Understanding water quality in runoff from degraded, shallow peatlands on Exmoor and the short-term impacts of restoration

- Pre-restoration, low water tables were linked to elevated dissolved organic carbon concentrations.
- Restoration has not had a statistically significant impact on any of the water quality parameters studied.
- Average DOC concentrations during runoff events pre-restoration range from 4.8 to 14.3 mg L^{-1} and post-restoration (3.5 to 13 mg L^{-1}).
- Water discolouration has not changed significantly post-restoration, and remains above EC standards (Abs^{400} of 1.5 Au m^{-1}).
- Greater improvements to the ecohydrological function, particularly vegetation change are needed before significant changes in water quality can be detected following restoration, such as the reduction in carbon loads which is only just becoming evident in the Spooners catchment.

The quality of the water running off Exmoor's peatlands impacts on aquatic life and drinking water management downstream. Due to the carbon-rich nature of peaty soils, the degradation of peatland function has been linked to elevated dissolved organic carbon (DOC) concentrations in the water leaving peatland catchments in recent decades. DOC enrichment in water leaving upland catchments represents an important pathway of carbon loss. DOC also discolours water and therefore has implications for water treatment as removing DOC from water is complicated, costly and can result in carcinogenic by-products.

Water held back by a peat dam post-restoration on one of the monitored ditches at Spooners.

Prior to this study little was known about the processes controlling the quality of water leaving Exmoor's peatlands and assumptions about the effects of peatland restoration on water quality were largely based on results from the deeper peatlands of northern England. Rainfall event based monitoring of water quality at Aclands and Spooners pre-restoration demonstrated that increased DOC concentrations occurred following warmer periods with deeper water tables, likely to be due to the aeration of the peat and stimulation of microbial decomposition[2]. This suggests that encouraging water table depths to levels more typical of peatland environments (at or near the surface) could reduce DOC concentrations.

Pre-restoration, DOC concentrations leaving the catchments (4.8 to 14.3 mg L^{-1}) were lower than the national average (31 mg L^{-1})[1], but were frequently in excess of the target of 5 mg L^{-1} (Figure 22A). Up to 4.5 years post-restoration there has not been a statistically significant change in DOC concentrations (3.5 to 13 mg L^{-1}) leaving either catchment (Figure 22A), though mean concentrations have slightly lowered at both locations.

The amount of carbon lost from the catchment (carbon load) is related to DOC concentrations and the total amount of runoff generated by rainfall events. Pre-restoration, carbon loads ranged between 3 and 264 kg in the monitored events, where average loads were 30.6 and 76.4 kg at Aclands and Spooners, respectively (Figure 22B). The reduction in rainfall in the years monitored post-restoration (as described in the Exmoor hydrology

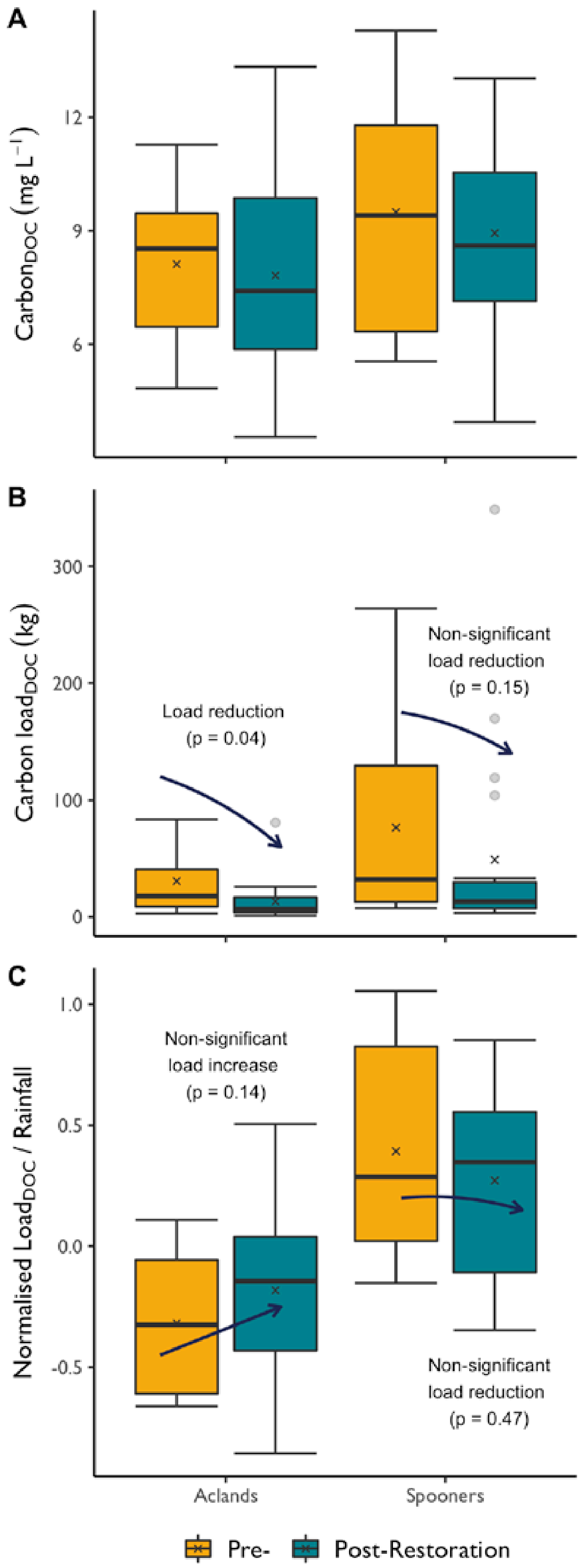

Figure 22 Observations at the flumes during monitored rainfall events A) flow-weighted mean dissolved organic carbon (DOC) concentrations B) total mass of DOC exported rainfall event, and C) Normalised (Log_{10}) relationship between DOC Load and rainfall to account for differences in rainfall pre and post-restoration. 'x' marks the average (mean) value, 'o' indicates observations that are considered outliers.

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Looking downstream from Aclands flume towards the River Barle.

section, Figure 15) means that a significant decrease in DOC loads at Aclands (p=0.04), and a non-significant (p=0.15) decrease at Spooners (Figure 22B) were observed, with average post-restoration loads of 48.9 and 13.2 kg, respectively. This change becomes non-significant at both Aclands and Spooners when normalised for total event rainfall (Figure 22C). Normalising for rainfall allows the changes in load to be considered irrespective of the variation in rainfall for pre- and post-restoration monitored events. Positively, this indicates that restoration activities have not contributed to a significant increase in DOC loads. However, it does illustrate that a longer post-restoration period is needed to see if reductions in DOC concentrations can be achieved in these degraded moorlands.

In the short-term restoration has not had a statistically significant effect on the colour of the water (as measured by UV-Vis spectrometry at 400 nm) leaving the catchments (Figure 23A). Both catchments discharge water colour which remains above the European Commission standards (Abs^{400} of 1.5 Au m^{-1})[2].

The colour to carbon ratio (Colour$_{Abs400}$/Carbon$_{DOC}$) and the Specific Ultra-Violet Absorbance (SUVA -Abs^{254}/DOC) are useful tools for understanding the chemical characteristics of the DOC, which can then be used to infer the type of carbon being lost (e.g. from the decomposition of fresh plant material over that from more humified peat). Neither changed significantly post-restoration at Spooners (Figure 23B and C). In contrast, there was a significant change in both parameters in the Aclands catchment post-restoration. The results suggest that post-restoration the more humified peat (i.e. old peat) remains the primary source of the DOC leaving the catchments during rainfall events, rather than a shift towards DOC arising from fresh material as observed on Dartmoor (see next section). Further research is needed to attribute the significant changes observed at Aclands more robustly, which could be linked to the disturbances caused by restoration efforts, a change in the source of the DOC, or alterations to flow routing through the catchment.

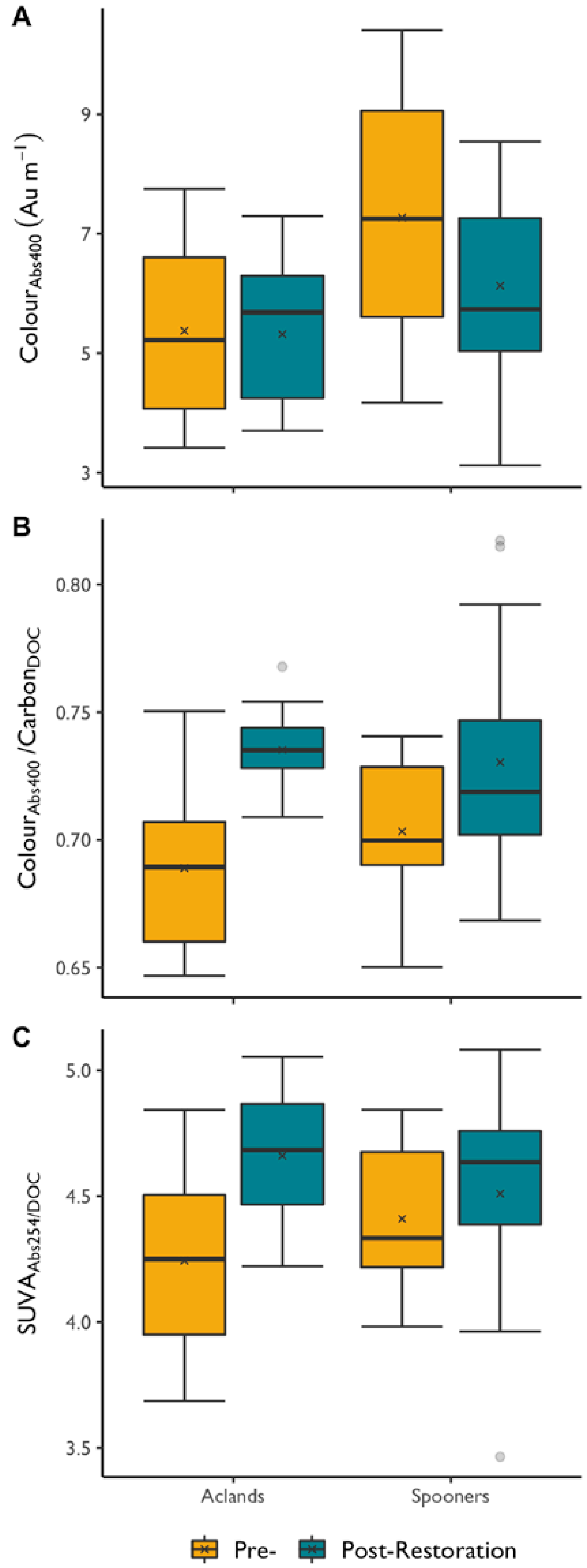

Figure 23 A) average water discolouration (Abs400), B) average Colour per unit Carbon relation (Colour$_{Abs400}$/Carbon$_{DOC}$), and C) Specific Ultra-violet Absorbance (SUVA – Abs$_{254nm}$/DOC), observed during monitored rainfall events at the flumes pre- and post-restoration. 'x' marks the average (mean) value, 'o' indicates observations that are considered outliers.

Figure 24 Discharge monitoring at Spooners catchment.

If the vegetation communities change in response to restoration works, as is likely if higher and more stable water tables can be achieved and/or through *Sphagnum* re-introduction programs, it is expected that the amount and chemical characteristics of the DOC will change; DOC would be sourced from fresher material, as seen on Dartmoor (see next section). Importantly, this should also result in changes to the colour of the water leaving the catchments.

REFERENCES

The appendices are available to view at **www.exeter.ac.uk/creww/research/casestudies/miresproject**

1. Armstrong, A. *et al.* The impact of peatland drain-blocking on dissolved organic carbon loss and discolouration of water; results from a national survey. *J. Hydrol.* **381**, 112–120 (2010).

2. Grand-Clement, E. *et al.* Antecedent conditions control carbon loss and downstream water quality from shallow, damaged peatlands. *Sci. Total Environ.* **493**, 961–973 (2014).

How does restoration effect dissolved organic carbon run-off from a deep, eroding blanket bog?

- Post-restoration, the total load of dissolved organic carbon leaving the mire during monitored storm events was roughly 1/3 of the pre-restoration loads.
- Restoration had no statistically significant effect on dissolved organic carbon concentrations or water colour.
- Chemical characteristics of the water (C_{Abs400}/C_{DOC}, SUVA) changed significantly post-restoration suggesting a shift in the source of dissolved organic carbon to fresher organic matter.
- Restoration caused a step-change in hydrological connectivity; post-restoration, dissolved organic carbon took longer to reach the sampler as either sources were further away, transport was slower and/or pathways more tortuous.

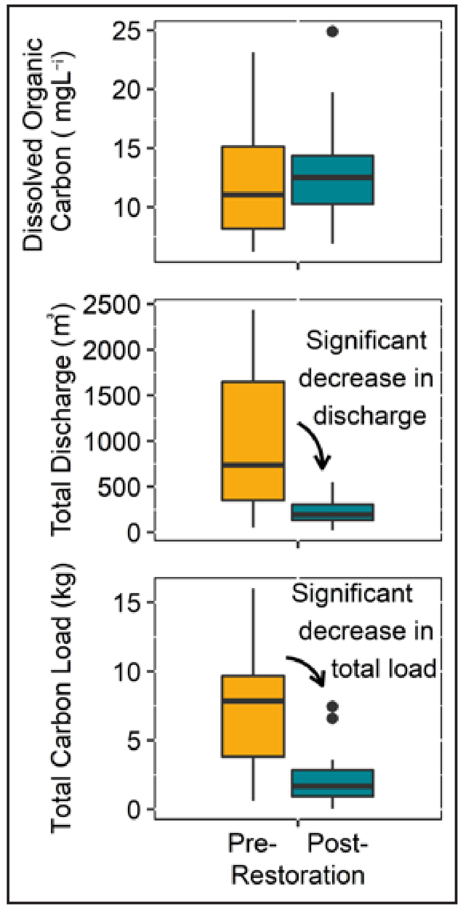

Figure 25 **Despite no significant effect of restoration on dissolved organic carbon concentrations (p=0.694) (top), a significant reduction in total sampled event discharge (middle) results in a significant decrease (p=0.001) in total cumulative carbon load (bottom).**

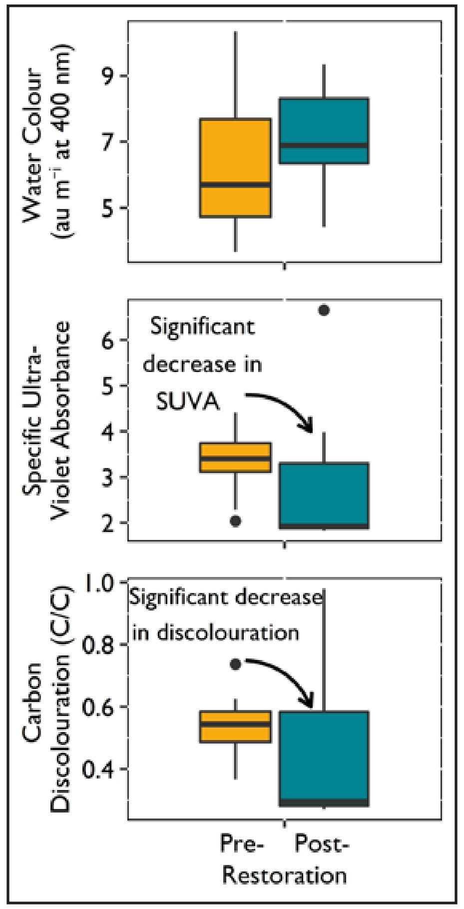

Figure 26 **Restoration had no effect on water colour (p=0.522) (top) but significantly decreased specific ultra-violet absorbance (p=0.011) (middle) and carbon discolouration (p=0.048) (bottom) suggesting a fresher source of organic carbon post-restoration.**

Rain falling on peatlands and flowing into rivers is a vital drinking water source. In their current state, organic carbon is being flushed from peatlands and carried downstream. As this dissolved organic carbon reacts with disinfectants to produce carcinogenic by-products, South West Water has a statutory duty to remove organic carbon in drinking water[1] at the Water Treatment Works. Restoration aims to improve ecological functioning of the peatlands; reducing the production of dissolved organic carbon at the source and therefore the total volumes reaching Water Treatment Works.

Water samples collected during storm events pre-restoration had dissolved organic carbon concentrations from 6.2 to 23.1 mg L^{-1}. This was similar to concentrations found on Exmoor (4 to 21 mg L^{-1})[2] but lower than more northerly peatlands (20 - 62 mg L^{-1})[3] heightened levels of degradation in response to environmental change have resulted in an increased loss of dissolved organic carbon (DOC).

Up to 3-years post-restoration there was no significant decrease ($p=0.694$) in dissolved organic carbon concentrations (6.9 to 24.9 mg L^{-1})[4] (Figure 25 top). Although the carbon concentration did not change post-restoration, the volume of water flowing though the gully decreased (Figure 25 middle) and therefore the total load of carbon being exported during monitored storm events was significantly ($p=0.001$) lower (Figure 25 bottom).

Restoration had no significant effect ($p=0.522$) on water colour (Abs^{400}) (Figure 26 top), however, the carbon in the water was significantly paler ($p=0.048$) (decrease in C_{Abs400}/C_{DOC}) (Figure 26 bottom) and more hydrophilic ($p=0.011$) (decrease in Specific ultra-violet absorbance (Abs^{254}/DOC)) (Figure 25 middle) suggesting a shift towards carbon from fresh plant litter, as opposed to release of deeper and older carbon within the peat soil (Figure 27).

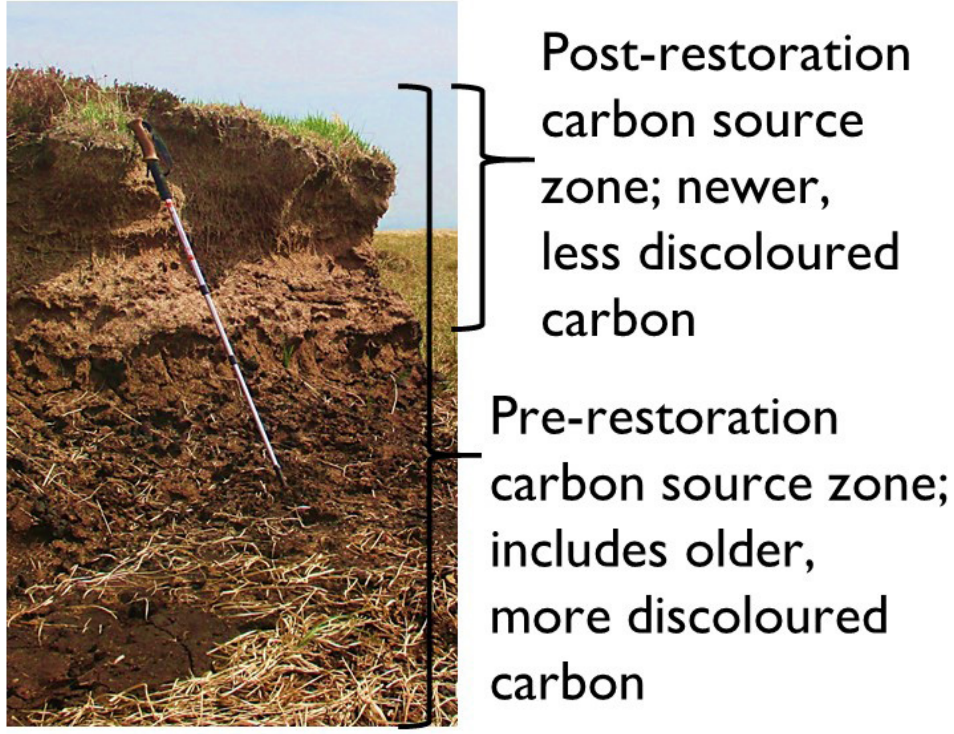

Figure 27 **A change in water chemistry suggests a shift in the dissolved organic carbon source post-restoration to paler, more hydrophilic, fresher organic material.**

The change in dissolved organic carbon concentration over time during a storm event (hysteresis index)[4] suggests a step-change in the hydrological connectivity (Figure 28). In a degraded mire, at the onset of rain, rapid surface/subsurface flow transports carbon from the degraded peat into the gully. As the rainfall continues these sources are depleted leading to dilution. Post-restoration dissolved organic carbon concentration increased over the storm, suggesting carbon sources were more distant, pathways were longer or transport slower. Post-restoration rainfall raised the water level in the pools until they overflowed (Figure 29). This overland flow, together with slower subsurface flow transported dissolved organic carbon to the gully later in the storm.

Figure 29 **Slower overland flow occurring above the water quality monitoring location (at base of the tube in the foreground) post-restoration. A wooden dam is visible in the foreground.**