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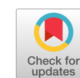
Plant functional group controls litter decomposition rate and its temperature sensitivity: An incubation experiment on litters from a boreal peatland in northeast China



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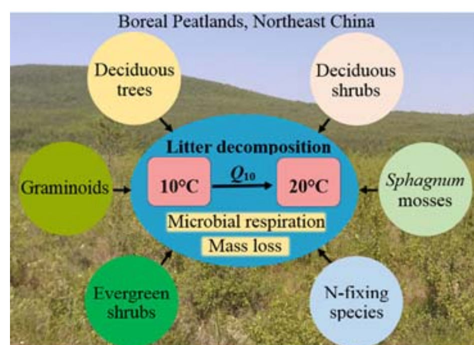
HIGHLIGHTS

- We measured decay rates of six functional groups in a peatland at 10 °C and 20 °C.
- Decay rate varied with functional group, wherein *Sphagnum* moss had lowest value.
- Litter decay greatly accelerated with increasing temperature except for *Sphagnum* moss.
- Litter decay rate of vascular plants was highly dependent on litter C:N and C:P.
- For vascular plants, Q_{10} of microbial decay was closely related with litter C:P.

GRAPHICAL ABSTRACT



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ABSTRACT

In boreal peatlands, litter decomposition plays an important role in modulating ecosystem carbon (C) cycling and nutrient turnover. However, how climate warming and plant functional group interact to affect litter decomposition is still unclear in these ecosystems. Here, we collected fresh litters of six plant functional groups (nitrogen (N)-fixing species, deciduous tree, deciduous shrub, evergreen shrub, graminoid, and *Sphagnum* moss) from a boreal peatland located in northeast China. A laboratory incubation experiment was used to determine the effect of temperature (10 °C vs. 20 °C) on microbial respiration and mass loss during decomposition. Among the six functional groups, the litters of N-fixing species and deciduous shrub, followed by deciduous tree, generally had the greatest mass losses and microbial respiration rates, whereas the *Sphagnum* moss decomposed with the slowest rate at both incubation temperatures. Increasing incubation temperature from 10 °C to 20 °C, microbial respiration rate and mass loss increased slightly for *Sphagnum* moss litters (25% and 19%, respectively), but increased dramatically for vascular plant litters (84–135% and 49–85%, respectively). For litters from vascular plants, both decomposition rate and temperature sensitivity showed a tight linear correlation with the initial C:N and C:phosphorus ratios. Considering that climate warming will cause increased dominance of woody plant species coupled with decreased cover by *Sphagnum* mosses, this study provides clear evidence that climate warming and the associated changes to vegetation community composition can synergistically accelerate plant litter decomposition in boreal peatlands.

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1. Introduction

In many terrestrial ecosystems, the majority of plant productivity enters the detritus food web through plant litters. Thus, litter decomposition plays an essential role in regulating soil carbon (C) sequestration and nutrient availability (Mann, 1988; Mcnaughton et al., 1989; Menéndez et al., 2003). Litter decomposition rates are influenced by both abiotic and biotic factors, including climate and litter identity (Aerts, 2006). In general, traits of the litter species are intrinsic determinants controlling litter decomposition rates (Aerts and Chapin, 1999; Cornwell et al., 2008), while climate is regarded as a primary abiotic factor (Hobbie, 1996; Fierer et al., 2005). Therefore, climate change and altered litter quality could cause substantial changes in litter decomposition rates, exerting crucial influences on C budget and nutrient turnover in terrestrial ecosystems.

Boreal peatlands, despite the low plant productivity, have accumulated a large amount of organic matter in soils since the Holocene mainly because of the extremely slow rates of decomposition, and now contain approximately one-third of the world soil C pool (Gorham, 1991; Yu et al., 2011). In these ecosystems, litter decomposition is strongly constrained by low temperature and recalcitrant substrate quality (Aerts, 2006; Moore et al., 2007). In recent decades, both observational and modeling studies have found that boreal peatlands are subject to severe climate warming (Aerts, 2006). This warming may enhance soil microbial activity and accelerate the decomposition of plant litters in these ecosystems (Cornelissen et al., 2007). Meanwhile, climate warming generally leads to changes in vegetation composition and structure (Dieleman et al., 2015; Robroek et al., 2017), which can indirectly influence litter decomposition rates by altering the quality of litter inputs into soils. In these peatlands, litter quality differs markedly among plant functional groups (Hobbie and Gough, 2004; Dorrepaal et al., 2005). For example, *Sphagnum* mosses generally produce a higher proportion of recalcitrant plant litter than vascular plants (Lang et al., 2009). Moreover, previous studies have found that the responses of litter decomposition to warming are modulated by the initial substrate quality (Fierer et al., 2005; Kim et al., 2015; Zhang et al., 2017). However, empirical studies that determine the interactive effect between elevated temperature and litter quality on litter decomposition are still limited for boreal peatlands. Given the critical role of litter decomposition in regulating C accumulation and nutrient availability, it is essential to understand the influences of elevated temperature on decomposition of plant litters with contrasting substrate quality in these C-rich ecosystems.

Here, the interactive effects of temperature and litter quality on decomposition rates were assessed in fresh litters from 16 species belonging to six plant functional groups (*Sphagnum* moss, graminoid, deciduous shrub, evergreen shrub, deciduous tree, and nitrogen (N)-fixing species) that are most commonly distributed in boreal peatlands in northeast China. The decomposition rates of these plant litters were measured under different temperature conditions using a laboratory incubation method. We assessed litter decomposition rates by measuring CO_2 production and mass loss, which have been widely used to characterize litter decomposability (Hobbie, 1996; Güsewell and Verhoeven, 2006). The aims of this study were to (1) determine the differences in litter decomposition rates among plant functional groups at different incubation temperatures, and (2) reveal how plant functional group affects the temperature sensitivity of litter decomposition in boreal peatlands.

2. Materials and methods

2.1. Study site

The study was conducted in a boreal peatland (52°56′N, 122°51′E, 467 m a.s.l.) north of Great Hing'an Mountain, Heilongjiang Province, Northeast China. The Great Hing'an Mountain is located at the southern boundary of the Eurasian continuous permafrost and boreal peatlands, where the mean air temperature has increased by >1.5 °C since the 1960s (Jin et al., 2006). Mean annual temperature (1980–2010) is −3.9 °C, and mean annual precipitation is about 450 mm. In this peatland, the thickness of the peat layer ranges from 50 to 120 cm, and the thickness of the active layer ranges from 45 to 65 cm above the permafrost layer. The soil characteristics are pH 4.9, 395 mg organic C g^{-1}, and 15.6 mg total N g^{-1} (Chen et al., 2017). In this peatland, the dominant species are *Betula fruticose* (deciduous shrub), *Ledum palustre* (evergreen shrub), *Eriophorum vaginatum* (graminoid), and *Sphagnum* mosses, and other common species include *Vaccinium uliginosum*, *Salix rosmarinifolia*, *Chamaedaphne calyculata*, *Rhododendron lapponicum*, *Carex globularis* and *Deyeuxia angustifolia* (Song et al., 2014; Chen et al., 2017). Tree seedlings, such as *Larix gmelinii*, *Betula platyphylla*, and *Alnus sibirica*, have widely expanded into the peatland (Chen et al., 2017). These species belong to six plant functional groups: N-fixing species, deciduous tree, deciduous shrub, evergreen shrub, graminoid (including grass and grass-like species), and *Sphagnum* moss. Detailed information on the classification of these species into plant functional groups is presented in Table 1.

2.2. Plant litter collection and preparation

In late August 2011, four 50 m × 50 m plots were randomly selected in the peatland. The distance between any two neighboring plots was at least 350 m to minimize the potential for spatial autocorrelation. In each plot, 16 common plant species belonging to six plant functional groups were chosen, and fresh litter was collected in early September 2011. Specifically, tree and shrub fresh leaf litters was collected after shaking the plant gently (Cornelissen, 1996), graminoid leaf litter was collected from fresh standing-dead shoots, and *Sphagnum* litter was sampled from the middle part of the shoots (Dorrepaal et al., 2005). Leaves with symptoms of obvious herbivory were avoided. For each species, plant litter sampled from at least eight random sites from the same plot was mixed, air-dried, and divided into two subsamples. One subsample was used in the incubation experiment, and another subsample was oven-dried to the constant weight at 65 °C to determine the moisture content, milled to pass through a 0.15-mm sieve for chemical analyses. Litter organic C concentration was measured using the dry combustion method (Multi N/C 2100 Analyzer, Analytik Jena, Germany). Following digestion with concentrated H_2SO_4 at 365 °C in the presence of mixed catalyst (K_2SO_4: $CuSO_4$ = 10: 1), litter N and phosphorus (P) concentrations were determined by the colorimeter analysis (Temminghoff and Houba, 2004) on a continuous-flow autoanalyzer (AutoAnalyzer III, Bran+Luebbe GmbH, Germany). The detailed chemical properties of the litters from the 16 selected species are shown in Table 1.

2.3. Experimental design and litter decomposition experiment

Litter decomposition rate was determined using a standard laboratory incubation method according to Aerts et al. (2003) and Güsewell and Verhoeven (2006). One gram of dried litter was re-wet with deionized water until saturation, and placed into a 1 L glass incubation jar. The bottom of these jars was covered with quartz sand (650–850 μm dia.) to a depth of 1 cm, and subsequently covered by polyethylene mesh (0.3 mm pore size). In each jar, litter was inoculated with 3 mL homogeneous soil surface water collected from the peatland. An additional eight jars were set up without litter samples to serve as negative controls. All jars were weighed, closed with a rubber stopper, and incubated in the dark at 10 °C and 20 °C, which are very representative for average air temperature during the growing season (12 °C) and in July (18 °C), respectively. After 5, 10, 20, 30, 45, 70, 95, 120, 150, 180, 210, 260, and 315 days of incubation, 20 mL gas samples were taken from each jar and analyzed for CO_2 concentration using a gas chromatograph (Agilent 6890, Agilent Technologies, USA). Following gas sampling, the

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