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Production and decomposition rates of different fen species as targets for restoration

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ABSTRACT

There is an increasing interest in considering ecosystem processes after fen restoration, and not solely species composition. To evaluate the success of ecological restoration, comparisons with targets from reference ecosystems are required. We documented net primary production (NPP) and decomposition of the main vegetation components in order to describe a reference data set for ecological restoration of moderately rich to rich minerotrophic peatlands (fens) in southeastern Canada. Data collection included three growing seasons for herbs and shrubs and two growing seasons for belowground biomass, trees and bryophytes. Average NPP for above and belowground biomass of three selected natural basin fens were 450 $g\,m^{-2}\,yr^{-1}$. Belowground NPP represented 45% of the total NPP. *Sphagnum warnstorfii* was the most productive bryophyte (140 $g\,m^{-2}\,yr^{-1}$) and the slowest plant species to decompose (exponential decomposition constant $k = 0.07\,yr^{-1}$). The brown mosses *Tomenthypnum nitens*, *Campylium stellatum* and *Scorpidium cossonii* had a NPP of 79, 69 and 92 $g\,m^{-2}\,yr^{-1}$, respectively, and decomposed at the same rate (identical k values of 0.14 yr^{-1}). Trees covered a large surface area in the fens, with an average NPP of 73 $g\,m^{-2}\,yr^{-1}$. *S. warnstorfii* contributed to hummocks having a higher peat accumulation potential than lawn vegetation. The graminoid *Trichophorum cespitosum* significantly increased NPP in lawns and should be targeted in restoration plans for fens. To restore peat accumulating processes (production and decomposition) in fens, bryophytes should be the primary focus for re-introduction, specifically species that are adapted to living in drier conditions, such as hummock species. The range of variability for NPP and decomposition established by this study should be considered as a decision tool in restoration projects to monitor restored ecosystems trajectories and successes.

1. Introduction[1]

Peatlands are ecosystems where plant biomass production is greater than decomposition (Moore and Bellamy, 1974). Over a long period of time, partially decomposed vegetation (peat), forms organic soils rich in carbon. To be considered a peatland, the waterlogged ecosystem must have at least 30–40 cm of accumulated peat which must contain more than 30% organic matter according to various national classification systems (National Wetlands Working Group, NWWG, 1997). Peatlands are classified into two broad types based on vegetation, water regime and chemistry. Ombrotrophic peatlands, or bogs, are exclusively rain fed and dominated by *Sphagnum* mosses that help to maintain the pH under 4.0 (Rydin and Jeglum, 2013; Rochefort et al., 2012). Minerotrophic peatlands, or fens, are to some extent connected to the regional watershed. The hydrology and water chemistry determine the gradient from poor to moderately rich to extremely rich fens, which influence vegetation composition (Sjörs, 1950; Chee and Vitt, 1989; Sjörs and Gunnarsson, 2002; Vitt, 2006; Rydin and Jeglum, 2013; Rochefort et al., 2012). Poor fens have a pH between 4.2 and 5.5 and, like bogs, are dominated by *Sphagnum* mosses. Moderately rich or intermediate and rich fens have a pH above 5.5 and are dominated by brown mosses, an ecological group of species mostly of the Amblystegiaceae and Calliergonaceae, and fen-adapted species of *Sphagnum* mosses. Rich fens can also be composed in part or exclusively of graminoid plants. There is a great variation between poor and rich fens in terms of vegetation and water chemistry. This study focused on moderately rich to extreme rich fens as described by Rochefort et al. (2012).

The ability to store large amounts of carbon over millennia is unique to peatlands (Gorham, 1991; Vasander and Kettunen, 2006). The estimates of accumulated carbon in northern peatlands are 500 (± 100) Gt (Yu, 2012). Disturbances and modification of vegetation composition affect peatland functions by switching the carbon balance from sinks to

Abbreviations: NPP, net primary production

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[1] Nomenclature: Integrated Taxonomic Information System on-line database (2015) for vascular plants and Faubert (2007) for bryophytes.

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source (Waddington et al., 2002; Turetsky et al., 2011; Rankin, 2016). The estimate of total peatland losses worldwide is 10–20% (Joosten and Clarke, 2002). In southeastern Canada, pressure on peatlands for agriculture, forestry and peat extraction is critical at a regional scale (Pellerin and Poulin, 2013). The release of greenhouse gases by disturbed and unrestored peatlands is a concern in a climate change context because this contributes to positive feedback loops of rising temperature and precipitation (IPCC, 2013).

Peatland restoration aims to re-establish the carbon sequestration function by the recovery of suitable hydrology and adequate plant diversity after a disturbance event (Rochefort et al., 2003; Grand-Clement et al., 2013; Lamers et al., 2015). Restoration efforts include rewetting through ditch blocking and, if necessary, reprofiling the peat surface with bunds and terracing to evenly redistribute the water (Price et al., 2003; Malloy and Price, 2014). In a long-term perspective, the rewetting of the peatland encourages vegetation to recolonize the former degraded peatlands, and may be sufficient to recover some of the carbon sequestration function (Tuittila et al., 1999). But the trajectory of the restored community toward the targets remains hard to predict (Triisberg et al., 2011; Gagnon, 2017). Active reintroduction of vegetation (i.e. by targeting slow to decompose species such as *Sphagnum* spp. or highly productive species such as tall or tussock sedge species) may accelerate peat accumulation recovery (Lucchese et al., 2010). Projects to restore moderately-rich to rich peatlands that have undergone land-use changes have increased in interest over the last decade in North America as the awareness of the need to preserve fen ecosystem increases (Graf et al., 2012; Schimelpfenig et al., 2014; Chimner et al., 2017).

Inclusion of a reference ecosystem is part of the planning and is essential to any restoration project. Throughout the project, the reference will act as a standard for comparison and evaluation (SERI, 2004; Clewell and Aronson, 2013; Shackelford et al., 2013). It will help define realistic goals and will be used during the monitoring phase to assess if the restored ecosystem reached the desired state of recovery (SERI, 2004). To define the reference, studies of similar natural ecosystem from the region are usually used (White and Walker, 1997). There is a gap in knowledge about reference targets for fens in southeastern Canada, particularly regarding the ecological function of peat accumulation. An estimate of the net primary production (NPP) and the decomposition decay constant from vegetation communities are required to estimate peat accumulation potential.

Variations in vegetation influence net primary production (NPP) and decomposition in peatlands. Among other important environmental variables impacting NPP, there are the level of photosynthetic radiation, water table depth, and nutrient availability (Blodau, 2002; Wieder, 2006), while the decomposition is affected by the chemical composition of the litter (Thormann and Bayley, 1997a), abiotic conditions such as climate, soil temperature, and water table depth (Moore et al., 2007), and microbial biota (Andersen et al., 2010). Moderately rich fens produce more biomass than bogs or extreme rich fens because of well-developed vegetation layers including mosses, sedges and shrubs (Szumigalski and Bayley, 1996; Thormann and Bayley, 1997b). Accumulation of peat in sedge-dominated fen occurs because the process can rely on the high production of sedges that overcome their fast decomposition rate (Brinson et al., 1981; Vitt, 1990; Thormann et al., 1999). In brown moss-dominated fens, the herb layer is less developed and the peat accumulation process is heavily influenced by the slower decomposition rate of brown mosses rather than their production rate (Vitt, 1990). In both sedges and moss-dominated fens, the belowground compartment may play an important role in the peat accumulation function, but its production and decomposition rates are rarely estimated (e.g. Reader and Stewart, 1972; Wallén, 1986; Backéus, 1990; Sjörs, 1991). Finally, microtopographic gradients are present in fens dominated by mosses, but have not been specifically studied in the literature. Particular species colonize hummock, lawn and hollow biotopes (Gignac, 1992) and have different production and decomposition patterns (Vitt, 1990; Johnson and Damman, 1991). There is an interest in studying the plant communities colonizing these main biotopes in fens as it can impact decision making during restoration planning. Therefore, an accurate knowledge of NPP and decomposition for the main vegetation classes and biotopes will improve estimation of the peat accumulation potential of a peatland community, and therefore target the preferred plant community for restoration.

The aim of this study was to establish indicators for fen restoration success for two important processes of fens: biomass production and decomposition. We estimated above and belowground net primary production, as well as the litter decomposition decay constant of the main vegetation classes (bryophytes, herbs, shrubs and trees). We also determined if either hummock or lawn plant communities present higher peat accumulation potential. Based on the observation that the dominant species colonizing the hummock biotope is *Sphagnum* spp., a group recognized for its slow decay rate that should contribute to increased peat accumulation potential, we hypothesized that the hummock plant community should be targeted during restoration. The general outcome was to select a plant community as a functional indicator to improve the restoration of the peat accumulation of peatlands. We used simple methods that could be used for monitoring fen restoration programs to evaluate the progress of the return of functions over time.

2. Materials and methods

2.1. Site description

Production and decomposition measurements were conducted in three natural fens located in the Appalachian foothills of the St. Lawrence Lowlands, Quebec, Canada. Mean annual temperature of the area is 5.5 °C over the past 100 years, with a minimum average temperature of −11.4 °C in January and maximum average temperature of 18.3 °C in July. Average precipitation is 959 mm per year of which 71% falls as rain (Environment Canada, 2015).

From previous inventories in the same area, we found that basin fens mainly composed of *Sphagnum warnstorfii* and *Thuja occidentalis* were a suitable reference when the main restoration objectives focus on the establishment of peat-accumulating plant communities and biodiversity (Bérubé et al., 2017). For this study, fens were selected based on the presence of the dominant species (*S. warnstorfii* and *T. occidentalis*), water pH and electrical conductivity.

The three fens, BSF (Bic-Saint-Fabien), Joncs (Lac des Joncs), and Ouellet, were classified as basin peatlands, that is, fens located in a defined basin without surface inlets (NWWG, 1997). The studied peatlands are all located at the margins between bogs and forested uplands, and can be considered part of the lagg ecotone (Paradis et al., 2015). All studied peatlands also receive groundwater inflows from adjacent calcareous bedrocks. They have a moderately rich to rich water chemical status (according to criteria of Chee and Vitt, 1989). A general description of the three sampled peatlands is presented in Table 1.

2.2. Production measurements

In each peatland, three permanent plots of 20 m by 20 m that are representative of the sites were established. Plant biomass production and decomposition were measured in each of these permanent plots.

For production, aboveground biomass of four species of bryophytes and of each major vascular group (herbs, shrubs and trees), as well as belowground biomass (roots) was measured using the methods described below.

2.2.1. Bryophytes

Four bryophytes species commonly found in moderately rich fens were selected. *Sphagnum warnstorfii* and *Tomenthypnum nitens* form