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Holocene peatland carbon dynamics in Patagonia

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ABSTRACT

Patagonian peatland ecosystems have received very little attention in the scientific literature despite their widespread distribution in the regional landscape and the anthropogenic pressure they experience from the peat extraction industry. The functioning of these southern peatlands is strikingly similar to that of northern peatlands, but they have developed under very different climate boundary conditions. Therefore, studying these ecosystems provides a unique opportunity to test ideas and hypotheses about the sensitivity of carbon-rich peat accumulating ecosystems to climate change, in addition to filling significant data and knowledge gaps. Here we provide a synthesis of detailed peat accumulation records for southern Patagonia using a combination of new peat-core analysis (from 4 sites) and a data review from previously published studies (from 19 sites). We also present the modern climate space (temperature, precipitation, and seasonality ranges) of Patagonian peatlands on the basis of modern peatland distribution and gridded climate data to discuss climate controls of Patagonian peatlands at the present and in the past by inference. Results indicated that Patagonian peatlands occupy a distinct climatological niche that corresponds to an end-member of the northern peatland climate domain, with a mild mean annual temperature (from 3 to 9 °C) and very weak temperature seasonality. We also found that Patagonian peatlands have been efficient land carbon sinks since their initiation, with a mean soil carbon density of 168 kg C m^{-2} ± 10%. The total carbon pool for these ecosystems was estimated at 7.6 GtC. Modeled peat addition rates to the catotelm in Patagonian peatlands were significantly higher than what has been reported for northern peatlands, but decay coefficients were similar between these two high-latitude regions. These results support the idea that long, mild growing seasons promote peat formation in southern Patagonia. At the regional scale however, the lack of correlation between climatic parameters and peat accumulation indices suggests that autogenic controlling factors might be at play. Overall, southern peatlands provide a unique opportunity for studying peatland–carbon–climate linkages under a new set of climatic conditions.

1. Introduction

Peat-accumulating wetlands cover extensive areas of the boreal, austral, and subarctic regions of the world. In addition to storing about 10% of the world's freshwater (Martini et al., 2006), northern peatlands are globally important as they constitute one of the largest carbon (C) pools in the biosphere (500 ± 100 gigatons of C (GtC); Gorham, 1991; Yu et al., 2010; Yu, 2012). Since the last deglaciation (~15 ka; 1 ka = 1000 calibrated years before present), these ecosystems have also played a dynamic role in the global C cycle by acting as carbon dioxide (CO_2) sinks and methane (CH_4) sources to the atmosphere (MacDonald et al., 2006; Frolking and Roulet, 2007; Gorham et al., 2007; Korhola et al., 2010; Yu, 2011). However, as peat–C sequestration and peat–C fluxes are sensitive to the regional climate (e.g., Aaby, 1976; Barber, 1981; Chambers and Charman, 2004; Jones and Yu, 2010), their contribution to the atmospheric CO_2 and CH_4 concentrations has varied significantly over time (Yu, 2011; Charman et al., 2013), raising concern about the fate of these large C reservoirs in a warmer world (Yu et al., 2011).

A recent review indicated that the role of peatlands for the 21st century will probably be that of a relatively small (0.2 GtC yr^{-1}), but persistent contributor to the atmospheric CO_2 and CH_4 burdens, with occasional large pulses due to droughts, fires, and permafrost thaw (Frolking et al., 2011). For example, peatland fires in Indonesia have released 1–2 GtC in 1997 alone (Page et al., 2002). Catastrophic scenarios involving rapid and large C losses to the atmosphere due to permafrost thaw and drought (up to 10 GtC yr^{-1}) have also been proposed (e.g., Ise et al., 2008; Dorrepaal et al., 2009; Fenner and Freeman, 2011). Overall, it can be said that climatically-induced alterations of the peatland C-sink capacity have happened in the past and will also take place in the future, but the sign and

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magnitude of this climate feedback remains uncertain. To alleviate such uncertainties, it appears evident that peatland ecosystems must be better understood in their full complexity to allow for realistic peat–carbon–climate model predictions (see Belyea and Baird, 2006). In addition, new databases of peat–C accumulation in understudied, peatland-rich regions would better inform the community on the climate sensitivity of peat–C sequestration by providing datasets for new portions of the peatland domain.

Here we present the first Holocene peat–C sequestration history of Patagonian peatlands as a means to expand our current knowledge on global peatland dynamics and linkages to climatic conditions. Patagonian peatlands are strikingly similar to their northern counterparts in terms of structure and functioning (see Section 2; Rydin and Jeglum, 2006), but these southern ecosystems have developed under very different climate boundary conditions from northern peatlands. Therefore, we argue that southern peatlands provide a unique opportunity to test ideas and hypotheses about the sensitivity of high-latitude, C-rich peatland ecosystems to past and ongoing changes in climate. We provide a synthesis of detailed peat–C accumulation records for southern Patagonia using a combination of new peat-core analysis (4 sites) and a data compilation from previously published studies (19 sites). This analysis fills significant data and knowledge gaps on Holocene C dynamics in this region, as data on peatland initiation, peat–C measurements, and C accumulation rates remain sparse in southern Patagonia and in the southern hemisphere in general (but see Yu et al., 2010). Secondly, we examine the Patagonian peatland climate space (temperature, moisture, and temperature seasonality parameters) and compare it to the northern peatland climate domain to discuss inter-hemispheric differences in modern peatland distribution on the basis of climatological parameters, as well as to assess the potential control of climate on long-term peat–C sequestration patterns under the assumption that similar differences in climate conditions at different sites existed in the past (see Clymo et al., 1998). To our knowledge, this is the first climate envelope analysis for Patagonian peatlands. Thirdly, we use an exponential decay model (Clymo, 1984) to estimate long-term peat addition rate (PAR) and peat decay coefficient (α) for all 23 sites, which are then compared to values from northern peatlands. Overall, these results should be particularly useful for testing and validating peatland ecosystem models, in addition to providing new information to policy makers, stakeholders and conservation groups that are evaluating the importance of Patagonian peatlands at the regional scale.

2. Distribution and ecology of Patagonian peatlands

In southernmost South America (45–55°S), peatlands today cover about 45,000 km^2, roughly equivalent to 25% of the landmass (Fig. 1; Pisano, 1983; Arroyo et al., 2005; Grootjans et al., 2010; Yu et al., 2010). Throughout the region, peatland complexes have developed following the last deglaciation, around

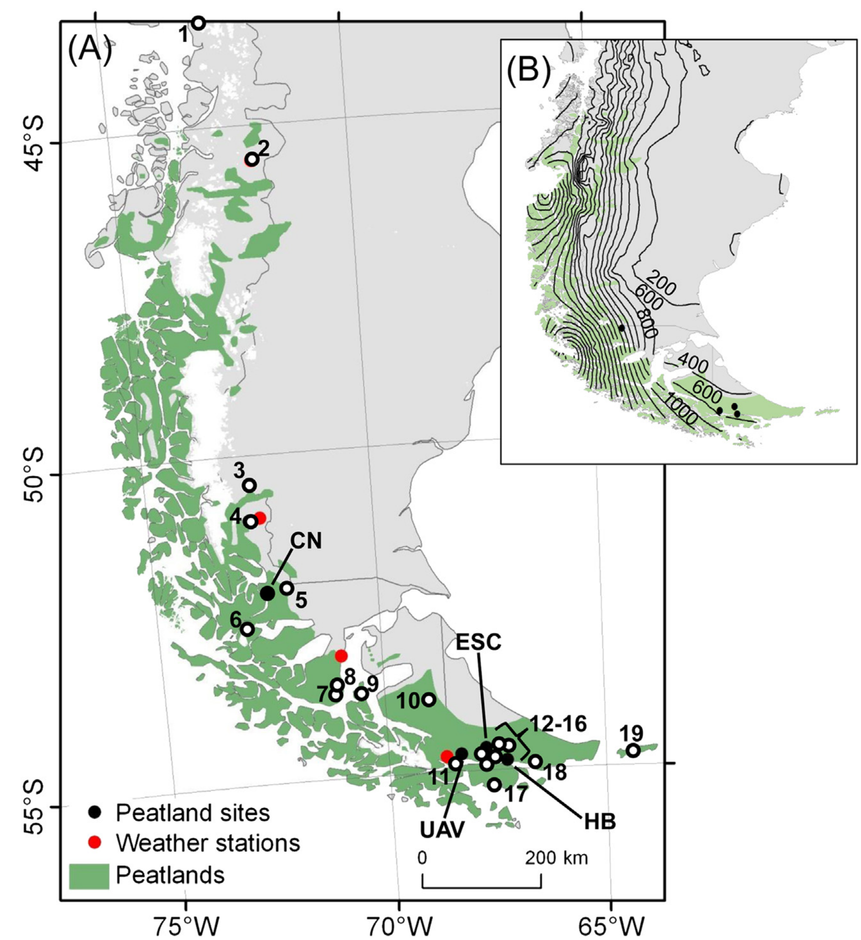

Fig. 1. Location maps and study sites. (A) Map of southern Patagonia, South America, showing the distribution of southern peatlands (green area; from Yu et al., 2010), as well as the location of weather stations (red dots), our 4 new study sites (black dots), and the 19 sites from the literature review (white dots; site ID is the same as in Table 3). (B) Map of southern Patagonia showing mean annual precipitation isohyets for the period 1961–1990 (data from New et al., 2002).