Science of the Total Environment 505 (2015) 573–586

Contents lists available at ScienceDirect

Science of the Total Environment

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

Landscape analysis of nutrient-enriched margins (lagg) in ombrotrophic peatlands

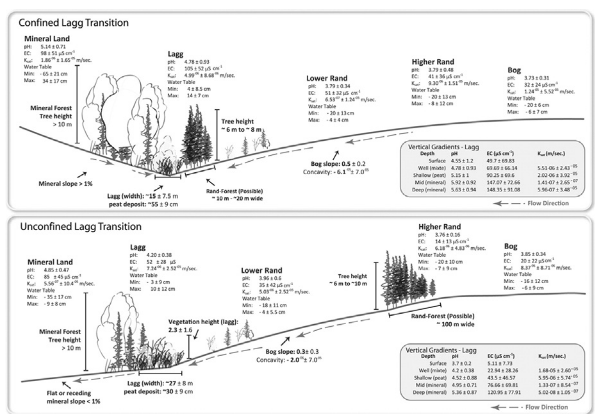
Mélanie N. Langlois [a], Jonathan S. Price [a,*], Line Rochefort [b]

[a] Department of Geography and Environmental Management, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada
[b] Département de phytologie, pavillon Paul-Comtois, Université Laval, 2425, rue de l'Agriculture, Québec, QC G1V 0A6, Canada

HIGHLIGHTS

- Hydraulic, hydrochemical, geomorphic, and vegetation gradients characterize laggs.
- Lagg morphology can be categorized as confined or unconfined.
- Lagg water quality and variability are intermediate between bog and mineral terrain.
- Laggs are an integral part of the peatland, and contribute to ecosystem function.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 1 October 2014
Accepted 1 October 2014
Available online xxxx

Edited by: F. Riget

Keywords:
Lagg
Ecotone
Bog
LiDAR
Ecohydrology
Geomorphology

ABSTRACT

Scientific knowledge of the wet zone – the lagg – that tends to form at the edge of ombrotrophic peatlands is surprisingly limited. In this study, we aim to improve the understanding of the ecohydrological functions of this transition by describing the form and abiotic controls of the laggs and margins of bog peatlands. Data collected in wells and piezometers along 10 transects (within 6 bogs), of the New Brunswick Eastern Lowlands are used to analyse the hydraulic and hydrochemical gradients, while airborne LiDAR data provides new insight on the geomorphology and the vegetation patterns of the bog–lagg–mineral transition zone. Based on their geomorphic character, the study transects are placed into 2 categories: confined and unconfined. Laggs of confined transition are found in a topographic depression, between the bog and a mineral slope >1%, while laggs of unconfined transitions are adjacent to a flat (≤1%) or receding mineral slope (sloping away from the lagg). Water level (4 ± 9 cm vs. −3 ± 9 cm), pH (4.8 ± 0.9 vs. 4.2 ± 0.4), electrical conductivity (EC_{corr}) (105 ± 52 μS cm^{-1} vs. 52 ± 28 μS cm^{-1}) and peat depth (55 ± 9 cm vs. 30 ± 9 cm) are found to be higher, respectively, for the confined laggs than for the unconfined. Saturated hydraulic conductivity (K_{sat}) of the lagg's upper peat layer resembles that of bog environments, but quickly reduces with depth, impeding vertical water flow. The greatest abiotic control of the lagg appears to be topography, which affects water flow rates and direction, thus water chemistry, nutrient transport and availability, hence vegetation characteristics. Our results suggest that the features of the

* Corresponding author. Tel.: +1 519 888 4567x35711.
E-mail address: jsprice@uwaterloo.ca (J.S. Price).

http://dx.doi.org/10.1016/j.scitotenv.2014.10.007

transition zone that include the lagg, influence the quantity and variability of water within the adjacent peatland, and should be considered as integral part of the peatland complex.

1. Introduction

"Lagg" refers to the transitional zone that forms at the margin of natural ombrotrophic peatlands; some are distinct and others are not. In its hydrology and hydrochemistry, it takes on qualities of both the bog and the adjacent mineral terrain (Whitfield et al., 2006). As acidic water from the bog meets mineral-enriched waters from surrounding environments, rapid ecohydrological changes occur over short distances (Howie et al., 2009; Paradis et al., 2014). This can easily be observed in the vegetation (Damman, 1986; Paradis et al., 2014), which transitions from dominantly *Sphagnum* mosses in the bog centre, to shrubs, then trees in the neighbouring mineral forest. The lagg plays three key functions in a raised bog ecosystem: 1) high water levels in this zone reduces the hydraulic gradient in the margin of the adjacent bog, which helps the bog retain water (Schouwenaars, 1995); 2) during wet periods the lagg can efficiently move excess water away from the system (Godwin and Conway, 1939); and 3) it plays a role in the bog growth and expansion by impeding lateral expansion thus promoting vertical growth of the peatland (Godwin and Conway, 1939; Hobbs, 1986; Damman, 1986). Groundwater exchanges through the lagg zone affect water quality within and beyond the margin of the bog in both directions (Keough and Pippen, 1984), although their capacity to attenuate non-point-source water pollution (e.g. Zeng et al., 2012) is not known.

Laggs are not commonly recognized as an integral part of the peatland complex. Due to this lack of recognition, adjacent land-uses often encroach on laggs (Pellerin and Lavoie, 2003; Pellerin et al., 2008; Howie and Meerveld, 2013), or they are drained or otherwise damaged in peat harvesting, resource extraction operations or urban development. Little attention has been paid to their restoration and management, in part because their hydrological and ecological functions have not been well described, and remain poorly understood (Whitfield et al., 2006; Howie et al., 2009; Howie and Meerveld, 2013; Howie and van Meerveld, 2011). This lack of knowledge and understanding compromises the ability of land managers, who must make decisions without a clear understanding of the impact of developing within the margin, or in peripheral areas of bog peatlands (Murphy et al., 2007).

In Canada, most of the research on lagg function comes from the study of a large urban peatland: Burns Bog (Vancouver, British Columbia) – which has lost much of its natural lagg to anthropogenic disturbances and land use changes – and other costal bogs through the work of Hebda et al. (2000), Whitfield et al. (2006), and Howie et al. (2009, 2013). After several decades of restoration efforts, researchers are recognizing that for a raised bog to be viable and maintain its integrity, lagg zones must be present and functioning (Hebda et al., 2000). Whitfield et al. (2006) conceptualized the lagg structures that might have existed prior to the disturbance of Burns Bog. They identified 4 forms of transition from peatland to mineral terrain likely to have occurred at different locations around the peatland: 1) between the bog and a relatively steep mineral slope, 2) confined between a natural river levee and the bog, and subject to occasional flooding from the nearby river, 3) spreading across an ancient beach formation, and 4) in an area assumed to have been dominated by natural discharge from the bog across a flat deltaic terrain (Whitfield et al., 2006; Howie et al., 2009). Whitfield's model was later refined by Howie et al. (2009), using historical aerial photography and stereography to hindcast the historical location of the lagg, based on vegetation height. This latter model includes predictions of the expected presence of 4 ecological gradients for the bog–lagg–mineral terrain transition where 1) the height of the vegetation is expected to increase from bog to lagg and mineral forest, 2) the hydrological gradient is presumed to be steeper on the upland side (relatively steep mineral slope) compared to the bog side, 3) the chemical gradient is suspected to have higher concentration in the mineral soil and gradually decreasing towards the bog, and 4) the soil permeability is expected to be lower in the catotelmic bog peat than in the mineral land.

The presence and the character of the lagg vary within and between peatlands, and its lateral and longitudinal extents remain a challenge to define (Paradis et al., 2014). This is true within a single geographical region and it becomes more problematic to generalize for different climatic, hydrogeomorphic and ecological regions. Consequently, this has resulted in inconsistent terminology and/or definitions for this zone, which has variously been referred to as marginal ditch (Rigg, 1925; Rigg et al., 1927; Rigg and Richardson, 1938), marginal fen (Conway, 1949), wet margin (Hobbs, 1986), lagg fen (Bragg, 2002; Rydin and Jeglum, 2006), lagg stream (Millington, 1954) and lagg (Couillard and Grondin, 1986; Payette and Rochefort, 2001; Whitfield et al., 2006; Howie et al., 2009,2013; Richardson et al., 2010; Howie and van Meerveld, 2011). Among the few studies specifically focussed on laggs (Blackwell, 1992; Smith et al., 1999; Howie et al., 2009), few have studied truly undisturbed ecosystems (e.g. Mieczan et al., 2012).

The impact of the landscape on the formation and functioning of the lagg has been mentioned by many authors (Godwin and Conway, 1939; Damman, 1986; Hebda et al., 2000; Whitfield et al., 2006; Howie et al., 2009; Howie and Meerveld, 2013), but few (Richardson et al., 2010) have quantified its geomorphology. The lagg is hydrologic in nature, and influenced by both the bog and the adjacent mineral land. To understand the landscape processes that control the form and functions of the lagg, its neighbouring ecosystems also need to be examined (Howie et al., 2009; Howie and Meerveld, 2013; Paradis et al., 2014). Based on the conceptual model of Whitfield et al. (2006) and Howie et al. (2009), our goals are 1) to describe the form and abiotic controls of the transition from *Sphagnum* dominated bog ecosystem to the surrounding mineral forest and, 2), to suggest a conceptual model of the "bog–lagg–mineral land" transition for the Canadian Atlantic provinces.

2. Study area

All study sites were part of the New Brunswick Eastern Lowlands, located between the town of Bertrand (47°45′N, 65°03′W), and the eastern limit of Miscou Island (47°59′N, 64°31′W) (Fig. 1). The region is characterized by a cool, moist climate, with 4 months below freezing (Canadian Climate Normals 1971–2000, Bathurst, NB). Mean annual temperature in the region is 4 ± 1 °C, and mean annual precipitation is 1059 mm (30% as snowfall) (Canadian Climate Normals 1971–2000, Bathurst, NB). The growing season of 2011 – the study period – was particularly wet with an average May–September precipitation of 617 ± 10 mm compared to the 435 mm average for normal years (Canadian Climate Normals 1971–2000, Bathurst NB). The peninsula is underlain by red and grey sandstone, interbedded with mudstone and conglomerate, which combined with the flat topography (ranging from 0 m to ~45 m above sea level (MASL) for the region studied), often results in poor drainage (Colpitts et al., 1995). Consequently, organic soils have developed in many of the regional glacial depressions, and nearly half of New Brunswick wetlands are found in the eastern lowlands (Zelazny, 2007).

In June 2011, 6 relatively undisturbed ombrotrophic peatlands of various sizes (between 31 and 1500 ha) were instrumented with a total of 10 transects comprising wells and piezometers, straddling the bog and the adjacent mineral land (Table 1). Each of these was selected to cover lagg transitions ranging from wet and well defined, to dryer and more diffuse. These ecotones were identified mainly based on the