



Peatbank response to late Holocene temperature and hydroclimate change in the western Antarctic Peninsula

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ABSTRACT

The western Antarctic Peninsula experienced rapid warming in the second half of the 20th century, which has increased vascular plant abundance and moss productivity. To better understand long-term ecological responses, we used paleoecological and microclimate data to investigate dynamics of late-Holocene peatbank development and landscape influences. In peatbank cores from three locations on Litchfield Island (64°46'S; 64°06'W) high-resolution plant macrofossil and geochemical analysis show contrasting ecological and environmental changes. Two peatbanks on the southwest- and west-facing slopes of two separate hills are about 500 years old in contrast to a north-facing peatbank that is 2700 years old. The period from 1350 to 450 calibrated years before present (cal yr BP) at the north-facing peatbank had low accumulation (0.25 mm yr⁻¹, 36 g OM m⁻² yr⁻¹), which we interpret as a period of low temperature and increased snow cover. Microclimate differences were amplified by this regional climate cooling, causing the delayed peat initiation on non-equator-facing slopes. Over the last 500 years, the north-facing peatbank had an accumulation rate (0.7 mm yr⁻¹, 76 g OM m⁻² yr⁻¹) that was lower than the southwest- and west-facing peatbanks (1–1.4 mm yr⁻¹, 97–110 g OM m⁻² yr⁻¹). Microclimate data suggest that slope aspect on Litchfield Island influences soil temperature, snow cover, and water availability that in turn affect growing-season lengths and peat accumulation. Plant macrofossils preserved in the north- and west-facing peatbanks show a centennial-scale pattern of fluctuation in relative abundance of dry-adapted *Polytrichum strictum* and wetter *Chorisodontium aciphyllum* mosses. Our results suggest that moss communities responded to external environmental influence, particularly those affecting moisture conditions, while topography and resultant microclimate differences had a strong influence on peat accumulation.

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1. Introduction

The western Antarctic Peninsula (AP) has undergone a rapid increase in temperature in the second half of the 20th century. Over the last several decades, the warming trend on the western AP is nearly five times greater than the global average (Vaughan et al., 2003). This trend is driven mostly by winter warming (Turner et al., 2013), but there is an absence of this trend into the 21st century due to large-magnitude natural climate variability over the Peninsula (Turner et al., 2016). A driving force of regional climate on the western AP is the Southern Annular Mode (SAM), described as a

zonal mean pressure difference between ~40 and ~65 °S that exhibits decadal-scale variations (Marshall, 2003). For instance, a positive SAM intensifies the westerlies over the mid- to high-latitudes (50–70 °S), leading to a southern shift in regional storm tracks and changes in the regional moisture source to the Bellingshausen Sea (Marshall et al., 2006). In general, a positive SAM is responsible for increased summer warming and precipitation in the western AP (Thomas et al., 2008). A reconstruction of the evolution of the SAM over the past 1000 years shows that since ~1950 AD the index has been at its most positive level (Abram et al., 2014). This extended positive phase may influence terrestrial ecosystems along the western AP coastline and islands.

A multitude of studies have documented recent changes in terrestrial ecosystems in the western AP, mostly in response to climate warming. For example, moss growth rates and microbial

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activity in peatbanks have increased since the 1960s (Royles et al., 2013; Amesbury et al., 2017). Carbon accumulation rates in *Polytrichum strictum* peatbanks have also increased due to warmer and wetter conditions since the 1980s (Yu et al., 2016). Vascular plant species *Deschampsia antarctica* and *Colobanthus quitensis* have become more abundant across the western AP region (Fowbert and Smith, 1994; Smith, 1994; Convey et al., 2011) but appears to show less increase since the late 1990s (Parnikoza et al., 2009), possibly due to the absence of further warming over the past two decades (Turner et al., 2016). Although some modern response to warming has been documented, it is not well understood how terrestrial ecosystems have responded to climate change over the last few millennia.

The limited number of climate records available from the AP show complex and oftentimes opposite patterns during the late Holocene. For example, the marine record from Palmer Deep shows up to 3 °C sea surface temperature (SST) warming from 1600 to 500 calibrated years before present (cal yr BP) (Domack et al., 2001; Shevenell et al., 2011). In contrast, at Cape Rasmussen on the western AP, Yu et al. (2016) found *Deschampsia* dominated peat deposits buried under a *Polytrichum* peatbank, which suggest a warmer climate between 2300 and 1200 cal yr BP. In the eastern AP, which is generally considered to have opposite climate patterns than the western AP (Kwok and Comiso, 2002), cooling from 2500 to 600 cal yr BP has been found in the James Ross Island ice core record (Mulvaney et al., 2012). These records indicate that paleoclimate interpretations in the AP vary greatly depending on types of proxies and archives (e.g., terrestrial, marine or ice-core records), and other local or regional factors, including ocean and atmospheric circulation, or topography.

The overall goal of this study is to use the paleoecological and geochemical data from western AP peat deposits from Litchfield Island, near Palmer Station, to assess the sensitivity of these ecosystems to changing climate to better understand the trajectory of high-latitude terrestrial ecosystems under ongoing and future environmental changes. The objectives of this study were to (1) derive a high-resolution, multi-proxy record of late Holocene peatbank ecological history, (2) identify past changes in peat physical and geochemical properties, (3) link those changes to potential allogenic and autogenic factors impacting peatbank ecosystem dynamics, and (4) assess moss peatbank sensitivity to climate change.

2. Study region

The Maritime Antarctic biogeographic region is characterized by simple ecosystems dominated by bryophytes, lichens, and two vascular plant species (Longton, 1967; Gimingham, 1967). This region encompasses Graham and Palmer Lands, and nearby islands including Anvers, the Argentines, Adelaide, the northern portion of Alexander, the South Shetlands, and the South Orkneys (Fig. 1A). The climate in the study region is strongly influenced by the westerly wind belt that brings moist air, providing precipitation in the form of rain or snow at any time of the year (Marshall et al., 2006). The Maritime Antarctic is subjected to milder weather than the continental Antarctic and is characterized by approximately 10,000 km² of ice-free land area (Bockheim and Haus, 2014), with some turf-forming species such as *Polytrichum strictum* and associated moss deposits being found as far south as 69 °S (Convey et al., 2011; Royles et al., 2013).

2.1. *Polytrichum* – *Chorisodontium* peatbank ecosystem

Peatbanks are deposits of moss where decomposition is inhibited by cold temperatures, rather than high water table and waterlogged conditions. These systems are typically found in high-

latitude regions such as the western AP (Fenton and Smith, 1982). The slow, yet continuous accumulation of moss organic material over time makes peatbanks natural archives for past climate changes, particularly in the low-lying coastal regions of the Maritime Antarctic, where they can be over 5000 years old (Fenton, 1980; Björck et al., 1991; Royles et al., 2012). However, their description as true peat, as opposed to simply communities of frozen moss, has been brought into question because of the exceptional preservation, and possibly continued growth after being thawed (Roads et al., 2014).

In Antarctica, the two moss species, *Polytrichum strictum* and *Chorisodontium aciphyllum*, are dominant in these peatbanks. Photosynthesis response curves for *C. aciphyllum* and *P. strictum* show that these species are psychrotolerant—they can survive cold temperatures, but growth increases with temperature. For example, while gross photosynthesis of *Polytrichum* has been shown to increase with temperature up to 20 °C (Davey and Rothery, 1997), it can also survive extremely cold temperatures, down to –20 °C, without unreparable damage (Kennedy, 1993). These attributes suggest that *Polytrichum* productivity increases with increasing temperatures and growing season length.

In addition to being subjected to cold weather, mosses on the AP can experience a wide variation in moisture conditions. In general, bryophytes depend on a moisture boundary layer to facilitate CO₂ uptake, and desiccated conditions will cause cessation of metabolic processes (Royles et al., 2014). While *Polytrichum* has specific adaptations, such as photosynthetic lamellae, that facilitate gas exchange under a wider range of moisture conditions, *Chorisodontium* may be more sensitive to desiccation (Royles et al., 2012). Also, *Polytrichum* has a hydrome-leptome system that functions like the xylem and phloem in higher plants (Schofield, 1981) as well as tomentum, a thick mass of fine rhizoids, that fills the interstices adding structure to the moss turf, and allows the plants to maintain adequate moisture levels (Collins, 1976). *Polytrichum* transports water from below with capillary action of the tomentum, while *Chorisodontium* requires precipitation, acquiring its water by transporting surface moisture from its apices (Longton, 1967). In summary, for AP moss-dominated ecosystems, *Polytrichum* is found in drier environments while *Chorisodontium* is generally found in wetter locations (Longton, 1979; Smith, 1982; Ochyra et al., 2008; Royles and Griffiths, 2015).

On the AP, *Chorisodontium* is more abundant farther north (more equatorward) than *Polytrichum*, which is found as far south as 69 °S (Ochyra et al., 2008; Convey et al., 2011; Royles et al., 2013, 2016). Where their ranges overlap we know that *Polytrichum-Chorisodontium* peatbank ecosystems can be in a constant state of flux, with shoot turnover from *Chorisodontium* to *Polytrichum* linked to water stress and micro-habitat (Collins, 1976). Our current understanding of the relationship between peatbank species is that wetter species such as *Chorisodontium* are the primary initiators of peatbanks, while *Polytrichum* typically grows in drier sites or on pre-existing *Chorisodontium* turf (Fenton and Smith, 1982) as expected by autogenic sequence of ecological succession. For example, Fenton and Smith (1982) found that moss turves that form on terrain with a regular supply of groundwater were dominated by *Chorisodontium*, while *Polytrichum* established on existing *Chorisodontium* turf or drier substrates. This successional pattern is observed in multiple peatbank records from the western AP (Collins, 1976; Royles, 2012; Yu et al., 2016). In this region and nearby subantarctic islands, records derived from moss peatbanks have been used for paleoclimate research based on plant macrofossils (Van der Putten et al., 2009), stable isotopes, and microfossil assemblages such as testate amoebae (Royles et al., 2016; Amesbury et al., 2017). This research into the developmental ecology of peatbanks and the expected competitive responses of

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