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CARBON ACCUMULATION SHOWS THE INTERPLAY BETWEEN THE NATURALSUCCESSION OF MIRES AND CLIMATE CHANGE

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SUMMARY

Holocene carbon accumulation was examined from 41 peat profiles throughout Finland and Russian Karelia, and climate variability was interpreted using records of carbon accumulation rates from three raised bogs in southern Finland and one near the White Sea in Russian Karelia. Natural succession, interacting with local factors and climate, leads to differences in vegetation species composition and thus in the productivity of the resulting vegetation types. In sedge-dominated northern aapa mires, the natural development of mires and changes in the vegetation conditions have contributed more to the decreasing trend in carbon accumulation than climatic factors. The stratigraphy of raised bogs suggests that carbon exchange and accumulation have always been sensitive to the climatic fluctuations that have characterized the entire Holocene. A comparison was also made with a raised bog in the coastal area of the White Sea in Russian Karelia, which revealed a similar trend in carbon accumulation to that in the Finnish data, thus suggesting that climate fluctuations are the driving force and overshadow local factors.

KEY WORDS: carbon accumulation, climate, peatlands, Holocene, Finland, Russian Karelia

MATERIALS AND METHODS

Holocene carbon accumulation was examined throughout Finland and Russian Karelia in 41 peat profiles from 21 mires. Climate variability was interpreted using records of carbon accumulation rates in five peat profiles from three pristine raised bogs in southern Finland and one near the White Sea in Russian Karelia (Fig. 1). The carbon accumulation was calculated using peat columns of known dry bulk density, carbon content and age.

The homogeneity and age of peat deposits is of primary importance when studying the carbon accumulation dynamics in different periods of the Holocene. Mires provide widespread material for palaeoenvironmental analysis covering the Holocene (van Geel 1978, Barber *et al*. 2004, Mäkilä and Saarnisto 2008). The purpose of the present article is to illustrate how carbon accumulation shows the interplay between the natural succession of mires and climate change.

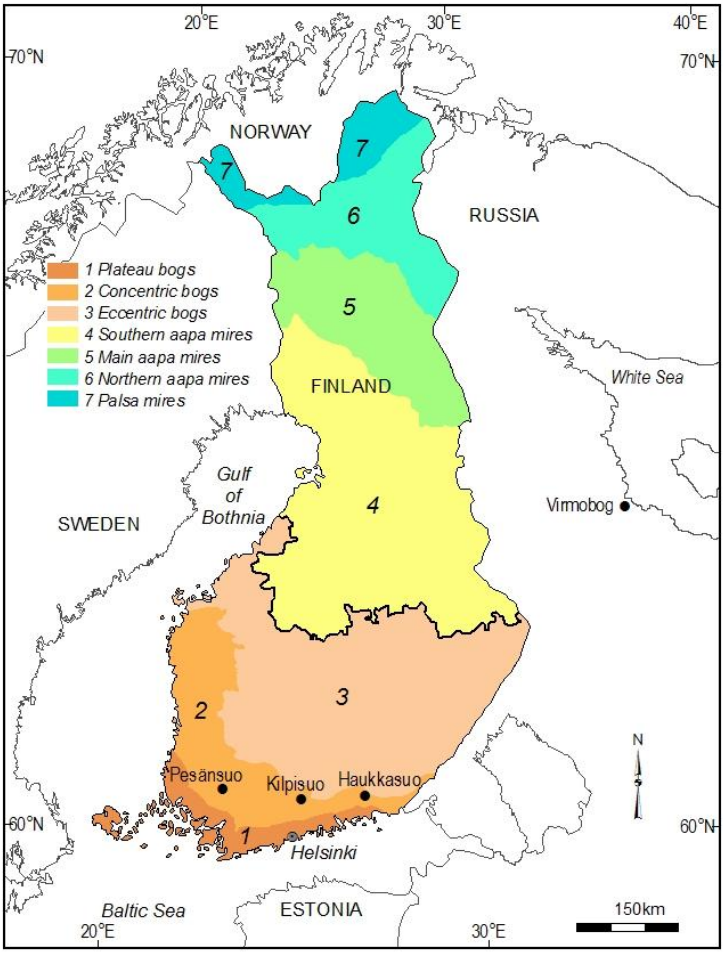

Figure 1. Locations of the study bogs and the regional distribution of the mire complex type regions of Finland according to Ruuhijärvi and Hosiaisluoma (1989). The raised bog region occurs to the south of the black line (regions 1–3) and the aapa mire area to the north (regions 4–7).

Peat deposits are mainly autochthonous and relatively suitable for dating with radiocarbon, especially when mosses dominate the peat. *Sphagnum* (moss) and *Carex* (sedge) peat form in different ways (Mäkilä 2011). *Sphagnum* moss grows from the apical bud, and the lower parts of stems die and form peat (Fig. 2). In *Carex* peat (and also in the formation of peat due to the decay of other vascular plants), the most important constituents are roots (Fig. 3). A certain proportion of roots dies and regenerates, so besides living roots there are also dead roots of different ages in the same peat unit. All roots eventually die and form peat.

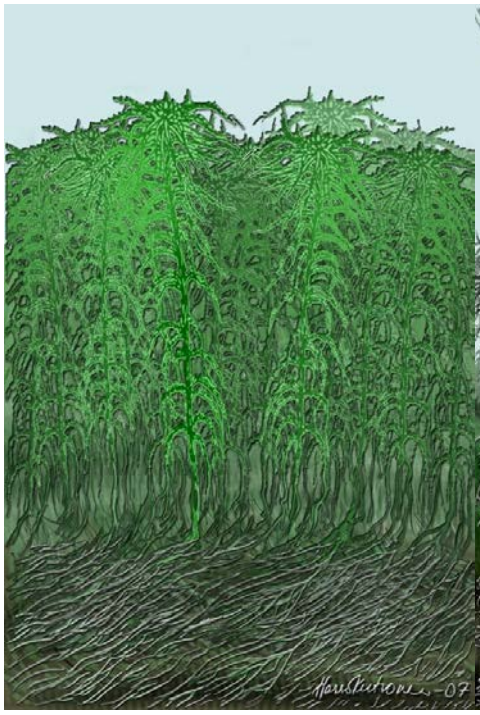

Figure 2. Formation of *Sphagnum* peat. Picture drawn by Harri Kutvonen.

Figure 3. Formation of *Carex* peat. Picture drawn by Harri Kutvonen.

RESULTS

Actual rate of carbon accumulation (ARCA)

The high carbon accumulation in the surface layers of mires is temporary and mainly related to the development of the mire. Only sub-surface carbon accumulation rates can indicate any

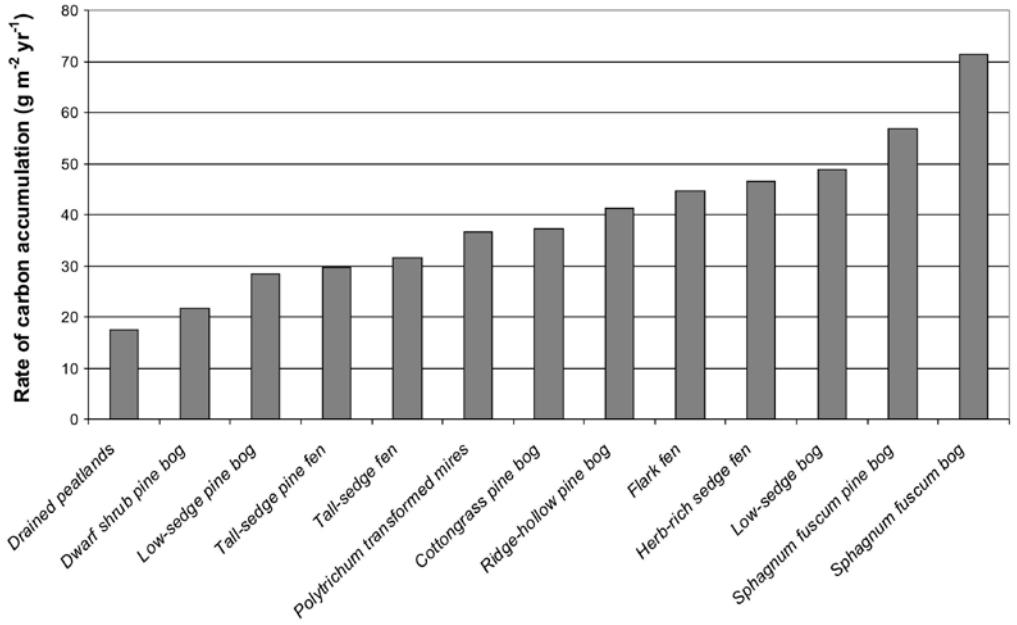

Figure 4. The average carbon accumulation rate in layers younger than 300 years in relation to the mire site type.

real (delayed) long-term trends in net carbon accumulation rates, which incorporate the effects of autogenetic development of the mire and climatic change on primary production and decomposition in the surface layers of mires. The highest carbon accumulation rates in layers younger than 300 years were measured in ombrotrophic mire site types *Sphagnum fuscum* bog and *Sphagnum fuscum* pine bog (Mäkilä & Goslar 2008), (Fig. 4). Wet oligrotrophic and minerotrophic treeless mire site types came next. The lowest carbon accumulation was recorded in the most transformed, sparcely forested and forested mire site types. These mires have the lowest water table.

Long-term apparent rate of carbon accumulation (LARCA)

The long-term carbon accumulation of mires has always varied due to different climate periods, mire developmental stages, geographical locations and mire fires (Mäkilä 1997, Mäkilä *et al*. 2001, Heikkilä *et al*. 2006, Mäkilä and Moisanen 2007, Mäkilä and Saarnisto 2008). Hydrological, topographical and edaphic factors have mainly controlled variations in the carbon accumulation of aapa mires. As long as litter accumulates under anoxic conditions below the water table, peat accumulation rates mostly depend on organic matter production, and thus on the fertility of the mire water (e.g. Damman 1996). After the most productive initial stages of development, net carbon accumulation rates in mires generally decline (Mäkilä *et al*. 2001, Mäkilä & Moisanen 2007). The carbon accumulation of the sedge peat became slower in the mires (Fig. 5) during the warmest period of the Holocene 9000-6000 years ago.

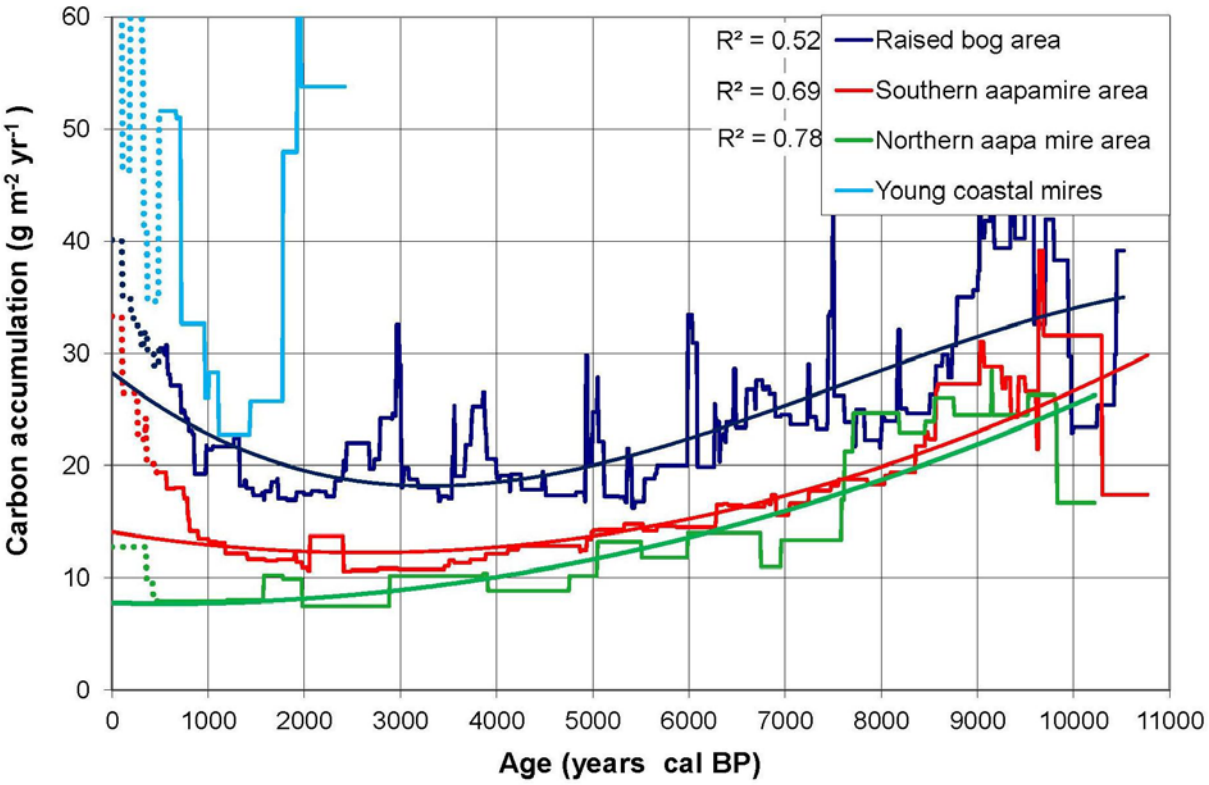

Figure 5. Carbon accumulation rates in raised bog regions, aapa mire regions and coastal mires.

In the future, it appears that carbon accumulation in surface layers will increase most in raised bogs with a dense cover of *Sphagnum fuscum* on hummocks (Fig. 5). There will also be slight increase in accumulation in southern aapa mires after the mires become overgrown with *Sphagnum*. In sedge-dominated northern aapa mires, the natural mire development and changes in the vegetation conditions have contributed more to the decreasing trend of carbon accumulation than climatic factors. In young coastal bogs, carbon accumulation is gradually decreasing, because they have mainly passed the early stage of their development.

Carbon accumulation versus climate change

High net carbon accumulation rates can be attributed to low decomposition rates and wet-inhabiting species associated with humid periods with a more positive precipitation–evaporation balance. A marked decline in the carbon accumulation rate may indicate a period with a relatively dry and warm climate (e.g. Mäkilä and Saarnisto 2008, Charman *et al*. 2008, Saarnisto 2009). Dry periods of this kind occurred, for example 6350–5950 and 4900–4600 years ago. Between the dry periods there was a moist period about 5000 years ago when carbon accumulation greatly increased (Fig. 6). Thereafter, the climate varied considerably with regard to precipitation and became cooler. The leveling-out and subsequent increase in carbon accumulation rates in the raised bog region after 4500 cal BP indicates the development of *Scheutzeria-Sphagnum* (section *Cuspidata*)-dominated plant associations connected with an increasingly humid climate. It was especially cold and moist 2600–2800 years ago, as revealed by the evidence from plant macrofossils of *Sphagnum* (section *Acutifolia*) and relatively low peat decomposition. Lower carbon accumulation rates between 1400–2400 cal BP may indicate a dry climate shown by more humified peat and charcoal layers in the studied bogs.

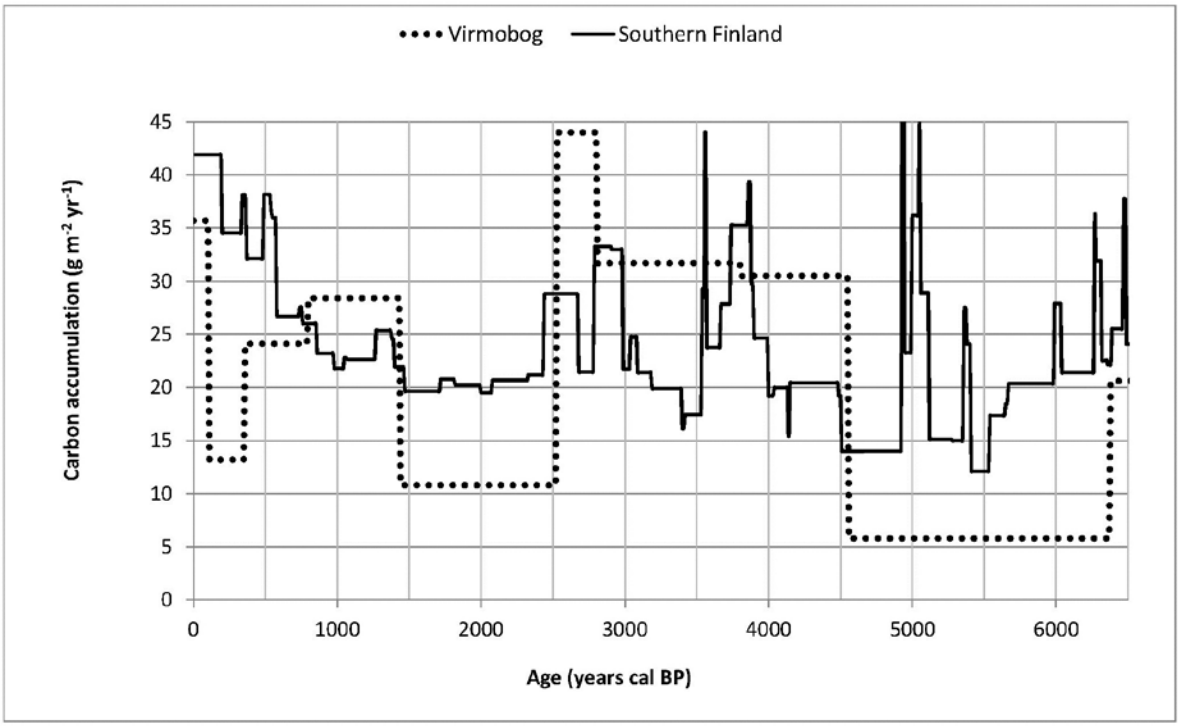

Figure 6. Average rate of long-term carbon accumulation during the last 6 600 years in three raised bogs in southern Finland and Virmobog near the White Sea in Russian Karelia.

CONCLUSIONS

Natural succession, interacting with local factors and climate, leads to differences in vegetation species composition and thus in the productivity of the resulting vegetation types. The surface layers of mires are still undergoing a rapid carbon cycle. This means that carbon accumulation rates measured in the uppermost layers cannot be used in estimating long-term carbon sequestration rates. In sedge-dominated aapa mires, the natural development of the mires and changes in the vegetation conditions have contributed more to the decreasing trend in carbon accumulation than climatic factors.

Sphagnum moss is more sensitive to changes in climate than *Carex* peat, and also more suitable for radiocarbon dating. The stratigraphy of raised bogs suggests that carbon exchange and accumulation have always been sensitive to the climatic fluctuations that have characterized the entire Holocene (Mäkilä and Saarnisto 2008). A comparison with a raised bog in the coastal area of the White Sea in Russian Karelia revealed a similar trend in carbon accumulation to that in the Finnish data, thus suggesting that climate fluctuations are the driving force and overshadow local factors.

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