CLIMATE CHANGE

Extreme Responses to Climate Change in Antarctic Lakes

Wendy C. Quayle,[1] Lloyd S. Peck,[1*] Helen Peat,[1] J. C. Ellis-Evans,[1] P. Richard Harrigan[2]

We report data for maritime Antarctic lakes showing extremely fast physical ecosystem change, combined with the ecological responses to that change. Nutrient levels at some sites exhibit order of magnitude increases per decade.

Polar lakes are early detectors of environmental change because snow and ice cover variation markedly affect all ecological variables. Freezing and thawing patterns of Northern Hemisphere lakes and rivers correlate with air temperature increases of 1.2°C/100 years (*1*). In some arctic localities, air temperatures increased by 0.05° to 0.07°C/year between 1961 and 1990 (*2*). These values compare with 0.32°C global mean temperature increases from 1980 to 1999 (*3*).

Polar lake sensitivity to change relies on thermal proximity to freezing, which applies critical limits to environmental responses including temperature, ice extent, snow cover, light availability, and albedo (*4*). The Antarctic Peninsula has experienced some of the most rapid air temperature increases on Earth (2°C over the past 40 to 50 years. years).

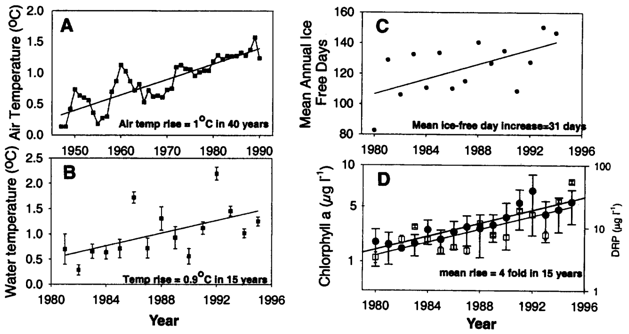

Fig. 1. (**A**) Five-year running mean of summer (December to February) air temperature. (**B**) Mean winter (July/August) lake water temperature of nine Signy Island lakes ($R^o = 0.5671, P < 0.05$). Lake temperature increased faster than air temperature (generalized linear model analysis of variance, $F = 5.28, P = 0.025$). (**C**) Mean number of annual ice-free days (ice-free days $= 87.4 + 2.43 \times$ year, $R^2 = 0.32, P = 0.017, F = 7.43$). (**D**) Relation between time and mean winter (July/August) chlorophyll a of the nine Signy lakes on left *y* axis ($R^2 = 0.5735, P < 0.001$) and mean winter (July/August) DRP concentrations on right *y* axis ($R^2 = 0.8146, P < 0.001$). All nine lakes increased significantly ($P < 0.05$). All error bars (SE) depict variation between lakes. Note *y* axis logarithmic scales in (D). Chlorophyll a extraction methods have been previously described (*6*).

Signy Island (60°43′S,45°38′W) lies at the confluence of the ice-bound Weddell Sea and warmer Scotia Sea. Its climate is governed by the interaction of cold and warm air masses from the two areas. Its location, low altitude, and a relatively thin, low-density ice cap make it sensitive to environmental change (*5*). Its 17 lakes represent all maritime Antarctic lacustrine environments. Altitudes range from 4.5 to 150 m, and aspects differ markedly. In winter, large snow accumulations on the island cover the frozen lakes. Seasonal variations in photosynthetically active radiation (PAR) are large (*6*). Declining permanent ice cover, coinciding with an almost 1°C rise in summer air temperatures (Fig. 1A), has radically affected Signy Island since the 1950s (*5*).

Mean winter temperatures for nine Signy Island lakes increased by 0.9°C between 1980 and 1995 (Fig. 1B). Individual lakes increased by 0.2° to 1.3°C, with six increasing significantly themselves ($P < 0.05$) (Fig. 1B). Individual lakes increased by 0.2° to 1.3°C, with six in creating significantly themselves ($P < 0.05$), whereas local sea temperatures were unchanged. The mean increase is three to four times global mean temperature increases (*3*) and two to three times local summer air temperature increases.

Reduced lake snow and ice cover are caused by reductions in both permanent terrestrial ice cover and albedo, which facilitate catchment warming. Earlier opening of lakes allows water and sediments to absorb more solar energy, creating a forcing effect. During winter, heat is transferred from sediments to the water column. Heat loss is reduced by ice cover insulation, and water warming is amplified compared with air temperature increase.

Photographic estimates suggest that Signy's permanent ice cover has receded by ~45% since 1951. Lake ice records (1980–95) indicate that the open-water period has increased significantly. It was 63 days longer in 1993 than in 1980, reflecting a 0.5°C increase in mean summer air temperatures (Fig. 1C).

Antarctic lake phytoplankton respond extremely sensitively to light (*6*). Analyzing winter chlorophyll a concentrations removes large interannual variations seen in summer measurements. Chlorophyll a concentrations significantly increased in seven of the nine oligotrophic lakes, and means rose from 1.4 μg/liter in 1981 to 3.5 μg/liter in the mid-1990s (maximum 6.8 μg/liter in 1995; Fig. 1D). Large snow accumulations on lakes from May to September reduce PAR penetration to undetectable levels, photosynthesis becomes undetectable, cells sediment from the water column, and chlorophyll a concentrations decline to ~1 μg/liter (*6*). Levels of winter snow cover on maritime Antarctic lakes suggest that increasing winter pigment concentrations are unlikely to result from photoautotrophic activity. They probably result from enhanced summer phytoplankton levels (*6*), promoted by increasing nutrient concentrations (Fig. 1D), and persist because of extended open-water periods. Increased densities of mixotrophic plankton may also be important (*7*).

During the initial stages of ice cap retreat 40 to 50 years ago, meltwater drained mainly over ice, with little nutrient leaching. More recently, streams have accumulated higher nutrient concentrations [especially dissolved reactive phosphorus (DRP)] by draining exposed fell-field soils, thawed ground, and plant and microbial communities, whereas nitrogen intputs are ultimately atmospheric via snow melt. Summer nutrient enrichment promotes increased autochthonous carbon production, much of which accumulates in sediments. DRP (Fig. 1D), ammonium, and alkalinity rose 5.0, 2.5, and 2.2 times, respectively. These winter increases are an indirect consequence of summer allochthonous inputs. They are explained by remineralization of sedimented summer detritus and changing bottom water redox conditions.

Trends in Signy Island lakes from 1980 to 1995 indicate that local climate change has been translated into extreme ecological change. Marked responses by lake biota and increased nutrient levels appear linked to deglaciation and reductions in lake snow and ice cover.

References and Notes

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[1]British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK. [2]BC Centre for Excellence, 603-1081 Burrard Street, Vancouver, BC V6Z 1Y6, Canada.

*To whom correspondence should be addressed. E-mail: lspe@pcmail.nerc-bas.ac.uk