HOW CAN CULM GRASSLAND HELP WITH NATURAL FLOOD MANAGEMENT?

A Ph.D. study by Nicola Ellis, Exeter University 2016-21

University of Exeter

Devon Wildlife Trust

Environment Agency

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This document summarises the method and conclusions from a Ph.D. study undertaken during 2016-21 by Nicola Ellis of Exeter University, working with the Environment Agency and Devon Wildlife Trust. The study investigated the extent to which Culm grassland could be used as a flood management measure.

The results of fieldwork indicate that Culm grassland (both *Molinia*-dominated and species-rich rush pasture) holds more water that improved grassland and has the ability to release the water more slowly into the catchment. Fieldwork also showed that Culm grassland holds up to four times as much carbon as intensive grassland. Modelling work indicated that if the Culm grassland potential in a sub-catchment was increased to 30%, then a 7% reduction in flood peak could be achieved in an extreme rainfall event.

This study indicates that increasing the amount of Culm grassland in a river catchment will bring significant flood management benefits, together with other ecosystem benefits.

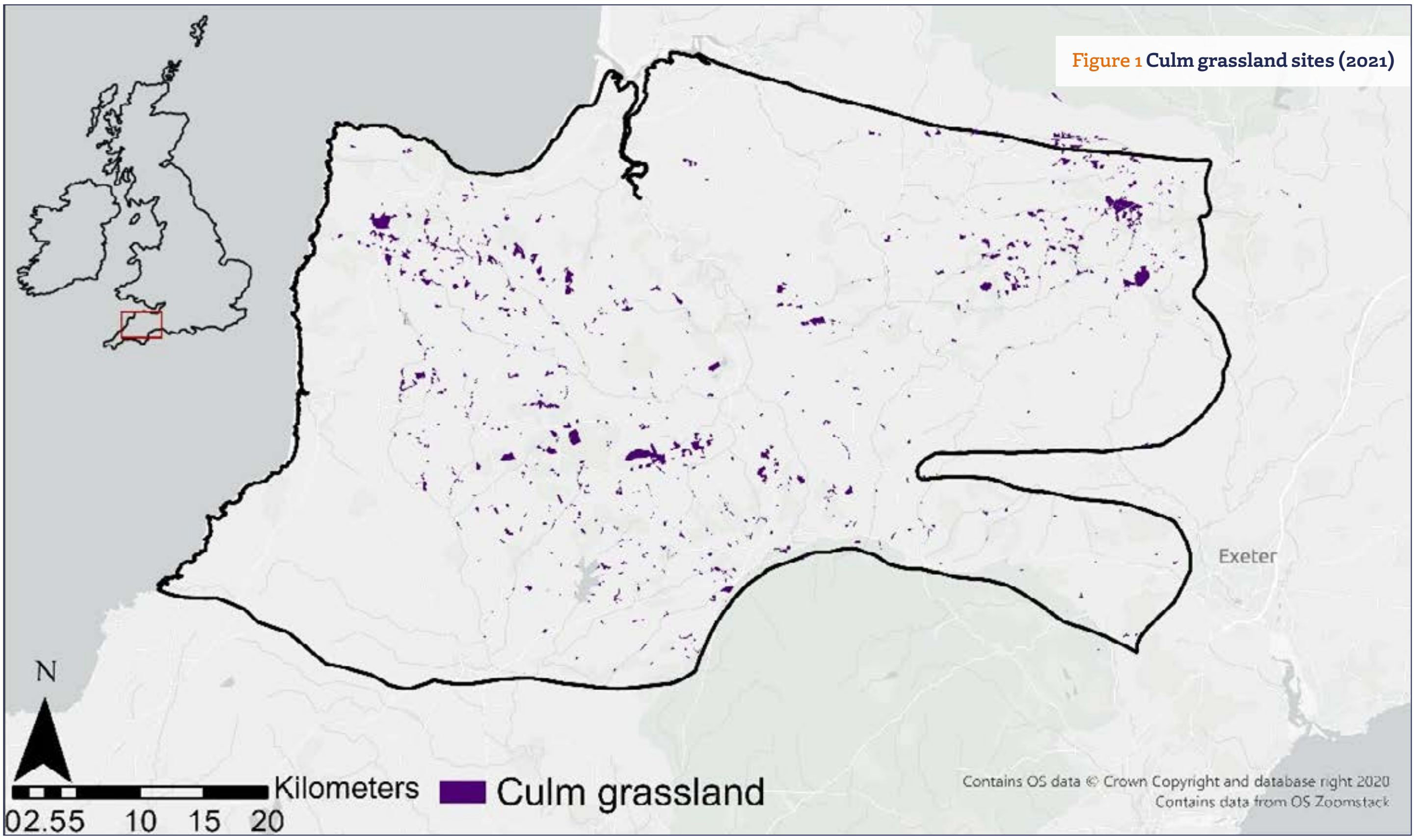


Figure 1 Culm grassland sites (2021)

Figure 2 Key types of Culm grassland

What is Culm grassland?

Species-rich grasslands are an important part of the British landscape but they have dramatically reduced as agriculture has intensified. During the 20th century, over 90% of species-rich grasslands were lost. The Wildlife Trusts estimate that there are 4.5 million hectares of grassland in England, of which just 2% are 'unimproved' or species rich.

In southwest England, lowland species-rich purple moor-grass (*Molinia*) and rush pasture is known as Culm grassland. This is a variable grassland type named after the Culm measures, a geologically distinct area in north Devon and Cornwall that produces wet, seasonally saturated clay soils.

Culm grassland has great value as a diverse habitat, including valuable plants such as orchids as well as being a habitat to rare insects such as the Marsh Fritillary butterfly. However, like all unimproved grasslands, at least 90% of Culm grassland has been lost since the 1950s due to drainage, conifer plantation, change of land use and neglect.

Since the late 1990s, Devon Wildlife Trust has worked with landowners in North Devon to protect, manage and re-create Culm grasslands. During the period 2016-2021 the Culm Grassland Natural Flood Management Project aimed to increase protection and creation of Culm grassland sites, and investigate how Culm grasslands could help to manage flood risk. The project was led by Devon Wildlife Trust, supported and funded by the Environment Agency (EA), Devon County Council (DCC) and the European Union through Interreg 2 Seas. Delivery was supported by a partnership of EA, DCC, the University of Exeter and Natural England.

What is natural flood management?

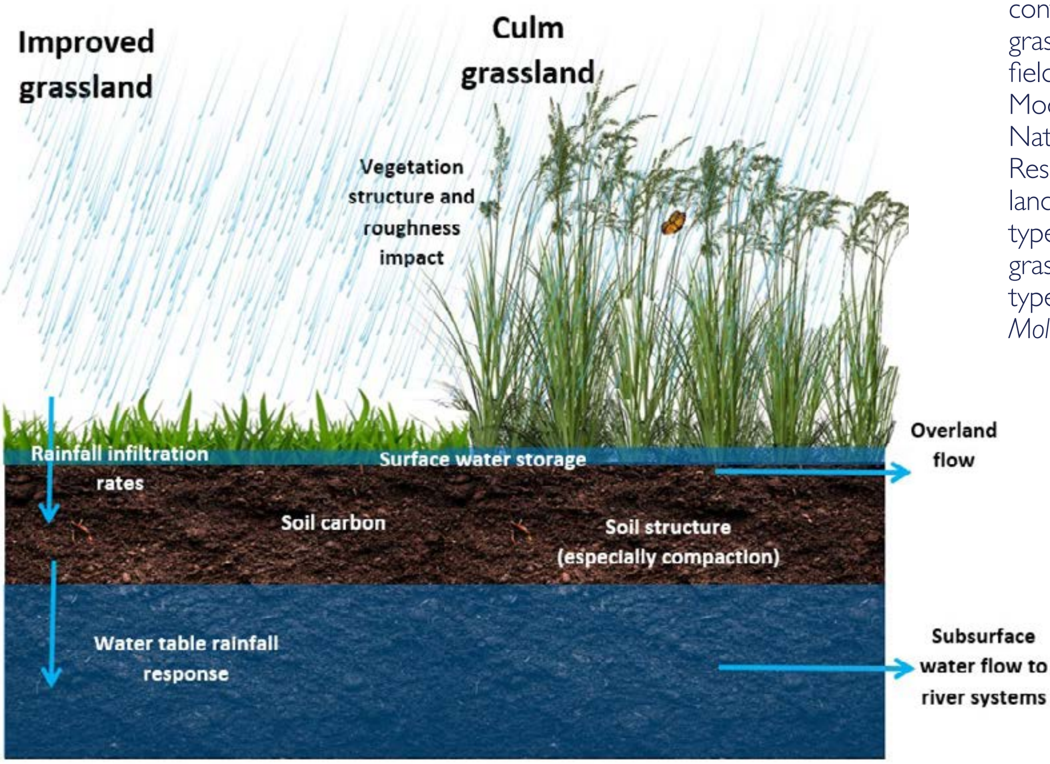
Flood management in Europe is currently undergoing a significant shift. Traditionally, flood management has been dominated by engineered structures such as flood walls, embankments and dams. While certainly valuable, engineered structures are not always the best solution for a community at risk of flooding. Hard engineering is insufficient on its own to address complex catchment and climate change issues, as well as being often fragmented and highly expensive. At present two third of the UK flood mitigation budget is spent on river and coastal defence maintenance (Department for Environment and Rural Affairs, 2016).

The flood management sector is now slowly embracing natural flood management (NFM), which utilises and enhances natural processes to reduce flood risk as well as bringing other environmental benefits (Burgess-Gamble et al., 2017). For example, tree planting is a popular flood management technique to intercept rainfall and improve soil structure. Hard engineering is supported by previous studies and evidence of its effectiveness. In contrast, the emerging NFM currently lacks a robust evidence base. NFM knowledge is constantly developing with new and novel studies, such as introducing beavers to rivers. Some habitats are less studied for their NFM potential; grassland is one such overlooked habitat despite covering 40.5% of the UK and 70% of UK agriculture (Silva et al., 2008). A full NFM review can be found at Ellis et al., (2021).

How does Culm grassland fit into natural flood management?

A preliminary study by Puttock and Brazier in 2014 explored the possibility that Culm grassland could not only offer a valuable wildlife habitat, but also flood management and pollution management potential. Early results showed that Culm grassland sites had greater carbon and nitrogen and less phosphate than improved grassland fields, as well as storing more water than improved grassland below the surface. An estimated 9429.8 ±2807 Ml (10^6 litres) of water was calculated to be stored in Culm soils.

Figure 3 **Grassland flood management properties investigated within the PhDs**



The PhD study

A detailed PhD study was undertaken by Nicola Ellis at Exeter University during the period 2017 to 2021. It built upon the pilot study to further understanding of the ways Culm grassland could reduce flood risk. The aim of the study was:

> To develop an understanding of the extent to which Culm grassland can provide natural flood management.

This was achieved through four key objectives through a range of spatial scales. They ranged from the small scale, assessing soil properties and water tables within fields, all the way to modelling the impact on river flow in a small river catchment were Culm grassland to be restored on a larger scale. All studies were undertaken with improved grassland (perennial ryegrass) as a comparison/control since this is the dominant grassland in the U.K. The first three field studies were conducted at Ash Moor Nature Reserve, Dunsdon Nature Reserve and Meshaw Nature Reserve over three fields with similar landscape properties such as soil type, slope and rainfall. Unimproved grassland was divided into two major types: species-rich rush pasture and *Molinia* dominated Culm grassland.

OBJECTIVE 1:

What's going on below the surface of Culm grassland?

The aim of this objective was to understand soil conditions and water table response to rainfall in Culm grassland (species rich rush pasture and *Molinia* dominated grassland) compared to improved grassland.


Figure 4 **Compacted soil in improved grassland**


Figure 5 **A dipwell monitoring the water table**

Method

At each field plot of 30m by 50m, five samples were taken to 0.15m depth, making a total of 45 samples. Each sample was divided into the organic layer of soil (O horizon) and the A horizon. Each sample was then processed in a laboratory to assess: soil moisture content, bulk density (soil compaction), O horizon depth, organic matter content and total carbon content.

At each field plot, five dipwells were installed to 0.5m depth with a data logger recording water table depth at 15 minute intervals. A rain gauge was also installed at each site for accurate rainfall measurements also at 15 minute intervals. Dipwells were in place from September 2018 to May 2020.

Results

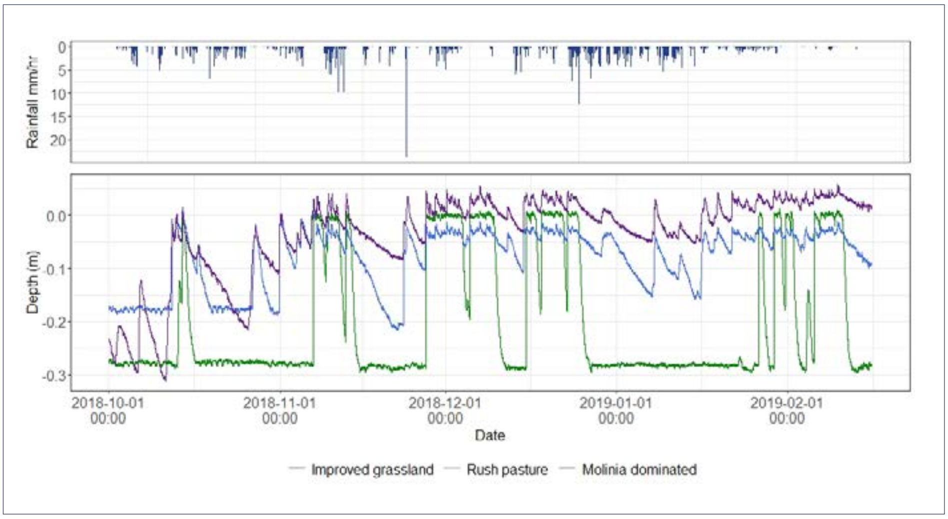
Water table monitoring

Figure 6 shows the water table depths across the three sites of *Molina*, rush pasture and improved grassland. The winter of 2019/2020 was notably wetter than 2018/2019 which is reflected in the water table results. Despite each of the fields at each site being close together, there were very different water table rainfall responses. At Ash Moor and Dunsdon, the improved grassland was notably flashier in response to rainfall compared to Culm grassland fields, which often had a slow release after rainfall events. This is likely due to the presence of drainage in these fields, which may result in large surges of water into rivers compared to Culm grassland fields which slowly release and store water. This is particularly obvious in summer heavy rainfall events (e.g. 25 mm/hr event in May 2019) which did not affect improved grassland fields but was stored in Culm grassland fields and slowly released over 72 hours after.

Soil condition

A summary of all soil properties in the O and A horizon are shown in Figure 7. Culm grassland had on average the greatest organic layer depth (O horizon) at 4.7cm, while improved grassland sites mostly had no organic layer present. Soil moisture content was above 45% in the O horizon and above 20% in the A horizon in all samples showing how wet the sites were. Culm grassland had more consistent soil moisture values compared to improved grassland which ranged between 20.3 to 52.5% water. *Molinia* dominated grassland consistently had the lowest soil bulk density in the O and A horizons less than 0.6 g/cm^3, with rush pasture fields displaying low values of soil bulk density with the exception of Ash Moor nature reserve. Improved grassland had the greatest range of soil bulk density which reflected the different range of management styles, ranging from 0.5 g/cm^3 (low compaction) to 1.4 g/cm^3 (highly compacted). There was a direct link between bulk density and soil moisture content, demonstrating

Figure 6 **Water table data**



Type	Mean SOC (%)	SOC g cm^3 (O horizon)	SOC t ha^{-1} (O horizon)	C t ha^{-1} (0.15m)
Molinia dominated grassland	14.73	29.42	29415.74	95042.35
Species rich rush pasture	11.49	20.07	20071.87	87645.11
Improved grassland	10.68	7.78	7783.85	96843.91

Table 1: Soil organic carbon (SOC) estimates based on soil carbon measurements in 0.15 m cores.

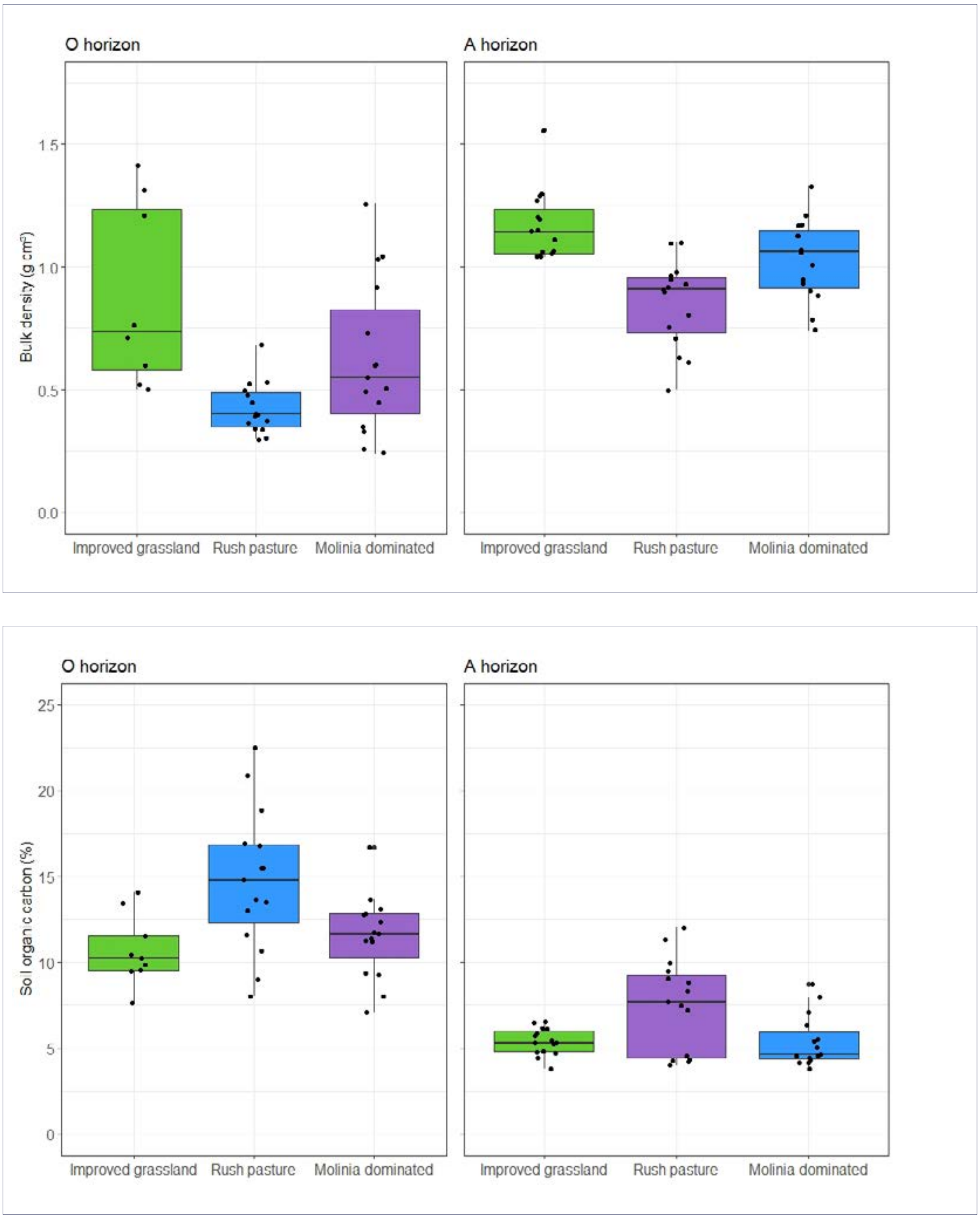


Figure 7 Key soil results

more compacted soils were likely to hold less soil moisture.

Finally, *Molinia* dominated fields had on average the greatest soil organic carbon content (SOC) in soils (25% in the O horizon). Estimates of carbon stocks for fields are shown in Table 1. Within the O horizon, rush pasture had 2.6 times more SOC (g cm^3) than paired improved grassland fields. *Molinia* dominated fields had on average 3.8 times more SOC (g cm^3) than paired improved grassland fields. This was largely a function of the greater O horizon depth in the Culm grassland compared to improved grassland. Carbon stock values calculated for 1ha to 0.15m – a useful measure of soil depth from a farming perspective - present more even values of SOC. This was due to the greater soil bulk density of improved grassland (on average 1.4 times greater than *Molinia* dominated fields) soils despite the greater percentage of SOC in the soil. It is likely due to the level of compaction and lack of O horizon carbon in improved grassland is being lost and not accumulated, unlike the organic rich Culm grassland sites.

OBJECTIVE 2:

How does Culm grassland respond to heavy rainfall?

The aim of this objective was to measure how the different types of Culm grassland respond to heavy rainfall events which would leave to flooding.

Method

A field rainfall simulator was built to simulate a 40mm/hr rainfall event over a 1m² area across the three sites in each field of improved grassland, species rich rush pasture and *Molinia* dominated grassland. The rainfall simulator was run twice per field plot. Runoff was recorded from a runoff collection ditch at one-minute intervals until saturation was reached. The simulator was then run for a further five minutes to assess saturated runoff volumes.

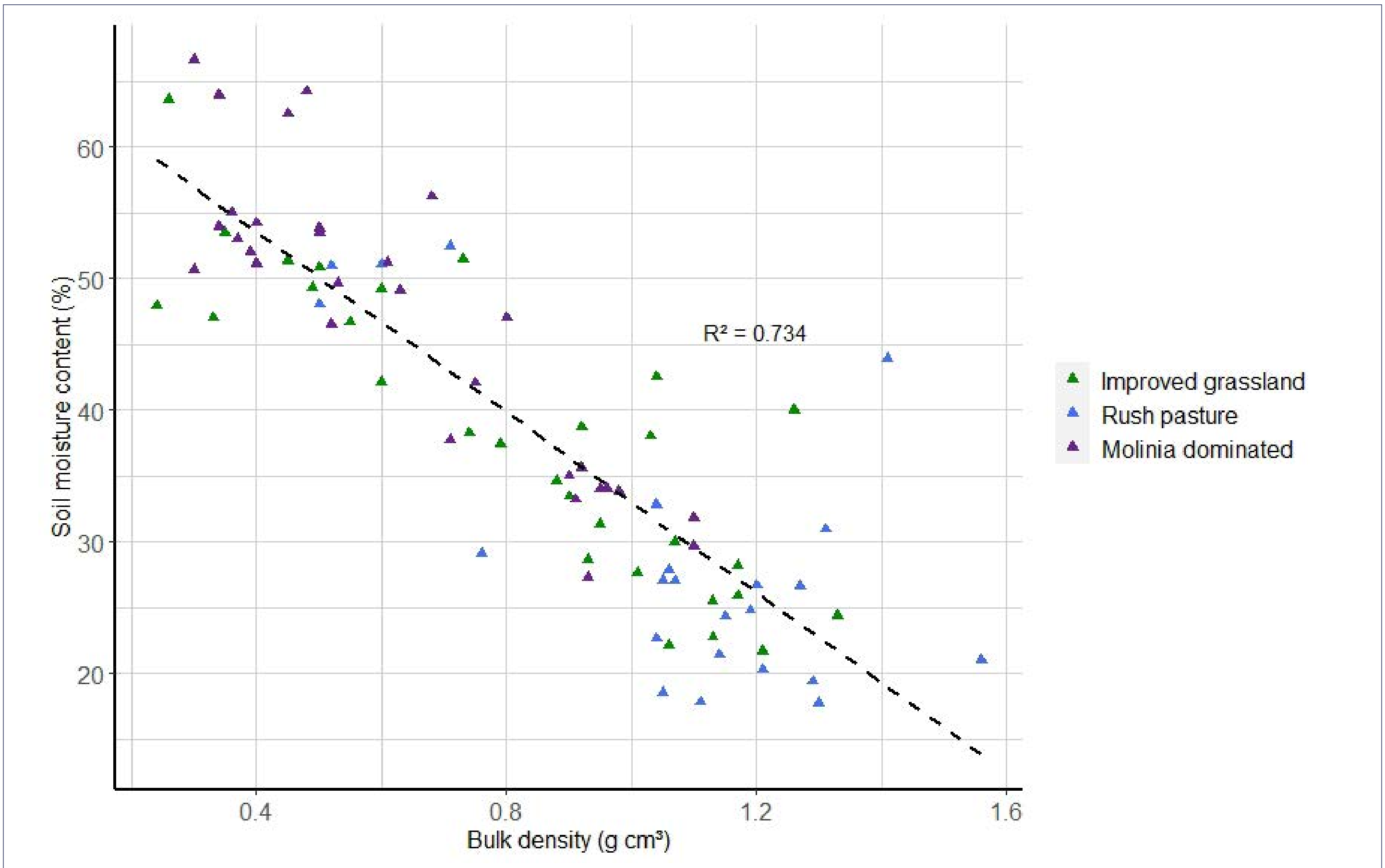
Results

Plots of runoff per minute at each site are shown in Figure. There was a wide variety of rainfall response, including three rush pasture plots which did not reach saturation after over 30 minutes. It is notable that runoff from *Molinia* dominated plots were mostly irregular as the large tussocks absorbed water and pools between tussocks formed and were released as a 'pulse' of runoff. On average improved grassland plots generated runoff fastest (after 5 minutes of rainfall), though Dunsdon was a clear exception to this rule. Heavily poached and/or compacted plots such as Ash Moor improved grassland and rush pasture plots generated the greatest runoff values. Culm grassland runoff never exceeded 85% of total rainfall input, showing even when plots were saturated water was still infiltrating the soil.

Figure 8 **Rainfall simulator**

The data shows a statistically significant relationship between high water table and faster runoff generation. Another significant relationship emerged between soil bulk density (soil compaction) and when soil reaches saturation point. This suggest soil compaction affects how much water a field could hold, and how quickly soil saturates. However, the volume of water running off appears not to be influenced by soil compaction. It is likely that vegetation type and density influence runoff volume.

Figure 9 **Soil bulk density against soil moisture content**



OBJECTIVE 3:

How does water flow through the structure of Culm grassland?

Figure 10 **Surface flow pathways between *Molinia* tussocks**

The aim of this objective was to explore the surface water processes in Culm grassland, specifically how water flows through *Molinia* dominated fields filled with dense tussocks in comparison to improved grassland. Species rich rush pasture was not included in this analysis.

Method

A drone was used to capture images of a *Molinia* dominated field and an improved grassland field at Ash Moor nature reserve. To avoid dense *Molinia* leaves covering the solid tussock, flights were done after prescribed burning of the field (a common management technique of Culm grassland). Using a structure from motion photogrammetry this create a 3cm resolution digital elevation model (DEM) re-creation of each field. The surface flow pathways and surface roughness were then modelled and measured over different areas (10, 20, 50, 100, 200, 500 and 1000 m^2) for comparing the two fields.

Results

Examples of the flow pathways generated from the DEMs of the *Molinia* dominated field and improved grassland field. The *Molinia* dominated field surface flow pathways were more sinuous through the dense tussocks, while the improved grassland field had flow pathways that were linear and followed the slope. The *Molinia* dominated field had an average of 2.54 m of flow pathway per 1 m^2, while the improved grassland field averaged 1.4 times shorter surface flow pathways at 1.82 m flow pathways per 1 m^2. There was no statistical difference in mean flow pathways length between the two fields below 1225 m^2, but there was a statistical difference at 2500 m^2. This work suggests that water takes longer to move across the surface of a *Molinia* dominated field than an improved grassland.

OBJECTIVE 4:

How would a river system respond to Culm grassland restoration?

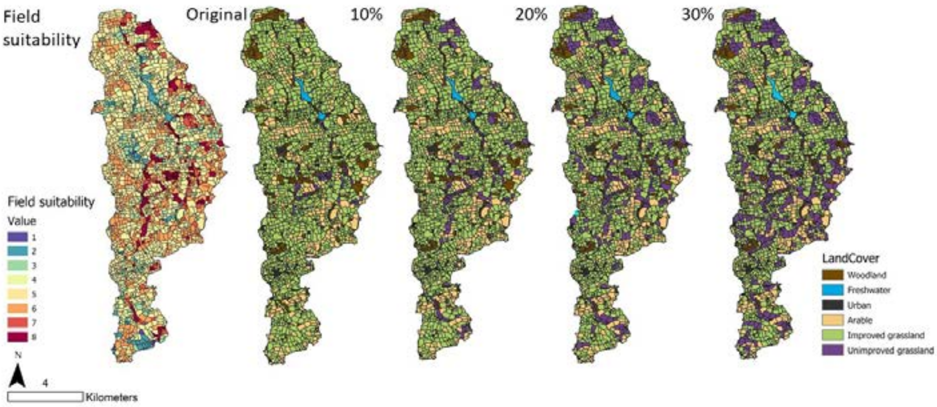


Figure 11: Field suitability for Culm grassland and restoration scenarios used for modelling

The three field experiments gained previously unknown knowledge of how Culm grassland can be a viable method of natural flood management. This understanding was used to model how Culm grassland behaves in a rainfall model. The essential objective was 'what would have happened in the upper Tamar between 2004 to 2014 with different extents of Culm grassland?'.

Method

A rainfall-runoff response model was used to simulate river flow at the site of two river gauges in the upper Tamar catchment. Suitability mapping was used to assess the best suited fields for Culm grassland restoration based upon slope, soil type, current land use and if the field was known to be Culm grassland in 1950 (not all land in a catchment could support Culm grassland). Data from 2004-2014 was used to inform the model. After this 0%, 10%, 20% and 30% potential Culm grassland was randomly 'restored' in the catchment and flow simulated from 2004-2014 with each of these restoration scenarios. Individual rainfall events and river peaks were then separated out over the ten year period for comparison.

Results

As of 2021 1.65 km^2 of the upper Tamar catchment is unimproved grassland. This increased to 5.51 km^2 with 10% of the potential restored unimproved grassland, 11.33km^2 at 20% and 16.53km^2 at 30%. The largest flow event is shown in Figure from 19th to 24th December 2012 at Crowford bridge gauge. Two weeks prior to this event 268 mm of rain fell in the catchment, with 53 mm falling between 21st to 22nd December (Figure). In 2012 at 30% Culm grassland the peak was reduced by 7%, and later attenuated after the event. In all other rainfall events the greater the Culm grassland extent, the smaller the peak flow value. There was a marginal increase of an average of 2.3% in peak flow at 0% unimproved grassland, suggesting the current extent of grassland has a small impact.

Key flow changes for river discharge are shown in Figure 12 for Crowford bridge gauge. Rainfall events on average became less flashy with Culm grassland restoration. At 30% Culm grassland coverage this resulted in an average of 6% peak Q reduction with a range of -1.56 to -9.62% across both gauges. There was also a decrease in total event volume as Culm grassland extent increased by an average of -4.54% at 30%. Finally, baseflow between events increased up to 7.65% in model simulations, particularly in the summer months and drought periods such as in 2010.

This modelling, although conceptual, indicates that increasing the amount of Culm grassland in a river catchment will bring significant flood management benefits, together with other ecosystem benefits.

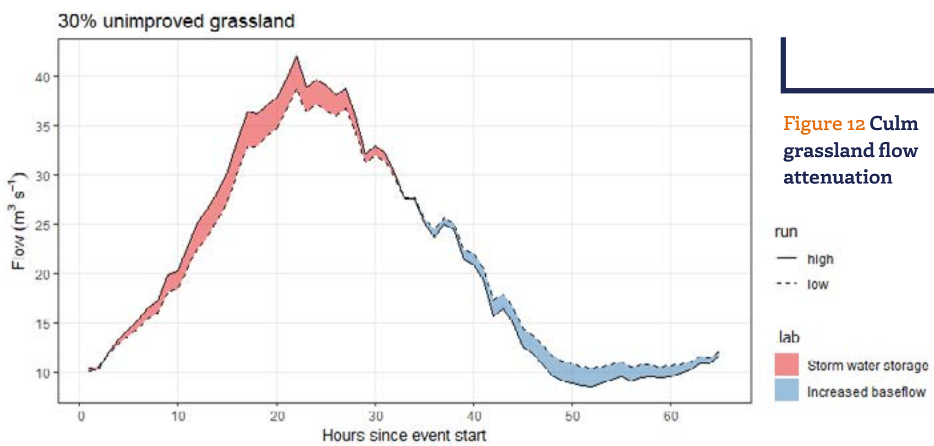


Figure 12 Culm grassland flow attenuation

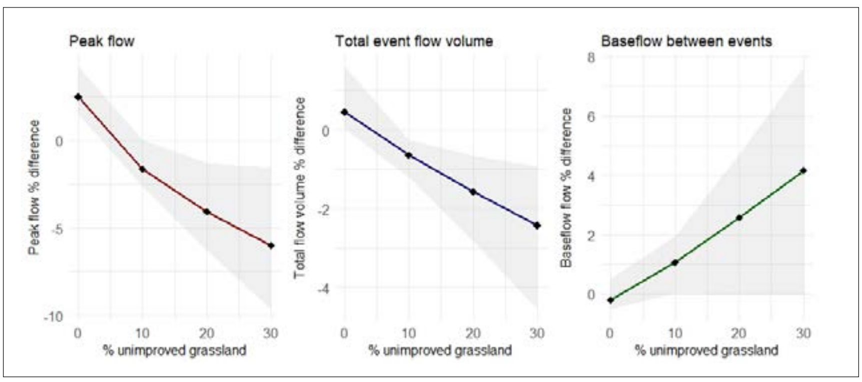


Figure 13 Key modelling statistics

STUDY IMPLICATIONS

Figure 14 Culm grassland from above

Importance of soil management

Soil sampling and rainfall simulations highlighted the importance of maintaining good soil conditions in both improved and unimproved grassland fields. Having reduced soil compaction with a healthy organic layer of vegetation built up by decaying vegetation resulted in better soil water storage and infiltration rates, therefore reducing overland flow to rivers. Some soil compaction was present in unimproved grasslands due to land management legacy, such as previously being heavily grazed. It is important both types of grassland are managed sympathetically to create good soil conditions.

Importance of vegetation diversity and vegetation structure

The importance of having diverse vegetation structure with rough vegetation was shown in rainfall simulations and surface flow pathways. The dense tussock structure and dense rushes were vital in reducing overland flow volume and disrupting surface flow pathways which would wash directly into the river in improved grasslands. The dense vegetation was also shown to store surface water when the ground was completely saturated in rainfall simulations compared to improved grassland.

Continuing unimproved grassland restoration

The sub-catchment modelling showed how vital the continued restoration of Culm grassland is to the entire catchment, with the potential to reduce flood peaks and flood volume. Studying surface flow pathways showed that fields of Culm grassland need to be at least 0.25 ha to have significantly greater surface flow pathway and storage compared to improved grassland.

Culm grassland as part of a resilient ecosystem

Modelling showed Culm grassland could reduce flood peaks by an average of 6% at 30% Culm grassland. This may seem small, but when used alongside multiple other NFM methods which reduce peaks ~5% such as storage ponds, leaky dams and woodland restoration the flood risk reduction could be huge. The catchment would also benefit from a diverse natural environment which hard engineering would not offer.

Not only did Culm grassland show potential to reduce flood risk, there were also benefits including storing carbon with the soil, greater above ground biomass, better soil quality and better water quality from fields (Puttock and Brazier 2014). Culm grassland is also a valuable habitat for insects, mammals and birds. Culm grassland has a valuable role as a resilient ecosystem against challenges such as increasing flood risk, climate change and biodiversity loss.

Conclusion

This study in partnership with Devon Wildlife Trust and the Environment Agency demonstrated the value of unimproved grassland in the southwest as a form of natural flood management and as a valuable habitat. More detailed methods, results and discussion for each of the study objectives can be found within the PhD thesis and associated publications.

This document should be cited as: Ellis, N. (2022) *How can Culm grassland help with natural flood management?* University of Exeter, Exeter, UK. For any questions please contact Nicola Ellis nicolaellis166@gmail.com or Richard Brazier R.E.Brazier@exeter.ac.uk

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