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Original Articles

Evaluating the potential of testate amoebae as indicators of hydrological conditions in boreal forested peatlands

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ABSTRACT

Testate amoebae are common proxies of past hydrological conditions in peatlands and are increasingly used as indicators of ecosystems ecological integrity. The ecology of these microorganisms is relatively well documented in non-forested ombrotrophic peatlands but there is a lack of data from forested peatlands, which are important ecosystems in boreal regions. This study provides the first testate amoebae modern training set (n = 72) from forested peatlands of the James Bay lowlands, eastern Canada. The relationships between testate amoeba communities and environmental variables (pH, water table depth, canopy openness, mineral particles concentration) were investigated using canonical correspondence analyses. Our data have shown that testate amoebae are sensitive environmental indicators in forested peatlands and can be used to reconstruct past hydrological conditions for these environments. A transfer function for water table depth (WTD) reconstructions was developed using weighted averaging models and was tested on a fossil testate amoebae record. In comparing forested and non-forested peatlands datasets we have shown that testate amoebae occupy similar ecological niches with respect to surface wetness in both ecosystems, but that their WTD optima is much higher (drier) in forested peatlands. The results show that the diversity and composition of testate amoeba assemblages do not vary significantly at the microform scale. This study provides new knowledge on testate amoebae ecology in forested peatlands that will improve further transfer function development in peatland ecosystems. This will allow a better evaluation of the responses of boreal forested peatlands to climate change, ecological disturbances and human activities.

1. Introduction

Testate amoebae, which are unicellular protists known to be sensitive proxies for hydrological variations in peatlands (Booth, 2008; Mitchell et al., 2008), are increasingly used as indicators of ecological integrity and restoration success (e.g. Daza Secco et al., 2016). The well-preserved tests of these microorganisms are commonly used to reconstruct paleohydrological conditions (water table depths) in peatlands across the world. These reconstructions are conducted with various testate amoeba transfer functions developed from modern datasets of different regions, mainly Europe and North America (e.g. Charman, 1997; Booth, 2002; Lamentowicz and Mitchell, 2005; Payne et al., 2006; Charman et al., 2007; Booth, 2008; Amesbury et al., 2013; Lamarre et al., 2013; Amesbury et al., 2016). The development of these transfer functions has been mostly restricted to non-forested ombrotrophic peatlands (bog) and minerotrophic peatlands (fen) in only a few cases (Booth, 2002; Lamentowicz and Mitchell, 2005; Payne et al., 2006; Lamarre et al., 2013). Very few studies have been conducted on the ecology of testate amoebae in forested peatlands and, to our knowledge, no transfer function has been developed from datasets of these environments. Forested peatlands are one of the most common type of ecosystems in boreal regions of Canada, particularly in the Clay Belt region (southern James Bay lowlands) where the poor drainage promotes high water tables and accumulation of thick organic matter layers (Lavoie et al., 2005a; Simard et al., 2009). The lack of testate amoeba modern datasets from forested peatlands is surprising considering the abundance of these ecosystems and their importance as carbon sinks in the boreal biome (Lavoie et al., 2005b).

Abbreviations: CCA, canonical correspondence analysis; FB, forested bogs; FF, forested fen; FP, forested peatlands; OP, open non-forested peatlands; RMSEP, root mean square error of prediction; SDI, Shannon-Weaver diversity index; WA, weighted averaging; WA-Tol, weighted averaging with tolerance downweighting; WA-Tol (inv), tolerance downweighting weighted averaging with inverse deshrinking; WTD, water table depth

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As forested peatlands are sensitive to hydrological variations (Lavoie et al., 2005b), modifications in surface moisture conditions related to climate change and anthropogenic perturbations can have important consequences on their ecological integrity and carbon sequestration function (Lavoie et al., 2005a). However, the resilience of the boreal forested peatlands to climate change and forest harvesting remains poorly documented. There is no specific tool to evaluate the past and recent hydrological changes in these ecosystems due to the lack of testate amoeba modern training sets. Consequently, it is difficult to evaluate the response of forested peatlands to anticipated climate change and ongoing forest exploitation activities.

This study aims to (1) understand the ecology of testate amoebae in forested peatlands by evaluating the relationship between their assemblages and different environmental variables; (2) evaluate the potential of testate amoebae as indicators of hydrological conditions in boreal forested peatlands; and (3) verify the spatial variability in the composition of testate amoeba assemblages at the microform scale by using multiple surface samples replicates.

2. Study region and sites

Surface samples were collected in the Clay Belt region in the James Bay lowlands in eastern Canada (Fig. 1; Table 1). The region, which is characterized by a flat topography and a cold climate, is covered by clayey deposits left by the proglacial lakes Barlow and Ojibway (Vincent and Hardy, 1977; Veillette, 1994). These particular conditions make the area prone to peat accumulation on the mineral soil (Fenton et al., 2005; Simard et al., 2009). The study sites present diverse levels of paludification noticeable by the variable organic layer thickness. Mean annual temperature (1971–2000) recorded at the closest meteorological station (Val-Saint-Gilles) is 0.1 °C and annual precipitation is 909.7 mm (Environment Canada, 2017). Three forested peatlands have been selected for this study: the bogs Lili and Villebois, dominated by black spruce (*Picea mariana*) and the fen Mélèzaie, dominated by eastern larch (*Larix laricina*). All these peatlands present a range of canopy structure varying between a closed-crown forest to semi-forested open bog where *Sphagnum* is dominant in the moss layer. The three sampled forested peatlands present a microtopographic gradient from lawns to hummocks. The lawns from the forested bogs (FB) Lili and Villebois are dominated by *Sphagnum angustifolium* while the hummocks are colonized mostly by *Sphagnum fuscum* and *Sphagnum capillifolium*. In the forested fen (FF) Mélèzaie, *Sphagnum teres* and *Sphagnum magellanicum* are the dominant species in lawns and hummocks respectively. Among *Sphagnum* mosses, ericaceous shrubs and forest mosses such as *Pleurozium schreberi* are found sporadically in the driest microforms. The main ericaceous shrubs, which are more abundant in open sites, are *Chamaedaphne calyculata*, *Kalmia angustifolia, Kalmia polifolia*, *Rhododendron groenlandicum* and *Vaccinium angustifolium*.

3. Methods

3.1. Field and laboratory work

Surface samples from the bogs Lili and Villebois were collected in four and five sites respectively, along a transect (toposequence) characterized by a variable canopy openness and a low diversity of microforms (biotopes). Two sites were sampled in the larch fen Mélèzaie in order to improve the modern analogues for wet and nutrient-rich forested environments because these ecosystems are also present at the regional-scale, although they are much less frequent than the forested bogs. At each site, a lawn and a hummock microforms were sampled (Fig. 2), except for two sites (Lili 1 and Villebois 1) from the black spruce bogs where there was no distinct microforms. In these specific cases, sampling was conducted in the two most abundant species of *Sphagnum* mosses and within *Pleurozium schreberi* which was also dominant in these sites. Because the response of testate amoeba communities to local environmental factors remains unknown in these environments, we have tested the variability of the assemblages at each sampling site and within each microform using three replicates. This procedure also increased the total number of tests counted per site and improved the representativeness of amoeba communities. Each microform from each site was sampled three times within a radius of 30 cm (Fig. 2), leading to a total of 72 modern samples collected from 11 sites.

Peat surface samples of approximately 10 cm^3 were cut with a serrated knife, following the method described in Lamarre et al. (2013). Water table depth (WTD) was measured relative to the peat surface using a ZIPLEVEL PRO-2000 High Precision Altimeter 24 h after digging a hole at each sampling site to make sure that the water table was stable. High WTD values correspond to low water table levels and therefore dry conditions. Peat pH was measured (Thermo Scientific Orion 230A) within the interstitial water of *Sphagnum* mosses. The tree canopy cover was estimated using a concave spherical densiometer and expressed in percentage of openness (Lemmon, 1956). The mineral and organic concentration (g cm^{-3}) of each sample was measured in laboratory using loss on ignition at 550 °C for 3 h, following a modified protocol of Dean (1974). A constant volume of peat was measured using a porcelain crucible of 33 cm^3 and moisture content (%) was obtained after drying the samples overnight at 105 °C (Chambers et al., 2011). The surface moisture content was not retained for analysis because we have noticed an important daily variability during the field campaign.

In laboratory, testate amoebae were extracted following a standard

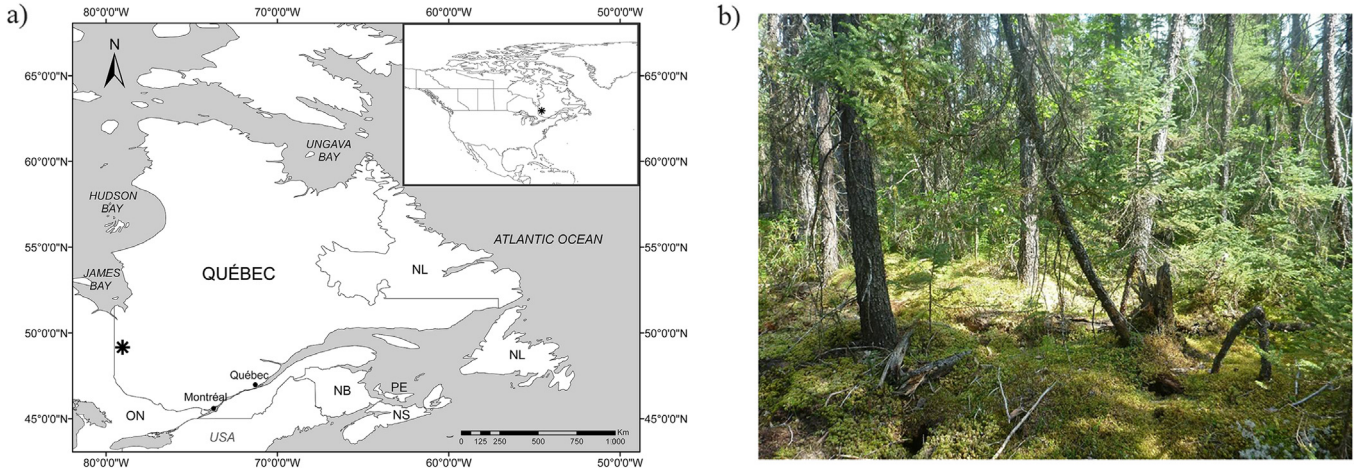

Fig. 1. a) Location of the study sites area and b) photograph showing an example of one of the studied forested peatlands (Villebois bog).