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ASSESSMENT OF THE IMPACT OF PHASED FELLING ON THE ECOLOGICAL QUALITY OF FIRST ORDER STREAMS AND SUBSEQUENTLY SALMONID RIVERS

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SUMMARY

Little is known about the impacts of forestry clearfelling and associated nutrient enrichment on phytobenthic assemblages in upland peat catchments, characterised as oligotrophic and naturally acidic. The objective of this study was to investigate the short term impact of forest harvesting on the phytobenthos and benthic invertebrates in three neighbouring peatland catchments. To achieve this multiple before/ after-control-impact (MBACI) experimental design was used. Three headwater streams sampled twice before harvesting and twice after harvesting and two undisturbed control streams sampled at the same dates were used. Significant increases in PO4-P concentrations were detected after the perturbation increasing from 4.3 to 108 µg/ L. Macroinvertebrate assemblages were severely impacted. The EPT, diversity and species richness decreased from 4, 1.3 and 7 to 1, 0.2 and 2 respectively. In contrast the diatom assemblages were not affected significantly. Therefore caution should be exercised when using diatoms as indicators in acidic catchments. No impact was observed above and below the confluence in the main river of one of the headwater streams. It can be concluded from this study that phased felling is therefore recommended as an efficient protection to mitigate short-term effects of harvesting impacts in salmonid streams.

KEYWORDS: Blanket peat forests, diatoms, macroinvertebrates, nutrients, low alkalinity.

INTRODUCTION

The Water Framework Directive (WFD) stipulates EU Member States must maintain "high and good ecological status" where it exists and to restore at least "good status" for all water bodies by 2015 (European Union, 2000). Ecological status incorporates chemical parameters in unison with ecological dynamics such as light availability and flow regimes (Leira and Sabater, 2005). Macroinvertebrates and the phytobenthos have been used successfully as indicators of the ecological quality of aquatic ecosystems worldwide (Leira and Sabater, 2005; Clarke and Hering, 2006; Chen et al., 2008).

Peatland afforestation was practiced in the UK and Ireland, Fennoscandia, and North America, during the late 20th century (Paavilainen and Päivänen, 1995). Many of these blanket peat forests are now reaching harvestable age and concerns have been raised about the potential impact of harvesting to the receiving aquatic systems. Forestry clearfelling can increase light availability and temperature, and the release of nutrients, suspended sediment and debris (Ponce and Brown, 1974; Ensign and Mallin, 2001; Baillie et al., 2005; Rodgers et al., 2010 and 2011). A reduction in the uptake of P by trees and the decomposition of logging residues combined with a low P adsorption capacity (Cummins and Farrell, 2003) means P can be easily transferred to receiving water by runoff in these upland spate catchments (Müller, 2000). Phosphorus at a concentration of about 30 μgL^{-1} is the limiting nutrient for algal growth in freshwaters (Boesch et al., 2001). Peatland catchments are characterised as naturally acidic and the diatom assemblages have been shown to be driven by alkalinity (O'Driscoll et al., 2012). There is a lack of address in the literature regarding the impact of nutrient enrichment in addition to the naturally occurring acidity pressure. Furthermore, O'Driscoll et al. (2012) reported no apparent lasting nutrient enrichment impact to the phytobenthos of forest clearfelling in forested peat catchments.

MATERIAL AND METHODS

This study was based in 5 rivers in three adjoining catchments, located in Mayo in the north west of Ireland (Fig. 1). The catchments are covered in blanket peat and overlie quartzite and schist bedrock. The catchment systems are described as acid oligotrophic and have a low buffering capacity. The main land uses are forestry and sheep grazing and the catchments receive average precipitation of over 2,000 mm per year (O'Driscoll et al., 2012). Commercial coniferous plantations were planted in blocks or coupes starting in the 1950s. The study streams are approximately 50 – 100 cm wide with 50 cm banks on either side. They typically flow over bedrock but in some sections have a peat floor. The study sites have upstream catchment sizes ranging from 10 ha to 32 ha. Alkalinity and nutrient values are very low (O'Driscoll et al., 2012). Five 10 m long stream reaches were included in the experiment. The five reaches were analogous in terms of slope, type of substrata, and land management use. The streams were first order streams and originated in the forestry and so separate control and study streams were chosen instead of above and below.

Starting in March 2009 the five reaches were monitored seasonally for water chemistry and environmental characteristics. The Teev1 and Teev2 catchments were clearfelled in autumn 2009 and the GSS catchment was clearfelled in January 2011. Benthic invertebrate and phytobenthic samples were collected at the 5 forested study streams (control n = 2; harvested n = 3) between March 2009 and June 2011 (n = 10). Similarly, benthic invertebrate, phytobenthic and water samples were collected from the main Glennamong river for the same period.

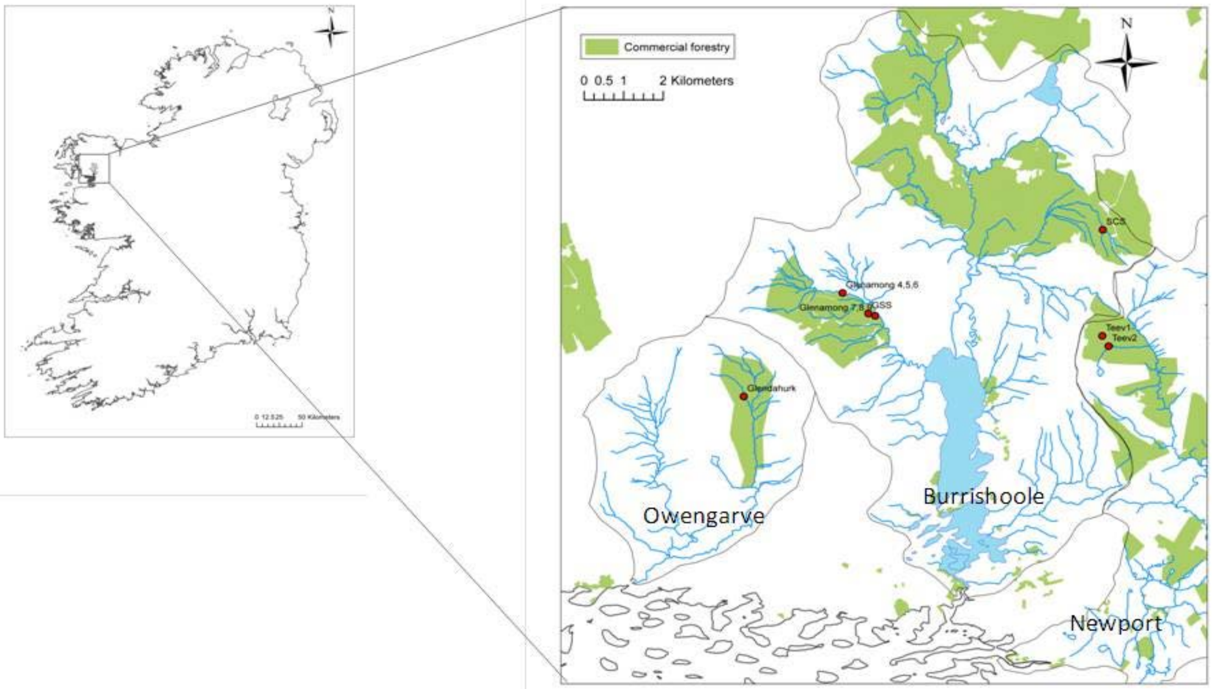

Fig. 1 Geographical location of the study site in Ireland (left) and of the 5 study sites (right).

RESULTS

In the control sites PO4-P, temperature and suspended sediment values were similar before and after harvesting ($p>0.1$) and in the study sites they were significantly higher ($p < 0.05$) after harvesting. In the study streams, the two-dimensional MDS plots of macroinvertebrate species data showed separation between groupings of the study sites before and after clearfelling. The before clearfelling samples (white circles) generally clump together with the control samples and away from the after clearfelling samples (black circles, Fig. 2a). There were two distinct groupings of study streams samples from before and after clearfelling in the two-dimensional diatom MDS (Fig. 2b). However, samples from the control streams before and after clearfelling (black and white squares) intermingled with the after clearfelling study streams samples (white circles Fig. 2b). This finding agrees with the PERMANOVA, as it revealed a significant ($P<0.05$) effect on macroinvertebrate time x treatment interaction (Table 1a) and an insignificant ($P>0.05$) effect on diatom time x treatment interaction (Table 1b).

Table 1. Permutation multivariate analysis of variance on macroinvertebrate (a) and diatom (b) species composition among levels of the factors treatment (control and study) and time (before and after clearfelling)

a. Source	*df*	SS	MS	F	P(perms)
Time	1	5978.20 (9.32)	5978.20	2.5717	0.025
Treatment	1	12219.00 (19.06)	12219.00	5.2566	0.001
Time x Treatment	1	6278.50 (9.78)	6278.50	2.7009	0.024
Residual	16	37193.00 (58.01)	2324.60		
Total	19	64119.00			

b. Source	*df*	SS	MS	F	P(perms)
Time	1	2656.90 (5.72)	2656.90	1.2323	0.261
Treatment	1	6083.20 (13.10)	6083.20	2.8216	0.087
Time x Treatment	1	1948.90 (4.20)	1948.90	0.9040	0.412
Residual	16	34495.00 (74.27)	2156.00		
Total	19	46445.00			

Results from pairwise comparisons between the control x before and the control x after show no significant variation in the macroinvertebrates and highly significant between the study x before and the study x after ($p<0.01$). The results from the diatom pairwise comparisons show no significant variation between the control x before and the control x after; and the study x before and study x after are marginally significant ($p = 0.76$).

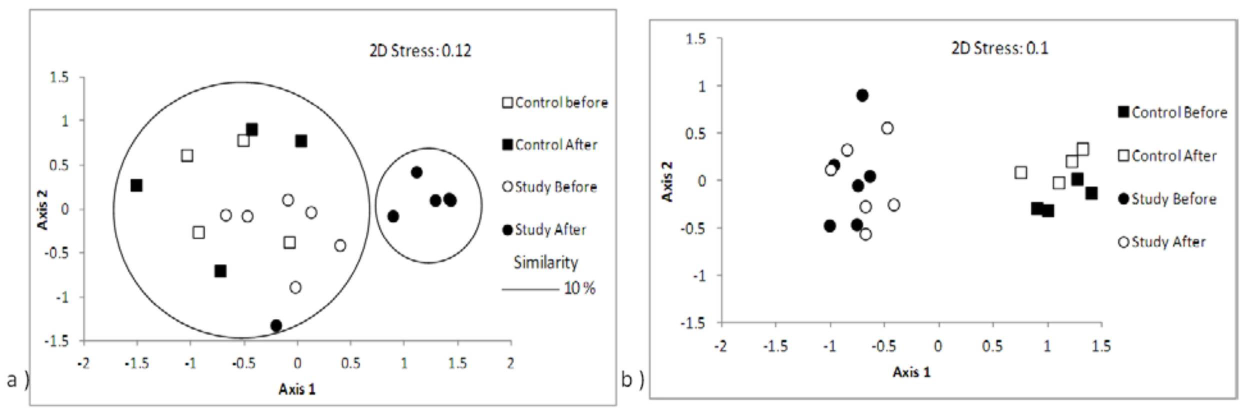

Fig. 2. MDS ordination of Bray – Curtis similarities from A) macroinvertebrates and B) diatoms species abundances data for the 5 study sites shown in Fig. 1 before and after felling; with superimposed cluster analysis at similarity levels of 10 % for macroinvertebrates.

The macroinvertebrate assemblages before harvesting at the study site consisted of mean abundances of *Nemoura cinerea*, *Leuctra hippopus*, *Simulidae* spp, *Chironomid* spp, *Dicranota* spp and *Polycentropus kingi*, and after clearfelling were largely composed of *Chironomid* spp, *Nemoura cinerea* and *Polycentropus kingi* (Figure 3a). The diatom assemblages before harvesting consisted of mean abundances of *Eunotia exigua*, *Pinnularia appendiculata*, *Eunotia paludosa*, *Eunotia subarcuatoides and. Frustules rhomboids* and after harvesting had mean abundances of *Achnanthes oblongella*, *Eunotia exigua*, *Pinnularia appendiculata*, *Gomphonema* *parvulum* and *Meridion circulare* (Figure 3b). The dissimilarity between times was due to the after high abundance of *Achnanthes oblongella* (35 %) and the appearance of *G. parvulum* and *M. circulare* (Figure 3b).

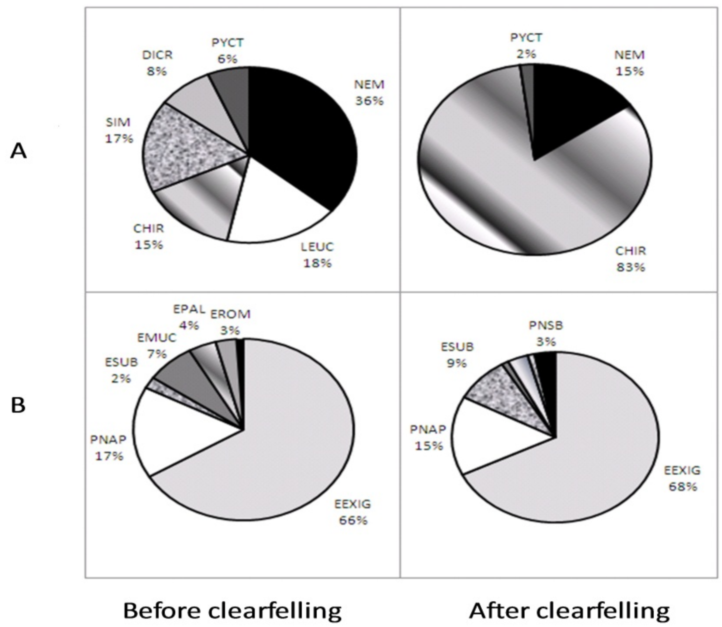

Fig. 3. Percentage abundance of the species of macroinvertebrates (A) and diatoms (B) contributing to the similarity measure obtained for the study site.

Phytobenthic indices showed no significant differences in the control and study sites before and after harvesting. There were significant changes ($p<0.05$) however at the study sites in the macroinvertebrate indices, EPT, diversity, species richness and evenness following the harvesting.

DISCUSSION

The analysis of stream water has shown phosphorus, sediment and temperature significantly increased after harvesting in the study streams compared to the control streams. This is consistent with similar nutrient impact studies carried out on these peatland soils (Nieminen, 2003; Cummins and Farrell, 2003; Rodgers et al 2010, 2011). Alkalinity is extremely low at all sites before and after harvesting. In this study multivariate analysis highlighted an impact on the macroinvertebrate assemblages. *Chironomid* spp had higher numbers and abundances and dominated at the forest impacted sites a pattern characteristic of a severely disturbed aquatic ecosystem (Adamus and Bandt, 1990). Organisms physiologically adapted to low oxygen tension exploit the excess nutrients available and thus dramatically increase in abundance. Families belonging to the plecopteran group are clear-water fauna (Bouchard, 2004) and abundances reduce as pollution load increases. A corresponding reduction in EPT, macroinvertebrate diversity and species richness was also observed. Diatoms have been demonstrated to be sensitive indicators of many kinds of disturbances in the streams responding quickly to changes in water quality (Stoermer & Smol, 2000). It was therefore expected that changes would be seen in diatom assemblages. Surprisingly no significant impact was observed in the diatom assemblages or indices. A slight shift in some of the clearfelled sites showed an increase in *A. oblongella*, *G. parvulum* and *M. circulare*. *A. oblongella* is reported to be very abundant in headwater streams with circumneutral pH and low nutrient concentrations. *G. parvulum* is thought to favour high nutrient concentrations optimally occurring between 0.35 and 1 mg l^{-1} P. *M. circulare* is reported to be confined to cool running waters where it not tolerant of low pH or high nutrient concentrations. The expected shift from oligotrophic species to nutrient tolerant species was lacking. It is probable that this is because of the acidic nature of the sites and impairment of the diatom assemblages due to acidity is prohibiting the succession of more nutrient tolerant diatoms. This study highlights a tolerance of diatom species occurring in naturally acidic water bodies to high concentrations of PO4-P and sediment.

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