Editorial: Peatlands - paleoenvironments and carbon dynamics

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Some of the earliest records of global change came from peatland archives. As early as 1837, Japetus Steenstrup published stratigraphic and macrobotanical analyses of Danish bogs. His study not only inspired the pioneering paleoclimatology of Blytt and Sernander later in the century, but had more immediate influence on Lyell, Darwin and Forbes, supporting their conclusions from biogeographic patterns that Europe had undergone significant climate changes not long before.

Peatlands remain an important paleoenvironmental archive. They combine relatively rapid accumulation rates, copious in situ organic material, hydroclimatic sensitivity, and diverse paleoenvironmental proxies to provide a rich store of environmental history over much of the globe (Fig. 1). Furthermore, the peat that provides the archives plays a key role in the global carbon cycle as one of the largest soil carbon stores on Earth. This issue of *PAGES news* highlights recent and ongoing applications of peatland archives to important problems in paleoclimatology, human activities, and global carbon dynamics. Development of this special issue was inspired in part by discussions at an international peatland-archives workshop in Estonia in May 2009, jointly sponsored by PAGES, INQUA, Quaternary Research Association, U.S. National Science Foundation, and the University of Tartu.

Until recently, most peatland paleoclimate research has been concentrated in Europe, where density and distribution of peatland records is sufficient to support synoptic-scale studies. In the opening article, Frank Chambers and colleagues describe results from the ACCROTELM synthesis of late Holocene European multi-proxy records, showing spatial coherence in major hydrological change that corresponds to independent lake-level records. Peatland archives are now also being increasingly exploited in paleoclimate studies in North America. Robert Booth and colleagues show that Medieval-period drought was much more extensive than previously thought, and explore links to broader changes in sea surface temperature variability. They describe a developing synoptic network of peatland records, deliberately designed to test specific hypotheses concerning mechanisms underlying late Holocene drought occurrence and climate dynamics.

Many peatlands offer extraordinary opportunities for high-precision chronologies, by virtue of their rapid accumulation, lack of sediment mixing, and abundant carbon for dating. Maarten Blaauw and colleagues have used peatlands for the development of new statistical approaches based on wiggle-matching of chronologies that provide narrowed and better-defined uncertainty estimates. Here, they show a powerful application of this approach to enable probability estimates for synchroneity in events recorded in independently derived records. Although these techniques have been developed and tested on peat sequences, they have broad applicability to other sedimentary archives. Coupling of highly resolved chronologies with proxy data can yield decadal-precision records spanning several millennia. Van Geel and Mauquoy apply such peatland chronologies to assess the influence of late Holocene solar variability on climate of northern Europe. Finally, in the field of paleoclimate research, attention is turning to the potential for testing and calibrating high-resolution records against instrumental climate data. Lamentowicz and colleagues describe one such application from a high-precision peatland record from the Swiss Alps.

These studies all utilize well-established peatland proxies: plant macrofossils, testate amoebae, humification indices, and pollen. An emerging frontier in peatland research is the application of organic and inorganic geochemistry and stable-isotope analysis. Erin McClymont and colleagues describe recent advances in organic geochemistry and compound-specific analysis of stable isotope proxies in peatlands. These analytical advances are opening a wide array of opportunities for refined paleoenvironmental inference from peatlands, including reconstruction of temperature, hydrology, and carbon cycle processes such as methanogenesis. Bing Hong and colleagues provide an application of compound-specific stable-isotope analysis to the important and topical question of Holocene history of the Asian monsoon systems, using $\delta^{13}C$ and $\delta^{18}O$ analyses of sedge peat in China. François De Vleeschouwer and colleagues present a different geochemical perspective: analysis of trace metals (particularly lead) in European peatlands to identify background flux and deposition from human activities.

Peatlands are important in the Earth system as a vast carbon store, providing a very large long-term sink of carbon dioxide, but also acting as a source of methane. They have a higher carbon density

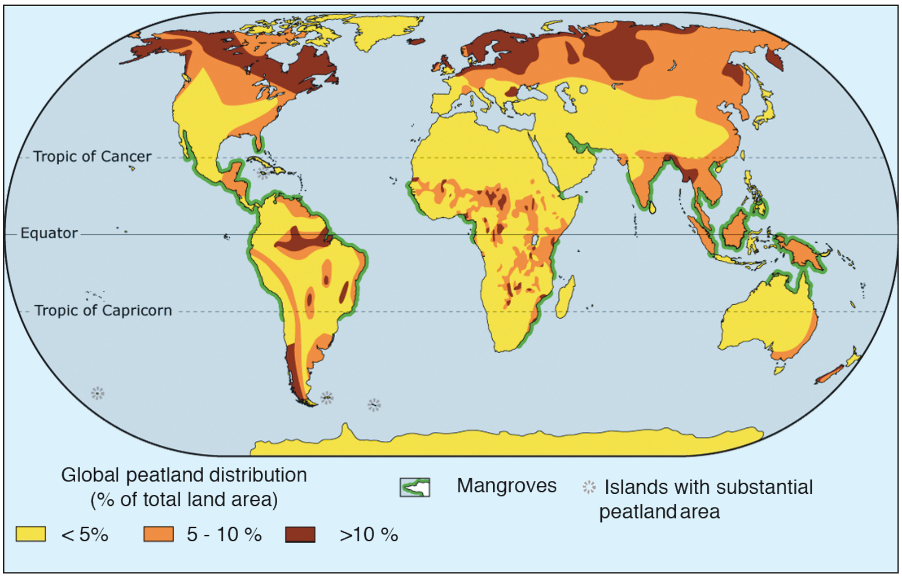

Figure 1: Generalized distribution map showing main areas of peatland occurrence expressed as a proportion of the landscape covered. Much of the existing work on peatland archives of past change has been concentrated in Europe and North America but other regions hold considerable potential. Even in areas where peatlands occupy only a limited proportion of the landscape, small peatlands often occur in hydrologically and microclimatically suitable locations. Based on Lappalainen (1996) and Charman (2002).

than any other ecosystem, globally comprising some 550 Gt C. As such, they comprise a vital component of the global carbon budget, and by providing time-series of site-specific carbon accumulation they can also play an important role in understanding many of the controls and feedbacks in global carbon dynamics. David Beilman and colleagues discuss the role of northern peatlands as carbon sinks during the Holocene, and reveal new insights into the contribution of these vast peatlands to the global carbon cycle emerging from analysis of large-scale patterns of peat accumulation and spread over time. Tropical peatlands are not as well known as northern and boreal peatlands, but are receiving increasing attention in view of their very high carbon density and potential for human- and climate-driven conversion from atmospheric sinks to sources. Sue Page and colleagues discuss the extensive peatlands of Southeast Asia in this context and demonstrate the severity of impacts on the global atmosphere when such carbon-rich ecosystems are disturbed. Many tropical peatlands remain undiscovered or imperfectly known. Outi Lähteenoja and Katherine Roucoux describe recently discovered ombrotrophic (precipitation-fed) peatlands in the Upper Amazon basin, and discuss their importance for carbon cycling and their scientific potential as paleo-archives.

The interactions among climate, carbon and peatlands are complex, and there are substantial risks of unexpected feedbacks and rapid transformations. Understanding these interactions will require increasing engagement between the peatland paleoscience community and scientists studying processes of gas exchange and energetics in modern peatlands and related ecosystems. The final paper by Torben Christensen and colleagues highlights improved understanding of methane dynamics in peatlands in permafrost regions and argues for greater integration of process studies with peatland paleoscience to better understand methane flux in high-latitude settings. This argument is broadly applicable to peatlands throughout the world; linking process and paleo-studies in peatlands will help advance our understanding of peatland dynamics, climate variability and the risks of unwelcome carbon-cycle feedbacks in the centuries ahead.

References

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Peatland archives of late-Holocene climate change in northern Europe

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Peatland archives in northern Europe now provide multi-proxy decadal records of past environmental change for the mid and late Holocene.

Peatlands in northern Europe have long been recognized as a climate archive, yielding the first climatostratigraphic division of the Holocene—the Blytt–Sernander scheme (Blytt, 1876; Sernander, 1908); however, their detailed exploitation awaited refutation of long-standing misconceptions about bog growth (cf., Backéus, 1990). Barber (1981) proposed instead that ombrotrophic (precipitation-fed) bogs provide a continuous record of past hydrological change, because they are "directly coupled" to the atmosphere. Though omitted as a climate archive from Bradley's (1999) compendium of paleoclimatology, studies on peat bogs have since gained greater prominence (Chambers and Charman, 2004); a wide array of climate proxies has been developed, involving an increasing number of specialists from a range of disciplines (de Jong et al., in press).

European peat–climate research has concentrated on blanket bogs (e.g., western Ireland; UK uplands; western Norway) and raised bogs (e.g., central Ireland; Britain; Denmark; northern Germany; southern Sweden; Estonia; southern Finland; Poland; Czech Republic). High rainfall, typically >1250 mm a^{-1}, sustains the blanket bogs, but raised bogs exist in areas of much lower precipitation. The latter owe their origin to low relief and impeded drainage, but their domed growing surfaces are (like blanket bogs) hydrologically isolated from groundwater. Some 90% of the mass of an actively growing bog is water, held mainly in the anoxic catotelm (bottom layer of peat permanently below the water table) where decay processes are markedly reduced compared with the thin upper layer of the bog, the acrotelm, which experiences a seasonally fluctuating water table, and in dry conditions can experience much higher decay rates.

ACCROTELM project

To examine the synchronicity, direction, magnitude, rate and causes of past climate changes in northern Europe, a recent, European Commission-funded project "Abrupt Climate Changes Recorded Over The European Land Mass" (ACCROTELM; Chambers et al., 2007a) included an East–West transect of ombrotrophic bogs, from Estonia and Finland to Ireland, for which proxy-climate data were generated for up to the past 4.5 ka. The E–W transect extended across the Atlantic to Newfoundland (Hughes et al., 2006), while a bog in northern Spain was included at the southern ombrotrophic limit. Lake sites also featured, allowing comparison with data on changing lake levels in west-central Europe (Magny, 2006).

ACCROTELM researchers developed and applied revised protocols of three proxy-climate measures in "multi-proxy" studies of the bogs: (1) the degree of peat humification—largely a measure of the decay rate of peat before becoming incorporated in the permanently saturated catotelm (cf., Aaby and Tauber, 1975; Aaby, 1976; Blackford and Chambers, 1993; Borgmark, 2005); (2) quantitative leaf count macrofossil analysis (QLCMA) of vegetation remains in the peat—reflecting the former surface plant community (Barber et al., 1994; McClymont et al., 2008, 2009); and (3) the species assemblage of testate amoebae—used to estimate water-table depth, calibrated using a transfer function from modern "training sets" (Charman et al., 2007). Each proxy is (to a greater or lesser degree) dependent on the prevailing environmental conditions at the time of peat formation, and reflects (with some caveats) past climate. These three principal measures provided a continuous record of past climate change, with dating provided by AMS ^{14}C (Yeloff et al., 2006), ^{210}Pb and spheroidal carbonaceous particles.