Suspended solid yield from forest harvesting on an upland blanket peat

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- *Forest harvesting activities, if not carefully carried out, can disturb forest soils and cause significant sediment increases in receiving waters.*
- *This study examined how harvesting, following forestry guidelines, influenced sediment concentrations and loads in the receiving waters of a blanket peat salmonid catchment.*
- *Good management practices such as the use of brash mats and harvesting only in dry weather were implemented to minimize soil surface disturbance and stream bank erosion.*
- *Sediment concentrations, yields and release patterns upstream and downstream were compared before and after harvesting. These showed that harvesting did not significantly increase the sediment concentrations in the receiving water, confirming that if the Forests and Water Quality Guidelines are followed and care is taken on site, the aquatic zone need not be adversely affected by sediment releases from sites without a buffer strip.*

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Introduction

European Communities (1998) have recommended that the suspended solid concentration in salmonid waters should be lower than 25 mg/l. Suspended solid concentrations can cause damage to the water ecology and reduce fish populations by increasing turbidity, restricting sunlight from reaching photosynthetic plants and reducing dissolved oxygen (DO) (Ryder et al. 2010). Forest harvesting can cause some mechanical disturbance of the ground surface that can lead to the release of soil to river systems (Robinson and Blyth 1982) and erosion from timber harvesting and reforesting operations can be significant in the absence of good management practice (Swank et al. 2001). In a catchment study inArkansas and Oklahoma, Scoles et al. (1996) found that where no specific erosion control measures were applied, annual soil losses in the first year were statistically significantly greater on clearfelled and harvested sites than on selectively harvested and control sites.

Since the 1950s, large areas of upland peat were afforested in Ireland. It was estimated that in 1990 about 200,000 ha of forest were on peatland (Farrell 1990). Before the 1980s, most Irish peatland forests were planted without riparian buffer strips in upland areas that contain the headwaters of many important salmonid rivers. These forests are now reaching harvestable age and due to the sensitivity of blanket peat to disturbance, concerns have been raised about the possible impacts of harvesting and associated activities on the sensitive receiving aquatic systems (Coillte 2007). In order to minimize the amount of suspended solids entering watercourses, good management practices were introduced in Ireland (Forest Service 2000a, 2000b, 2000c). These practices targeted the process of soil erosion, and included proper harvesting methods and the use of thick brash mats to limit surface disturbance. To date, few studies have focused on the impact of harvesting on suspended solid yields after the introduction of the guidelines. In this study, an assessment of the impact of postguideline harvesting on the suspended solid release was carried out in an upland

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blanket peat catchment that had been afforested in the 1970s without buffer strips - typical of most Irish forests now approaching harvestable age. This paper outlines the methodologies used and summaries results from the intensive monitoring study.

Study site description

The study site (9°55'W 35°55'N), which is a sub-catchment of the Burrishoole catchment drained by a small first-order stream (Figure 1), was planted with lodgepole pine (*Pinus contorta*) between January and April 1971.

The stream is equipped with two flow monitoring stations at stable channel sections, one upstream (US) and the other downstream (DS) of the experimental area (Figures 1, 2 and 3). The US measures flows from the control area (A) of 7.2 ha and the DS covers the control coupe (A) and the experimental coupe (B) with a total combined area of 17.7 ha.

In August 2005, a wind-blown tree blocked one of the collector drains, resulting in an increase of the upstream forest control area, to about 10.8 ha. Meanwhile the downstream harvested area increased to about 14.5 ha due to the blockage of a drain by a brash mat during the harvesting, incorporating another part of the total harvested area. Fortunately, in both cases the additional area had the same vegetation and soil characteristics, and the relative sizes of US and DS remained unchanged – US increasing only marginally from 41% of the total area to DS before harvesting to 43% afterwards.

All unit area depths in this paper have been calculated using these values. The blanket upland peat soil had been double mouldboard ploughed by a Fiat tractor on tracks creating furrows and ribbons (overturned turf ridges) with a 2 m

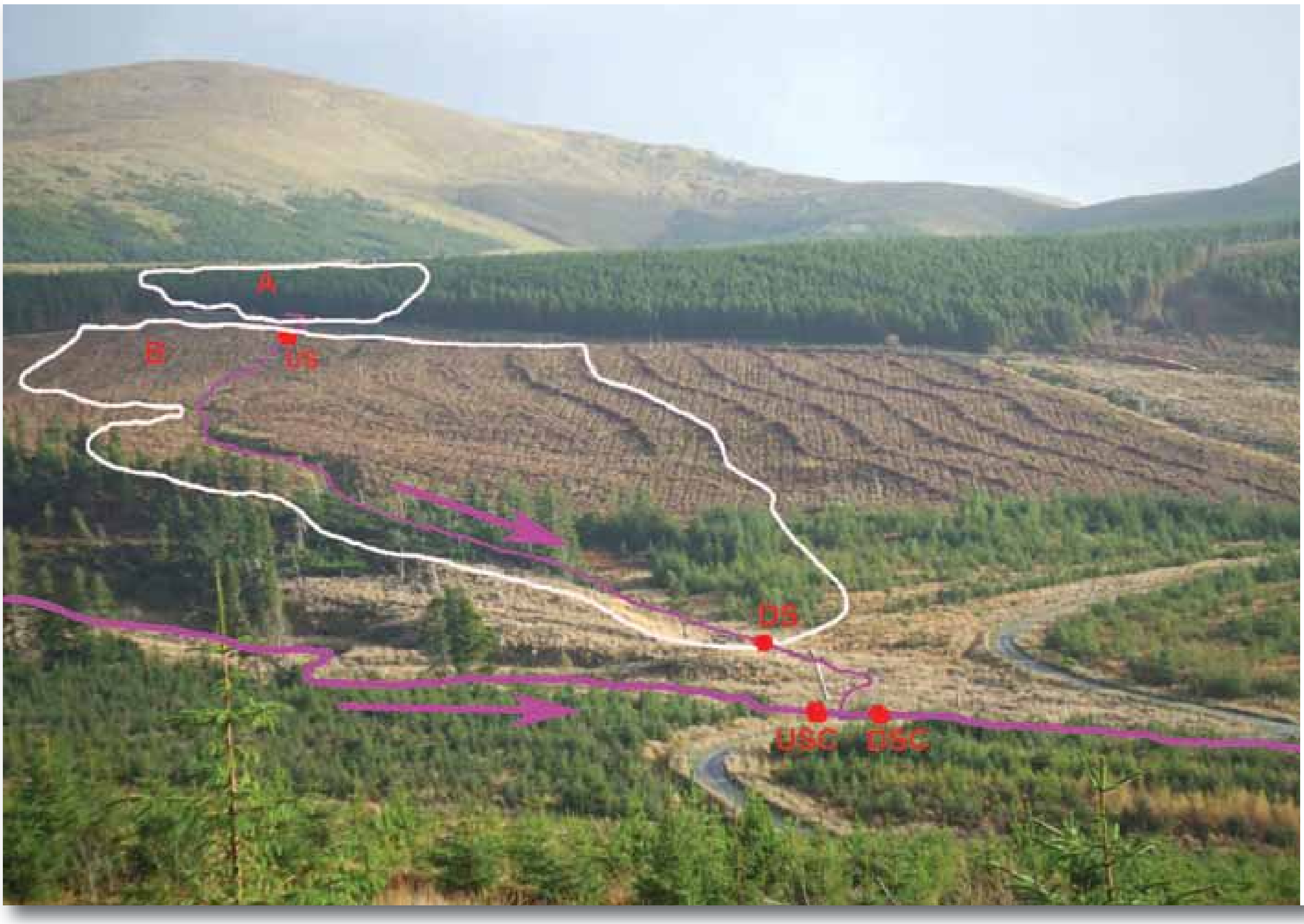

Figure 1: The study site (A: control area – untouched; B: experimental area-harvested; US: upstream station; DS: downstream station; USC: upstream of confluence; DSC: downstream of the confluence).

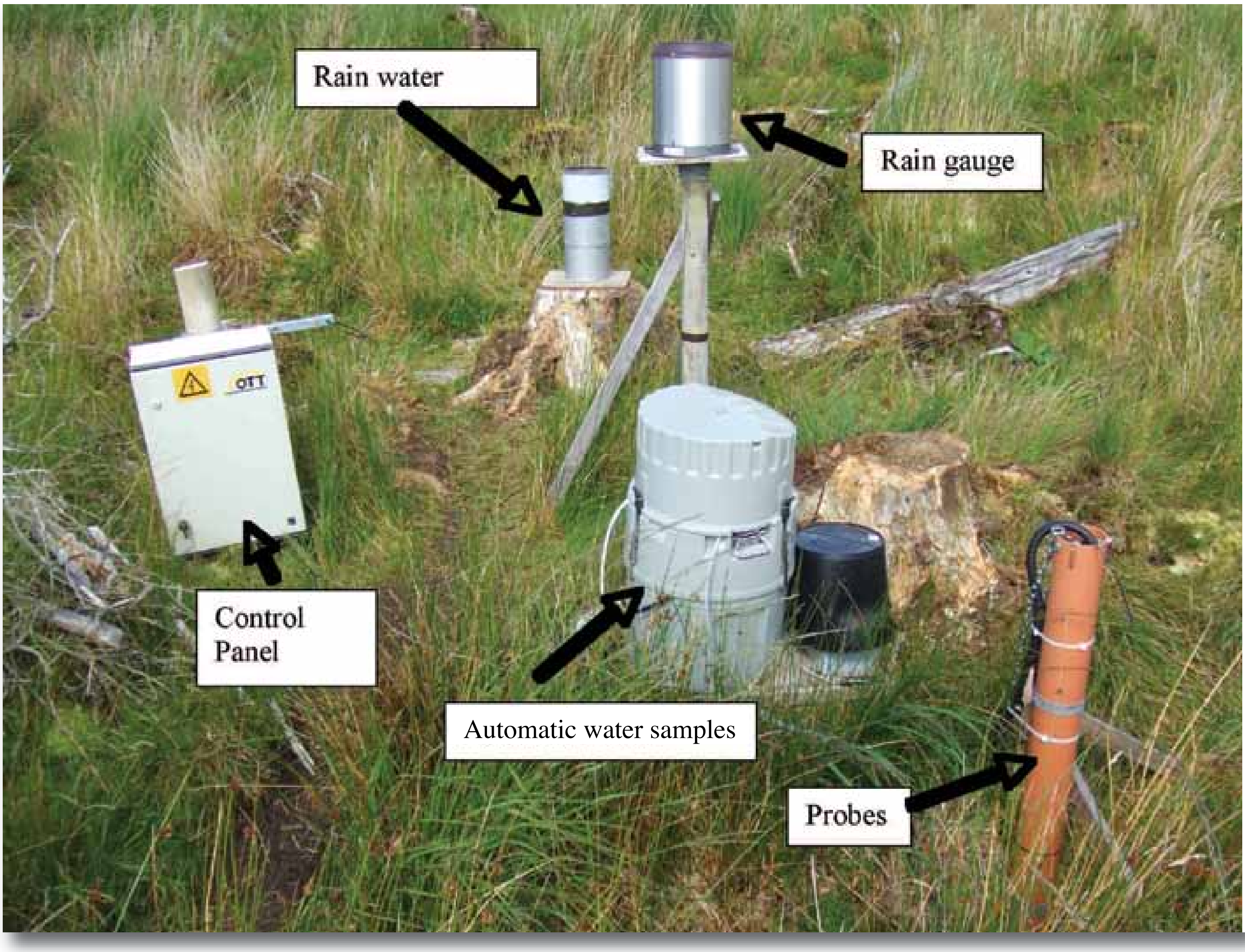

Figure 2: Monitoring station – control panel, water sampler, rain gauge, rain water sampler and probes.

Figure 3: Monitoring station – H flume (maximum flow rate: 158 l/s).

spacing, aligned down the main slope, together with several collector drains aligned close to the contour. The trees were planted on the ribbons at 1.5 m intervals, giving an approximate soil area of 3 m^2 per tree. The catchment had an average peat depth of more than 2 m above the bedrock of quartzite, schist and volcanic rock, and the peat typically had a gravimetric water content of more than 80%. In the catchments, the mean annual rainfall is more than 2000 mm and the mean air temperature is about 11°C. Hillslope gradients in areas A and B average 8° and range between 0° and 16°.

Harvesting was conducted in area B from 25 July to 22 September 2005 using a Valmet 941 harvester. Trees were cut to 7 cm top diameter and the residues (needles, twigs and branches) were left on the soil surface and collected together to form windrows. Logs were stacked beside the windrow for collection and extracted by a Valmet 840 forwarder to collection points beside the forest road.

To minimise soil damage, clearfelling and extraction were conducted only in dry weather conditions during the period from July to September 2005. That time period is recommended for harvesting in the Forest Harvesting and the Environment Guidelines, since ground conditions tend to be drier (Forest Service 2000a).

Mechanised operations were suspended during and immediately after periods of particularly heavy rainfall. Another important good management practice used during the harvesting operation was the proper use of brash mats for machine travelling. Tree residues (needles, twigs and branches) were collected together to form brash mats on which the harvesting machines travelled, thus protecting the soil surface, and reducing erosion.

The second rotation of lodgepole pine was planted in December 2005 at a density of 2,800 per ha with no cultivation, new drainage or fertilizer applied during the replanting operation. A buffer zone was established by replanting birch, rowan, alder and willow (instead of pine), in a 15-20 m wide strip on side of the stream. Furrows, ribbons, drains and brash/windrows were left in situ. Very little revegetation was observed in the harvested area until late summer 2008.

Sampling and measurement

From April 2004 to March 2005, continuous water levels in the study stream were recorded at both the upstream station (US) and downstream station (DS), and converted to flows by a rating equation based on dilution gauging and current meter measurements. In April 2005, H-flume flow gauges were installed at the sites for flow measurement (Figure 3). At US and DS, water samples were taken: (i) manually every 20 minutes from April 2004 to March 2005 during flood events; (ii) hourly from April 2005 to March 2006 using ISCO automatic water samplers (Figure 2) and (iii) manually in base flow conditions through the study period. Suspended solid concentrations of the water samples were measured at the Marine Institute in Newport, Co Mayo, in accordance with the standard methods (APHA 1995) using Whatman GF/C (pore size 1.2 μm) filter papers.

Results

The possible longevity of the impact

The longevity of impact of harvesting on suspended solid concentrations depends on the recovery of the catchments from soil disturbance, which are influenced by weather conditions, soil properties, ground slopes and the growth of vegetation. Previous studies reported that the impact of harvesting on solid concentrations could last from a few months to a few years (Macdonald et al. 2003, Stott 2005). Figures 4 and 5 show the daily mean and peak suspended

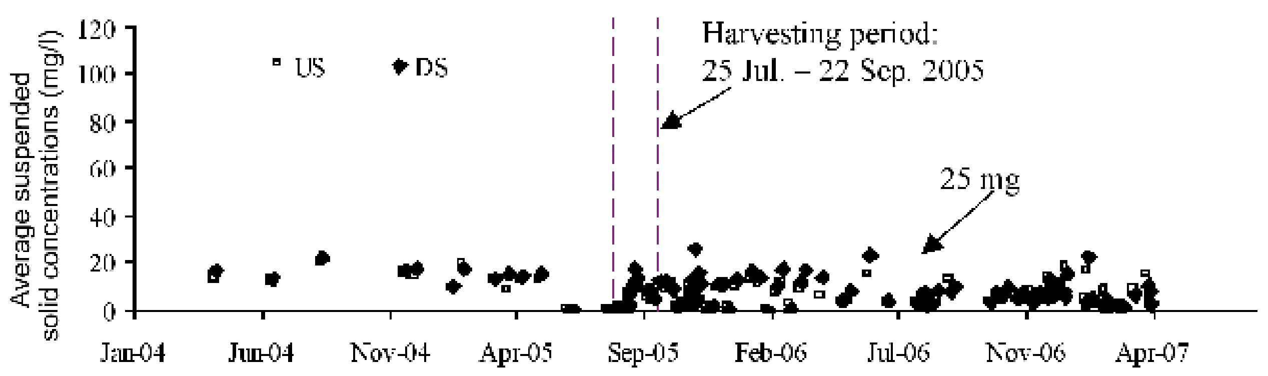

Figure 4: Daily average suspended solid concentrations at US and DS stations before and after harvesting.

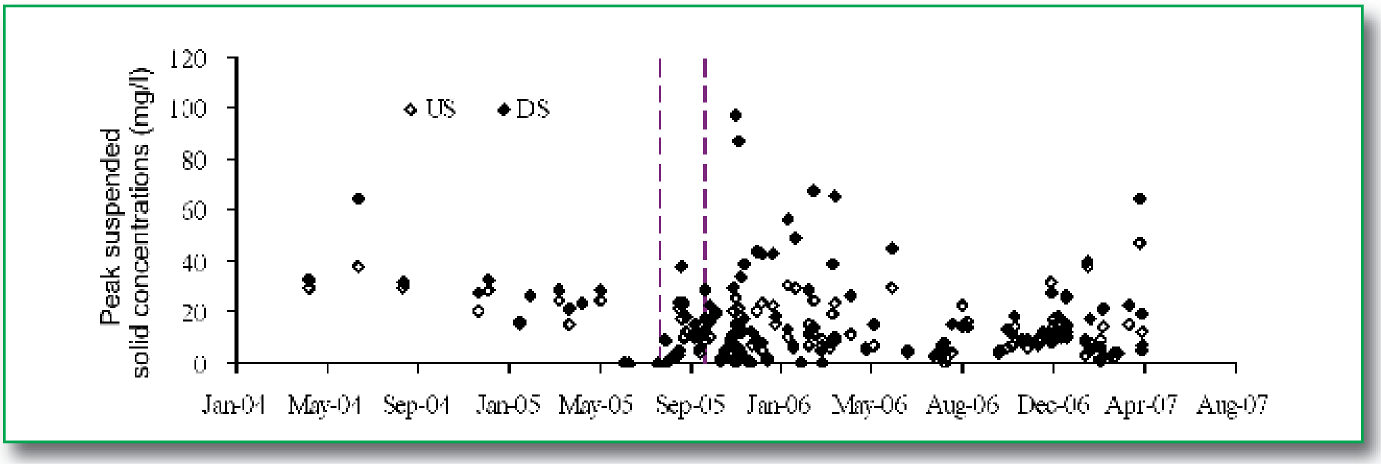

Figure 5: Daily peak suspended solid concentrations at US and DS stations before and after harvesting.

solid concentrations at US and DS stations during the study period. Harvesting did not result in an obvious increase in daily suspended solid mean concentrations at the DS station. However, daily peak suspended solid concentrations at the DS station increased after harvesting and lasted for about 7 months (September 2005 to March 2006) before returning to the US station levels. The 7-month increase in peak concentrations after harvesting could be due to flushing out of loose material exposed by the felling activities. Short-term elevation in suspended solid concentrations could damage the water ecology and result in reduction of survival rates of salmonid eggs and newly hatched alevins. Therefore this study focused on assessment of the impact of harvesting on the suspended solid concentrations in the first 7 months post-harvesting.

Suspended solid concentrations before and after harvesting

During base flow conditions, suspended solid concentrations at the US and DS stations were generally low before and after harvesting and ranged from 0.1 to 5 mg/l. Stream-suspended solids are usually episodic – most solid is carried in high flows – so this study focused on the storm events. A rainfall event was defined as a block of rainfall that was preceded and followed by at least 12 hours of no rainfall (Hotta et al. 2007). A total of 23 events were studied: 8 before and 15 after harvesting. 114 and 394 water samples were collected at both stations before and after harvesting, respectively. Figures 6 and 7 show the suspended solid concentrations and flows in storm events before and after the harvesting period. The largest storm event in the pre-harvesting period occurred on 22 June 2004 with 86.8 mm rainfall, a maximum intensity of

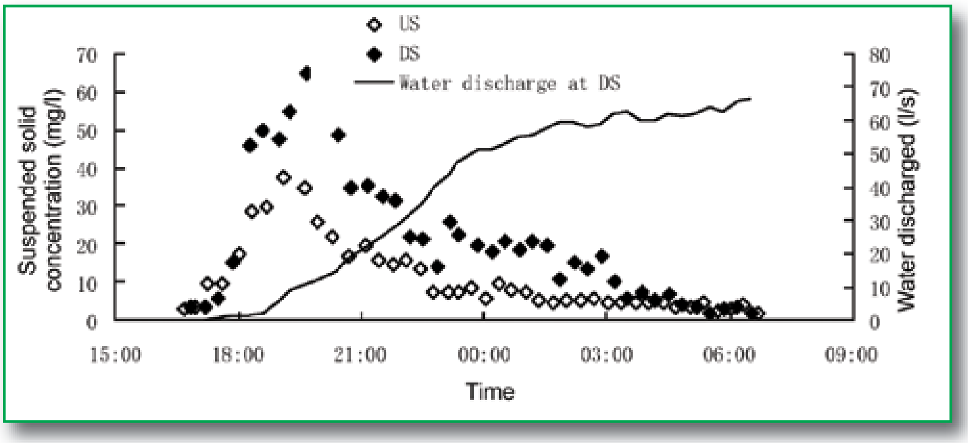

Figure 6: Pre-harvesting (22/06/2004).

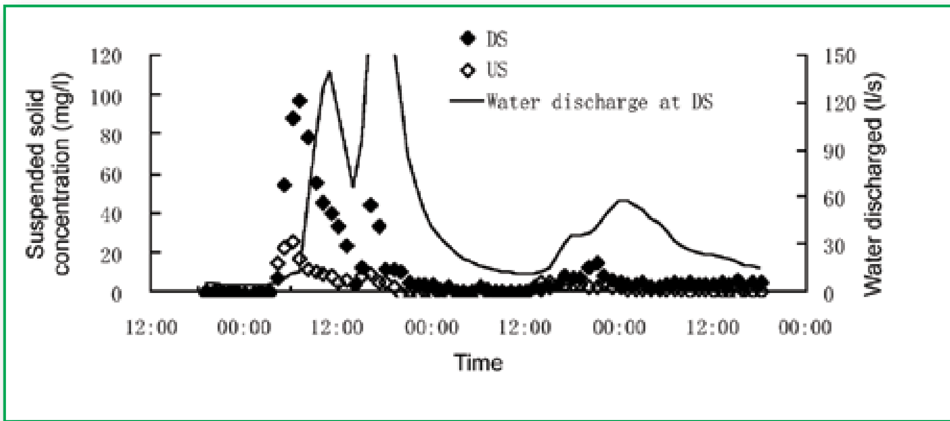

Figure 7: Post-harvesting (1-4/11/2005). (The flume capacity was about 158 l/5).

2.2 mm/5 min and duration of 32 hours. The highest suspended solid concentrations during this storm were 37.8 mg/l at US station and 65 mg/l at DS station, respectively, which were the maximum suspended solid concentrations observed during the pre-harvesting period. During the post-harvesting study period, the largest storm event occurred on 1 November 2005 with a total rainfall of 67.2 mm, maximum rainfall intensity of 3.2 mm/5 min, and duration of 82 hours. Suspended solid concentrations at the US station increased from 0.1 mg/l to 25.8 mg/l and then dropped back to 0.5 mg/l. At the DS station, suspended solid concentrations increased from 0.3 mg/l to a peak of 97.5 mg/l towards the beginning of the flood event as the flow rate increased from about 4.5 l/s to 12.5l/s, which was the highest suspended solid concentration observed during the post-harvesting study period. In most of the studied storms, suspended solid increased quickly at the beginning of the water discharge and reached the maximum prior to the water discharge peak, which could be due to the build up of the soil fraction available for release and erosion prior to rainfall. Similar phenomena were also observed by Drewry et al. (2008) and Baca (2002).

Suspended solid yield before and after harvesting

Figure 8 shows the relationship of monthly solid yields between the US and DS stations. Solid yields slightly increased after harvesting, which could be attributed to the increase in runoff. In order to examine the impact of the harvesting activities on the solid yield, the sediment at DS was estimated as the dependent variable by using the pre-

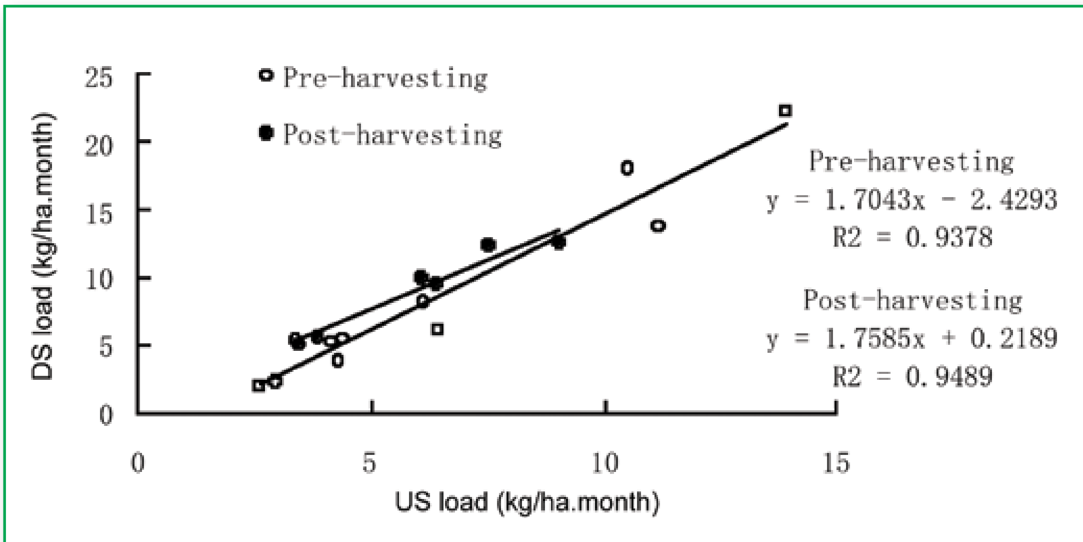

Figure 8: The relationship of calculated monthly solid loads of US and DS pre- and post-harvesting. (Preharvesting: April 2004 to June 2005, except January 2005, March 2005 and April 2005; post-harvesting: October 2005 to March 2006.)

harvesting linear regression equation and the observed post-harvesting sediment yield at US as the independent variable. The estimated and measured sediment yields at DS were compared using a paired samples t-test at the 95% significance level (P=0.05) (http://www.spss.com), which indicated that there was no significant difference between the estimated and measured sediment yield.

Discussion

Though higher daily peak suspended solid concentrations were observed, there was no significant increase in suspended solid concentrations after harvesting in this study. Hotta et al. (2007) indicated that if appropriate measures are undertaken to prevent surface disturbance, there may not be an increase in sediment concentrations during and following harvesting: they used a skyline harvesting treatment and found there were no sediment concentration or yield increases after harvesting. In this Burrishoole study, the soil disturbance and stream bank erosion during the harvesting operation were minimized as much as possible by applying best management practices (Forest Service 2000a): harvesting was conducted only in dry weather conditions; brash mats were properly used and maintained; the harvester had a 10 m reach which minimized the soil disturbance within 10 m of the study stream. No stream bank erosion due to the forest activities was observed at this study site. In their post-guideline harvesting study, Stott et al. (2001) emphasized the importance of the timing of harvesting work and recommended that the forestry guidelines should also include the hydrological and meteorological conditions under which work can be undertaken near watercourses.

A preliminary study carried out by the authors - using laboratory flume technology (Rose 1993) to monitor the effect of the harvest machine disturbance - indicated that suspended solid concentrations (data not shown) could increase by two orders of magnitude from dry to wet conditions. Owende et al. (2002) investigated the progression of ground disturbance on a peat site during forwarder extraction on a brash mat, and found that when maintenance of the brash mat was conducted on an ongoing basis, the deterioration of weak areas in the brash mat was prevented and, as a consequence, deep disturbance and rutting was minimised.

The solid yield was determined from the suspended solid concentrations and water discharge data. An increase in either or both could result in an increase of solid yield. Good management practice could prevent the suspended solid concentration increase by minimizing the disturbance of the soil, but cannot prevent the increase of water discharge after harvesting, due to the lower evaporation from the harvested area. This is especially the case in temperate maritime climates such as Britain and Ireland where frequent light rainfall means tree canopies are often wet and the interception losses are high (Robinson and Dupeyrat 2005). In this study, the slight increase in solid yields after harvesting could be due to the increase in water discharge, since no significant suspended solid concentration increases were observed.

Conclusions

The results of this study indicated that harvesting carried out according to the Forests and Water Quality Guidelines did not have a long-term impact on the suspended solid concentrations. Solid yields slightly increased after harvesting, possibly due to the increase in water discharge from the experimental area. The study indicated that it is possible to prevent the solid concentration increase after harvesting if good management practices are strictly followed.

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