Soil Biology & Biochemistry 38 (2006) 2011–2024
Soil Biology & Biochemistry
www.elsevier.com/locate/soilbio

Decomposition in peatlands: Reconciling seemingly contrasting results on the impacts of lowered water levels

Raija Laiho*

Peatland Ecology Group, Department of Forest Ecology, University of Helsinki, P.O. Box 27, FIN-00014 Helsinki, Finland

Received 9 September 2005; received in revised form 3 February 2006; accepted 22 February 2006
Available online 4 April 2006

Abstract

Northern peatlands represent about 30% of the global soil C pools. The C pool in peat is a result of a relatively small imbalance between production and decay. High water levels and the consequent anoxia are considered the major causes for the imbalance. As such, the C sink of a peatland is labile, and sensitive to disturbances in environmental conditions.

Changes in peatland ecosystem functions may be mediated through land-use change, and/or climatic warming. In both cases, lowering of the water level may be the key factor. Logically, lowered water levels with the consequent increase in oxygen availability in the surface soil may be assumed to result in accelerated rates of organic matter decomposition. Yet, earlier research has given highly contrasting results concerning the effects of lowered water levels on the rates of decomposition and the C sink/source behaviour of peatlands. The mechanisms controlling this variation remain unresolved.

This paper summarizes the changes observed in the biotic and abiotic controls of decomposition following natural or artificial lowering of peatland water levels and show that they are complex and their interactions have not been previously explored. Long-term changes in the C cycle may differ from short-term changes. Short-term changes represent a disturbance in the ecosystem adapted to the pre-water-level-lowering conditions, while long-term changes result from several adaptive mechanisms of the ecosystem to the new hydrological regime. While in a short term, the disturbed system will always lose C, the long-term changes inherently vary among peatland types, climates, and extents of change in the water level. The paper closes by identifying the gaps in our knowledge that need to be addressed when proceeding towards a causal and unifying explanation for the C sink/source behaviour of peatlands following persistent lowering of the water level.

Keywords: C cycling; Decomposition dynamics; Decomposer communities; Hydrological change; Litter quality; Long-term change; Secondary succession; Short-term change; Wetland ecology

1. Introduction

Peatlands represent a wide variety of wetlands that are characterized by an organic soil, but differ in hydrology, chemistry, and, consequently, vegetation composition. Northern peatlands have been a significant sink of carbon (C) from the atmosphere, representing about 30% of the global soil C pools with their estimated reservoir of 455 Pg (10^{15} g) (Gorham, 1991). This has been achieved by a relatively small imbalance between production and decay: only 2–16% of the net primary production of a peatland ecosystem gets deposited as peat over centuries or millennia (Päivänen and Vasander, 1994). High water levels and the consequent anoxia, accompanied with low soil temperatures are considered the major causes for the imbalance. As such, the C sink of a peatland is labile, and sensitive to variations in environmental conditions (Alm et al., 1999a; Griffis et al., 2000; Bubier et al., 2003a).

Peatlands slowly change along their successional development, which is regulated by both allogenic and autogenic factors (e.g., Klinger and Short, 1996; Hughes and Dumayne-Peaty, 2002). Relatively rapid changes in peatland ecosystem functions may be mediated through land-use change, and/or climatic warming. In both cases, lowering of the water level is a key factor (Gitay et al., 2001). Quite

*Corresponding author. Tel.: + 358 9 191 58139; fax: + 358 9 191 58100.
E-mail address: raija.laiho@helsinki.fi.

0038-0717/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2006.02.017

logically, lowered water levels with the consequent increase in oxygen availability in the surface soil may be assumed to result in accelerated rates of organic matter decomposition. During warm, dry summers that have resulted in temporarily lowered water levels, substantial C losses from boreal or subarctic bogs and fens have been observed (e.g., Schreader et al., 1998; Alm et al., 1999a; Moore et al., 2002). These short-term observations have strengthened the prevailing paradigm, that persistent lowering of the water level will reduce the C sink of a peatland, and eventually turn it into a source of C into the atmosphere (Armentano and Menges, 1986; Silvola, 1986).

In accordance with the paradigm, increased CO_2 effluxes have been measured from peatlands where a persistent lowering of the water level has been induced by ditching (i.e., those drained for forestry) (Glenn et al., 1993; Martikainen et al., 1995; Alm et al., 1999b). In great contrast, an extensive Finnish inventory on long-term (5–6 decades) changes in drained peatlands indicated that on average, peat C stores had increased following drainage (Fig. 1; Minkkinen and Laine, 1998b; Minkkinen et al., 2002). In individual peatlands, both decreases and increases in peat C stores following long-term drainage have been observed (Sakovets and Germanova, 1992; Vompersky et al., 1992; Minkkinen and Laine, 1998b; Minkkinen et al., 1999). In accordance with these contradicting results, in the few field experiments on drainage-induced changes in decomposition rates, increase, decrease, and no change have all been observed (Lieffers, 1988; Minkkinen et al., 1999; Domisch et al., 2000; Laiho et al., 2004).

Thus, earlier research may be summarized as follows: after persistent lowering of the water level, a peatland site may become a source of C into the atmosphere, remain a sink, or become a stronger sink. To some extent, these differences may be linked to peat soil nutrient level (vegetation type) and climatic conditions (Minkkinen and Laine, 1998b; Minkkinen et al., 1999); however, the mechanisms controlling this variation remain unresolved.

The aim of this paper is to synthesize current information on the changes, induced by natural or artificial lowering of the water level, in the biotic and abiotic factors affecting decomposition processes in peatlands. As the factors affecting aerobic decomposition in the surface layers may be considered to experience more changes than those affecting anaerobic decomposition deeper down, more emphasis will be given on those. The ultimate goal is to proceed towards a causal and unifying explanation for the observed variation in the C sink/source behaviour of peatlands following lowering of the water level. The review will limit on changes that might be discernible during the first 1–2 centuries, and will not examine peat accumulation and C sequestration over millennia, which is the time-scale of peatland succession generally.

Decomposition means mass loss of organic matter as gas or in solution, caused by either leaching or consumption by saprotrophic organisms. Terms decomposition, decay, breakdown and humification have been used in the literature, some times with varying emphasis (see Clymo, 1984). Here, only the term decomposition is used irrespective of the original terminology used by the authors in the studies referred to. Water level refers to the distance from mire surface to the saturated layer, which shows as a free water surface in a well, or tube inserted in the peat.

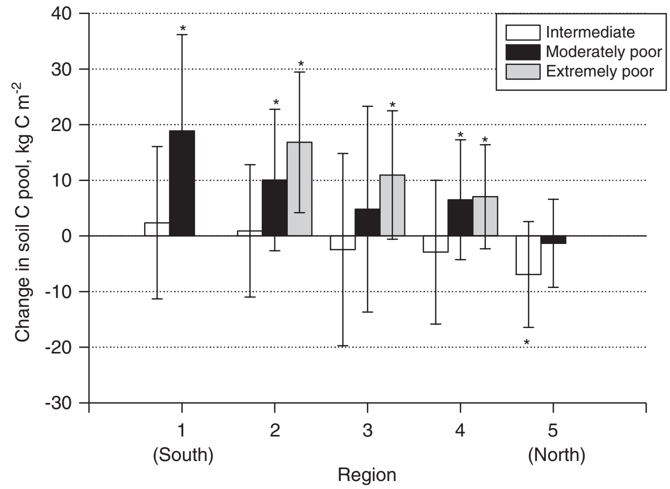

Fig. 1. Change in total peat soil C pool over 50–60 years following drainage for forestry in pine fens representing different nutrient levels, as reported by Minkkinen and Laine (1998). Stars show where the change was significantly different from zero. Region codes: 1 = South Finland, 2 = Central Finland, 3 = Eastern Finland, 4 = Northern Finland excluding Lapland, 5 = Lapland. Redrawn from Minkkinen and Laine (1998). Nutrient levels: intermediate fens correspond to mesotrophic, moderately poor to oligotrophic, and extremely poor to oligo-ombrotrophic.

2. Constraints for decomposition in pristine peatlands

Generally, decomposition of organic matter depends on four factors: substrate quality, environmental conditions, decomposers present, and nutrient availability. Nutrient availability is determined by both substrate and environmental characteristics: If decomposer fungi do not get enough of nutrients from the substrate that they utilize as an energy source, they may in some cases translocate it from the surroundings (e.g., Lindahl et al., 2001). These four factors all interact: environmental conditions and nutrient availability regulate the vegetation composition (Wheeler and Proctor, 2000; Økland et al., 2001), which in turn largely determines substrate quality (Hobbie, 1996), which then, together with environmental conditions and possibly nutrient availability, regulates the composition of the decomposer community (Borga et al., 1994; Panikov, 1999).

Substrate quality has usually been described as concentrations of C fractions (solubles, holocellulose, lignin), and/or nutrients. The effects of substrate quality on decomposition can be studied by incubating different litter types in constant environmental conditions in the laboratory, or in similar conditions within a site in the field. Generally, litters with high concentrations of soluble C compounds,