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The effect of forest windrowing on physico-chemical water quality in Ireland

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HIGHLIGHTS

- The effects of windrowing were investigated on a first order stream.
- First known study focussing on windrowing impacts 3. Substantial increases in sediment and phosphorus recorded during windrowing.
- High-resolution sampling necessary to capture total sediment and phosphorus export.
- Important for understanding catchment outputs for downstream physical water quality.

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ABSTRACT

Windrowing is widely practised, across Europe and North America, in bole-only harvested coniferous forest plantations before replanting. Forest harvesting has been shown to significantly increase sediment and nutrient losses to watercourses in other studies but windrowing effects, which are as bad, have not been investigated in detail. To determine physico-chemical impacts on water quality and to help inform forest managers, the effects of windrowing were investigated in a headwater catchment. Water samples were collected from storm events pre- (PWR), during (DWR) and after windrowing (AWR). Total suspended solids (TSS), total phosphorus (TP), soluble reactive phosphorus (SRP), total ammonia, nitrate, stream discharge, water level and velocity were measured. Results showed that peak and flow weighted mean concentrations (FWMC) of TSS concentrations increased significantly during windrowing when compared to pre-windrowing concentrations. Peak TSS increased from 88 mg/l (PWR) to 502 mg/l (DWR) and decreased to 163 mg/l (one year AWR) and 225 mg/l (two years AWR). Peak and FWMC of TP also increased during windrowing when compared to pre-windrowing concentrations. Peak TP concentrations increased from 0.1 mg/l (PWR) to 0.4 mg/l (DWR) and decreased to 0.1 mg/l (AWR). SRP and nitrate concentrations increased during windrowing when compared to pre-windrowing but remained low overall. TSS and TP concentrations were highest when flows greater than 0.3 m^3/s (exceeded 6.3% of time) were recorded in the channel. It was highlighted that high-resolution sampling of storm events is important, where precise measurements of windrowing-sourced outputs are required. Windrowing was shown to generate very high concentrations of TSS and TP, comparable to those recorded during harvesting. This research helps to identify potential impacts on physico-chemical water quality that arise during windrowing and demonstrates the need for measures to minimize impacts on surface waters as required by the EU Water Framework Directive and similar legislation elsewhere.

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1. Introduction

During the life cycle of a commercial forest plantation, there are a number of management stages. Afforestation is the term used to describe the establishment of a new forest plantation. Once established and growing, the first management stage is thinning. Thinning involves the selective removal of some trees, which improves the growth of remaining tree stems. Without thinning, a larger number of smaller sized tree stems are produced and these are less valuable. The first thinning typically takes place after ten years and between two and five thinnings can happen during a forest's life cycle. When a forest reaches maturity, the next management stage is harvesting. The most common type of harvesting is bole or stem only harvesting, i.e. only the tree bole is removed from the site and unwanted parts of the tree, called brash, are left behind. Conventional bole-only harvesting uses a specialised

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harvester that removes lateral branches and other unwanted parts of the tree, and cuts the main tree bole to a required length. When whole tree felling is practised, all parts of the tree are removed from the site and no brash is left behind. After conventional bole-only harvesting, the next management stage involves preparing the site for replanting. Before a site can be replanted, leftover brash needs to be removed to clear space for replanting new saplings. Windrowing involves the gathering of leftover brash into long, narrow rows and is typically done using an excavator with a grab bucket. Once the site is prepared, new tree saplings are planted.

Many studies have investigated impacts associated with forest harvesting, some of which are also associated with windrowing. These impacts can be categorised into three groups: (I) Hydrological changes, (II) sedimentation of watercourses, and (III) eutrophication of watercourses.

(I) Forest harvesting can influence catchment hydrology in a number of ways. Water yield and surface runoff can increase as interception by tree canopy and absorption by root networks are reduced significantly (Adams et al., 1991; Tijiu and Xiaojing, 2007; Zou et al., 2010). This increases the risk of mobilisation and transportation of sediment and nutrients to receiving watercourses. Re-growing vegetation such as new trees, weeds and grasses influence the response as they take up some of the surplus water that is available after felling. Vegetation regrowth after felling significantly reduces water loss from a catchment (Martin et al., 2000). Windrowing can remove re-growing vegetation when brash is scraped and lifted and it further exposes the soil to surface runoff.

(II) The risk of sedimentation of receiving watercourses increases during harvesting for the following reasons; (a) The protective cover provided by tree canopy is removed, (b) there is an increase in ground disturbance, (c) there is an increase in compaction and channelling of water by heavy machinery and (d) stream bank collapses are possible.

(a) When the protective cover provided by tree canopy is removed, the soil is more exposed to erosion (Anderson et al., 1976). After whole tree harvesting the surface is exposed to a greater extent when compared to bole-only harvesting. Leftover brash provides some protection to the surface in the months after harvesting. During windrowing, the protective cover provided by brash is removed and ground vegetation, if present, can be removed, exposing bare soil.

(b) Ground disturbance during harvesting is caused by the movement of heavy machinery in wet conditions. Deep rutting can occur on extraction routes when forwarders and skidders are used to transport logs from the plantation to the roadside. The use of brash mats and other measures are important. Cable logging systems cause minimal ground disturbance as logs are suspended in the air during transportation to the roadside. Similarly, ground disturbance can occur during windrowing as heavy machinery manoeuvre within the plantation. Further ground disturbance can occur when brash is scraped and lifted into piles exposing bare soil. The impact of windrowing alone on adjacent surface waters has not been the focus of previous research. However, impacts associated with other ground preparation measures were investigated. Sediment losses after mechanical site preparation of sites in the USA were recorded by Beasley (1979) and Beasley et al. (1986). Mechanical site preparation techniques included shearing followed by windrowing, chopping and bedding. Sites where windrowing took place were sheared first. In this operation, a V-blade on a bulldozer severs tree stumps and breaks up brash materials. All of the mechanical

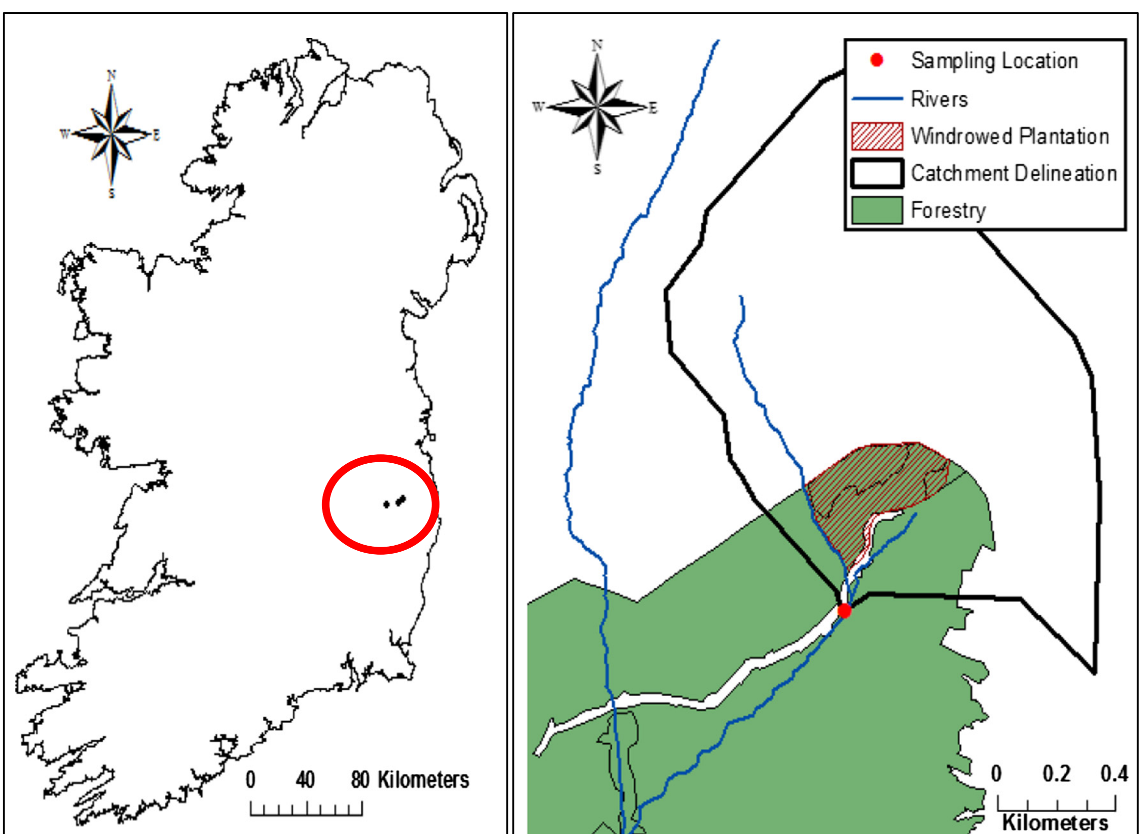

Fig. 1. The geographical location of the sampling sites in Ireland is shown on the left (circled in red) and a close up of the catchment delineation and the location of the sampling point at Annalecka is shown on the right. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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