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Whole-tree harvesting and grass seeding as potential mitigation methods for phosphorus export in peatland catchments

Connie O'Driscoll [a,b], Mark O'Connor [a], Zaki-ul-Zaman Asam [b], Elvira de Eyto [c], Russell Poole [c], Michael Rodgers [a], Xinmin Zhan [a], Mika Nieminen [d], Liwen Xiao [b,*]

[a] Civil Engineering, National University of Ireland, Galway, Ireland
[b] Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Dublin 2, Ireland
[c] Marine Institute, Newport, Co. Mayo, Ireland
[d] Finnish Forest Research Institute, Southern Finland Regional Unit, Vantaa 8, Finland

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ABSTRACT

Forest clearfelling is potentially a major environmental problem with respect to the degradation of water quality in receiving water courses due to phosphorus (P) release from soil and clearfelling residue stocks. Recent studies have highlighted the need to investigate the performance and benefits of potential mitigation methods such as whole tree harvesting (WTH) and grass seeding. In this study, fifteen plots (0.014 ha each) were constructed in a standing coniferous forest and P concentrations in plot runoff were monitored for one year prior to clearfelling. Following clearfelling three replicates of five forest harvesting management practices/treatments were applied to the plots: brash with grass seeding (Treatment 1), brash (Treatment 2), brash mat/ tree extraction route (Treatment 3), WTH (Treatment 4) and WTH with grass seeding (Treatment 5). These treatments were designed to comparatively assess the benefits of WTH and grass seeding practices on mitigating P released from forested peatlands following clearfelling and to determine the sources and sinks of P following clearfelling operations. Annual average total reactive phosphorus (TRP) concentrations in the plot runoff were < 20 $\mu g\ L^{-1}$ in all treatments before clearfelling, and increased to 79 $\mu g\ L^{-1}$, 160 $\mu g\ L^{-1}$, 335 $\mu g\ L^{-1}$, 50 $\mu g\ L^{-1}$ and 38 $\mu g\ L^{-1}$ in Treatments 1, 2, 3, 4 and 5, respectively, after clearfelling. These results highlight that WTH and grass seeding can be used efficiently as methods to improve water quality, aiding in the protection of the biota residing in the aquatic systems draining peatland catchments.

1. Introduction

Peatland conversion to afforestation was frequently practiced in north-western Europe, Fennoscandia, the former USSR, and North America, during the late 20th century (Paavilainen and Päivänen, 1995) driven by a need to improve a recognised economically valuable natural resource. The economic viability and environmental ethics of afforesting peatland, however, has long since been questioned (MacMillan, 1993; Renou and Farrell, 2005; Anderson, 2010) and the future management of low production forests is the topic of much debate (Delaney, 2008; Tiernan, 2008; Renou-Wilson et al., 2011; Vanguelova et al., 2011). Peatland fed catchments contain oligotrophic headwaters, many of which contain IUCN (International Union for the Conservation of Nature) Red List species (e.g. salmonids and freshwater pearl mussels) which make them important biodiversity refuges (O'Driscoll et al., 2012). The European Union (EU) Water Framework Directive (WFD) legislation requires implementation of measures to maintain high status of water bodies where it exists and achieve good ecological status where it does not by 2015 (European Union, 2000). In early afforestation operations in Ireland and the UK, sites were cultivated by ploughing (Carling et al., 2001), a method which was shown to account for 40% more site disturbance than subsequent methods such as mounding (Worrell, 1996). Trees were planted on ribbons at 1.5 m intervals, and separated by furrows. Surface water flows along the furrows into collector drains which connect to the stream network. Fertiliser was typically applied at the afforestation stage on blanket peat in the UK and Ireland to increase timber production (Harriman, 1978; Rodgers et al., 2010). Presently, plantations reach their final felling age between 35 to 40 years old, at which time they are typically 'stem-only' clearfelled. The clearfelling residues (i.e. needles, twigs and branches) are collected together to form brash material mats for stem extraction protecting the peat surface during clearfelling operations. Following clearfelling operations brash mats are collected together to

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* Corresponding author. Tel.: +353 1 8963741.
E-mail address: liwen.xiao@tcd.ie (L. Xiao).

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form windrows clearing the sites in preparation for subsequent rotation plantations.

Catchment scale studies have shown that clearfelling peatland forests can cause negative impacts on the receiving water quality with increased nutrient and suspended sediment release (Lebo and Hermann, 1994; Paavilainen and Päivänen, 1995; Ahtiainen and Huttunen, 1999; Ensign and Mallin, 2001; Nisbet, 2001; Cummins and Farrell, 2003; Nieminen, 2004; Rodgers et al., 2010, 2011). Phosphorus (P) is a key contributor to non-point surface water pollution causing nutrient enrichment of rivers and stimulating eutrophication (Reynolds, 1992). In three comparable studies (Nieminen, 2003; Cummins and Farrell, 2003; Rodgers et al., 2010) spanning national boundaries, similar P release patterns following a final harvesting event were observed. An immediate peak in P concentrations was measured in the runoff after harvesting, followed by a maximum peak the following summer with a long declining tail. The cause of this trend was not investigated in these catchment scale studies due to the complexity of P release and the many possible mechanisms controlling P concentrations (Cummins and Farrell, 2003). However, it has been suggested that the removal of the standing forest and associated lack of P uptake and mechanical site disturbance could be the reason for the initial peak and mineralisation of organic P from decomposing clearfelling residues could be the cause of the second peak (Hyvönen et al., 2000; Ganjeguntea et al., 2004; Rodgers et al., 2010).

Current economically feasible opportunities for reducing P losses in forest harvested peatland catchments include: whole-tree harvesting; buffer zones and constructed wetlands; phased felling; and reductions in the amount of fertiliser applied. Whole-tree-harvesting (WTH) is achieved by removing the whole tree (i.e., all parts of the tree above the ground) from the site in a single operation (Nisbet et al., 1997). Needles and branches have much higher P concentrations than stem wood, with 46 kg P ha^{-1} in needles and branches compared with 14 kg P ha^{-1} in stem wood, reported for a Sitka spruce forest growing on shallow peat (Carey, 1980). In addition, higher soil P concentrations are associated with areas below windrows/brash material (Nieminen, 2004; Rodgers et al., 2010) in clearfelled peatland catchments indicating that WTH could be used as a means to decrease P export. Yanai (1998) reported negligible P loss to streams over 3 years from WTH on mineral soil at the Hubbard Brook Experimental forest in New Hampshire. However, mineral soil has been shown to have a much higher P adsorption capacity than blanket peat (Tamm et al., 1974). The WTH practice as a method for mitigating P release has not been examined for blanket peat soils with low iron and aluminium concentrations and low P adsorption properties such as the peat soils found in the Burrishoole catchment (Asam et al., 2012). The by-products of WTH are gaining increasing value due to the rising demands for renewable energy (Vanguelova et al., 2010; Laudon et al., 2011) and concerns have been raised regarding decreased site productivity for subsequent forest rotations (Nisbet et al., 1997) necessitating scientific observations to underpin evidence-based policy developments. Buffer zones and constructed wetlands are commonly used by forestry practitioners in management of freshwater aquatic systems (Newbold et al., 2010). They can control runoff by reducing the flow thus increasing deposition and interaction between incoming nutrients and soil matrices, and plant and microbial nutrient processes. However, Rodgers et al. (2010) highlighted that traditional buffers of 15–20 m may not be adequate to reduce P export as the majority of P released occurred during storm events when buffer zones can have low residence times. Constructed wetlands are costly to establish and many earlier afforested peat catchments in Ireland and the UK were established without riparian buffer areas and trees were planted to the stream edge (Ryder et al., 2011; O'Driscoll et al., 2014). O'Driscoll et al. (2014) found that a grassed peatland buffer zone removed only 18% of the total reactive phosphorus (TRP) released from an upstream clearfelled blanket peat site. O'Driscoll et al. (2011) demonstrated a novel method whereby native grass species were seeded on a site immediately after clearfelling and before reforestation, confirming that vegetation could immobilise nutrient movement from a recently clearfelled blanket peat catchment. O'Driscoll et al. (2011) suggested that the observed uptake of P measured in the grass would render a corresponding reduction in the P exported by the stream after clearfelling.

Sources of non-point pollution are especially difficult to detect in catchment scale studies as they generally encompass large areas and involve complex biotic and abiotic interactions (Solbe, 1986). Catchment scale studies are very popular in observing human induced deterioration in water quality; however, they leave many unexplained questions and are difficult to replicate (van Es et al., 1998; Sliva and Williams, 2001; Townsend et al., 2004). Plot-scale studies are typically used to elucidate the mechanisms behind nutrient loss from soil to runoff (Buda et al., 2009); to evaluate different management practices which are applied as treatments; and to provide an experimental design that is statistically valid (van Es et al., 1998; Wainwright et al., 2000). Additionally, experiments using natural rain events tend to more accurately estimate P concentrations in runoff and runoff volumes than simulated rainfall experiments (Dougherty et al., 2004, 2008; Smith and Pappas, 2010). The sensitivity of clearfelling peatland catchments in the UK, Ireland and Fennoscandia has risen to prominence in recent years in terms of economic and conservational viability; however, sustainable protection methods are inadequately researched and insufficiently proven. While forest clearfelling impacts on runoff P concentrations in blanket peatlands have been addressed in various studies further research is needed to understand the mechanisms behind the increased export of P, and to assess the efficiencies of mitigation methods such as WTH and grass seeding in improving runoff water quality. Thus, this study employed a replicated treatment plot-scale experiment in a blanket peat forest catchment in order to (1) distinguish between the removal of the standing forest and mechanical site disturbance (2) assess the performance of WTH and (3) assess the novel practice – grass seeding immediately after clearfelling on P release control.

2. Materials and methods

2.1. Study sites

This study was primarily carried out in Srahrevagh, a sub-catchment of the Burrishoole Catchment, Co. Mayo (53°39′N, 9°32′W, 220 m a.s.l) (Fig. 1). A 7.65 ha forested sub-catchment of Srahrevagh which was drained by a small first order stream, was partially (65%) felled during the study period (Fig. 1). The study catchment was afforested in 1971 with Lodgepole pine (*Pinus contorta*) using double-mouldboard ploughing, creating furrows and ribbons (overturned turf ridges) with a 2 m spacing, aligned down the main slope, together with several collector drains aligned close to the contour. Nursery grown transplants were planted on the ribbons at 1.5 m intervals, giving an approximate soil area of 3 m^2 per tree and rock phosphate fertiliser (at a rate of 13.2 kg P ha^{-1}) was manually applied. Thinning is not generally carried out on upland western blanket peats due to high risk of windthrow (Cummins and Farrell, 2003). The average depth of the peat in the study site was about 2 m overlaying bedrock of quartzite, schist and basic volcanic rock. The peat typically has a gravimetric water content of greater than 80%. A more detailed description of soil characteristics can be found in Asam et al. (2012). The Burrishoole has a mean annual rainfall and air temperature of about 2000 mm and 11 °C, respectively. The first order stream draining the 7.65 ha