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# Temperature sensitivity of decomposition in a peat profile

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ABSTRACT

Soil microbes favour easily decomposable organic compounds, and, consequently, soil organic matter tends to enrich with recalcitrant carbon compounds. In theory, this leads to an increasing temperature sensitivity of decomposition towards older fractions of soil organic matter. We tested this theory in a Sphagnum peat profile. This profile was particularly suitable for this purpose because the age of organic matter increased with depth. The age correlated closely with the degree of decomposition in the oxic layer and soil minerals did not interfere with the relationship between the age and the temperature sensitivity of decomposition. We sampled and analysed the peat profile by layer. We took laboratory measurements of chemical characteristics, decomposability and temperature sensitivity of decomposition. We used the bomb-$^{14}C$ isotopic tracer to differentiate the sources of respired $CO_2$ into age-classes and to estimate the temperature sensitivity of the oldest fraction in each layer. We also used the natural abundance ratio of stable carbon isotopes as an indicator of the recalcitrance of the decomposing carbon fraction. The measurements showed that the decomposition of the older and more recalcitrant carbon compounds was enhanced more in response to increasing temperature than was the decomposition of the younger and more labile compounds. Our results support the theory tested and indicate that the temperature sensitivity of decomposition increases with depth, age and recalcitrance in the oxic layer of the studied peat profile.



## 1. Introduction

Carbon preserved in soils forms an important dynamic reservoir of the global carbon cycle. The size of this reservoir depends on, on one hand, the input of photosynthetically produced plant biomass, and, on the other hand, the rate in which microbes and other heterotrophs decompose the organic matter and release carbon to the atmosphere. The sensitivity of these input and output processes to climatic variables is still poorly known. Better knowledge is crucial for predictions of future atmospheric greenhouse gas concentrations and climate change.

The decomposition rate of soil organic matter (OM) varies, among other things, according to the chemical quality of the decomposing substrate and is positively related to temperature (Kirschbaum, 1995). According to the kinetic theory, the temperature sensitivity of decomposition increases with an increasing recalcitrance and complexity of the carbon compounds (Bosatta and Ågren, 1999; Ågren and Bosatta, 1996). However, several mechanisms can modify this theoretical temperature sensitivity by physically or chemically restricting substrate availability in enzyme-catalysed decomposition reactions (Davidson and Janssens, 2006).

Soil organic matter is not a homogeneous pool but consists of multiple different compounds. Litter from different plants varies in chemical composition and size and thus in the rates of decomposition (Straková et al., 2010, 2012). In soil, the OM pool is further modified by microbial procession and additions of carbon of microbial origin (Lerch et al., 2011). As microbial respiration removes easily decomposed compounds from soil OM pool over time, the decomposition rate of the remaining OM tends to decrease (Berg, 2000). This should lead to an increasing temperature sensitivity of the remaining carbon in the absence of any interfering

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environmental constraints. A growing body of evidence suggests that the temperature sensitivity of decomposition increases with the age or recalcitrance of soil OM (Biasi et al., 2005; Boddy et al., 2008; Conant et al., 2008a, 2008b; Hartley and Ineson, 2008; Karhu et al., 2010; Vanhala et al., 2007). However, systematic measurements of the temperature sensitivity of different soil OM age classes are still scarce, possibly because of difficulties in measuring the temperature sensitivity of decomposition of recalcitrant, slowly decomposing carbon fractions or age classes without interference of labile compounds (Trumbore, 2000).

Peatlands represent one third of the total terrestrial carbon pools (Gorham, 1991). Aerobic decomposition occurs in the oxic upper peat layer that lies above the water table surface. Sequestration of the remaining OM is facilitated by the anoxic conditions that slow down the decomposition in the water saturated lower layer (Clymo et al., 1998). Aggregate formation or bonding to mineral surfaces, important mechanisms stabilizing OM in mineral soils (Dungait et al., 2012; Six et al., 2002) are negligible in peat due to an absence of minerals. It is therefore possible to assume that the chemical composition of carbon compounds is a major factor in defining OM decomposability in peatlands. A typical ombrotrophic peat soil consists of the remains of *Sphagnum* mosses growing upwards from the apex whereas underneath shoots no longer receiving light gradually die and begin to decay. Such vertical age gradient should result in an increase in compounds resistant to decomposition towards a greater depth in a peat profile.

Several studies have observed a decline in soil respiration rate with an increasing depth in soil and related this decline to OM quality (Hogg, 1993; Hogg et al., 1992; Leifeld et al., 2012; Scanlon and Moore, 2000). However, only a few studies we know of have studied the temperature sensitivity of peat decomposition in relation to OM quality (Scanlon and Moore, 2000; Yavitt et al., 2000), age (Hardie et al., 2011) or depth (Hardie et al., 2011; Scanlon and Moore, 2000). Peat depth is not, however, a straightforward indicator for OM quality in all peatlands. Vascular plants are almost always present and their roots may reach great depths even in anoxic conditions. If an age gradient is to be measured care must be taken in selecting the study site and peat type. Also the experimental set up should be designed so that the carbon dioxide ($CO_2$) emitted is not obscured by decomposition of labile new carbon.

Our aim was to estimate the temperature sensitivity of decomposition of peat soil organic carbon up to a few decades of age. We hypothesized that with the ageing of the peat the enrichment of recalcitrant carbon compounds makes the peat decomposition increasingly temperature sensitive. This is because in this environment, under aerobic conditions, decomposition is not limited by any interfering environmental factor. To test the hypothesis, we sampled a gradient of Sphagnum peat from the oxic surface layer. We divided the peat into layers that we assumed to have a different age of the oldest fraction and determined the temperature dependence of respiration for each layer by short term laboratory incubations. We used radiocarbon ($^{14}C$) as a tracer utilizing the “bomb” peak in the soil reservoir (Trumbore, 2009) to confirm the age gradient. Further, we separated the old, initial, carbon pool from the recent carbon pool as a source of respired $CO_2$, and estimated the temperature sensitivity of the old carbon pool in each layer based on $^{14}C$ measurements (Gaudinski et al., 2000; Karhu et al., 2010). In addition we used the natural abundance ratio of carbon stable isotopes $^{13}C/^{12}C$ to detect whether the shift in the age of the decomposing carbon source is accompanied with a shift towards more recalcitrant carbon sources (Biasi et al., 2005; Bol et al., 2003). This method is based on the systematic difference between isotopic signatures of soil OM constituents, recalcitrant compounds being more depleted than labile compounds (Bowling et al., 2008). These measurements were combined with an analysis of isotopic signature of the OM fractions and other analysis of the proportions of those fractions in the peat layers.

## 2. Materials and methods

### *2.1. Study site and sampling*

Our study site was in Lakkasuo, an eccentric raised bog complex in Central Finland (61°48′N, 24°19′E, ca. 150 m a.s.l) described in detail in Laine et al. (2004). We sampled a *Sphagnum fuscum* dominated bog in September 2011. The vascular vegetation at the site consisted of *Andromeda polifolia*, *Eriophorum vaginatum*, *Rubus chamaemorus*, *Vaccinium oxycoccos* and small *Pinus sylvestris*. We chose for sampling a *S. fuscum* hummock with as little vascular vegetation as possible. The sampled area was approximately 15 cm × 40 cm. The green parts of the *S. fuscum* and the aboveground vascular vegetation were clipped off. The peat was sampled by cutting off a piece from the surface down to the depth of 44 cm, and this sample was further divided into five layers. The uppermost layer was 20 cm thick, and the others 6 cm each. The first layer was thicker than the others, since we presumed that only very little decomposition had taken place there yet. The three uppermost samples represented the peat layer that had remained above the water table for most of the time whereas the lower two layers represented anoxic conditions. The lowest water table at the site is approximately at 30 cm. Living and recently died roots of vascular plants were removed from the samples in the laboratory. This was necessary in order to be able to take homogeneous subsamples. The samples were stored at 4 °C before and in between the analysis.

### *2.2. Laboratory analyses*

The temperature dependence of the peat soil respiration rate was measured within two weeks after the field work using the fresh peat having the original moisture content. 15 ml of moist peat was weighed into a 120 ml bottle, the bottle was aerated and closed with a rubber stopper, and the bottle was placed in a water bath. $CO_2$ was allowed to accumulate in the bottle for 24 h before it was sampled from the headspace. $CO_2$ was sampled, from the bottles at temperatures 5.2, 12.2, 19.2 and 26.4 °C, in this order, and analysed by gas chromatography (Hewlett Packard 6890). The same subsamples were used throughout the experiment. We used as short incubation time as possible in order to minimize the change in the OM quality. In between the measurements the samples were allowed to settle in the new temperature overnight. Respired $CO_2$ was calculated per dry weight. The respiration ($R$) was modelled as $R(T) = ae^{bT}$, where $a$ is the respiration rate at 0 °C, $b$ the temperature dependence coefficient and $e$ is the base of the natural logarithm. The temperature sensitivity is expressed as $Q_{10}$ values, derived as $Q_{10\ total} = e^{(b10)}$. These values represent the proportional increase in soil respiration in response to a 10 °C increase in temperature. The temperatures we used in our experiment are comparable to a temperature range measured at 20 cm depth of peat close to our study site over a vegetation period (Straková et al., 2012).

The radiocarbon ($^{14}C$) signature of the respired $CO_2$ was used to detect the sources of soil respiration that differed in age. This method utilizes the $^{14}C$ “bomb” peak in soil reservoir resulting from atmospheric nuclear weapon tests (Trumbore, 2009). As a consequence of these tests, the atmospheric $^{14}C$ peaked in the early 1960s and, when these tests were stopped, it started to decrease since 1964. The $^{14}C$ and $\delta^{13}C$ signatures in soil respired $CO_2$ were measured at 6 and 20 °C from $CO_2$ trapped to a molecular sieve. To ensure adequate production of $CO_2$, 1–2 kg of peat having the original moisture content was weighed to a 5 L glass bottle. The samples were allowed to settle in the measurement temperature