EFFECTS OF MICROALGAL BLOOMS ON SIERRA NEVADA SNOW ALBEDO

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ABSTRACT

Initial (1993) investigations of snow albedo and snow color (caused by algae) in the Sierra Nevada of California showed that albedo was reduced in red snow patches as compared with that in white snow patches. In May-June, 1994, extensive concurrent measurements of snow albedo, snow algae numbers, and snow water content were made in the Tioga Pass area (upper LeeVining Creek watershed) of the range. Statistically significant negative correlations were found between albedo and algal cell numbers and water content. However, red snow did not decrease mean albedos in large representative snowfields that contained algae. This was due to the patchiness of the algae, and mean albedos probably would not decrease because of algae over the whole LeeVining Creek watershed. Thus water supply from melting snow would not be affected by the presence of algae. Especially in the early algal season, dirt, as well as algae, contributed to decreases in albedo.

INTRODUCTION

Colored snow, caused by surface blooms of microscopic algae, is common in mountainous and polar regions throughout the world (Kol, 1968). The color is generally pink to red in open areas near timberline, but green snow can be found in lower, forested areas. In the Sierra Nevada, red snow was first reported in the early 1900s and is distributed widely at high elevations throughout the range (Thomas, 1972). At the area near Tioga Pass, where we have studied the algae extensively, red snow was first reported over 60 years ago (Sharsmith, 1935). For 25 consecutive summers before 1969, it was found there (W. M. Heisey, personal communication).

We hypothesized that algal blooms would reduce snow albedo—the ratio between sunlight intensity reflected by the snow and incident intensity, expressed as a percentage. This hypothesis was first suggested to the senior author by Professor John D. Isaacs of Scripps in 1971, but we have investigated this idea only recently. If albedo was reduced over a whole watershed, snow melting and runoff could be increased.

STUDY AREA

We carried out these investigations in the watershed of upper LeeVining Creek, which is northeast of Tioga Pass. This watershed is a catchment basin, with several dammed lakes, for a hydroelectric plant operated by the Southern California Edison Company in LeeVining Canyon. Figure 1 shows the location of Tioga Pass in relation to the towns of Bishop and Mammoth Lakes, California and also shows the location of SNARL—the Sierra Nevada Aquatic Research Laboratory—where we processed samples. Figure 2 shows the location of specific sampling and albedo measuring sites.

METHODS

Snow albedo was measured with a LiCor quantum sensor (broad band, 400-700 nm) mounted on the end of a 2-meter pole and positioned 15 cm normal to the snow. The sensor was connected to a Campbell Instruments datalogger or to a LiCor Model 189 radiation readout meter. The reading was not affected by shading by the observer. First the sensor was pointed at the sun; then it was turned over to obtain the reflected

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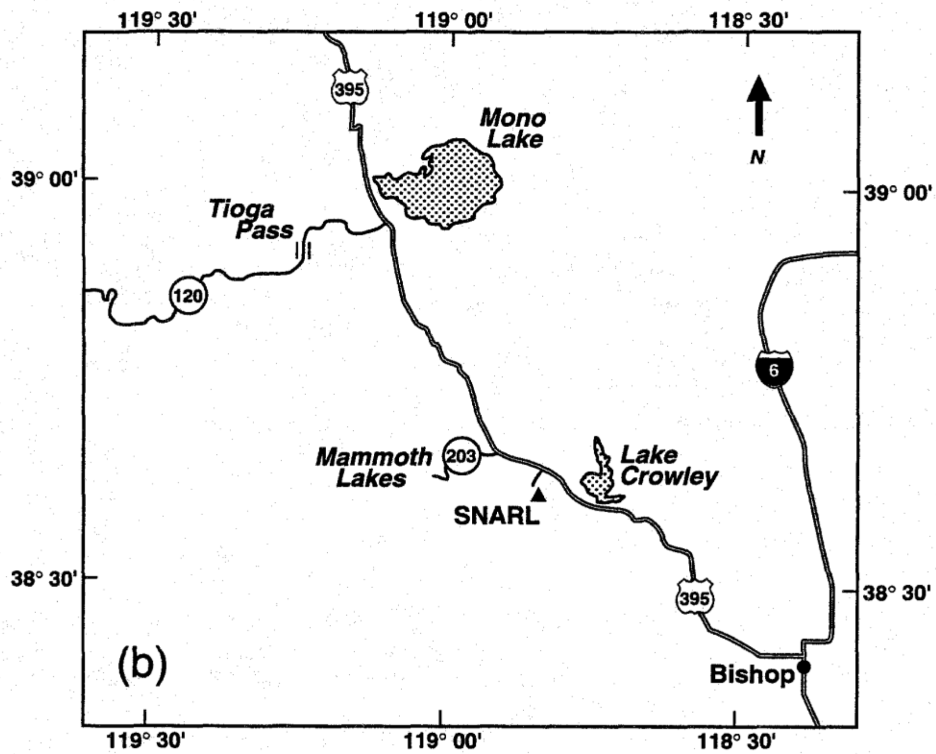

Figure 1. Location of Tioga Pass in California.

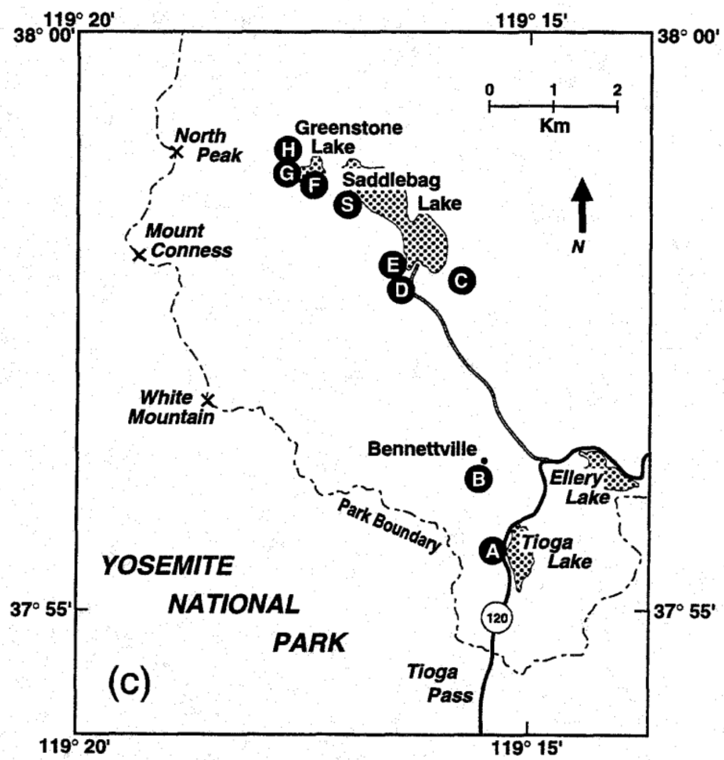

Figure 2. Specific sites sampled near Tioga Pass.

light intensity. Albedo was calculated from the ratio of the two measurements, as a percentage of sunlight irradiance. All measurements were made within 1-2 hours of noon in the late spring or early summer.

Surface algal concentrations were measured by placing 10-12 ml of snow in glass vials, fixing the algae with 4 drops of Lugol's iodine solution, and enumerating the cells microscopically at SNARL. The only algae observed were red aplanospores of the common snow alga, Chlamydomonas nivalis.

Snow water content was estimated by placing a measured volume of snow in a glass vial and measuring the volume of water after melting. This measurement was semiquantitative (± 5%) and water content was expressed as %water by volume.

Statistical tests ("t" tests and estimates of correlation coefficients) were done with the FASTAT program on a Macintosh computer. Small sample size tests were non-parametric, also performed with FASTAT.

RESULTS AND DISCUSSION

In 1993, near Tioga Pass, one of us (B. D.) made six initial measurements of albedo in visually red and white snow. The mean albedo in red snow was 46.2 ± 11.2% (SD) while that in white snow was 58.3 ± 8.4%. This difference was statistically significant ($p<0.01$) and seemed to confirm that the presence of algae would lower albedo, but algal cell numbers were not measured. In 1994, 35 paired measurements showed that red snow albedo was 51.0 ± 6.6% and that for white snow was 58.0 ± 5.5%. This difference, while not large, was significant ($p<0.01$). These 1994 measurements were part of a set of 100 observations of albedo, cell numbers, and water content.

In 1994 (13 Samplings), we noted that there were two temporal stages in snow algae development in the Tioga Pass area. Stage I (early season, 20 May-13 June) had few (2 out of 25) red patches and had some fresh snowfall. As Stage I progressed, the snow was mostly visually dirty rather than red. During Stage II (13 June-8 July), we observed 39 red patches and 29 dirty white ones. These results indicated that visually the two stages differed.

During Stage I, at Site A near Tioga Lake, for Sampling 1 (20 May) the mean albedo was 89.3 ± 1.8%. Later (Samplings 2 and 3, 31 May and 6 June), the albedo had decreased to 65.5 ± 11.4%. This difference was statistically significant ($p<0.001$) but was probably due to dirt buildup on the snow surface since no red patches were observed and algal cell numbers were low (approximately 300 cells mL^{-1}). Later (Stage II) we noted that when dirt was scraped off the surface of non-red snow patches, the albedo increased by about 10%. Previously it was shown that dirt on snow can decrease albedo (Warren, 1982).

Although the association of reduced albedo with red color suggested that algae were a cause of the reduction, more convincing evidence came from regressions of on cell numbers. During Sampling 8 (Stage II, 20 June, Site F), there was a strong negative relationship (Figure 3) between albedo and cell numbers for a small data set (n=4). For this relationship, $r=-0.855$ and the regression was statistically significant ($p<0.05$).

Other negative correlations were found for larger data sets: for all Stage I data, $r=-0.402$, $p<0.01$, and $n=41$; and for all Stage II data, $r=-0.338$, $p<0.01$, and $n=59$. For both Stage I and Stage II data combined, $r=0.466$, $p<0.001$, and $n=100$. Figure 4 shows these latter data. Because the correlations were not strong (r values are low), factors other than algae, such as dirt on the snow , may explain more of the reduction in albedo.

We did not measure the dirt content of surface snow, but it is an obvious factor in reducing albedo. It would be possible to measure dirt by weighing filtered dried particulate material in given volumes of snow meltwater and subtracting the calculated algal dry weight from the total particulate weight. Algal dry weight could be estimated from cell numbers and sizes by assuming that the algae have a density of 1.0 and that 10% of the total algal fresh weight = dry algal weight. While dirt is one additional factor along with algae that reduces albedo (Warren, 1982), another is water content, as Winther (1993) has suggested. We also obtained a negative correlation between albedo and water content (Figure 5). This correlation was statistically significant ($r=-0.566$, $p<0.001$, and $n=100$). Snow grain size may also affect albedo (Marks and Dozier, 1992).

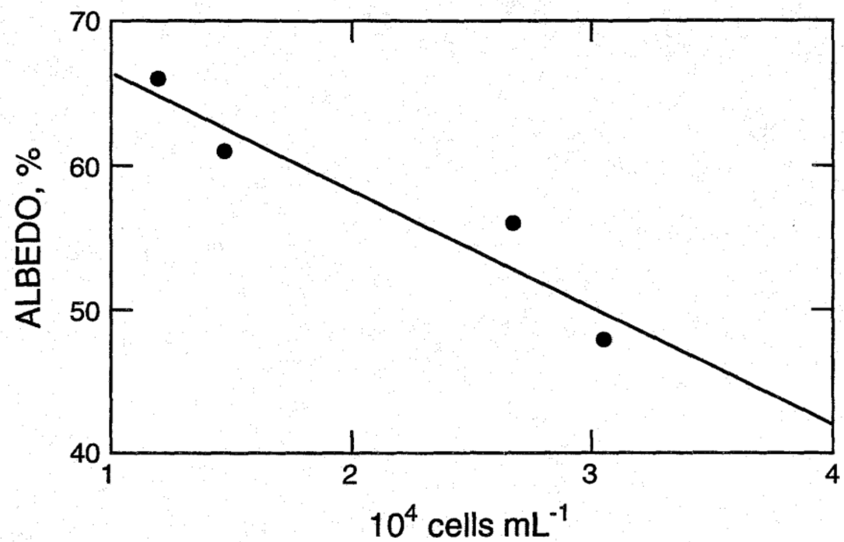

Figure 3. Negative relationship between snow albedo and algal cell numbers; 20 June 1994; Site F near Tioga Pass.

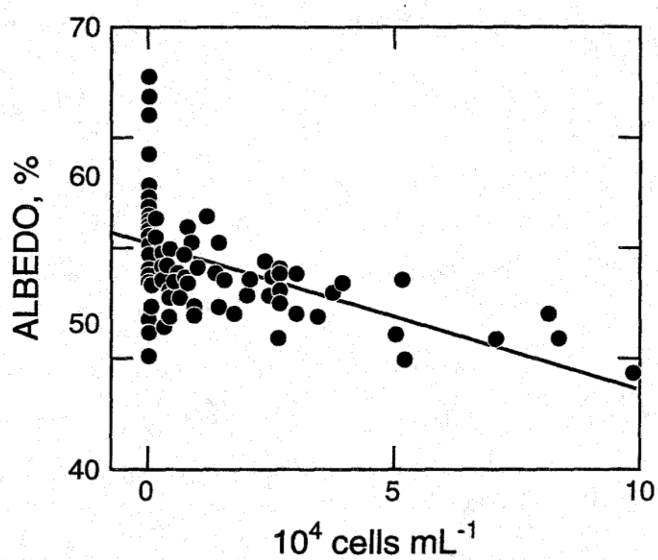

Figure 4. Relationship between snow albedo and algal cell numbers. All Stage I and Stage II data from several sites near Tioga Pass combined.

Since algal blooms seem to have reduced albedo, a question to consider is whether this effect extended over the whole watershed and could have increased snow melting and runoff. During Sampling 9 (23 June, Site S), a small (20 x 100 meter) completely red snowfield was observed; nearby was a dirty white snowfield approximately the same size. The mean albedo for the red snowfield (n=6) was 45.5 $\pm$ 1.7% and algal cell numbers ranged from 35,200 to 286,000 cells mL^{-1}. In the white snowfield (n=6), the mean albedo was 59.5 $\pm$ 3.2% and cell numbers ranged from 60 to 360 cells mL^{-1}. Albedo and cell numbers differed statistically ($p<0.001$) in the red snowfield as compared with those in the white snowfield. This is an example that algae can affect the albedo of a whole, although small, snowfield.

However, in four later (27 June, 30 June, 5 July, and 8 July 1994) Stage II samplings of a larger (300 x 500 meter) snowfield above Greenstone Lake at Sites G and H, the red color was highly patchy. Patchiness

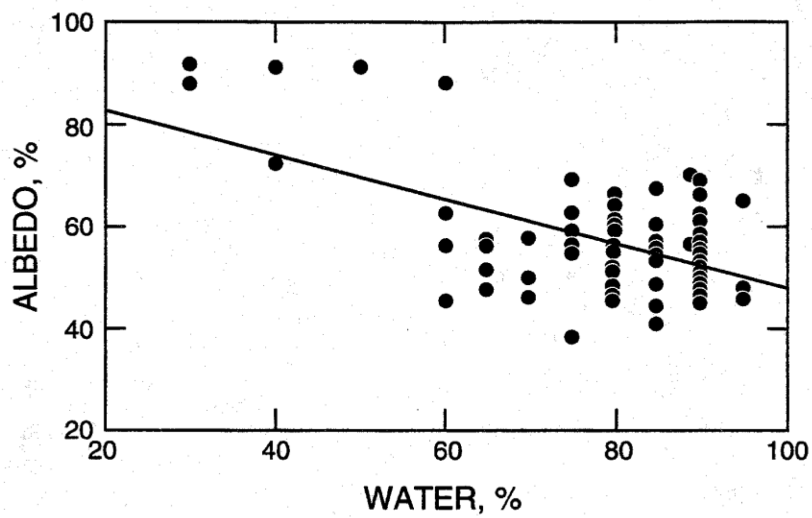

Figure 5. Negative correlation between snow albedo and water content.

in red color and algal distributions in snow, with strong differences within a few meters, has been observed previously (Thomas, 1972). At Sites G and H, albedos measured in red patches were within the standard deviations of mean albedos for all patches—red or white. Thus the algae did not seem to have affected the mean albedo of this whole, large snowfield. An example of patchiness is shown in Figure 6 which is a transect within the Site G snowfield on 27 June. Albedos and cell numbers were very patchy, particularly considering that logarithms of the latter were plotted.

The mean albedo for all patches shown in the figure was 57.4 ± 6.7% (n=10), while for red patches the mean albedo was 54.8 ± 6.7% and for white patches, 60.0 ± 6.5%. When standard deviations are considered, the mean albedo for the whole transect falls within those for both red and white snow. We do not have a good explanation of patchiness, but it may involve concentration of surface algal blooms by ablation and movement of water on the snow surface.

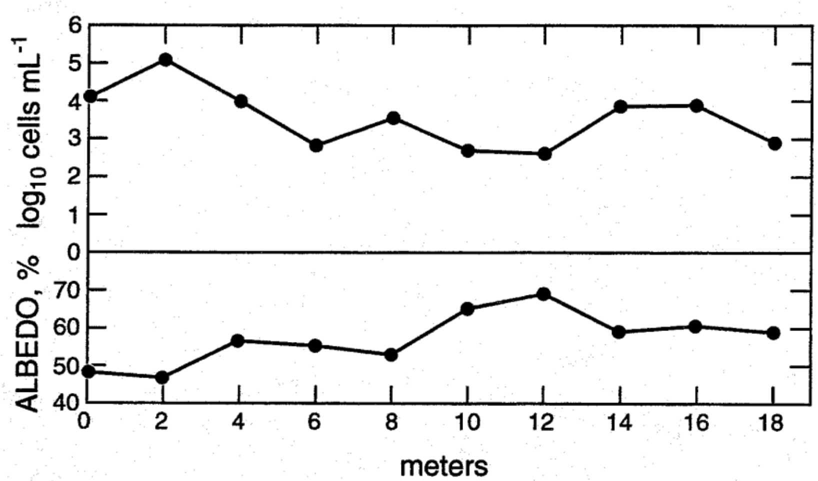

Figure 6. Snow albedos and logarithms of algal cell numbers along a north-south transect at Site G near Tioga Pass (27 June 1994). When cell numbers were high, albedo values were low, and vice versa.

We conclude that, due to patchiness, the presence of algae would not appear to affect albedo over a whole, large snowfield and probably not over the whole watershed. This indicates that melting and runoff would not be affected by the presence of algae alone. This is particularly so when other factors in snow aging, such as dirt on the snow, are considered.

ACKNOWLEDGMENTS

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