Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Management effects on greenhouse gas dynamics in fen ditches

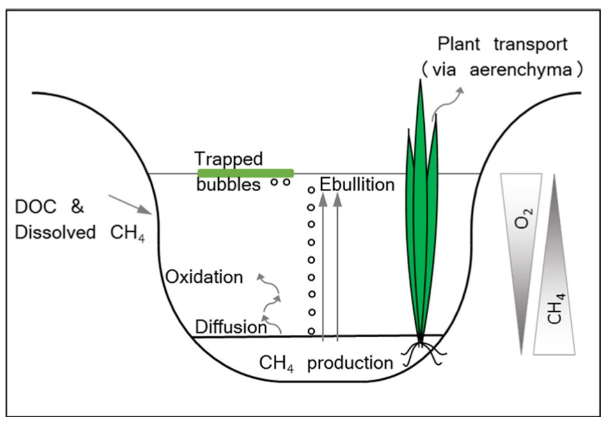
Mike Peacock [a,*], Luke M. Ridley [b,c], Chris D. Evans [d], Vincent Gauci [a]

[a] School of Environment, Earth and Ecosystem Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom
[b] School of Environment, Natural Resources and Geography, Bangor University, Bangor, Gwynedd, LL57 2UW, United Kingdom
[c] School of Geographical Sciences, Bristol University, Bristol, BS8 1SS, United Kingdom
[d] Centre for Ecology and Hydrology, Bangor, Gwynedd, LL57 2UW, United Kingdom

HIGHLIGHTS

- Fen ditches release greenhouse gases (GHGs) to the atmosphere, but data is lacking.
- We measure dynamics of GHGs in ditches in three fens.
- All ditches emitted CO_2 and N_2O, but emissions of CH_4 were particularly large.
- There was considerable spatial and temporal variation in greenhouse gas dynamics.
- Fen ditches are important contributors to landscape-scale GHG emissions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 September 2016
Received in revised form 28 October 2016
Accepted 1 November 2016
Available online xxxx

Editor: Jay Gan

Keywords:
Peatland
Carbon dioxide
Methane
Nitrous oxide
Ditch flux
Restoration

ABSTRACT

Globally, large areas of peatland have been drained through the digging of ditches, generally to increase agricultural production. By lowering the water table it is often assumed that drainage reduces landscape-scale emissions of methane (CH_4) into the atmosphere to negligible levels. However, drainage ditches themselves are known to be sources of CH_4 and other greenhouse gases (GHGs), but emissions data are scarce, particularly for carbon dioxide (CO_2) and nitrous oxide (N_2O), and show high spatial and temporal variability. Here, we report dissolved GHGs and diffusive fluxes of CH_4 and CO_2 from ditches at three UK lowland fens under different management; semi-natural fen, cropland, and cropland restored to low-intensity grassland. Ditches at all three fens emitted GHGs to the atmosphere, but both fluxes and dissolved GHGs showed extensive variation both seasonally and within-site. CH_4 fluxes were particularly large, with medians peaking at all three sites in August at 120–230 mg m^{-2} d^{-1}. Significant between site differences were detected between the cropland and the other two sites for CO_2 flux and all three dissolved GHGs, suggesting that intensive agriculture has major effects on ditch biogeochemistry. Multiple regression models using environmental and water chemistry data were able to explain 29–59% of observed variation in dissolved GHGs. Annual CH_4 fluxes from the ditches were 37.8, 18.3 and 27.2 g CH_4 m^{-2} yr^{-1} for the semi-natural, grassland and cropland, and annual CO_2 fluxes were similar (1100 to 1440 g CO_2 m^{-2} yr^{-1}) among sites. We suggest that fen ditches are important contributors to landscape-scale GHG emissions, particularly for CH_4. Ditch emissions should be included in GHG budgets of human modified fens, particularly where drainage has removed the original terrestrial CH_4 source, e.g. agricultural peatlands.

* Corresponding author.
E-mail address: michael.peacock@open.ac.uk (M. Peacock).

http://dx.doi.org/10.1016/j.scitotenv.2016.11.005
0048-9697/© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Northern peatlands store approximately 547 Pg of carbon (Yu et al., 2010) and contribute to the global atmospheric balance of GHGs through the release and uptake of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Intact peatlands are typically net sinks for CO_2, and sources of CH_4 and N_2O (Freeman et al., 1993; Nykänen et al., 1995; Smith et al., 2004; Kirschke et al., 2013). On a 100-year timescale CH_4 and N_2O have global warming potentials (GWP) of 28 and 298, respectively, relative to CO_2 (IPCC, 2013). Insights into biogeochemical cycling in peatlands are therefore important in developing understanding of global GHG dynamics and future climate change.

Globally, peatlands have been extensively drained for conversion to agriculture, forestry and peat extraction. Drained lowland fens, such as those of eastern England, the Netherlands and the southern Baltic coast are extremely fertile, and are therefore principally converted to intensive agricultural use (Morris et al., 2000). Conversion to agricultural use often includes strict hydrological management, such as the use of subsurface irrigation and, in part due to the long-term subsidence which is an inevitable consequence of peat drainage, the active pumping of water around fields (e.g. Morrison et al., 2013). There is now growing interest in the restoration of agricultural fens to wetlands (e.g. Höll et al., 2009; Peh et al., 2014), although there are strong commercial factors, as well as food security considerations, that favour their continued agricultural use (Glenk et al., 2014).

Drainage and conversion of fens to agricultural use has the capacity to alter the cycling of GHGs. It is generally considered that peatland drainage leads to a decrease in CH_4 emissions (to near-zero values), but increases in CO_2 and N_2O emissions (Glenn et al., 1993; Martikainen et al., 1995; Alm et al., 1999; Haddaway et al., 2014). Upon draining, peatlands therefore become a diminishing carbon reservoir, releasing carbon into the atmosphere that was fixed over thousands of years.

CH_4 fluxes from drained peatlands were previously assumed to be insignificant (IPCC, 2006). However, a number of studies have shown that the ditches created during drainage can themselves be significant CH_4 sources (Best and Jacobs, 1997; Sundh et al., 2000; Minkkinen and Laine, 2006; Hendriks et al., 2007; Hyvönen et al., 2013), contributing 60–70% of total CH_4 emissions in one study (Schrier-Uijl et al., 2010), over 84% in another (Teh et al., 2011) and with measured fluxes as high as 366 mg CH_4 m^{-2} h^{-1} (Schrier-Uijl et al., 2010). Where the space between ditches is small, drainage could in theory actually result in a net increase in landscape-scale CH_4 fluxes compared to undrained sites (Roulet and Moore, 1995).

Large ditch CH_4 fluxes are usually associated with productive, high-nutrient, sites with low water flow and high labile carbon inputs (e.g. agricultural grasslands; Best and Jacobs, 1997). Conversely, faster-flowing ditches in nutrient-poor upland bogs typically have small fluxes; Cooper et al. (2014) recorded an annual mean CH_4 flux of 59.7 kg CH_4 ha^{-2} yr^{-1} from an open ditch in a blanket bog, and Sirin et al. (2012) measured a growing season flux of 9.9 mg CH_4 m^2 d^{-1} from ditches in a forested bog. A recent review found mean fluxes for different peat/land-use types varied from approximately 30 g CH_4 m^{-2} yr^{-1} in forest/semi-natural peatlands, to 200 g CH_4 m^{-2} yr^{-1} in tropical deforested peatlands (Evans et al., 2016a). It is important to recognise that methane emissions can occur via different pathways, and the rates of flux via these pathways will have different controls (Fig. 1). Diffusive/steady emissions result from the CH_4 concentration differential between the ditch and the atmosphere. Wetland plant aerenchyma may provide a chimney through which oxygen is transported into sediment and CH_4 escapes to the atmosphere. Finally, steady emissions may be punctuated by temporally and spatially heterogeneous ebullition, which can contribute significantly to net CH_4 fluxes (Vermaat et al., 2011). The importance of ditches in GHG cycling has therefore been recognised by the IPCC and incorporated into their guidelines (IPCC, 2014).

As well as CH_4, drainage ditches emit N_2O (Reay et al., 2003; Teh et al., 2011; Hyvönen et al., 2013). Some ditches have been found to emit CO_2 (Best and Jacobs, 1997; Sundh et al., 2000; Teh et al., 2011; Hyvönen et al., 2013), while others with emergent vegetation have sometimes been observed to fix CO_2 (e.g. Vermaat et al., 2011). However, whilst ditches appear to be consistent hotspots for CH_4 emissions, CO_2 and N_2O fluxes are of a considerably smaller magnitude in terms of their overall contribution to GHG emissions, and are typically more similar to fluxes from drained peat adjacent to ditches (Evans et al., 2016a). For example, Hyvönen et al. (2013) found ditches in a boreal cutaway peatland being used to cultivate *Phalaris arundinacea* contributed just 1% and 5% of total ecosystem emission of N_2O and CO_2.

Internationally, there is a lack of information on GHG emissions from drainage ditches; in a recent review of published studies, a total of just 19 studies were identified in which peatland CH_4 emissions had been reported, for a total of 69 individual peatland sites where CH_4 was measured (Evans et al., 2016a). The same analysis suggested that studies of CO_2 and N_2O are still too few to allow the data to be collated in a meaningful way. Just two studies to date have reported CH_4 fluxes from ditches in the UK. In contrast to this dearth of information on ditches, numerous studies have looked at GHG emissions associated with other freshwaters. For instance, Cole et al. (2007) noted that carbon emissions from lakes and rivers could be approximately 0.8 Pg C yr^{-1}; enough to exert effects on regional budgets, despite these features occupying small areas. Similarly, Bastviken et al. (2011) suggested that CH_4 emissions from inland waters have the capacity to offset 25% of the terrestrial carbon sink, whilst Deemer et al. (2016) calculate that reservoirs emit 1.5% of global anthropogenic CO_2-equivalent emissions from CO_2, CH_4 and N_2O. Considering N_2O, rivers and estuaries could account for 20% of global anthropogenic emissions (Seitzinger and Kroeze, 1998).

To help address this knowledge gap, we carried out seasonal fieldwork for one year in ditches at three lowland fens in East Anglia, England. Each site was under a different management regime: 1) a semi-natural fen under conservation management; 2) former cropland that has been restored to extensive grassland, and; 3) intensive deep-drained cropland. We measured dissolved GHGs within ditches, diffusive fluxes of CO_2 and CH_4 from ditches, and a variety of physical ditch attributes and water chemistry determinands. Our aim was to quantify the differences in GHGs between and within sites, and across seasons, and to attempt to elucidate the drivers behind GHG dynamics.

2. Materials and methods

2.1. Field sites

All three field sites were located in East Anglia, in eastern England. This region was once the largest area of lowland fen peatland in the UK, covering several thousand square kilometres. Since the 17th century, drainage of the land resulted in the loss of most of the natural fenland, with only a handful of intact fragments remaining. The principal land use of the drained areas is intensive arable and horticultural agriculture. The drainage and conversion of the fens has resulted in extensive peat wastage, with much of the original deep peat area now reduced to a dense, thin intermixed organic and mineral layer (Hutchinson, 1980; Burton and Hodgson, 1987). The altitude of the land is close to (and in many areas below) sea level. Mean annual rainfall in the area is 574 mm, and mean annual temperature is 10.1 °C (data from UK Met Office station in Mepal, within 30 km of all study sites). The sites were:

1. Sedge Fen (semi-natural fen). 52.31 N, 0.28 E. Area = 61 ha. Sedge Fen is part of the Wicken Fen National Nature Reserve. Peat depth is 3.8 m, bulk density is 0.37 g cm^{-3}, C/N is 15.8 (Evans et al., 2016b). Vegetation comprises reedbeds dominated by *Cladium mariscus* and *Phragmites australis*, with some *Phalaris arundinacea* and *Calamagrostis canescens* (Eades, 2016), as well as areas of fen