Environment No. 13

Phosphorus release from forest harvesting on an upland blanket peat

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- *The aim of this study was to investigate the release of phosphorus to receiving waters that resulted from clearfelling and harvesting 34-year-old lodgepole pine trees in an upland peat catchment.*
- *The daily mean phosphorus (P) concentration at downstream increased from about 6 µg total reactive phosphorus (TRP)/l pre-clearfelling to 429 µg L^{-1} in August 2006, which was more than 10 times higher than the acceptable level of 30 µg L^{-1} By October 2009, four years after clearfelling, the phosphorus concentrations at downstream had returned to the pre-clearfelling level. In the first three years following harvesting, up to 5.15 kg ha^{-1} of TRP were released from the catchment to the receiving water; in the second year alone after harvesting, 2.3 kg ha^{-1} were released.*
- *During the study period, about 80% of the total phosphorus in the study stream was soluble and more than 70% of the phosphorus release occurred in storm events, indicating that traditional buffer strips might not be efficient for P immobilization.*
- *In this catchment, the dilution in the receiving river maintained the average P concentrations in the water downstream of the confluence of the stream and river at less than 30 µg TRP/l.*
- *This finding indicates that the bestmanagement-practice of selecting felling areas based on available upstream dilution capacity in the catchment can limit P concentrations in the receiving waters from clearfelling activities.*

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Introduction

Phosphorus (P) is an essential element for plant growth. However, P at a concentration of about 30 µg L^{-1} in freshwater can cause eutrophication, resulting in abundant algal growth and reduction in oxygen, which in turn affects in-stream biota and fish (Boesch et al. 2001). Blanket peat has extremely low P adsorption capacity (Tamm et al. 1974). Therefore, P in peat soil can be easily transferred to receiving water by runoff (Cummins and Farrell 2003).

Since the 1950s, large areas of upland peat were afforested in Ireland (Farrell 1990) and ground rock phosphate was applied to establish the trees. P taken up by the trees are concentrated in the needles and twigs and conserved well in the standing forest by nutrient cycling. Many of these blanket peat forests are now reaching harvestable age. There is concern that harvesting will increase P release by disrupting P cycling and significantly reducing the uptake of P by plants. The decomposition of P-rich logging residues (i.e. needles, twigs, roots and branches) left on the harvested area could further increase P release after harvesting (Piirainen et al. 2004).

In this note, P release from an upland blanket peat forested area in the Burrishoole Catchment, Co Mayo, Ireland, was studied for four years after harvesting. The hypothesis is that P release is increased significantly due to a combination of poor P adsorption capacity in blanket peat soil, high annual rainfall (>2000 mm) and runoff in the study area, and P sources being available after harvesting. Buffer strips with a width of 15-20 m are recommended as one of the means to reduce P release to recipient water courses. However, their effect may be limited if most of the P release occurs in storm events, when there would be low residence times for the vegetative uptake of soluble P. Thus, a specific aim of the study was to investigate the P release pattern in storm events, and to quantify the P release occurring during storm events and base flow conditions. Whole-tree harvesting has been recommended as another means of decreasing P release.

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To increase the understanding of the effect of whole-tree harvesting on P release, a small-scale pilot survey was performed to investigate if the water extractable P (WEP) contents in soil below windrow/brash material are significantly higher than for areas without windrow/brash material. Phased felling has been used in Ireland to mitigate the negative impact of harvesting on receiving water. In this study, water samples were also taken from the main river at above and below the confluence of the main river and study stream to examine the impact of phosphorus release on the main rivers after harvesting (Figure 1).

The details of the study site can be found in the COFORD Connects note *Suspended solid yield from forest harvesting on upland blanket peat* (Environment No. 12).

Sampling, measurement and data analysis

Water

From May 2005 to September 2009, water samples at the US and DS stations were taken hourly during flood events and, on selected days, in base flow conditions using a DISCO automated water sampler. Grab water samples were taken above (USC) and below the confluence (DSC) of the study stream and the main river (Figure 2) about once every two weeks. Rainfall water samples were also collected by placing an open, clean plastic container near the DS station during storm events. All water samples were frozen at -20°C in accordance with standard methods (APHA 1995) until water quality analyses were conducted. Total reactive phosphorus (TRP) – the phosphorus that can be directly up taken by plants – was measured using a Konelab 20 Analyser (Konelab Ltd., Finland).

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).

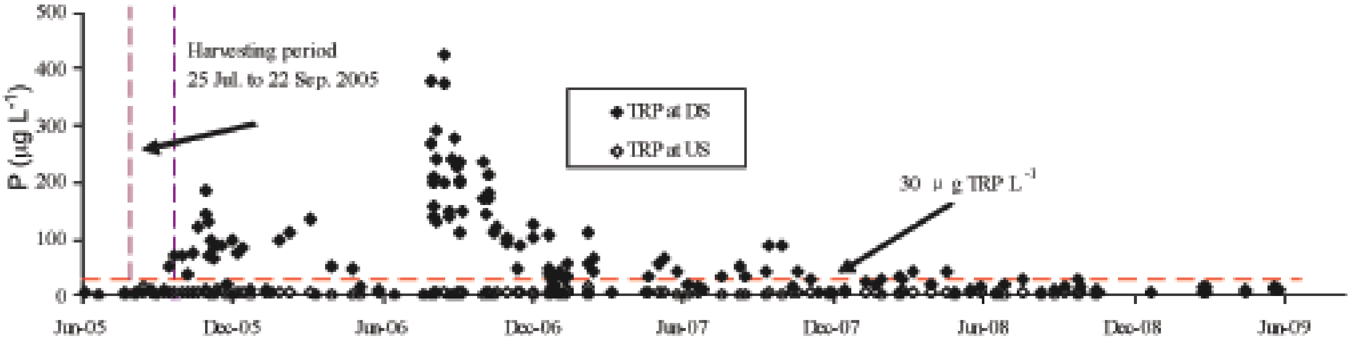


Figure 2: Total reactive phosphorus concentrations (TRP) at upstream station (US) and downstream station (DS) stations during the study period.

Soil

Sites of about 1 ha in areas A and B were chosen for soil sampling (Figure 1):

- 40 and 38 100 mm-deep soil cores consisting of the humic and upper peat layers were collected using a 30 mm diameter gouge auger from the ribbons in areas A and B in May 2005, April 2006, March 2007, April 2008 and March 2009.
- 15, 26, 25 and 28 more soil cores were taken under the windrow/brash in the DS harvested area in April 2006, March 2007, April 2008 and March 2009, respectively.

Soil samples were analyzed for gravimetric water content and water extractable P (WEP).

Results and discussion

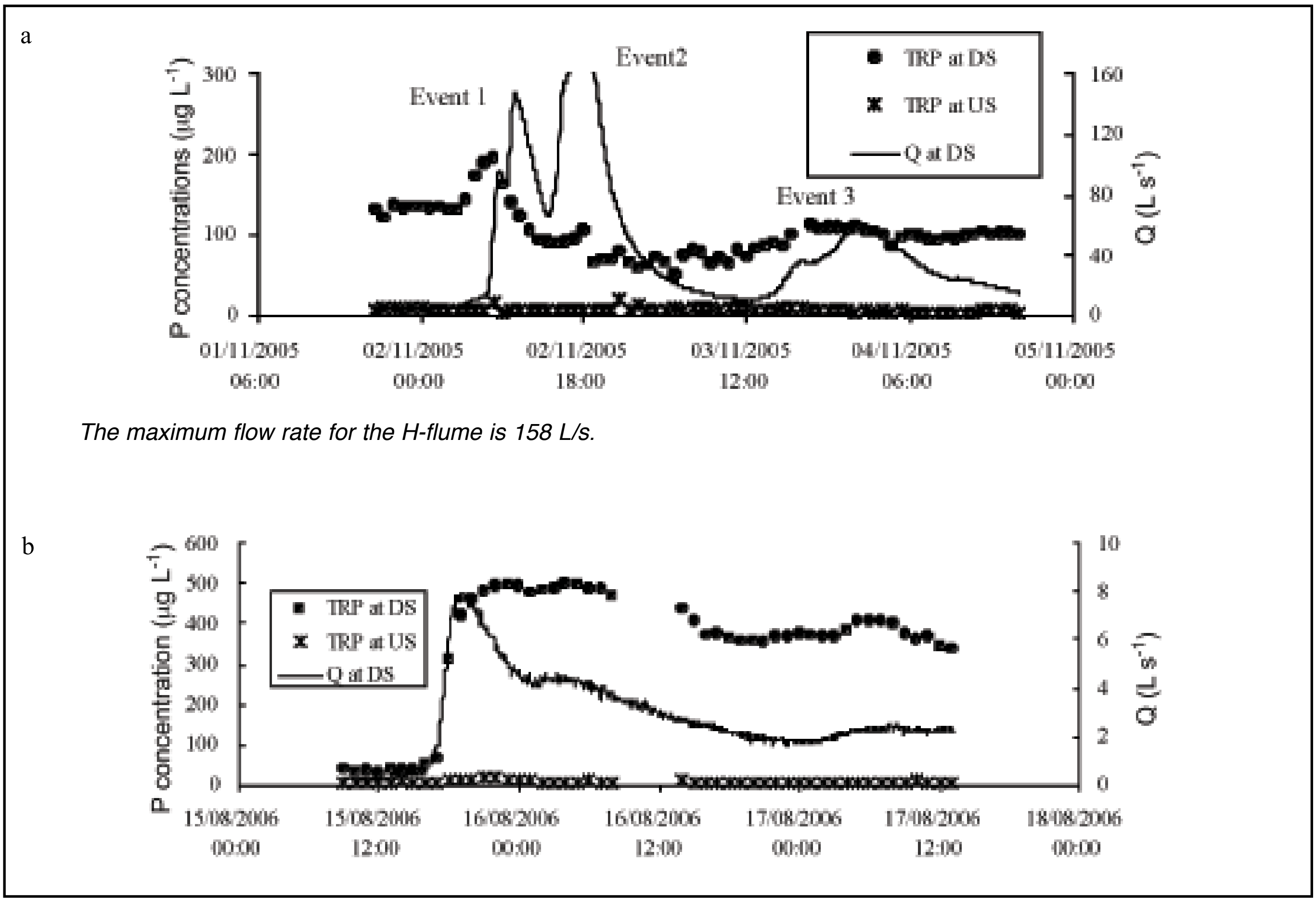
P concentrations in the stream water after harvesting

General trends

Figure 2 shows the P concentrations at US and DS stations during the study period. Measured P concentrations at the US station were low during the study period, with average values of 6 ± 5 μg L^{-1} of TRP, which were close to the values in the rainfall. Four weeks after harvesting operations began, daily discharge-weighted mean P concentrations at the DS station started to increase gradually to about 73 μg L^{-1} of TRP at the end of harvesting period, and, on 28 October 2005, they reached peak mean concentrations of about 183 μg L^{-1} of TRP. By the end of December 2005 – 10 weeks after clearfelling – they decreased to about 10 μg L^{-1} of TRP. From the end of July to the middle of August 2006, P concentrations at the DS station increased dramatically to 429 μg L^{-1} of TRP – the highest concentrations recorded in the study. The release pattern of P concentrations – increasing to a clear peak after harvesting, experiencing a distinct declining tail, and then increasing to the maximum peak in the next summer – was also observed by Cummins and Farrell (2003) in a study carried out in a blanket peatland forest in the west of Ireland. The maximum peak in the next summer after harvesting was also observed by Nieminen (2003) in a Scots pine-dominated peatland in southern Finland.

The P concentration peak in summer 2006 was followed by a long declining tail. The daily discharge-weighted mean P concentrations at the DS station reduced to less than 15 μg L^{-1} of TRP in July 2009, four years after harvesting. Statistical analysis indicated that P concentrations at the DS station were significantly higher than that at the US station (P=0.05) in the 4-year period following harvesting.

Figures 3a and 3b show the P concentrations and flow in two storm events during the study period. In the storm event of 2 November 2005, peak TRP concentrations were 197 μg L^{-1}, 106 μg L^{-1} and 113 μg L^{-1} in Events 1, 2 and 3. The peak TRP concentration in Event 2 was lower than in Event 1, although the flow rate was higher, which could be due to less P sources being available for release in Event 2. When a storm event follows immediately after a previous storm event, much of the available P has already been removed by the previous flood (Bowes et al. 2005). Figure 3b shows the



The maximum flow rate for the H-flume is 158 L/s.

Figure 3: Total reactive phosphorus (TRP) concentrations at upstream station (US) and downstream station (DS) station in two storm events during the study period.

storm event in which the highest P concentrations were recorded during the study period. There was a drought period before this storm event, resulting in little release of P by hydrological flushing, and large amounts of the labile P pool had accumulated. The TRP concentrations increased from about 10 μg L^{-1} to about 550 μg L^{-1} when the flow rate increased from about 0.5 L s^{-1} to the peak of 8 L s^{-1}. The P concentrations maintained high values at the end of the storm event, which could be due to the relatively small water discharge that could not remove the large amount of mobile P that had accumulated before the storm event.

P concentrations in downstream river

In the present study, the P concentration at the DS station in the study stream did not have a large impact on the P concentration in the main river, which covers an area of 200 ha above its confluence with the study stream and should have a dilution factor of about 8 for the study stream. Figure 4 shows the TRP concentrations at the DS station, DSC and USC of the main river in a storm event. When the TRP at the DS station increased from about 3 μg L^{-1} to 292 μg L^{-1}, the TRP concentrations at the DSC increased from about 5 μg L^{-1} to about 11 μg L^{-1}, giving a measured dilution factor of about 26.

Phosphorus loads

Annual TRP loads from the control area were steady and low during the study period, with values of less than 60 g ha^{-1}. Figure 5 shows the TRP loads from the harvested area in base flow and storm flow in the years 1, 2, 3 and 4 after harvesting. A total of about 5.15 kg ha^{-1} of TRP was released from the harvested area in the four years after harvesting, and mainly occurred in the first three years. The highest TRP load of 2.3 kg ha^{-1} was recorded in the second year after harvesting. In the years 1, 2, 3 and 4 years after harvesting, it was calculated that the respective annual

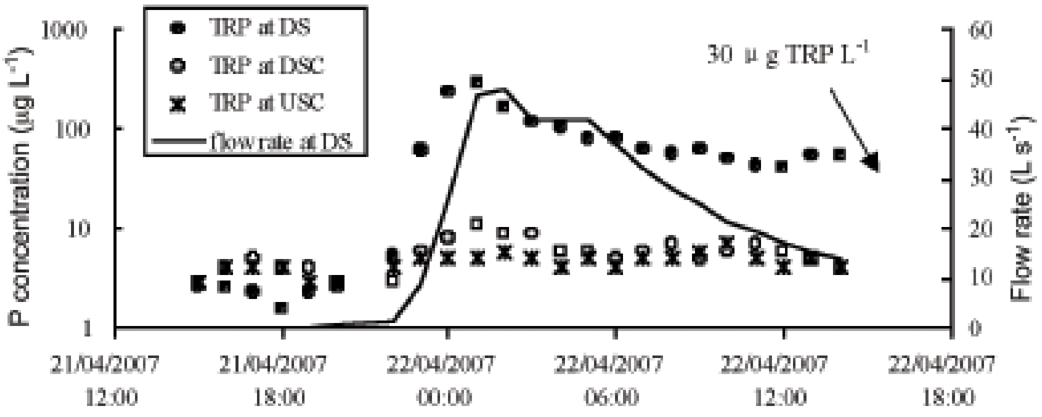


Figure 4: The total reactive phosphorus (TRP) concentrations at the downstream station (DS) in the study stream, upstream confluence (USC) and downstream confluence (DSC) of the main river in a storm event.

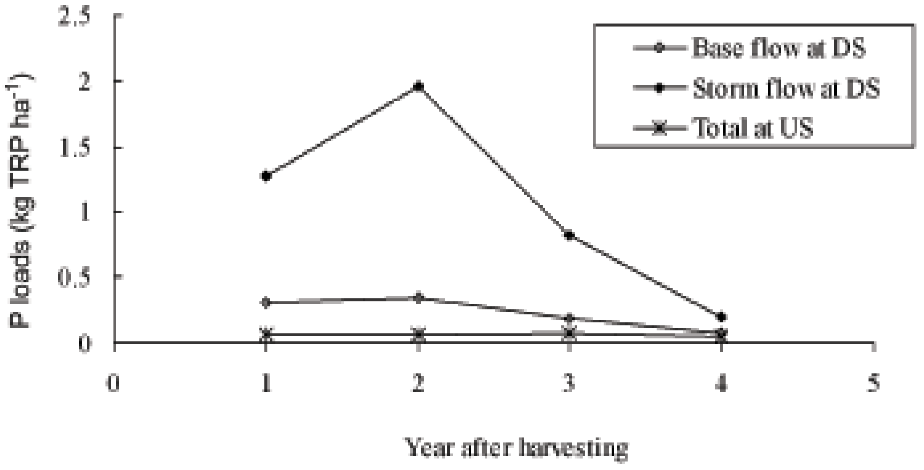


Figure 5: Annual total reactive phosphorus loads at upstream station (US) and in base flow and storm flow at downstream station (DS) during the study period.

storm-flow TRP releases were about 80.3 %, 85.2 %, 82 % and 80.9 % of the total annual TRP release.

Water extractable P concentrations of the soil after harvesting

Figure 6 shows the WEP of the soil between the windrows and areas under the windrows in the DS harvested area and the US control area in May 2005, April 2006, March 2007, April 2008 and March 2009. Before harvesting, the WEP values in the US and DS areas were similar, at about 17 and 18 mg (kg dry soil)$^{-1}$. Most of this P was cycled in the forest system since very little P was leaving the catchments in runoff. After harvesting, both WEP in the soils covered and not covered by brash/windrow material increased, reaching peaks of 67 and 40 mg (kg dry soil)$^{-1}$, respectively, in 2007. The WEP under the windrows/brash was about 136%, 152.3%, 235% and 188.9% of the WEP in the windrow/brash-free soil in 2006, 2007, 2008 and 2009, respectively. Higher WEP concentrations, found under the windrows/brash material, were due to P release from decomposing logging residues. The WEP was 1.5 kg ha^{-1}, 2.5 kg ha^{-1}, 1.8 kg ha^{-1}, and 1.3 kg ha^{-1} under the windrow/brash material in 2006, 2007, 2008, and 2009, respectively, accounting for about 31%, 36%, 39%, and 34% of the total WEP in the harvested area. This observation is for soil only and ignores P remaining in the decomposing brash mats/windrows. Hyvönen et al. (2000) found that the logging residues may contribute 8-31 kg ha^{-1} of TP to the harvested area. The high WEP value under the windrows/brash material lasted longer than for the windrow-free areas, which could be due to the relatively low decomposition rates of bark and branches (Ganjegunte et al. 2004). This indicates that whole-tree harvesting could be used as a means to decrease P release from blanket peats.

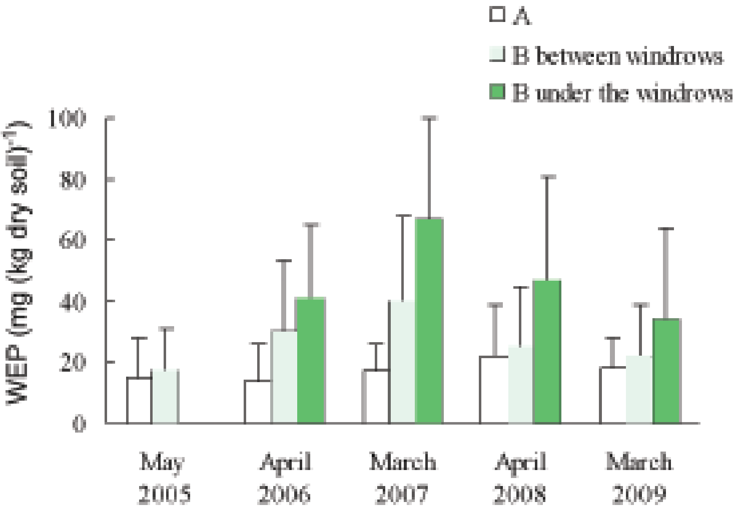


Figure 6: Soil water extractable phosphorus (WEP) in non-harvested (A) and harvested (B) areas between the windrows and under the windrows in May 2005, April 2006, March 2007, April 2008 and March 2009 (The bars indicate the standard deviation).

Possible mitigation methods

This study showed that the harvesting of the blanket peat forest increased the TRP export in the study stream, and this impact could last for more than four years. P concentrations increased from 6 µg L^{-1} of TRP pre-clearfelling to a peak value of 429 µg L^{-1}, one year after harvesting. In another blanket peatland forest catchment study, Cummins and Farrell (2003) monitored P concentrations in three blanket peatland forest drains in the west of Ireland from 1996 to 2000, and found that the TRP in the three drains increased from 9 µg L^{-1}, 13 µg L^{-1} and 93 µg L^{-1} before harvesting to peak values of 265 µg L^{-1}, 3530 µg L^{-1} and 4164 µg L^{-1}, respectively, one year after harvesting. As most of the blanket peat forests planted in Ireland before the 1980s are reaching their harvesting age, efficient and feasible practices are required to minimize the possible P release after harvesting to receiving waters.

In order to reduce nutrient sources after harvesting, wholetree harvesting has been recommended (Nisbet et al. 1997). Needles and branches have much higher nutrient concentrations than stem wood. Whole-tree harvesting may reduce nutrient sources by 2 to 3 times more than bole-only harvesting (Nisbet et al. 1997). This study found higher WEP contents in harvested areas below windrow/ brash material than for the brash-free sites, indicating that wholetree harvesting could be used as a means to decrease P release.

A buffer zone is an area adjacent to an aquatic zone and managed for the protection of water quality (Forest Service 2000). Within buffer zones, natural vegetation and/or planted suitable tree species are allowed to develop. Buffer zones have been widely used by forestry practitioners in the protection of freshwater aquatic systems (Newbold et al. 2010). However, this study shows that traditional buffer zones with a width of 15-20 m may not be an efficient method to mitigate the P release from all harvested areas, since, in this study, most of the P in the study stream was soluble and more than 80% of the P release occurred in storm events when there would have been low residence times for the uptake of soluble P in the buffer zones. If buffer zones are used to mitigate P release, larger buffer areas than those used presently may be needed (Väänänen et al. 2008).

Phased felling and limiting size to minimise negative effects have been recommended in the UK (Forestry Commission 1988) and Ireland (Forest Service 2000). Harvesting a proper proportion of a catchment at any one time can reduce the nutrient concentrations on the main aquatic systems. This study found that due to the dilution capacity of the main river, the P concentrations in the river were low after harvesting, indicating that catchment-based selection of the harvesting coupe size could limit the P concentrations in the receiving waters after harvesting. However, the management strategy does not reduce the P concentrations in the study stream and does not reduce the total P load leaving the harvested catchment.

Before the replanted trees grow up, vegetation could immobilize the nutrients throughout the harvested catchment. As ground vegetation develops, P uptake and recycling can be expected to diminish leaching over time (Piirainen et al. 2007). In the present study, vegetation such as *Molinia caerulea* cover was observed in 2008 and became well established in 2009. Since the development of the vegetation, P release to the receiving water reduced, though the WEP in the harvested area was still high. It could take 3 to 4 years for natural revegetation of the blanket peat harvested forest area to occur. Stimulation of vegetation cover immediately after harvesting, e.g. through seeding the harvested area with fast growing native grasses, should also be studied as a practice to minimize the P release from the blanket peat forest after clearfelling.

Conclusions

This study showed that the harvesting of the blanket peat forest increased the TRP export in the study stream, and this impact could last for more than four years. In the first three years following harvesting, up to 5.15 kg ha^{-1} of TRP were released from the catchment to the receiving water; in the second year alone after harvesting, 2.3 kg ha^{-1} were released. P concentrations increased from 6 µg L^{-1} of TRP during pre-clearfelling to a peak of 429 µg L^{-1} one year after harvesting. More than 80% of the P release occurred during storm events. Due to the dilution capacity of the main river, the P concentrations in the river were low during the study period, indicating that rational sizing of the harvesting coupe could be an efficient practice to limit the P concentration in the receiving waters following harvesting.

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