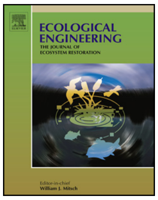
Ecological Engineering xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Greenhouse gas emissions in natural and managed peatlands of America: Case studies along a latitudinal gradient

Gert Veber[a], Ain Kull[a], Jorge A. Villa[b], Martin Maddison[a], Jaanus Paal[c], Tõnu Oja[a], Rodolfo Iturraspe[d], Jaan Pärn[a,e,f], Alar Teemusk[a], Ülo Mander[a,*]

[a] Department of Geography, Institute of Ecology & Earth Sciences, University of Tartu, Estonia
[b] Corporacion Universitaria Lasallista, Caldas, Colombia
[c] Department of Botany, Institute of Ecology & Earth Sciences, University of Tartu, Estonia
[d] National University of Tierra del Fuego, Ushuaia, Argentina
[e] School of Geography, Geology and the Environment, Keele University, United Kingdom
[f] School of Geography, Earth and Environmental Sciences, University of Birmingham, United Kingdom

ARTICLE INFO

Article history:
Received 11 May 2017
Received in revised form 30 June 2017
Accepted 30 June 2017
Available online xxx

Keywords:
Bog
Carbon dioxide
Fen
Methane
Nitrous oxide
Páramo
Patagonia

ABSTRACT

Processes affecting CO_2 and CH_4 emissions and their budgets have been relatively well studied in northern temperate peatlands, whereas similar studies are almost absent in southern Patagonia and the high-altitude Andean peatlands, both of which are currently under heavy anthropogenic pressure. The objectives of this study were to compare greenhouse gas (GHG) emissions in natural and managed peatlands to examine the effect of management on GHG emissions and identify the environmental parameters affecting them. We analysed CO_2, CH_4 and N_2O emissions related to the physical and chemical conditions of the peat: in a natural and managed transitional bog in Quebec, Canada, a natural páramo and grazed peatland in the Colombian Andes, and a bog and a fen in Tierra del Fuego, Argentina. GHG fluxes were measured using the dark static chamber method. Groundwater table, temperature, O_2 content, pH and redox potential were measured from observation wells, soil temperature was measured at four depths, peat samples were analysed for pH, soil organic matter and dry matter content, P, K, Ca, Mg, NH_4-N, NO_3-N, total N and C. In all regions, human-impacted peatlands showed significantly higher CO_2-C, N_2O-N and CH_4-C emissions than their natural counterparts. The Canadian managed transitional bog showed the highest average CO_2-C ($575\,mg\,C\,m^{-2}\,h^{-1}$) and N_2O-N ($0.08\,mg\,N\,m^{-2}\,h^{-1}$) emissions, whereas the Colombian pasture was the largest emitter of CH_4-C ($2.35\,mg\,C\,m^{-2}\,h^{-1}$). CO_2-C emissions were controlled by soil temperature and C content, whereas CH_4-C flux was negatively correlated to dissolved oxygen content in peat water, and positively to water table level and soil log (C/NO_3-N) ratio. Total Inorganic Nitrogen (TIN), C/N ratio, and soil temperature were the main factors controlling N_2O emissions. Intensive peatland management alters the soil C/N balance, and increases and leads to higher variability of GHG emissions. Agricultural activities, especially crop production in peatlands, as well as intensive grazing in mountain peatland pastures, are the main factors increasing GHG emissions in the peatlands studied. Mitigation is possible via regulation of grazing intensity and replacing arable fields with grasslands.

1. Introduction

Undisturbed peatlands are important sinks for carbon dioxide (CO_2), sources of atmospheric methane (CH_4) and nearly neutral to nitrous oxide (N_2O) (Frolking et al., 2011). In drained organic soils, depending on management intensity, CH_4 fluxes are lowered, but CO_2 and N_2O emissions can increase significantly (Freeman et al., 1993; Kasimir-Klemedtsson et al., 1997; Maljanen et al., 2010). Processes and parameters affecting CO_2 and CH_4 emissions and their budgets have been relatively well studied in northern peatlands (Frolking et al., 2011; Haddaway et al., 2014; Oertel et al., 2016). The water table level has been found to be one of the key factors governing methane emission from northern peatlands. Numerous studies have reported a negative relationship between mean water table depth and seasonal or annual CH_4 emission from non-flooded northern peatlands (Moore and Roulet, 1993; Bubier et al., 1993;

---

* Corresponding author.
E-mail address: ulo.mander@ut.ee (Ü. Mander).

http://dx.doi.org/10.1016/j.ecoleng.2017.06.068
0925-8574/

Please cite this article in press as: Veber, G., et al., Greenhouse gas emissions in natural and managed peatlands of America: Case studies along a latitudinal gradient. Ecol. Eng. (2017), http://dx.doi.org/10.1016/j.ecoleng.2017.06.068

Pelletier et al., 2007; Munir and Strack, 2014; Webster et al., 2013) but temperature can also exert a considerable influence on CH_4 emissions in northern peatlands (Dise et al., 1993; Bellisario et al., 1999; Levy et al., 2012). Dunfield et al. (1993) showed that CH_4 production and oxidation in temperate and subarctic peat soils attained an optimum at around 25 °C. The magnitude of CH_4 flux from northern peatlands is a function of the availability and quality of organic substrate, water table depth, temperature, pH, as well as vegetation type and productivity (Lai, 2009; Turetsky et al., 2014).

Drainage for forestry or conversion to agriculture or pasture exposes the peat soil to oxygen and accelerates aerobic decomposition of organic matter with increased carbon dioxide emissions rather than methane, which is partly due to attenuated methanogenesis in the oxic soil layer but also because of the significant potential for microbial methane oxidation in the aerated soil layer (Segers, 1998; Kip et al., 2012; Preuss et al., 2013). Carbon stocks, which are resistant to decay under the anaerobic conditions prevalent in wetland soils, can be lost by aerobic respiration after drainage (Minkkinen and Laine, 1998). Historically, the destruction of North American wetlands through land-use change has had the greatest effect on carbon fluxes. The primary effects have been a reduction in their ability to sequester carbon, oxidation of their soil carbon reserves upon drainage and a reduction in CH_4 emissions (Bridgham et al., 2006).

Nitrous oxide emission from soils is derived from nitrification and denitrification processes. Nitrogen availability is a growth-limiting factor in many peatland ecosystems (Bridgham et al., 1996), especially in natural wet conditions (Graham and Vitt, 2016). However, in some Eastern Canadian and European peatlands that have experienced chronically high nitrogen deposition (5–40 kg ha^{-1} yr^{-1}), they are thought to be phosphorus limited (Limpens et al., 2006). Thus in general peatlands are a very weak source of nitrous oxide (N_2O; ~0.00002 Pg N_2O-N y^{-1}), while its share increases with anthropogenic disturbance (Frolking et al., 2011; Carter et al., 2012; Salm et al., 2012). Climatic factors that regulate N_2O emission, include temperature, precipitation and freezing and thawing regimes (Burton and Beauchamp, 1994), resulting in significant emissions outside the growing season or even exceeding them (Wagner-Riddle et al., 1997, 2017).

A better understanding of local and regional effects and the interaction between factors controlling the delicate balance of GHG emissions is still required (Groffman et al., 2000; Bridgham et al., 2008; Fritz et al., 2011; Frolking et al., 2011; Butterbach-Bahl et al., 2013; Olson et al., 2013; Henneberg et al., 2015). In contrast to the extensively studied greenhouse gas balances in northern peatlands, e.g. in Canada (Klinger et al., 1994; Liblik et al., 1997; Roulet, 2000; Turetsky et al., 2002; Cleary et al., 2005; Bridgham et al., 2006; Petrescu et al., 2010; Kroetsch et al., 2011; Euskirchen et al., 2014; Haddaway et al., 2014), similar studies about greenhouse gas emissions in southern Patagonia (sphagnum and cushion bogs, fens) and high-altitude Andean wetlands (páramos) are almost non-existent. High-altitude mountain peatlands are typically small compared to low-altitude peatlands, although they are abundant across the Andean landscape and are likely a key component in regional carbon cycling (Comas et al., 2017). The same applies partly to Patagonian peatlands, which are often developed along the narrow bottoms of valleys, on shallow depressions of highland grasslands and on low-gradient slopes (Grootjans et al., 2010).

Both páramos and southern Patagonian peatlands are currently under heavy anthropogenic pressure, with the main threats caused by agricultural land conversion, drainage, mining activity and climate change (Buytaert et al., 2006; Grootjans et al., 2010, 2014; Benavides, 2014; Maldonado Fonkén, 2014; Salvador et al., 2014; Ochoa-Tocac et al., 2016). Nevertheless páramos, of which Colombia has the largest extent, covering a total of 35,000 square kilometres in South America, provide important ecosystem services, including water provision and carbon sequestration. Water retained and released by the soil in páramos is used both by local communities and downstream for irrigation, drinking water, and hydroelectric power. Large Andean cities such as Mérida, Bogotá, Quito, and Cajamarca, as well as many others, depend substantially on páramos for their water (Mena-Vásconez and Farley, 2016). On the other hand, human activities, such as agriculture, the intensification of livestock grazing, *Pinus* plantations and tourism, are increasing in the páramos (Buytaert et al., 2006). Grazing alters the ground cover and can lead to soil compaction and erosion, while also altering nutrient cycles and runoff. The changing land use to pasture increases the rates of soil respiration, which is a direct pathway for soil carbon loss (Buytaert et al., 2011; Houghton et al., 2012).

Our literature review (see Material and Methods for details) reveals that there are only three regions in Peru and two in the Ecuadorian páramos and five areas in Patagonia where GHGs have been reported in scientific papers (Table 1). Furthermore, only two studies have reported all three major GHGs (CO_2, CH_4, N_2O) in páramos. No studies of all three GHGs or N_2O measurements in Patagonian mires have been published in scientific journals.

The first aim of our study was to contribute, with exploratory *in situ* simultaneous measurements of CO_2, CH_4 and N_2O with static chambers, to filling in the gap in the modestly studied GHG emissions of páramo and Patagonian region peatland ecosystems. Although páramo peatland plant communities are considered a crucial component of the Andes biodiversity hotspot, and Patagonian cushion bogs are regarded as a unique type of mire, there is only modest understanding of the dynamics of plant communities affected by human disturbance (Young and León, 2007; Heusser, 1995). Thus our second and third objectives were to compare greenhouse gas (GHG) emissions along a north to south gradient – from continental to Andean high-altitude and southern Patagonian maritime climates in both natural and managed peatlands, and to examine the effect of management intensity on GHG emissions, and identify the environmental parameters that drive GHG emissions in peatlands.

We hypothesize that more intensive peatland management (1) alters the soil C/N balance, (2) increases emissions of CO_2-C, N_2O-N and (3) lowers the emissions of CH_4-C and also (4) leads to higher variability in GHG emissions.

2. Material and methods

2.1. Study sites

The data were collected in a global soil and gas sampling campaign between July 2012 and June 2015, following a uniform protocol (Pärn et al., 2015). We sampled six temperate peatland sites in three regions across North and South America (Fig. 1). According to their latitudinal and altitudinal gradients, these peatlands represent most characteristic types of extratropical peatlands of the continents.

In our context "intensive management" means there has been/is soil cultivation and fertilization, "moderate management" means intensive grazing but no soil cultivation, and "low-intensity management" means low-intensity grazing. The distinction between intensive and low-intensity grazing is based on the number of livestock units.

The study regions and sampling times were chosen to cover the expected near-annual mean emission in Argentina in spring (Peria et al., 2015) and in the continental summer conditions in Canada, where the expected spatial variability of the GHG emissions between the natural and managed peatlands is highest. There is no significant seasonal variability in the Colombian Andes.

Please cite this article in press as: Veber, G., et al., Greenhouse gas emissions in natural and managed peatlands of America: Case studies along a latitudinal gradient. Ecol. Eng. (2017), http://dx.doi.org/10.1016/j.ecoleng.2017.06.068