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Relationship between plantation forest and brown trout growth, energetics and population structure in peatland lakes in western Ireland

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ABSTRACT

Much of the conifer plantation forest in Ireland is on peat soils. Plantations on this soil type are known to pose the greatest risk to degrading water quality by increased sedimentation, acidification and heavy metal accumulation. Peat soils are also known to leach phosphorus (P), nitrogen (N) and dissolved organic carbon (DOC) as a result of forestry operations. In moderation, such nutrient enrichment may have positive trophic impacts in oligotrophic freshwater systems such as those typical of peat catchments in western Ireland.

In this study, the water chemistry and brown trout (*Salmo trutta*) populations of peat-land lakes were investigated to assess the associations of conifer plantation forest on the growth, energetics and population structure of brown trout. We conducted this study over a three-month period in the summer of 2010 by comparing brown trout populations and water chemistry in lakes with three distinct catchment land uses: (i) unplanted blanket bog, (ii) moderate levels of conifer plantation forest (30–40% of catchment afforested), and (iii) high levels of conifer plantation forest (80–90% of catchment afforested).

Changes in hydrochemistry associated with conifer plantations resulted in elevated concentrations of N, P and DOC, but no change to pH, with increasing levels of plantation forest within the catchment. Whereas there was no consistent trend in brown trout density between land uses, highest densities were recorded in lakes with afforested catchments. Trout populations in lakes with afforested catchments were dominated by younger fish, primarily 1+ (year old) and 2+ (2 year old) individuals with some 0+ (young of the year) trout present, compared to control lakes, which were largely dominated by 2+ and 3+ (3 year old) individuals.

Older age classes of trout had larger body sizes in lakes with high levels of plantation forest within the catchment relative to the other lakes, indicating higher empirical growth rates, likely due to the trophic enrichment effects of forestry. Brown trout specific growth models that incorporate the potential confounding influence of different temperature regimes, showed no consistent relationship between growth and forest cover over the study period. Food consumption models indicated that trout in all sites were energetically challenged during the summer when sampling took place. Discrepancies between the observed body size and estimated growth of trout in lakes may potentially be due to (a) a significant amount of growth occurring outside of the summer study period and/or (b) unusually elevated temperature regimes during the study period, particularly in the afforested sites.

No negative impacts of conifer plantation forests on brown trout populations were recorded. However, forest managers may wish to minimise felling coupe within peatland plantations as felling operations may exacerbate nutrient and/or heavy ion input into aquatic systems in such catchments.

1. Introduction

In the last few decades, Ireland's landscape has experienced a very high rate of commercial afforestation, such that plantation forests established in the last 60 years now account for approximately 10% of total land cover. Over 90% of total forest cover in Ireland is comprised of plantation forest, more than in any EU member state except Malta (Forest Europe et al., 2011). Plantation forest practises are recognised as a potential source of pollution to associated freshwater systems and represent a considerable risk to the ecological status of surface waters (Rask et al., 1998; Steedman, 2000; Giller and O'Halloran, 2004). While a majority of studies have focused on surface water acidification associated with conifer plantation forests (Harriman and Morrison, 1982; Ormerod et al., 1989; Kelly-Quinn et al., 1996a; Cosby et al., 2001), more recent research has demonstrated the potential for plantation forest mediated eutrophication of freshwater systems, primarily through

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phosphorus fertilisation at the planting stage (Miller et al., 1996; Cummins and Farrell, 2003b; Foy and Bailey-Watts, 2007; Drinan et al., 2013b).

Forestry practises have been shown to lead to enhanced concentrations of nutrients leaching into aquatic systems (Cummins and Farrell, 2003b; Rodgers et al., 2010; Drinan et al., 2013b). The capacity of catchment soils to retain phosphorus is a considerable determinant of phosphorus loadings to freshwater systems (Cummins and Farrell, 2003b). In Ireland, approximately 42% and 77% of state and privately owned forests, respectively, are located on peat soils (NFI, 2007), resulting in 27% of Irish blanker bog now being afforested (Conaghan, 2000). Forests planted on this soil type are considered to pose the greatest risk to water quality (Hutton et al., 2008). Peat soils are known to leach phosphorus, nitrogen and dissolved organic carbon as a result of forest operations (Cummins and Farrell, 2003a, 2003b; Renou-Wilson and Farrell, 2007; Rodgers et al., 2010) and peat soils have a very low capacity to absorb and retain phosphorus in particular (Cuttle, 1983). The application of phosphorus fertilisers to forests on peat bogs therefore may pose a considerable risk to freshwaters, particularly considering the inherently oligotrophic status of water bodies in peatland areas (Cummins and Farrell, 2003b; McElarney et al., 2010; Rodgers et al., 2010). The source of leached nitrogen from afforested peatlands into water bodies is predominantly from the peat soil through mineralisation of soil organic matter (Nieminen, 1998, 2003), while dissolved organic carbon inputs are generally as a result of canopy leachate from living trees and litterfall (Qualls et al., 1991; Fröberg et al., 2007) and the decomposition of the organic matter of the forest peat soil (Michalzik et al., 2001).

The impact of commercial plantation forest operations on aquatic ecology has been investigated to a greater extent in lotic than in lentic habitats. However, plantation forest-mediated chemical effects on rivers may be somewhat difficult to discern due to the pulsed nature of these inputs which are concentrated at times of major disturbance, particularly planting, thinning and harvesting (Giller and O'Halloran, 2004). Concentrations of instream plant nutrients and other forest-derived materials are highly dependent on rainfall which not only washes chemicals into streams and rivers but also dilutes and flushes them, further exacerbating the difficulty of determining the scale of plantation forest inputs. As a consequence, many studies investigating the impact of hydrochemical change on aquatic biota have found little or no impact of forest operations (Liljaniemi et al., 2002; McKie and Malmqvist, 2008; Heino, 2009). However, dissolved and particulate substances tend to accumulate in downstream lakes which act as nutrient sinks due to their enhanced nutrient cycling and internal loading in comparison to streams (Søndergaard et al., 2003). Lakes may therefore be more suitable systems to assess chemical fluxes associated with forestry operations within a catchment (Drinan et al., 2013b).

Studies investigating the relationships of plantation forests on the ecology of aquatic systems have reported a wide range of results including slight and short lived changes in species assemblages (Rask et al., 1998; Patoine et al., 2000; Planas et al., 2000) whereas other show increases in primary production (Rask et al., 1998; Planas et al., 2000; Prepas et al., 2001) and significant impacts on invertebrate communities (Jutila et al., 1998; Rask et al., 1998; Köster et al., 2005) and fish (Jutila et al., 1998; Rask et al., 1998) although there are relatively few studies investigating impacts of forest practises on the latter (Northcote et al., 2004).

Conifer plantation forest acidification of aquatic habitats has received greater research focus compared to other issues concerning forest-surface waters interactions (Nisbet, 2001). Canopy interception of airborne pollutants is considered the main process by which coniferous plantations contribute to the acidification of freshwaters (Reynolds et al., 1994). Low pH levels and elevated levels of labile monomeric aluminium are known to impoverish fish communities (Driscoll et al., 1980) and the early life stages of fish, including salmonids, are highly sensitive to acidification (Kelly-Quinn et al., 1993; Sayer et al., 1993). The distribution and density of brown trout (*Salmo trutta* L.) have been shown to be negatively impacted by forest associated acidification (Stoner et al., 1984; Rees and Ribbens, 1995; Kelly-Quinn et al., 1996b).

Salmonids have been shown to be negatively impacted by nutrient enrichment and eutrophication-mediated declines of salmonid populations have been documented in both lentic (Colby et al., 1972; Persson et al., 1991) and lotic environments (Eklöv et al., 1998). Negative effects of eutrophication on salmonids are usually attributed to two main processes: deterioration of water quality conditions, and nutrient enrichment-mediated alterations in competitive balance with other taxa of fish. Anoxia, arising through either the respiration of excessive algal and plant growths at night, and/or due to microbial decay of organic matter is generally thought to be the critical factor through which eutrophication impacts salmonids (Eklöv et al., 1998, 1999), although eutrophication associated sedimentation of spawning gravels is known to reduce survival of eggs and alevins (Bagliniere and Maisse, 1990; Crisp, 1996; Jutila et al., 1998). Both Colby et al. (1972) and Persson et al. (1991) showed that fish communities of lakes can switch from dominance by coregonids and salmonids to dominance by percids and, finally, cyprinids, as a result of progressive eutrophication.

Sustainable land management aims to ensure that ecosystems are not altered by human activities to such a degree that it impairs function. Management alternatives are informed by quantification of ecosystem responses to changes in land use (Stephenson and Morin, 2009). However, studies of anthropogenic impacts on lake water chemistry and biota generally involve evaluating the relative impact of multiple stressors and it can prove difficult to evaluate the impact of one particular element (Dodson et al., 2005) such as forests or their operations on aquatic biota, due to background environmental perturbation (Paterson et al., 1998). However, recent studies in homogenous and otherwise undisturbed blanket bog lakes, have demonstrated a clear deleterious impact of conifer plantations on the water quality of lakes in blanket bog catchments, with forests and their operations mediating elevated levels of nitrogen, phosphorus and dissolved organic carbon (Drinan et al., 2013b), resulting in alterations to Chydoridae communities (Drinan et al., 2013c), aquatic macroinvertebrate assemblages and conservation value of these systems (Drinan et al., 2013a). Our study objective was to investigate relationships between lake hydrochemical conditions and brown trout population biology in two non-randomly selected lakes within each of three land-use treatments at catchment scales: blanket bog reference conditions, and bog catchments converted to low and high levels of plantation forest.

2. Methods

2.1. Site selection and description

Eighteen potential study lakes were identified based on geographic location, size, soil type, geology and catchment land use in areas of blanket bog throughout western Ireland using ArcGIS (ESRI ArcMap v.9.3). Blanket bog is an area of peatland, formed where there is a climate of high rainfall and a low level of evapotranspiration, allowing a peat layer of variable depth to develop over large expanses of ground. All candidate lakes were approximately 10–35 ha in area, on lowland blanket bog overlying igneous (granite) geology with minimal human impact within their