga. Again, whether the vitamins are coming from the canopy itself or from some other source (bacteria in snow, coniferous leachates at the top of the snowbank, lichen pieces or fungi) is not known. Notosolenus has been found in snow from Whiteface Mtn. N.Y. (Hoham 1987), and the Laurentian Mtns, Québec.

The snow fungus, Chionaster nivalis, is found in surface snow of residual snowbanks. It is not understood how this fungus gets into snow or how it might interact with other organisms. Since it is a fungus, it needs an external source of carbon. The likely source of carbon is from the photosynthetic algae (Chloromonas or Chromulina) or from lichen fragments. There is no physical evidence that Chionaster forms any type of lichen association with the snow algae, but the fungus is probably receiving nutrients passively in snow from algae, bacteria or from coniferous leachates. Chionaster is known from the Pacific Northwest (Garric 1965), the northern Rocky Mountains (Kol 1964), New York State (Hoham 1987), New Hampshire (Hoham 1987) and Québec, but it appears to be absent from the southwestern United States (Hoham & Blinn 1979).

Lichen pieces and fragments are numerous on surface snow and within the snowpack in the Laurentian Mtns, Québec. Their impact on interactions with other snow microorganisms and snow chemistry is not known. However, their presence in greater numbers in Laurentian snow than in the Adirondack snow should be of interest when comparing these two snow ecosystems. There is more spruce surrounding snowpacks containing algae in the Laurentians than in the Adirondacks (mostly balsam fir), and this may relate to differences in greater lichen densities on snow in the Laurentians.

Primary consumers, protozoa and rotifers, are part of the snow ecosystem (Hardy & Curl 1972, Hoham et al. 1983, Pollock 1970). These microscopic animals prefer to select and digest green cells over the more brightly-colored orange and red cells (Pollock 1970). Otherwise, little is known concerning the role that primary consumers play in the snow ecosystem. Some questions for consideration include how generally distributed are primary consumers in snow, how much do they deplete snow algal populations, what is their life history and how does it relate to other snow microorganisms, and how do they fit into the overall picture of snow chemistry. In addition to rotifers and protozoa, there are other animals which may be found in association with melting snowbanks. These include nematodes, water bears, snow worms, insects, spiders and mites, birds and larger mammals. The nematodes and water bears may be consumers of detritus, but it is not clear what part, if any, the other larger animal forms may play in the snow ecosystem.

REFERENCES:

Curl, H., Jr., J. T. Hardy, and R. Ellermeier. 1972. Spectral absorption of solar radiation in alpine snowfields. Ecology, 53: 1189-1194.

Hardy, J. T. and H. Curl, Jr. 1972. The candy-colored, snowflaked alpine biome. Nat. Hist., 81 (9): 74-78.

Garric, R. K. 1965. The cryoflora of the Pacific Northwest. Amer. J. Bot., 52: 1-8.

Hoham, R. W. 1975. The life history and ecology of the snow alga Chloromonas pichinchae (Chlorophyta, Volvocales). Phycologia, 14: 213-226.

Hoham, R. W. 1980. Unicellular chlorophytes - snow algae. In Cox, E. R. [Ed.], Phytoflagellates. Elsevier North Holland, Inc., New York, pp. 61-84.

Hoham, R. W. 1987. Snow algae from high-elevation, temperate latitudes and semi-permanent snow: Their interaction with the environment. In Lewis, J. [Ed.], Proceedings of the Forty-fourth Annual Eastern Snow Conference., pp. 73-80, Fredericton, New Brunswick, Canada.

Hoham, R. W. 1989a. Snow as a habitat for microorganisms. In McKay, C. P. and W. L. Davis [Eds.], Exobiology and Future Mars Missions, NASA Conf. Publ. 10027, pp. 32-33, Ames Res. Center, Moffett Field, California.

Hoham, R. W. 1989b. Snow microorganisms and their interaction with the environment. Proceedings of the Fifty-seventh Annual Western Snow Conference, Ft. Collins, Colorado: in press.

Hoham, R. W. and D. W. Blinn. 1979. Distribution of cryophilic algae in an arid region, the American Southwest. Phycologia, 14: 133-145.

Hoham, R. W. and W. W. Mohn. 1985. The optimum pH of four strains of acidophilic snow algae in the genus Chloromonas (Chlorophyta) and possible effects of acid precipitation. J. Phycol., 21: 603-609.

Hoham, R. W., J. E. Mullet, and S. C. Roemer. 1983. The life history and ecology of the snow alga Chloromonas polyptera comb. nov. (Chlorophyta, Volvocales). Can. J. Bot., 61: 2416-2429.

Hoham, R. W., S. C. Roemer, and J. E. Mullet. 1979. The life history and ecology of the snow alga Chloromonas brevispina comb. nov. (Chlorophyta, Volvocales). Phycologia, 18: 55-70.

Kol, E. 1964. Cryobiological research in the Rocky Mountains. Arch. Hydrobiol., 60: 278-285.

Kol, E. 1968. Kryobiologie. Biologie und Limnologie des Schnees und Eises I. Kryovegetation. In Elster, H.-J. and W. Ohle [Eds.], Die Binnengewässer, Vol. 24, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. 216 pp.

Leedale, G. F. 1967. Euglenoid Flagellates. Prentice-Hall, Inc., Englewood Cliffs, N. J., 242 pp.

Pollock, R. 1970. What colors the mountain snow? Sierra Club Bull., 55: 18-20.

Prescott, G. W. 1978. How to Know the Freshwater Algae, 3rd ed. Wm. C. Brown and Co., Dubuque, Iowa, 293 pp.

Thomas, W. H. 1972. Observations on snow algae in California. J. Phycol., 8: 1-9.