Sophistication in simplicity: chemical signatures in Antarctic moss cells reveal past water environments

By Jessica Bramley-Alves and Sharon Robinson

Organisms displaying a certain level of intricacy are those that are most likely to fascinate us. Mosses – non-vascular plants from the division Bryophyta – do not readily fall into this category. Moss is small, underfoot and displays none of the complex grandeur that flowering plants or magnificent conifers exhibit. As our recent paper in *Global Change Biology* demonstrates, however, it is this simplicity that provides Antarctic mosses with a fascinating utility; as a sophisticated measure of one of the world's most important resources – bioavailable water (see Bramley-Alves et al. 2015).

The importance of water for life is indisputable. Every carbon based organism on Earth relies on water for survival, with a number of past extinctions of both species and civilisations attributed - on some level - to extreme droughts. The impact of climate change on bioavailable water, and its subsequent ecological effect, is therefore of considerable concern for the global population. And rightly so, as current predictions from the International Panel of Climate Change (IPCC) suggest an increase in both the duration and frequency of extreme droughts worldwide. While the predictive power of current climate models is strong; our understanding of global changes to bioavailable water will only improve through gathering more information.

Antarctica is a significant location in assessing climate variation as its isolation provides a clear climate change response signal relatively independent of confounding anthropogenic influences. The continents isolation has meant, however, that there are very few data records available for the study of climate change. For scientists who are interested in mapping trends in bioavailable water in Antarctica, and indeed across the globe, this is frustrating. Previously there were two main forms of gathering climate information on continental Antarctica: low temporal resolution records from inland ice-cores, which do not provide good year to year data, or meteorological records from weather stations. While weather stations give a clear indication of year to year changes they are sparsely peppered across Antarctica and usually only extend back 1950s. Moreover using information from these weather stations to examine trends in biologically accessible water is arguably inadequate. Weather stations generally just recorded precipitation in the form of rain (or snow), yet in Antarctica bioavailable water depends on a balance between a multitude of interacting inputs (snow and meltwater) and outputs (loss as sublimation, run off and evaporation). These are in turn dictated by climatic factors such as temperature, wind speed and irradiation. What scientists have been missing, up until now, was a means of looking closely and accurately at trends in bioaccessible water in Antarctica since the advent of the industrial era. Though simple and seemingly uninspiring, Antarctic mosses have emerged as unlikely heroes in the search for this climate proxy.

The amazing age and resilience of Antarctic moss

Mosses are able to survive the long, harsh Antarctic winter months by entering a suspended state, similar to hibernation. They desiccate – literally dry out – and survive freeze-dried beneath the snow. This tenacity and hardiness explains why mosses are the dominant plants around the coast of Antarctica. Most other plants do not respond well to nine months a year in a freezer. When the intermittent Austral summer arrives on the Antarctic coastal fringe, mosses are able to quickly reactivate and must seize the opportunity to grow as they only have a few months with optimal conditions. They build upwards on the previous season of growth in a sequential fashion, similar to tree rings' outward growth but within a summer season a moss shoot can only manage a couple of millimetres. This means that an Antarctic moss shoot the length of an average hand has the potential to have been growing for centuries and could, if examined correctly, act as a long-term climate archive in the way that tree rings are used to reconstruct climate in warmer locations (Figure 1).

Figure 1. A long core of moss collected from King George Island in the South Shetland Islands.

The astonishing age of intact Antarctic moss shoots and the ability to precisely determine shoot section dates was discovered through the use of the 'bomb pulse' method. This method is based on our knowledge that nuclear testing in the 1950s and 1960s caused global ^{14}C levels to soar to almost double pre-existing numbers. Once such testing was banned in 1963, scientists documented the successive decrease of ^{14}C in the atmosphere, due to rapid exchange of carbon with reservoirs such as the biosphere and oceans, leading to the establishment of high-resolution ^{14}C curves. These curves, recognized in moss tissue globally, enable scientist to predict the calendar year of the sample based on the samples ^{14}C levels (Figure 2).

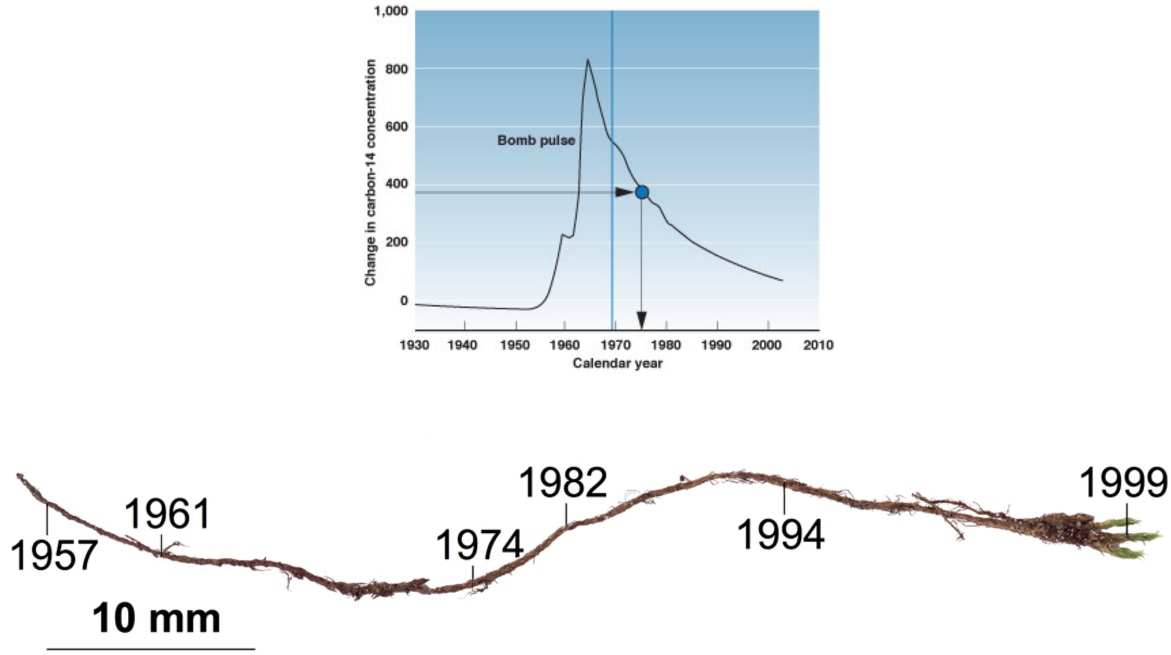

Figure 2. An example of how the ‘bomb pulse’ curve allows for the conversion of 14C levels in a sample to Calendar year dates. Taken from Science and technology review: https://str.llnl.gov/AprMay10/buchholz.html/. A single Antarctic moss shoot with representative dates measured using the ‘bomp pulse’ method.

For accuracy, plants that don’t mix carbon records from different years and that record many years in succession, are needed. In this way Antarctic mosses, which form vertical profiles of growth, can therefore be precisely dated by matching the core ^{14}C profile to established atmospheric ^{14}C calibration curves. The ability to date these mosses exactly, over both long and short timescales, provides the foundation to develop a fine-scale proxy for past growth conditions, including the possibility of tracing water availability over the duration of a moss’ lifetime, which can be several centuries in length.

Mosses can write water histories through chemical signatures due to their simplicity

We know that unlike vascular plants, mosses are able to reflect immediate water conditions through chemical signatures known as stable carbon isotopes. Stable carbon isotopes exist in the atmosphere in two different forms; a heavier form, ^{13}C, and the lighter form ^{12}C (one less neutron). Under ‘dry’ conditions mosses will always favour the uptake of the lighter carbon isotope (^{12}C) as the lighter isotope will be easier for the plant to process. Think of the effect on your digestive system of a heavy meal! If the moss becomes submerged beneath a film of water, however, carbon dioxide becomes limited and mosses become less fussy about which carbon isotope they use. In this way moss tissue that grows submerged beneath water contains a greater proportion of heavier ^{13}C isotopes than we would expect under dry conditions (Figure 3). Analysis of this chemical signature in moss tissue therefore provides us with a clear description of the water environment experienced at the time of growth.

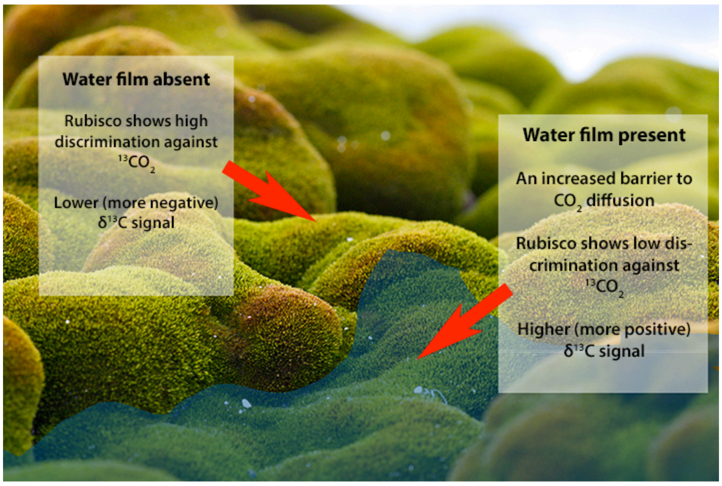

Figure 3. Chemical signatures differ between mosses under wet and dry conditions.

In our study we set out to see if this signature was apparent - and reliable - in Antarctic moss species. Our aim was to quantify the carbon isotope signals within Antarctic moss growing across a range of water environments to see if growth in wet Antarctic environments did indeed evoked heavy carbon isotope signatures when compared to growth in dry environments where we would expect a lighter signature. We knew that, if successful, this would allow interpretation of past Antarctic water trends, perhaps over centuries, due to the slow growth of mosses in Antarctica. Correlating such water trends to climatic drivers would expand our knowledge of current climate change in the region and might indicate trends elsewhere.

Can mosses really describe the amount of water in the environment 50 years ago?

In short: yes – and much further back! Our research shows that tracing carbon isotopes down long shoots of dated moss is a viable and valuable proxy for assessing past water environments in coastal areas of Antarctica. We demonstrated that the stable carbon isotope signature of moss growing in wet Antarctic environments is significantly different to those growing in dry environments. This held true across all test species and study locations. We were able to quantify what signatures were produced by moss when it experienced growth in wet, intermediate or dry water environments for different species. This important step gives us the capacity to understand changes in water availability over time and through this understanding we have explored past water trends in intact shoots of moss from Antarctica. Our preliminary explorations have found a significant drying trend in study sites in the past few decades, which is most likely down to the combined influence of the ozone hole (Robinson 2014) and global warming.

Moss is small, simple and liable to be dismissed as dull. Its very simplicity, however, makes it useful to scientists, and the implications of its use are fascinating. Locked in a few centimeters of dried moss is a detailed climate history, as stable carbon isotopes in Antarctic moss effectively reflect growth water. If successfully applied, this method of 'reading' the chemical signatures of mosses could allow them to be used as paleo-hydrological proxies in Antarctica, polar regions in general, and potentially other cold climate areas where meteorological records are limited. Small and simple, yes, but our study has hopefully shown moss to be no less fascinating than many more complex organisms.

Bramley-Alves, J, Wanek, W, French, K & Robinson, SA (2015) Moss $\delta^{13}C$ is an accurate proxy for past water environments in polar regions. *Global Change Biology* **21**: 2454–2464, DOI: 10.1111/gcb.12848

http://onlinelibrary.wiley.com/doi/10.1111/gcb.12848/abstract