Understanding Antarctic terrestrial biological systems in a changing climate

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Figure 1 Profesor Gustavo Zúñiga and Dra Melinda Waterman measuring moss fluorescence, as a measure of plant health, in open top chambers simulating climate change via passive warming. Picture by INACH (Harry Diaz) at Collins Harbour, January 2019.

Antarctica is known for its unique flora and fauna; however, the current rate of change occurring across the continent threatens many of these species. Rapid changes in Antarctic ecosystems have been observed. Long-term monitoring, an essential component of ecological research, is needed to monitor these changes. Knowing how Antarctica's ecological communities are responding to environmental changes is vital in understanding community resilience and resistance, predicting regime shifts, and providing crucial information for management and policy development. Current long-term biodiversity monitoring of Antarctic terrestrial communities is limited by spatial and species biases. Inconsistencies in the methodologies used for monitoring further limits our ability to draw comprehensive comparisons between studies. This demonstrates the need for harmonised protocols and data sharing in Antarctic research.

Antarctic communities are shifting as climate changes

Climate change is the greatest challenge species and ecological communities are facing this century. As greenhouse gas concentrations continue to rise, communities in polar regions are predicted to be severely impacted by temperature increases (Goosse *et al.*, 2018). Already, the Antarctic peninsula and sub Antarctic Islands have seen large scale shifts in environment, including glacial retreat (Cook *et al.*, 2016), extreme weather and anomalous events (Robinson *et al.*, 2020) and changing sea ice distributions (Hobbs *et al.*, 2016).

Change in Antarctica has been highly regional. In the last half of the 20th Century, surface warming in parts of the Antarctic Peninsula and West Antarctica was among the most rapid on the planet (Turner *et al.*, 2005; Turner *et al.*, 2014; Turner *et al.*, 2016). Although East Antarctic has not experienced the long-term warming trends observed in the west, other climate factors, including stronger winds and modified precipitation, mean that ecological communities in this region are experiencing drought (Robinson *et al.*, 2018).

On the peninsula, rapid warming can alter biological communities and increase the risk of establishment of invasive species, as the rate of non-native species introductions outweighs natural colonisation in Antarctica (Siegert *et al.*, 2019). It is expected that the "greening" trend on the Peninsula will continue, as ice retreats and the native vascular plants and moss communities continue to expand (Siegert *et al.*, 2019).

Water availability is a major limiting factor in Antarctic communities, the presence or absence of this key resource drives community structure and function. Terrestrial biodiversity is largely limited to ice-free havens along the continent's coast (Terauds & Lee, 2016). The harsh ecosystem restricts permanent residents to smaller, hardier organisms, including bryophytes, lichens, invertebrates and micro-invertebrates, as well as microbes and fungi (Convey *et al.*, 2014). Despite the regional variation in climate change across Antarctica, climate factors promoting or restricting the availability of water can modify species' distributions and community structure around the whole of Antarctica. The wetter and warmer conditions in the West are promoting vegetation growth, favouring vascular species such as the invasive *Poa annua*, over endemic plants (*Deschampsia antarctica, Colobanthus quitensis* and bryophytes) (Frenot *et al.*, 2005; Duffy *et al.*, 2017). In the East, however, the increased winds have enhanced drying and reduced snowmelt, decreasing the water available to the region's moss beds and lichens (Robinson *et al.*, 2018). This has resulted in a rapid shift in community composition, from moss species preferring wet habitats to those tolerating drier conditions (Robinson *et al.*, 2018). Modified water regimes on sub-Antarctic Macquarie Island have also attributed to the rapid dieback of the now critically endangered cushion plant, *Azorella macquariensis* (Bergstrom *et al.*, 2015). These examples illustrate how long-term trends in climate regime shifts are already reshaping Antarctic terrestrial communities (Bergstrom et al 2021), however, what is more difficult to capture is the effects that extreme climate events may have on Antarctica's fragile ecosystems.

Extreme climate events, such as heatwaves, can place ecological communities at the edge of their physiological limits. Such events can have considerable impacts on species, but their stochastic nature means their effects are more difficult to document. The summer of 2019/2020 saw one of the first documented heatwaves in East Antarctica (Robinson *et al.*, 2020). Pulses of extreme heat events, on top of the constant pressure of warming temperatures, threaten to exacerbate change in Antarctica (Bergstrom *et al.*, 2021).

The threat of climate change on Antarctic terrestrial vegetation communities is heightened when considered in addition to increasing human presence on the continent (Bender *et al.*, 2016; Leihy *et al.*, 2020). The rapidly changing Antarctic environment highlights the need for ecological monitoring. However, successful monitoring of broadscale changes across Antarctic ecosystems requires consistent standards of data collection. This is particularly important to compare changes across Antarctic ecosystems and determine which regions, communities and species are at risk and need stronger protection.

Figure 2 Dra Sharon Robinson (left) and Dra Melinda Waterman (right) at Ardley Island, an Antarctic Specially Protected Area, after setting up temperature loggers to track environmental conditions in the rich moss beds. Picture by Andrew Netherwood at Ardley Island, January 2015.

Standardising biodiversity monitoring across Antarctica

Currently, monitoring studies are limited by methodological inconsistency, making it difficult to compare results from one study to another and draw wide conclusions about the state of Antarctic ecosystems. Antarctic biodiversity has been measured in the field using sampling and photographic techniques and comparing changes in growth and species composition over at least two time points. However, field techniques and analyses undertaken are highly variable and often only occur over short periods, e.g. less than 3 years. This makes comparisons over time, between studies and sites extremely difficult. To capture and compare how Antarctica's terrestrial biodiversity is changing across the continent, we need comprehensive biological monitoring combined with real time meteorological data from the same site. This entails uniform data collection and data sharing, and places emphasis on international collaborations in research efforts.

Standardised protocols for data collection are being developed by the Scientific Committee on Antarctic Research's Antarctic Nearshore and Terrestrial Observation System Expert Group (ANTOS, https://www.scar.org/science/antos/home/), ensuring data collected are consistent, compatible and comparable. Across the continent, biological monitoring is biased towards larger sea birds and mammals, namely penguins and seals, and regions of the continent which are more readily accessible for research efforts, such as Maritime Antarctica (Jones et al, in prep). Biological communities that do not fall within these categories are either under monitored, or not monitored at all.

Development of an Antarctic wide observation system, as proposed by ANTOS, aims to close the gaps in current monitoring, harmonising data collection protocols, facilitating data sharing and international collaborations. To combat biases in monitoring locations, proposed monitoring sites will focus on biodiversity hotspots, be evenly distributed and represent all 16 Antarctic Conservation Biogeographic Regions (Terauds and Lee 2016). Modern instrumentation and satellite communications would allow access to real-time data of both biodiversity health and the current environmental conditions. Through data sharing, the impact of sampling could be minimised through greater efficiency, saving time, effort, improving expedition outcomes and protecting Antarctica's precious biodiversity.

If we had an Antarctic-wide monitoring system, we would already know how Antarctic ecosystems responded to the 2020 heatwave! It would mean that school children around the globe could study Antarctica from their schools, and the public could engage in Antarctic citizen science from home. They would see how climate change is impacting the icy continent firsthand. Thirty years ago, the Environmental Protocol designated Antarctica as a "natural reserve, devoted to peace and science", ANTOS could make Antarctic science open to all.

Figure 3 The international NSF/INACH project team, led by Profesora Angelica Casanova-Katny, working at the Collins Glacier field site, where open top chambers simulate climate change by warming the air surrounding the mosses. The team pictured here include researchers from the University of Wollongong, Portland State University and Universidad de Catolica de Temuco. Picture by Andrew Netherwood at Collins Field Site, January 2015.

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