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# Can abandoned peatland pasture sequestrate more carbon dioxide from the atmosphere than an adjacent pristine bog in Newfoundland, Canada?

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ABSTRACT

Net ecosystem exchange of carbon dioxide (NEE) and its components, gross primary productivity (GPP) and ecosystem respiration (ER), were compared between a bog and an abandoned peatland pasture within the same peatland complex in western Newfoundland, Canada. Measurements based on the eddy covariance technique from April 2014 to April 2016 were used to examine the influence of agricultural management and abandonment on peatland carbon dioxide ($CO_2$) exchange. NEE, GPP and ER at both sites showed pronounced seasonal variation, peaking near the middle growing season. The maximum net $CO_2$ uptake rate of $-28.61\ \mu mol\ m^{-2}\ s^{-1}$ and emission rate of $14.39\ \mu mol\ m^{-2}\ s^{-1}$ at the pasture were significantly higher than those at the bog ($-9.67\ \mu mol\ m^{-2}\ s^{-1}$ and $5.50\ \mu mol\ m^{-2}\ s^{-1}$, respectively). Daytime average GPP was related to photosynthetic photon flux density and air temperature and the nighttime average ER decreased with soil water content, but increased with surface soil temperature for both sites. Annual NEE of the pasture ($-128 \pm 60\ g\ C\ m^{-2}\ yr^{-1}$ in 2014–15 and $-124 \pm 56\ g\ C\ m^{-2}\ yr^{-1}$ in 2015–16) was considerably larger than that of the bog ($-46 \pm 36\ g\ C\ m^{-2}\ yr^{-1}$ in 2014–15). GPP of $1086 \pm 141\ g\ C\ m^{-2}\ yr^{-1}$ in 2014–15 and $982 \pm 123\ g\ C\ m^{-2}\ yr^{-1}$ in 2015–16 and ER of $957 \pm 129\ g\ C\ m^{-2}\ yr^{-1}$ in 2014–15 and $858 \pm 112\ g\ C\ m^{-2}\ yr^{-1}$ in 2015–16 at the pasture were approximately twice the magnitude of the corresponding fluxes at the bog. The difference in GPP between the bog and pasture was mainly related to their different aboveground biomass. Higher ER at the pasture was probably related to its lower water table depth, greater substrate availability and higher autotrophic respiration. Unlike previous findings that managed peatlands are large $CO_2$ emitters, our results suggest that abandoned peatland pastures can function like natural grasslands and sequester considerable amounts of $CO_2$ from the atmosphere.

## 1. Introduction

Despite only covering 3% of the earth surface, carbon (C) storage in northern peatlands accounts for approximately one-third of the world's soil C stock (Gorham, 1991; Turunen et al., 2002; Yu et al., 2010). Cold, waterlogged conditions and *Sphagnum*-dominated recalcitrant litter in peatlands leads to low decomposition of peat organic matter (OM), benefiting C accumulation (Gorham, 1991). Approximately 20% of natural peatlands have been converted for agricultural cultivation worldwide (Couwenberg, 2011; Joosten and Clarke, 2002; Turetsky and Louis, 2006). Such management involves drainage and crop cultivation (Turetsky and Louis, 2006), which can alter the peatland C exchange making agriculturally managed peatlands "hotspots" for carbon dioxide ($CO_2$) and other greenhouse gas emissions (Grønlund et al., 2006, 2008; Kasimir-Klemedtsson et al., 1997; Lohila et al., 2004). On one hand, $CO_2$ emissions at agriculturally managed peatlands are promoted by two factors. Firstly, drainage and subsequent lowering of the water table level exposes more peat to aerobic conditions and accelerates the aerobic mineralization rate of peat (Laiho, 2006). As a result, accumulated C is emitted to the atmosphere mainly as $CO_2$. Secondly, agriculturally managed peatlands are usually dominated by crop plants or forage grasses, which produce highly decomposable litter (Couwenberg, 2011; Grønlund et al., 2008; Minkkinen et al., 1999), accelerating the decomposition rate of the newly accumulated OM. On the other hand, agricultural management can also increase the $CO_2$ uptake capacity of peatlands through cultivation of productive plants

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like reed canary grass (Karki et al., 2016; Shurpali et al., 2009, 2010) and the addition of nutrients (Järveoja et al., 2015).

It has been estimated that approximately 25.8 t $CO_2$-C $ha^{-1}$ $yr^{-1}$ are lost from agriculturally managed peatlands globally (Couwenberg, 2011). However, this estimate is very uncertain since it is based largely on a limited number of peat subsidence measurements where the C loss is estimated from peat shrinkage, peat bulk density and C content (Couwenberg, 2011). Subsidence rates are highly variable among different managed systems, ranging from 2 to 40 mm $yr^{-1}$ (Grønlund et al., 2008; Hooijer et al., 2012; Kasimir-Klemedtsson et al., 1997; Leifeld et al., 2011; Lohila et al., 2004; Pronger et al., 2014) depending on the site type, pre-drainage peat thickness, time after drainage and other factors (Hooijer et al., 2012; Pronger et al., 2014). In addition, peat subsidence results from not only the oxidation of peats, but also other processes such as soil compaction due to loss of supporting pore water pressure, wind and water erosion and leaching of soluble organic matter (Hooijer et al., 2012; Leifeld et al., 2011; Pronger et al., 2014). The percentage of C loss attributable to peat oxidation is variable, making it difficult to accurately determine the direct on-site C losses (Couwenberg, 2011; Leifeld et al., 2011; Page et al., 2011). Moreover, the subsidence method only estimates the mean C loss since drainage was initiated (which may be decades ago) and does not provide information on the contemporary and ongoing $CO_2$ exchange (Couwenberg, 2011; Krüger et al., 2015) preventing us from predicting their current role in the global C cycle.

The eddy covariance (EC) technique, which measures landscape-scale $CO_2$ exchanges between the ecosystem surface and the atmosphere with high temporal-resolution, has been applied to study the contemporary $CO_2$ fluxes for several managed peatlands (Fleischer et al., 2016; Hatala et al., 2012; Morrison et al., 2013; Mudge, 2009; Rutledge et al., 2015; Schrier-Uijl et al., 2010; Veenendaal et al., 2007). Earlier results suggested a large variability in $CO_2$ fluxes from these ecosystems with both losses and sinks of $CO_2$ reported, but most showing significant losses (Aslan-Sungur et al., 2016; Grønlund et al., 2008; Hargreaves et al., 2003; Karki et al., 2016; Knox et al., 2015; Lloyd, 2006; Maljanen et al., 2001, 2004, 2010; Matthes et al., 2015; Rutledge et al., 2015; Soussana et al., 2004; Vuichard et al., 2007). Combining this with an accounting for other greenhouse gases (GHGs) and the effects of management practices, a recent synthesis study concluded that wetland conversion for agricultural management generally leads to a large positive radiative forcing on the Earth's climate (Petrescu et al., 2015). However, such studies have almost exclusively considered active agricultural management, the effects of long-term abandonment after agricultural conversion is largely unknown.

In Canada, peatlands cover an area of approximately 1.136 million $km^2$, second only to those in Russia (Tarnocai et al., 2005). During the past century, extensive areas of Canadian peatlands have been drained for various purposes, such as agriculture, forestry, horticulture and other uses (Joosten, 2009). Agricultural management of peatlands is the most common type of non-harvesting use in Canada (Joosten, 2009), with an area of 170,000 $km^2$ having been converted for such use, accounting for 15% of the total national resource of peatlands and mires (Oleszczuk et al., 2008). The principal uses are vegetable and small fruit production and pasture (Stewart, 1977). An estimated 3.5 Mt $CO_2$ $yr^{-1}$ is emitted from Canadian peatlands drained for agriculture (Joosten, 2009). As in other cases, noted above, this estimate was based on limited number of subsidence measurements and is therefore quite uncertain. To the best of our knowledge, very few studies have measured the landscape-scale $CO_2$ fluxes from an agriculturally managed peatland system in Canada. The purpose of this study was to fill this knowledge gap by comparing the year-round landscape-scale $CO_2$ fluxes from EC measurements between an undisturbed boreal bog and an adjacent abandoned peatland pasture, both belonging to the same peatland complex. Our main objectives were to quantify and compare multi-year net ecosystem exchange of $CO_2$ flux for these two systems and identify the controls on $CO_2$ flux at different temporal scales. In this study, we considered the bog to be the control, or background case.

## 2. Materials and methods

### 2.1. Study site

The research sites are located in the Robinsons pasture, western Newfoundland, Canada (48.264° N, 58.665° W). According to the data from the nearest (31 km away) weather station in Stephenville (48.541° N, 58.55° W) (http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=6740&autofwd=1), the average annual air temperature and precipitation are 5.0 ± 1 °C (mean ± standard deviation) and 1340 ± 180 mm for the past 30 years [1981–2010], respectively. Mean annual precipitation is partitioned into 995 ± 133 mm as rainfall and 393 ± 89 mm as snowfall. For the growing period, May to October, the temperature and precipitation averaged ~12.2 ± 1.2 °C and ~705 ± 102 mm.

The sites are part of a peatland complex that comprises an undisturbed boreal bog and an abandoned peatland pasture. The abandoned peatland pasture (~0.2 $km^2$) was originally an ombrotrophic bog that was drained by ditches in the 1970s. The drainage ditches (~0.5 m in depth and ~30 cm in width, with a distance of 20–30 m between ditches) oriented along an east-west transect are still intact. At the time of initial drainage pasture forage grasses were introduced. The site was used as a managed pasture for ~10 years and then abandoned. After the abandonment, the site was left to regenerate for ~25 years. The bog (~0.36 $km^2$) was located immediately to the east of the abandoned peatland pasture (Fig. 1). The bog is a typical peatland type in Newfoundland, with component landforms of hollows, hummocks and pools and a substrate dominated by bog moss species (*Sphagnum Warnstorfii* and *Sphagnum capillifolium*) and partly with gray reindeer lichens (*Cladina* spp.). A high abundance of ericaceous shrubs and sedges grows in both hollows and hummocks, but hollows are dominated by sedges and hummocks by shrubs. The dominant species of sedge is *Trichophorum cespitosum* and the main species of ericaceous shrubs are *Gaylussacia* spp. and *R. groenlandicum*. The abandoned peatland pasture is a mosaic of patches, which are dominated by canary grass (*Phalaris arundinacea*), various low herbaceous and graminoid species (*Carex* spp., *Ranunculus acris*, *Ranunculus repens*, *Hieracium* sp.), and several dwarf shrubs [sweet gale (*Myrica gale*), labrador tea (*Rhododendron groenlandicum*), mountain fly honeysuckle (*Lonicera villosa*), rhodora (*Rhododendron canadense*), and chokeberry (*Photinia* sp.)]. In 2013, the dry aboveground biomass (AGB) was estimated at 197 ± 87 g $m^{-2}$ for the hummocks and 191 ± 41 g $m^{-2}$ for the hollows at the bog, significantly lower than that of 591 ± 246 g $m^{-2}$ for patches dominated by shrubs and reed canary grasses at the pasture (Luan and Wu, 2015).

### 2.2. Eddy covariance flux and meteorological measurements

Two identical EC systems were operated for the period from April 2014 to August 2015 in the bog and from April 2014 to April 2016 in the abandoned peatland pasture (Fig. 1). Data for the bog from the end of August in 2015 to April 2016 were unavailable due to equipment failure. Each EC system consisted of a three-dimensional (3-D) sonic anemometer (Gill WindMaster Pro, Gill Instruments) and a fast response infra-red gas analyzer (IRGA: LI-7200 Enclosed $CO_2$/$H_2O$ Analyzer, LI-COR Inc., Nebraska, USA). The 3-D sonic anemometers measured wind speed (u, v, w) and direction and sonic temperature at 3.44 m height for the bog and 3.7 m height for the abandoned peatland pasture. The LI-7200 analyzers were mounted at the height of 3.21 m for the bog and 3.54 m for the abandoned pasture to simultaneously measure instantaneous variations in $CO_2$ and water vapor ($H_2O$) molar densities. Air was pulled by a diaphragm pump through a 1 m long sample tube to the IRGA at a rate of 16.1 L $min^{-1}$ for the bog and 16.7 L $min^{-1}$ for the abandoned pasture. In order to calculate the $CO_2$ and $H_2O$ fluxes, instantaneous measurements of air temperature and air pressure inside the sampling cell were made. Two thermocouples were