Cyfoeth Naturiol Cymru
Natural Resources Wales

Natural capital, ecosystem services and restoration potential of semi-natural habitats in Welsh floodplains

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Natural Resources Wales Evidence Report No: 265

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Crynodeb Gweithredol

Asedau cyfalaf naturiol pwysig yw gorlifdiroedd, sy'n dwyn amryw fanteision i bobl, gan gynnwys storio carbon a llifogydd, cylchu maetholion a darparu cynefinoedd. Mae'r rhyngwyneb rhwng ecosystemau daearol a dŵr croyw mewn gorlifdiroedd yn creu cyfoeth a chymhlethdod o adnoddau sy'n heriol i'w mesur a'u cymharu, ac mae graddfa'r ddarpariaeth o wasanaethau ecosystemau'n amrywio yn dibynnu ar y math o ddefnydd tir o fewn gorlifdiroedd. Wrth i fwyfwy o bwyslais gael ei roi ar ddarparu gwasanaethau ecosystemau trwy gynlluniau cymorth amaeth-amgylcheddol, mae angen gwell dealltwriaeth o raddfa'r gwahanol ddefnyddiau tir yng ngorlifdiroedd Cymru a'u darpariaeth gwasanaethau berthynol.

Astudiaeth gychwynnol yw'r adroddiad hwn i ganfod graddfa'r gwahanol ddefnyddiau tir a chynefinoedd lled naturiol yng ngorlifdiroedd Cymru – yn genedlaethol, ar raddfa ardal Cyfoeth Naturiol Cymru, ac mewn un dalgylch (dalgylch Afon Gwy). Hefyd, mae'n darparu tystiolaeth o werthoedd gwasanaethau ecosystemau a chyfalaf naturiol trwy adolygiadau o ddeunyddiau darllen ac astudiaethau achos. Yn olaf, mae'n treialu dull o fapio potensial ail-greu glaswelltiroedd sy'n gyfoethog o ran rhywogaethau ac sy'n gallu darparu amrediad ehangach o fuddiannau gwasanaethau ecosystemau na defnyddiau tir amaethyddol dwys, a hynny ar gyfer un dalgylch (dalgylch Afon Gwy).

Mae gan orlifdiroedd Cymru arwynebedd o 1,229 km2, y mae 59% ohono yn cael ei ddefnyddio at ddibenion amaethyddiaeth ddwys a 2.5% yn unig sy'n laswelltir niwtral. Yn ardal weithredol canolbarth Cymru Cyfoeth Naturiol Cymru, 82% o orlifdiroedd sy'n cael eu defnyddio at ddibenion amaethyddiaeth ddwys a dim ond 0.12% sy'n laswelltir niwtral. Mae defnyddiau tir âr a garddwriaethol yn darparu tri gwasanaeth ecosystemau, o'u cymharu â'r un ar ddeg a gynigir gan laswelltir niwtral. Cydnabyddir y bydd yr arferion rheoli a ddefnyddir ar laswelltiroedd yn cynyddu neu'n lleihau graddfa'r ddarpariaeth o wasanaethau ecosystemau. Mae tair astudiaeth achos yn dangos sut mae modd rhoi gwerth ariannol ar y gwasanaethau hyn a ddarperir gan gynefinoedd mewn gorlifdiroedd, yn ogystal â dangos gwerth ehangach cynefinoedd lled naturiol o'u cymharu â system ffermio dwys. Mae'r ymarfer mapio cyfleoedd yn dangos ei bod yn bosibl canfod o fewn un dalgylch lle gellid targedu ymdrech ar sail buddiannau bioamrywiaeth presennol, y math o bridd a hydroleg i gynyddu'r ddarpariaeth o wasanaethau ecosystemau trwy adfer ac ail-greu glaswelltiroedd sy'n gyfoethog o ran rhywogaethau.

1. Executive summary

Floodplains are important natural capital assets which deliver a wide range of benefits to people including flood and carbon storage, nutrient cycling and habitat provision. The interface between terrestrial and freshwater ecosystems in floodplains fosters both a wealth and a complexity of resources that are challenging to measure and compare and the extent of ecosystem service delivery varies depending on the landuse type within floodplains. With the increasing emphasis on delivering ecosystem services through agri-environment support schemes, a better understanding of the extent of different land uses in Welsh floodplains and their relative service provision is required.

This report is a preliminary study to establish the extent of different land uses and semi natural habitats in Welsh floodplains, both nationally, at an NRW Area scale, and in a single catchment (the Wye catchment). It also provides evidence of natural capital and ecosystem service values through literature review and case studies. Finally, it pilots a method for mapping the potential for recreation of species-rich grasslands able to deliver a larger range of ecosystem service benefits than intensive agricultural land uses, for a single catchment (Wye catchment).

Welsh floodplains cover 1229 km^2 with 59% subject to intensive agriculture, and only 2.5 % neutral grassland. In the mid-Wales NRW operational area, 82% is intensive agriculture, with neutral grassland occupying just 0.12%. Arable and horticultural land-uses provide three ecosystem services compared to the eleven offered by neutral grassland and it is recognised that the management practices applied to grasslands will increase or decrease the extent of ecosystem service delivery. Three case studies show how a monetary value can be placed on these services for floodplain habitats, and demonstrate the wider value of semi-natural habitats when compared to an intensive farm system. The opportunity mapping exercise demonstrates that it is possible to identify within a single catchment where effort could be targeted based on existing biodiversity interest, soil type and hydrology to increase the amount of ecosystem service delivery through the restoration and recreation of species-rich grasslands.

2. Introduction

The river floodplains of Wales support a wide range of different semi-natural habitats, as well as extensive areas of agriculturally improved grassland (Dargie, 2000). Restoration of more natural processes and more sustainable management of floodplains could provide multiple benefits to society whilst also promoting national targets and policies for biodiversity maintenance and enhancement.

This evidence report is focused on analysing the 'natural capital' (stocks/extent) of semi-natural habitats in Welsh floodplains, and assessing the multiple benefits of different land uses and habitats with regard to ecosystem services that come from this natural capital, including carbon storage, nutrient management, flood-risk alleviation and biodiversity conservation.

For the purposes of this report, natural capital is defined as those elements of the natural environment that directly or indirectly provide benefits for humans, in this case semi-natural floodplain habitats.

Floodplains are the areas of flat or gently undulating land associated with a river that periodically floods. Floodplains naturally support a wide range of different habitats and historically, their use by humans was limited to management practices compatible with the natural flooding regime of the river. Floodplains are complex, with both terrestrial and freshwater components. This complexity - the relationship between hydrological, physical, biogeochemical and ecological processes - provides many ecosystem goods and services that are difficult to obtain from other landscapes.

We depend on floodplains for many environmental goods and services. Floodplains have a widely recognised value in regulating flood events, as they provide essential space outside the river channel for floodwater to spread out. They also store carbon, support biodiversity, regulate nutrients, capture sediment, deliver agricultural products and constitute a rich cultural resource.

Floodplains cover over 122,908 hectares (1229 km^2) in Wales (as determined by combining the CEH 2015 land use data and NRW Flood Zone 2 polygon data following the method described in section 3.1), and are sometimes considered as a single element in the landscape. However, floodplains comprise a mixture of different land uses, from extensively managed natural and semi-natural habitats to intensive agricultural land and urban areas. Additionally, an estimated 42% of English and Welsh floodplains are deepened or embanked to such an extent that they are no longer connected to their former floodplains (Maltby *et al*, 2011).

The assessment here is a GIS exercise based around determining the extent of different land uses and, where possible, of semi-natural habitats in floodplains, their condition, and the extent to which they deliver ecosystem services and benefits.

3. Assessing extent of semi-natural habitats in Welsh floodplains

A number of studies have investigated the extents of various habitats in floodplains in Wales. A Phase1 habitat survey of lowland Wales was carried out between1987-1997, and Dargie & Dargie (1998 and 2000) utilised that survey to produce an inventory and review of grazing marshes and habitats on floodplains. More recently, modelling methods have attempted to map land uses across the UK (Rowland *et al*, 2017) and see https://www.ceh.ac.uk/services/land-cover-map-2015).

Additionally, a number of projects have worked on identifying priority areas for restoration. For example the Wales Biodiversity Partnership has identified priority areas for targeted conservation effort in Wales for wetland Priority Habitats (which include Lowland Fens; Lowland Raised Bog; Reedbeds; Coastal and Floodplain Grazing Marsh and Lowland raised bog), and lowland grassland and heathland Priority Habitats (which includes Lowland Dry Acid Grassland; Lowland Calcareous Grassland; Lowland Meadows; Purple Moor Grass and Rush Pastures; Calaminarian Grasslands; Lowland Heathland). Additionally, Natural Resources Wales published a report highlighting areas for targeting restoration effort to help address issues of ecological connectivity across Wales (Latham *et al*., 2013) based on a modelling approach.

Assessing the extent of semi-natural habitats and different land uses in floodplains is key in determining the natural capital of floodplains and the ecosystem services they deliver.

3.1. Method

A list of existing datasets was established (listed in Appendix 1) to compile as much information as possible about Welsh floodplains. These were sourced from various places, including data freely available through Lle, the geo-portal for Wales, and more detailed information from the Centre for Ecology and Hydrology (CEH), Cranfield University and directly from NRW.

A GIS analysis of land use and existing terrestrial habitats within the Welsh floodplain was undertaken using two different datasets for comparison (CEH land use data vs Phase1 habitat data) as follows:

NRW Flood Zone 2 polygons[1] were first clipped to the NRW operational areas boundary[2]. Polygons classed as purely tidal or coastal were then excluded from the dataset (polygons classed as mixtures of fluvial and tidal and/or coastal were retained). The resulting layer (the study area, Fig 1) was used to clip data from the

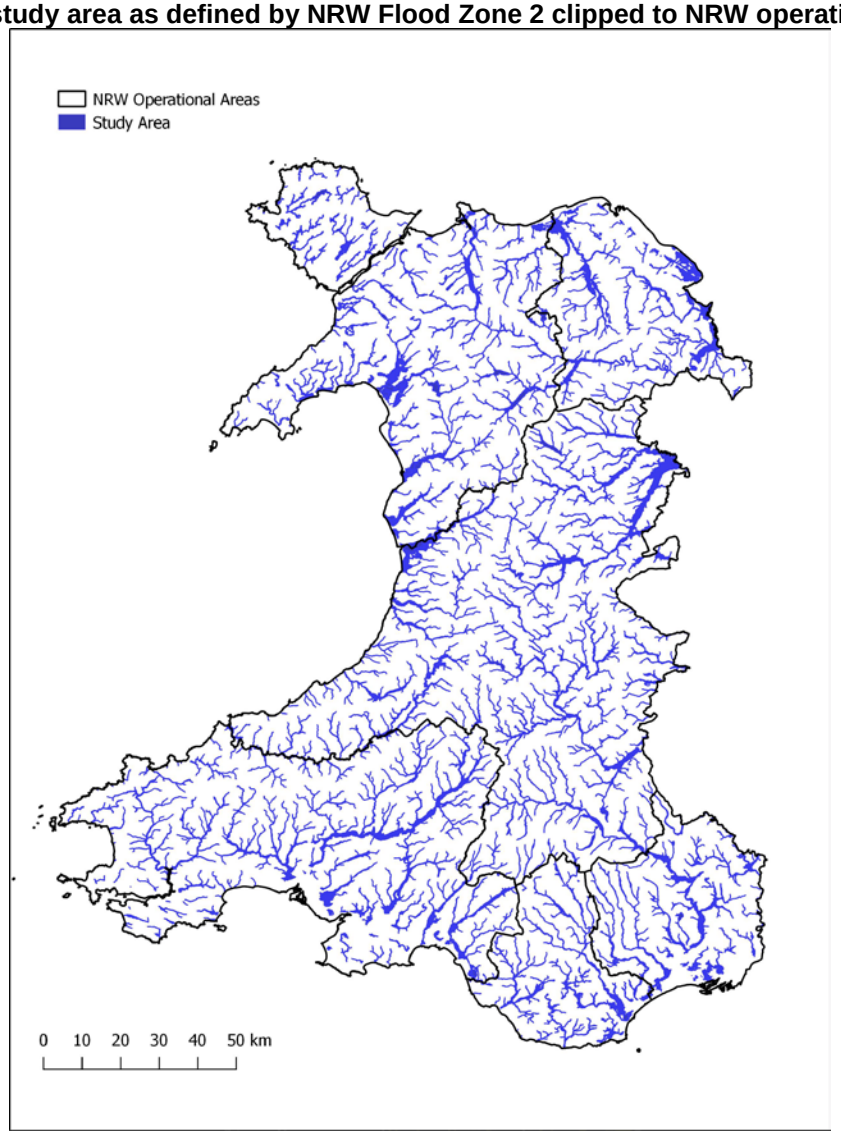
[1] Areas with a 1000 to 1 or greater chance of flooding in any year. http://lle.gov.wales/catalogue/item/FloodZ2/?lang=en

[2] http://lle.gov.wales/catalogue/item/NaturalResourcesWalesOperationalAreas/?lang=en. Note that some areas of this dataset extend beyond the Welsh administrative boundary & this must be taken into account in any comparison of CEH data between England and Wales.

national land cover map (LCM2015)[3] of Great Britain (CEH, 2017) and NRW's terrestrial Phase1 habitat survey[4] dataset (Figs 2a and b). Area values were then generated for both datasets, extracted to Excel and used to calculate percentage cover for each land use and Phase1 habitat type within the study area.

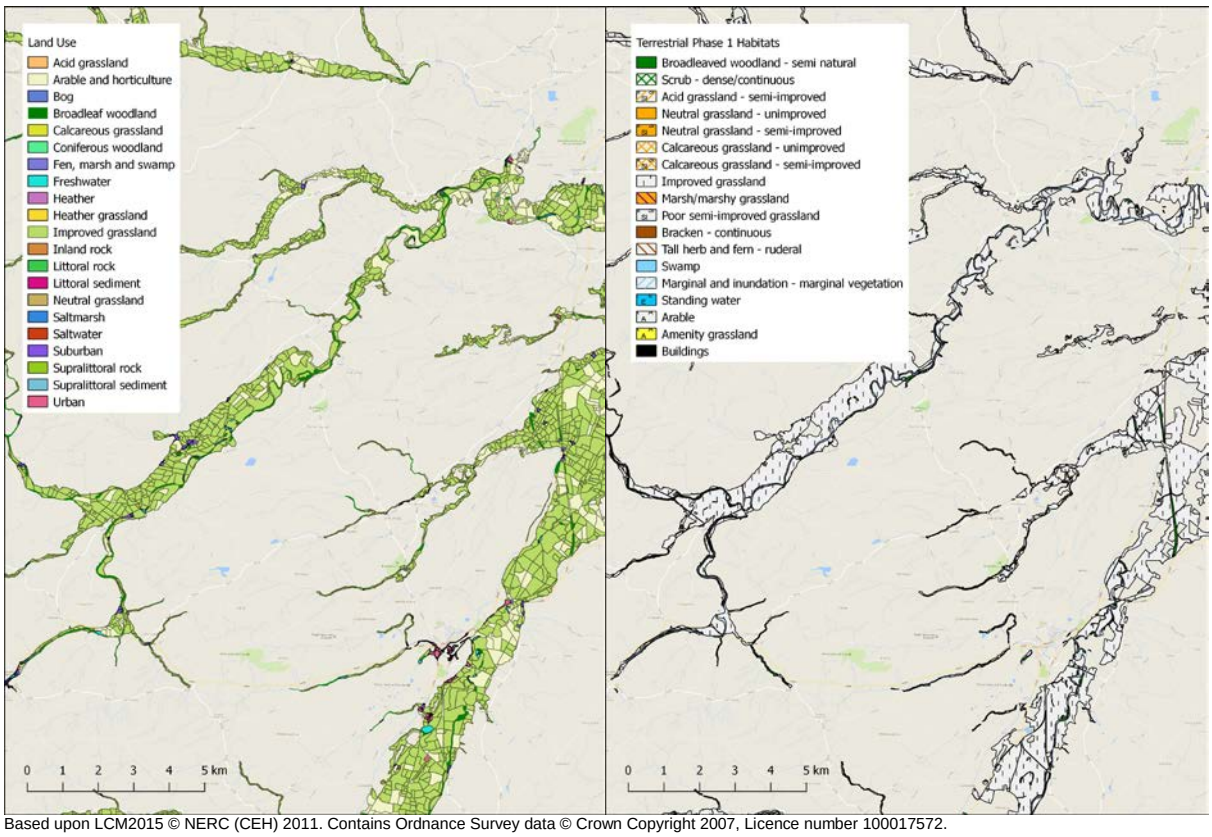
The total study area (Fig.1) amounts to 122,908 hectares (1229 km^2).

Figure 1. The study area as defined by NRW Flood Zone 2 clipped to NRW operational areas.



[3] https://www.ceh.ac.uk/services/land-cover-map-2015#data
[4] http://lle.gov.wales/catalogue/item/TerrestrialPhase1HabitatSurvey/?lang=en

Figure 2 a and b. a) (left), example of CEH land use data and b) (right) NRW terrestrial Phase1 habitat survey data within Flood Zone 2 and NRW operational areas as defined in Figure 1.



Based upon LCM2015 © NERC (CEH) 2011. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572.

The NRW Mid-Wales operational area, and a specific catchment, the Wye, were then looked at specifically to compare the datasets and assess their land uses and distribution of semi-natural habitats.

3.2. CEH land use assessment

3.2.1. All Wales

From the total study area of 122,908 hectares (1229 km^2) ,analysis of the CEH land cover data (Figure 3) shows over half (59.14%, 726.9 km^2) is subject to intensive agriculture, being made up of 49.89%, (613.2 km^2) improved grassland, widely distributed across Wales and 9.25% (113.7 km^2) arable and horticultural land, generally concentrated along the border with England (Fig. 4a and b). Urban and suburban development accounts for 5.44% (98.5 km^2) of the total land cover with major concentrations in the south-east (Fig 4c).

Broadleaved woodland (Figure 4d) and freshwater occupy 10.55% (129.7 km^2) and 6.91% (84.9 km^2) of the total study area respectively but other semi-natural habitats are very poorly represented in the floodplain, with neutral, calcareous and acid grassland patchily distributed and occupying <2.5% (<28 km^2) of the total land cover each. Distribution of neutral grassland in floodplains is shown in Figure 4e.

Figure 3. Land use cover for all Welsh river floodplains (km^2) from CEH landcover data (2015).

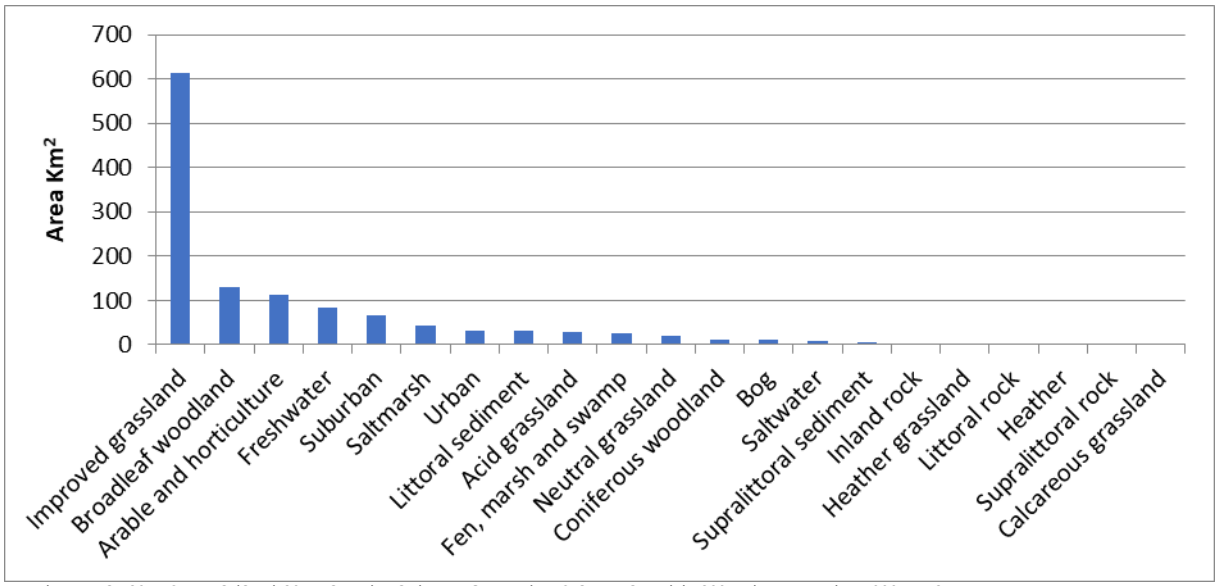
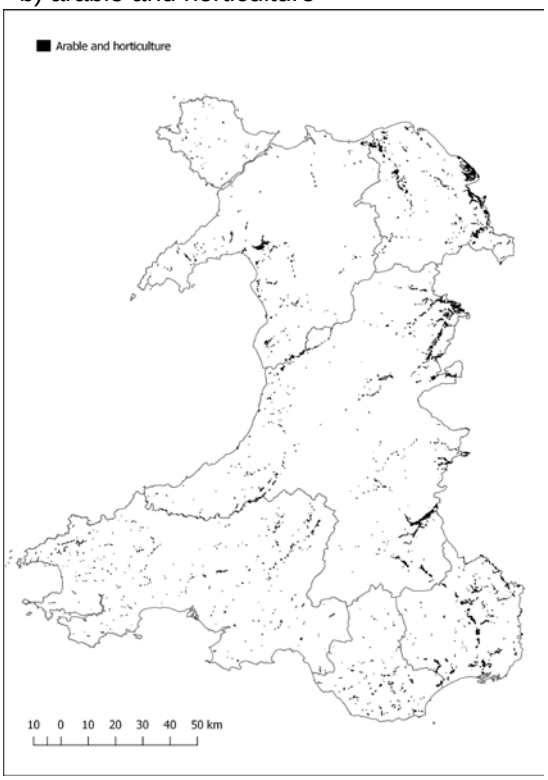


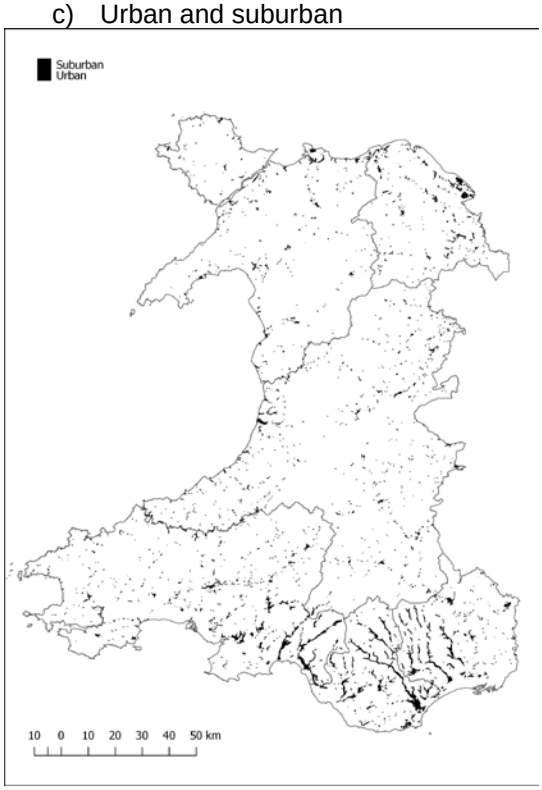
Figure 4. CEH land use distribution across Welsh floodplains.

a) Improved grassland

b) arable and horticulture



c) Urban and suburban



d) Broadleaved woodland

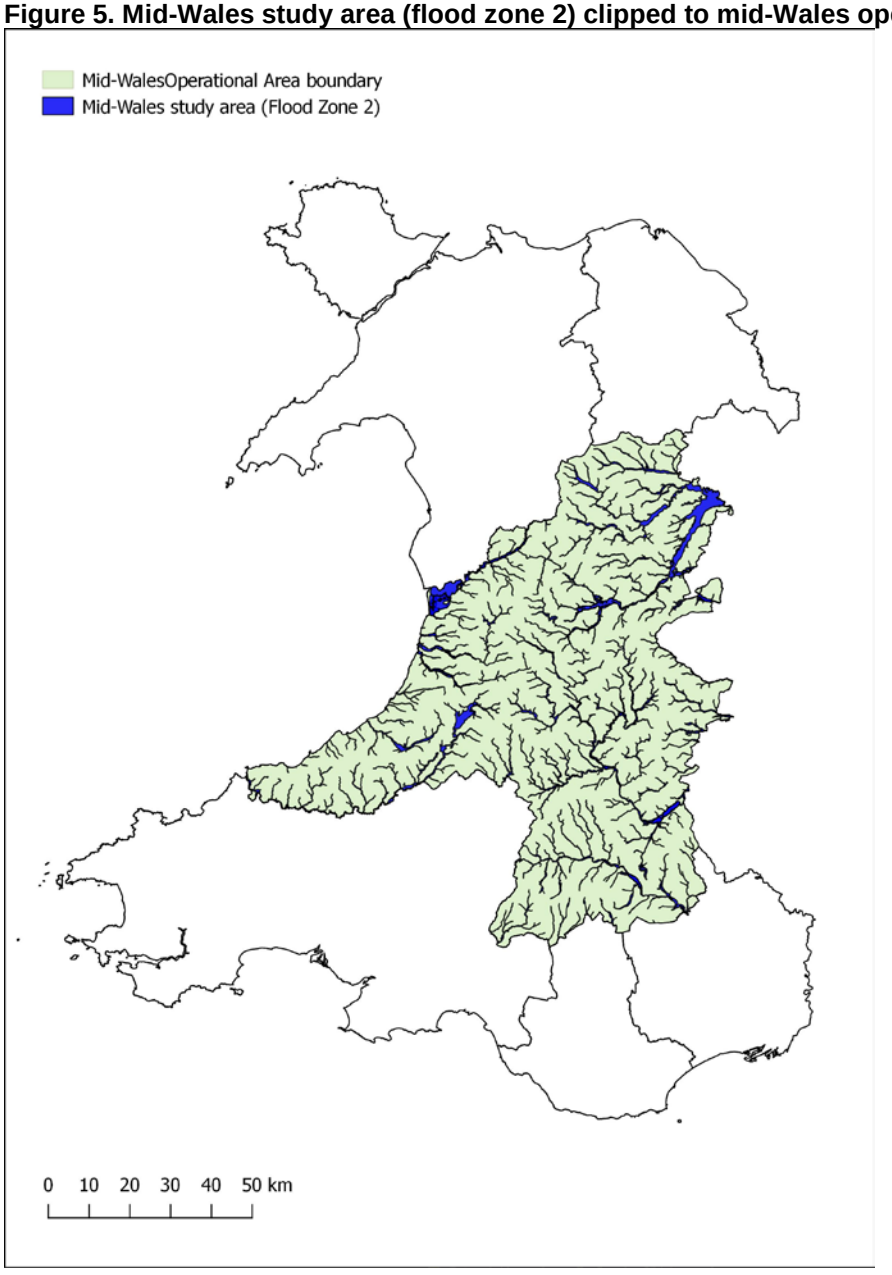
e) Neutral grassland

f) Fen, marsh and swamp

3.2.2. Mid-Wales operational area

The above datasets were also clipped specifically to the NRW mid-Wales operational area boundary (Fig 5). The clip of the NRW Flood Zone 2 to the NRW mid-Wales operational area boundary gave a total study area of 406.9 km^2. Area values and percentage cover for land use and Phase1 habitat type were then calculated for the mid-Wales operational area as described above.

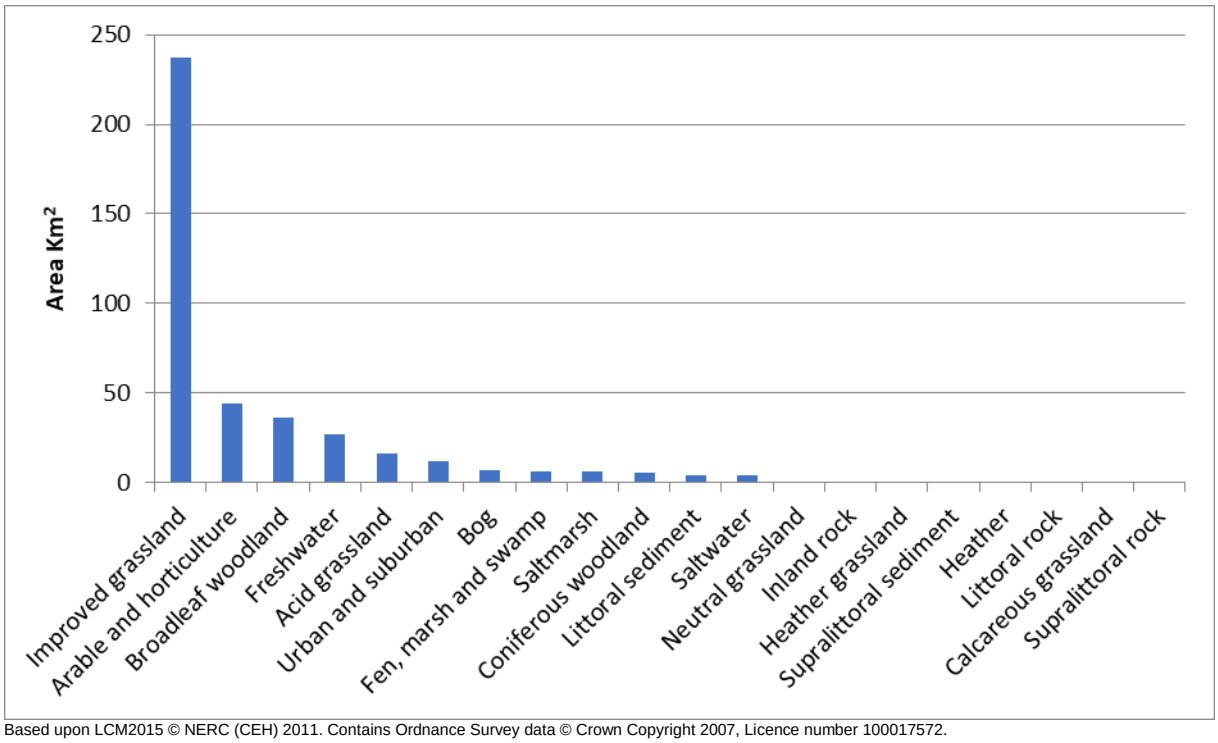
Figure 5. Mid-Wales study area (flood zone 2) clipped to mid-Wales operational area boundary.



Land use data in the mid-Wales operational area broadly reflects that of the overall Welsh floodplain with almost three quarters of land subject to intensive agricultural land use or development (Figure 6). Of the 406.9 km^2 of land within the mid-Wales study area, 72.02% (293.1 km^2) is occupied by improved grassland (237.2 km^2, 58.28%), arable (44 km^2, 10.8%) and urban/suburban development (11.9 km^2,

2.93%). Broadleaved woodland, freshwater and acid grassland are the most extensive semi-natural habitats within the floodplain, occupying 8.99% (36.6 km^2), 6.66% (27.1 km^2) and 3.94% (16 km^2) respectively. The remaining semi-natural habitats are limited in extent and patchily distributed, covering less than 2% of the total study area, with fen, marsh and swamp accounting for 1.51% (6.1 km^2) and neutral grassland occupying just 0.12% (0.5 km^2).

Figure 6. CEH land use data for river floodplains in mid-Wales (km^2).



3.3. Terrestrial Phase1 Habitat data assessment

3.3.1. All Wales

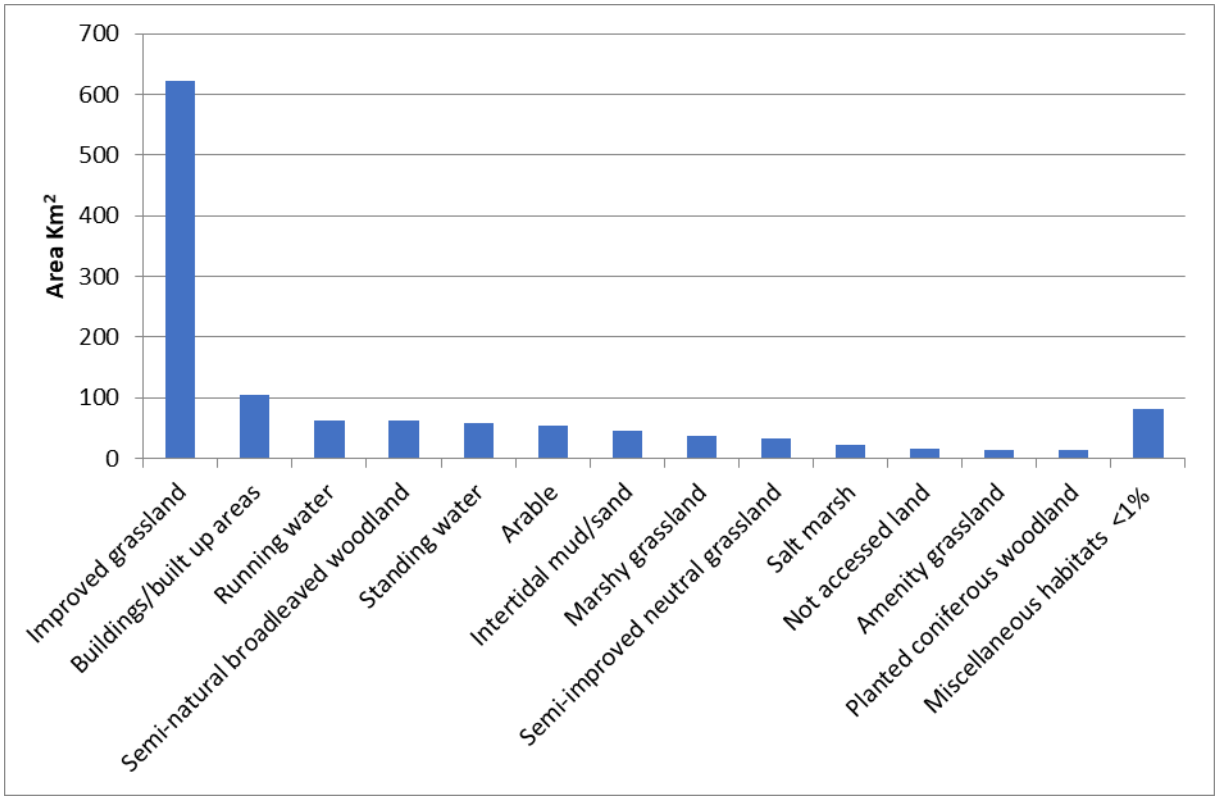
A similar picture emerges from analysis of the NRW Phase1 terrestrial habitat data across the Welsh floodplain (Figure 7). Intensive land uses account for 56.18% of the total study area (1229 km^2), comprised of improved grassland (50.61%, 622.1 km^2), arable (4.38%, 53.9 km^2) and amenity grassland (1.18%, 14.5 km^2). Buildings/built up areas account for 5.14% (104.7 km^2). Broadly in line with the CEH land use data, semi-natural broadleaved woodland and freshwater are the most extensive semi-natural habitats, covering 5.1% (62.7 km^2) and 9.84%[5] (121 km^2) respectively, although the Phase1 habitat survey figures indicate more freshwater and less woodland when compared to the CEH data.

Other semi-natural habitats account for <4% of the total study area each, with semi-improved neutral grassland and marshy grassland occupying just 2.7% (33.2 km^2)

[5] Incorporating 5.14% running water and 4.70% standing water

and 2.97% (36.5 km^2) respectively. Fragments of miscellaneous habitats, occupying less than 1% each, make up 6.69% (82.3 km^2) of the study area, and includes swamp, bog and fen.

Figure 7. Terrestrial Phase1 data for all Welsh river floodplains (km^2).

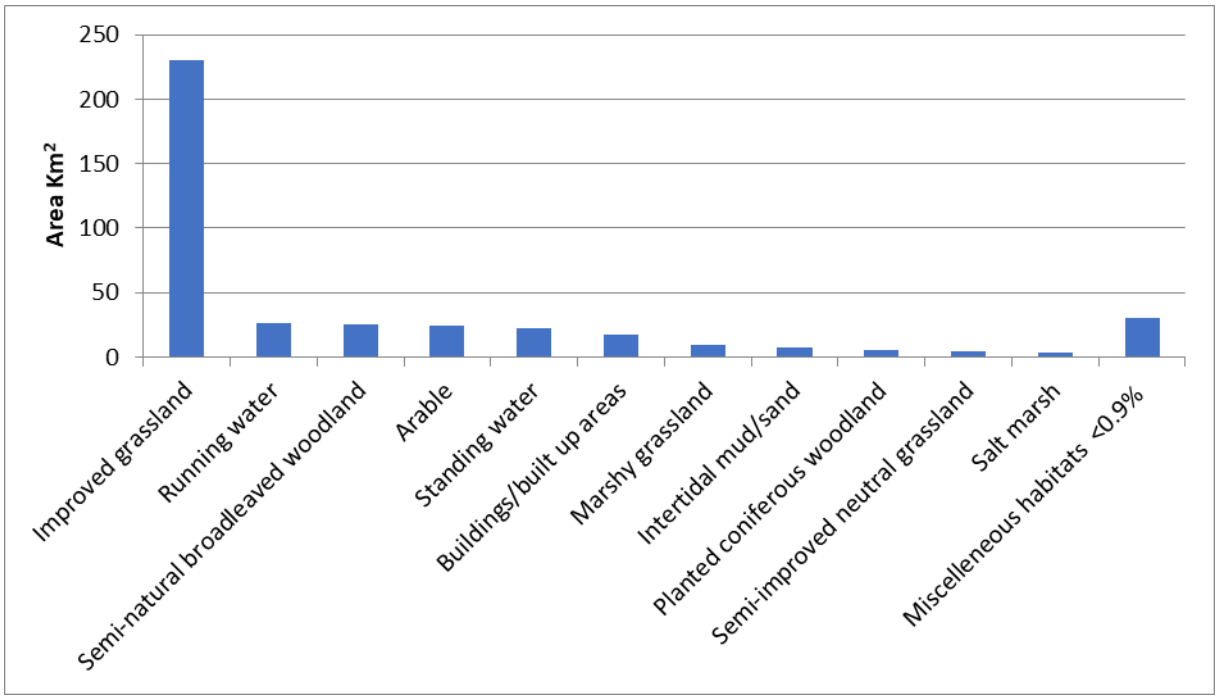


3.3.2. Mid-Wales operational area

Terrestrial Phase1 habitat data for the mid-Wales operational area shows a similar extent of intensive land use within the floodplains (Figure 8). Improved grassland is the dominant habitat type, covering 56.64% (230.5 km^2) of the total study area. Arable and buildings/built up areas occupy 6.07% (24.7 km^2) and 4.24% (17.3 km^2) respectively. Freshwater 12.03% (49 km^2)[6] and semi-natural broadleaved woodland 6.2% (25.2 km^2) are again the most extensive semi-natural habitats within the floodplain. The remaining habitat types occupy less than 2.5% each; the most extensive of these is marshy grassland, covering 2.31% (9.4 km^2). Semi-improved neutral grassland is recorded in just 1% (4.1 km^2) of the floodplain, although this figure is higher than modelled in the CEH land use data.

[6] Incorporating 6.52 % (26.5 km^2) running water and 5.52% (22.5 km^2) standing water.

Figure 8. Terrestrial Phase1 data for river floodplains in mid-Wales (km²).



The comparison of the two different datasets to compare floodplain land use shows good similarity and gives us confidence in the results[7].

4. Natural capital and ecosystem services of floodplain habitats

Natural capital is defined as those elements of the natural environment that directly or indirectly provide benefits for humans. Ecosystems, species, freshwater, land, minerals, the air and oceans, can all be referred to as natural capital.

Natural capital is a way of accounting for the amount of a resource we have (stocks), and the services that arise from these stocks (flows). These flows are either ecosystem services (produced by living systems e.g. crops, water filtration) or abiotic services (arising from geological processes e.g. minerals, oil). The value of an asset is a function of the benefit it provides though it can be difficult to express in financial terms.

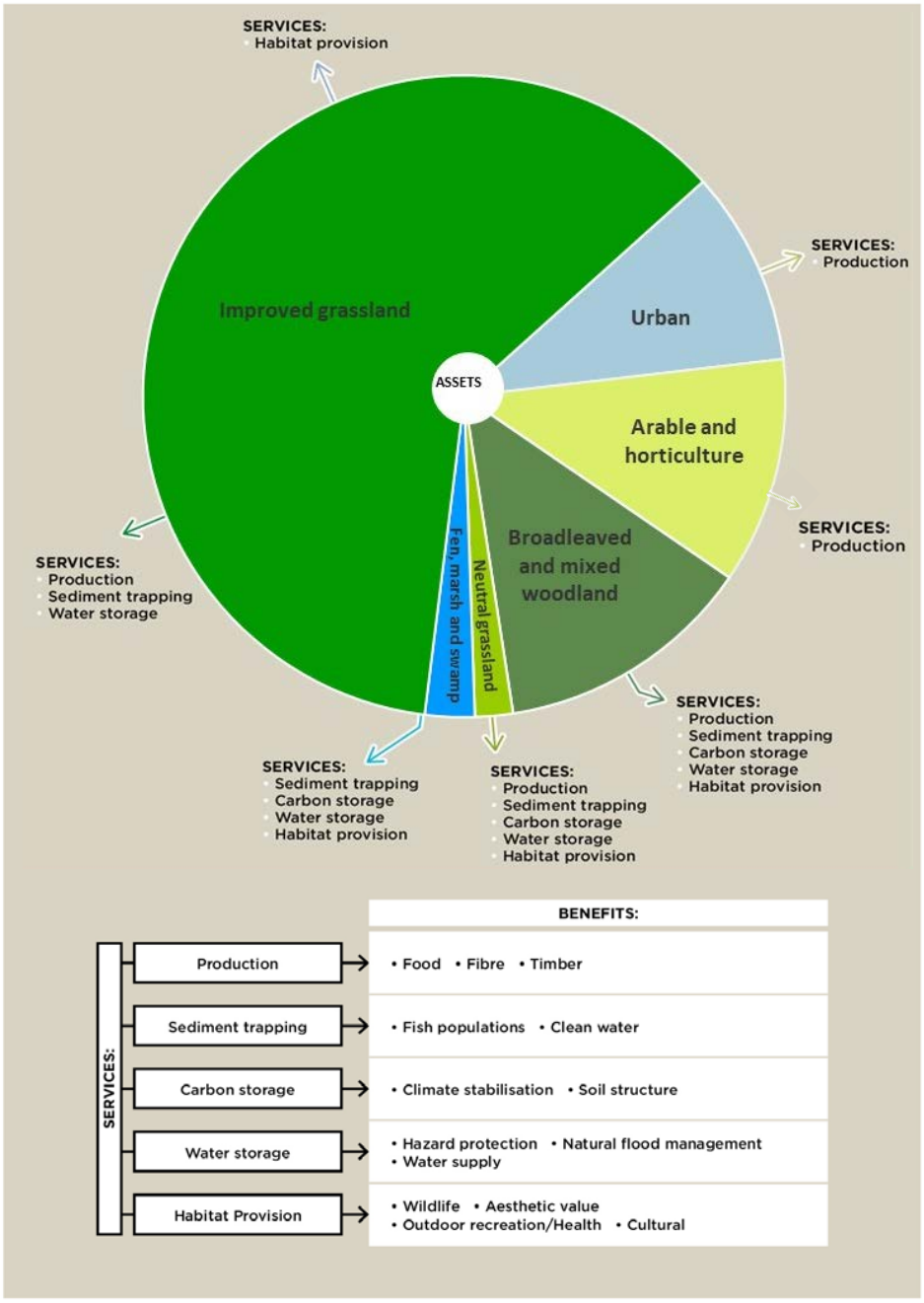
[7] However, there are different methods of assessing e.g. neutral grassland between the Phase 1 survey and the CEH Landuse assessment. For LCM2015, 'Neutral Grassland' is mapped spectrally, however, the inclusion of ancillary layers for slope and distance to rivers is expected to improve the classification of 'Neutral Grassland' on floodplains. Areas identified as 'Neutral Grassland' by LCM should probably be treated as having the potential to be 'Neutral grassland' as for a conclusive classification field survey is required to make a determination based on botanical composition. 'Neutral Grassland' also includes semi-improved grasslands managed for silage, hay or pasture which in LCM2015 will often be classified as 'Improved Grassland'. (https://www.ceh.ac.uk/sites/default/files/LCM2015_Dataset_Documentation_22May2017.pdf):

Natural capital assets are either renewable (providing benefits indefinitely so long as they are exploited sustainably) or non-renewable (cannot regenerate within human timescales so can only be used once, for example peat). Natural capital assets are currently in decline and there is insufficient evidence to show whether our current patterns of use are sustainable (NCC, 2013).

UK-wide natural capital accounts are currently being developed for floodplains and semi-natural grasslands. Those for wetlands, farmland and woodland have already been produced (ONS, 2017). There will be cross over between the accounts for farmland, semi-natural grassland, floodplain and woodland.

The flows of ecosystem services from natural capital of floodplain habitats, and then into benefits, are shown conceptually in Figure 9.

Figure 9. Schematic diagram showing how natural capital assets in floodplains are translated by providing services into benefits in Wales (Lawson *et al*, 2018).



The stock of natural capital in floodplains depends on land use and land management. For example, arable soils have a much lower stock of soil carbon than woodland or grassland. These comparisons are reflected in the amount of benefits the different land uses provide. Table 1 highlights the potential ecosystem goods and services of different land uses (Morris and Camino, 2011). Grasslands, fens, swamps and woodlands supporting diverse vegetation tend to deliver the most benefits, whilst arable and horticultural land uses tend to deliver the least.

Table 9. Ecosystem goods and services provided by the land use types found within floodplains (Lawson *et al*, 2018).

Benefit provided by floodplains	Description of the services delivering the benefit	Land Use					
		Arable and Horticulture	Improved Grassland	Broadleaved, mixed and yew Woodland	Coniferous Woodland	Neutral Grasslands	Fen, Marsh and Swamp
Food	Agriculture; crop and livestock production	+	+			+	
Fibre	Timber production, reeds & osiers			+	+		+
Climate Regulation	Carbon sequestration and storage	-		+	+	+	+
Pollination	Habitat for pollinating insects			+		+	+
Water quality	Sediment trapping	-	+	+	+	+	+
Air quality	Removal of atmospheric pollutants	-	-	+	+		
Natural Hazard Regulation	Flood storage	+	+	+	+	+	
Biodiversity	Species-rich habitats – high diversity and rare species.			+		+	+
Nutrient cycling	Nutrient Management	-		+		+	
Soil formation	Soil development			+		+	+
Cultural history	Strong ‘sense of place’ and social history, nostalgia			+		+	+
Aesthetic	Enhancement of the landscape, intrinsic appeal			+		+	+
Recreation	Enjoyment of the outdoors	+	+	+	+	+	+

Key:+ = identified as providing these goods and services – = negative or detrimental effect on ecosystem service

Whilst we can quantify the extent of semi-natural habitats and land uses in Welsh floodplains, it is more difficult to quantify the services and benefits they provide. A literature review (Lawson *et al*, 2018) has attempted to bring together known information about these services for habitats in floodplains and the evidence gathered through this review has been used to populate Table 1.

Many semi-natural habitats (now valued for their diversity and/or the rarity of their component species) have been destroyed as a result of land-use change (Blackstock *et al*., 1999). Traditional low input farming systems are necessary for the restoration of these habitats. For example, species-rich floodplain meadows (*Alopecurus pratensis – Sanguisorba officinalis* grasslands) are typically managed by making hay followed by grazing of the re-growth. Such habitats have a vital role to play in the conservation of our natural and social heritage, and can provide a much wider range of ecosystem-service benefits in floodplain than more intensive land-use types, as listed in Table 1. As species-rich systems, they also display greater resilience to environmental fluctuations and disturbances (e.g. drought, pests and diseases (Isbell *et al*., 2015)). Whilst production of food is predominantly through arable and horticulture, it is also provided through other more species-rich land uses. Semi-natural grasslands still form part of a farming system; they are used for livestock

production, but at a lower intensity than improved grassland, requiring no chemical inputs and therefore fewer costs.

Estimated agricultural production values in floodplains vary according to individual farm circumstances. Improved land drainage and flood management schemes have allowed floodplains to be used in this way, yet flooding still occurs. The cost of flooding to agricultural production varies, with estimated flood costs ranging from £80 ha^{-1} for extensive grassland, £160 ha^{-1} for improved grassland, £1100 ha^{-1} with intensive arable to £4800 ha^{-1} with horticulture for a single flood event (2010 prices) (Morris & Camino, 2011).

Because arable, improved grass and horticultural land uses limit the provision of services and benefits, and incur higher losses when floods occur, a greater focus on other less intensive agricultural land uses is required. These alternative land uses can contribute greater benefits overall, when carbon sequestration, soil development, nutrient cycling and biodiversity are taken into account. The case studies described in the following sections illustrate this point.

4.1. Placing a monetary value on ecosystem goods and services in floodplains

It is important to take account of all services and benefits when making decisions regarding the most appropriate and sustainable land use. This is particularly relevant to floodplains where there is such a diversity of benefit types spanning both financial and non-financial benefits.

A number of studies have attempted to value the natural capital of UK floodplains (e.g. case studies 1-3).

4.2. Influence of management on service delivery

Benefits delivered by floodplains from the stocks of natural capital are largely determined by hydrology and the effect it has on physical, biogeochemical and ecological processes, but also by land-management choices. Looking specifically at floodplain grasslands, where multiple management options exist, the matrix in Table 2 shows how different management scenarios alter the extent of ecosystem service delivery.

Table 10. How management changes affect delivery of goods and services in floodplain grasslands (all changes are expressed relative to an extensive system of continuous grazing with mean sward height of 10 cm).

Description of environmental or social goods and services	Management options			
	Supply of surplus nutrient via artificial fertilizers	**Drainage designed to relieve waterlogging within three days**	**Sufficient stocking to maintain year round sward height below 5 cm**	**Harvesting hay at peak-protein (typically mid-June to first week of July)**
Agriculture; crop and livestock production	↑	↑	↑	↑
Carbon sequestration and storage	↓	↑	↓	↑
Habitat for pollinating insects	↓	↑	↓	↑
Sediment trapping	-	↑	↓	↑
Flood storage	-	↑	-	-
Species richness	↓	↑	↓	↑
Nutrient capture	↓	↑	↓	↑
Soil development	↓	↑	↓	↑
Strong 'sense of place' and social history	-	↑	↓	↑
Enhancement of the landscape, intrinsic appeal	↓	↑	↓	↑
Enjoyment of the outdoors; health and well-being	-	↑	↓	↑

↑ increases benefit by taking the management option ↓ ; decreases benefit by taking the management option; – no relationship

The management decisions as shown in Table 2 reveal conflicts. For example, increasing fertiliser input increases productivity in the short to medium term, but decreases biodiversity, carbon storage, soil development and nutrient reduction. However, choosing management options that relieve waterlogging within 3 days and harvesting hay at peak protein can deliver positive services across the board.

Three case studies are used to illustrate how different approaches to assessing natural capital can be used.

4.1.1. Case Study 1: Chimney Meadows National Nature Reserve (NNR)

Change in land use from a commercial arable and grassland farm to a nature reserve with floodplain meadows.

Chimney Meadows NNR, adjacent to the river Thames in England, is partly designated as a SSSI for its species-rich lowland hay meadows. It was purchased by the Buckinghamshire, Berkshire and Oxfordshire Wildlife Trust (BBOWT) in 2003 as a 260 ha farm, which had been under predominantly intensive arable management. The vision was to restore the arable land to species-rich meadow and wetland habitats for wading birds. A comparison of the business as usual benefits (intensive farm) as opposed to those they hope to achieve through changes in management (nature reserve) was undertaken (Hölzinger & Haysom, 2017). This showed that the benefits realised through the nature-reserve vision were worth £7 million more over 30 years than if the farm had been run intensively. This is an additional value to the asset of 592 %.

Figure 10. Costed benefits of intensive management, capitalised over 30 years (Lawson *et al*, 2018).

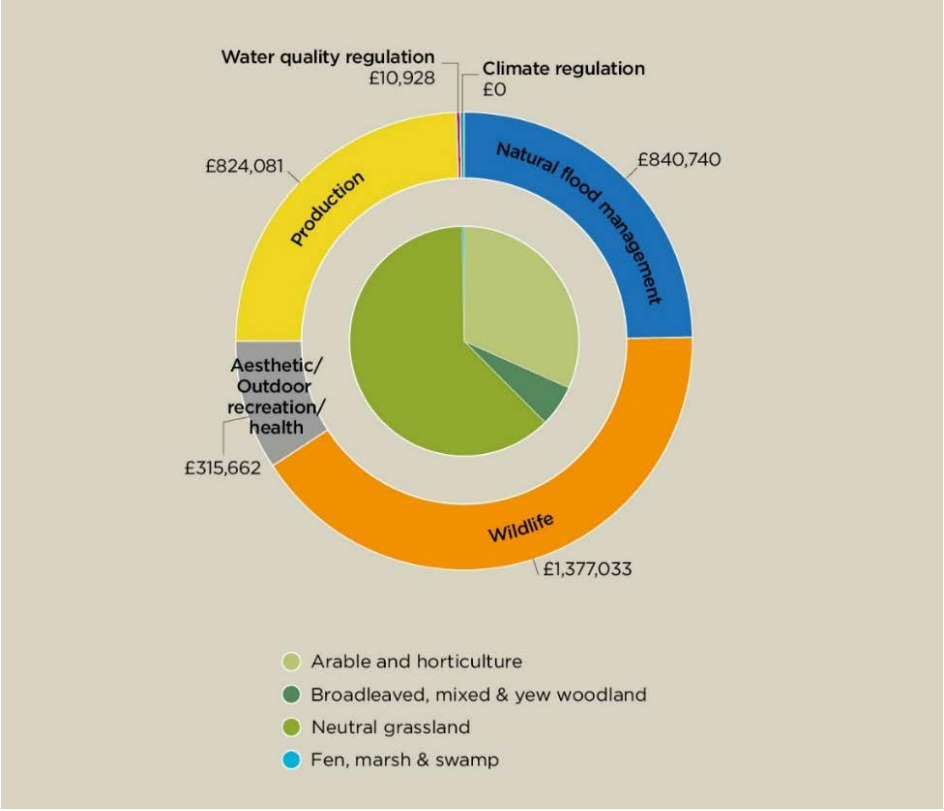
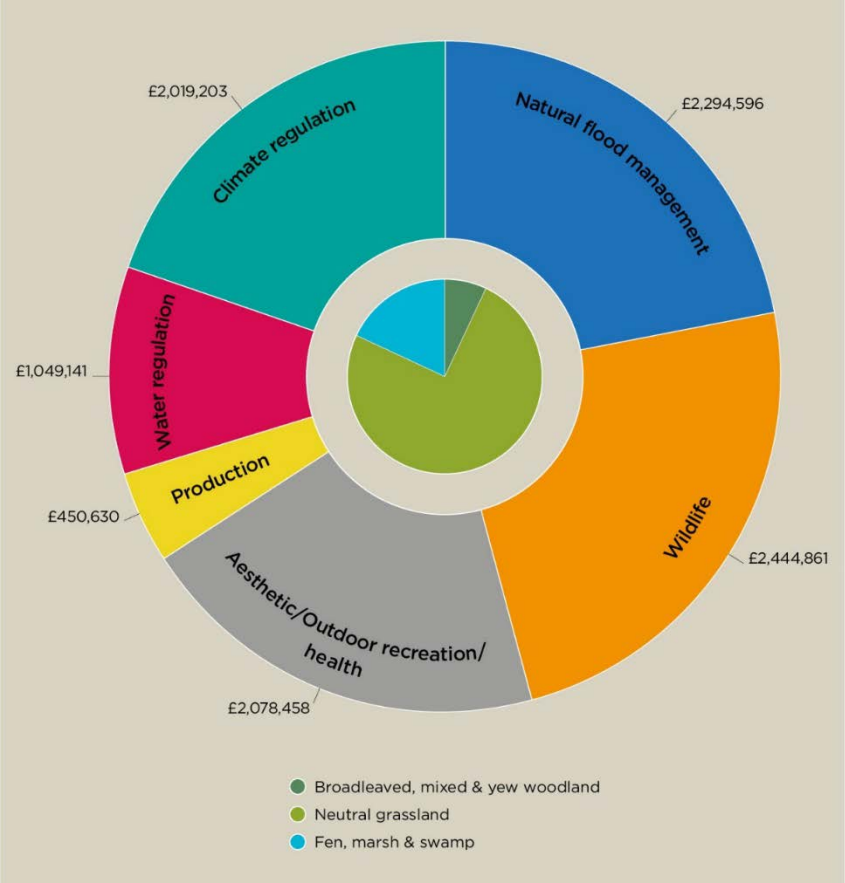


Figure 11. Costed benefits of nature reserve capitalised over 30 years (Lawson *et al*, 2018).



4.1.2. Case Study 2: North Meadow NNR, Wiltshire

Traditionally managed species-rich meadow.

North Meadow National Nature Reserve (NNR) is a 44.4 ha floodplain meadow in Wiltshire (Figure 12). It has been assessed in a similar way to Chimney Meadows NNR in Case Study 1, but additionally calculating the natural capital value of the reserve. This calculation shows that the present asset value of the NNR, taking into account the wide range of services shown in Table 3, is £2,425,686 compared to an agricultural value alone of £1,277,428. This is an additional value to the asset of 90%.

Table 11. Monetary values for North Meadow NNR, Wiltshire for a range of ecosystem services.

Benefit provided by floodplain	Description of the service delivering the benefit	North Meadow quantities	Value per unit	North Meadow total value
Food	Agriculture; crop and livestock production Hay values	Hay yield* 4 t ha^{-1} yr^{-1}	Gross margin = £40/t	£6,216
	Grazing land value	0.4 LU* ha^{-1}	£2.50 LU^{-1} $week^{-1}$	£375
Climate Regulation	Carbon sequestration (t/c/ha/yr)	Variable with season. Hay yield 4 t ha^{-1} yr^{-1}; Carbon content 47.5%** 1.9 t C ha^{-1} yr^{-1} = 7.0 t CO_2e ha^{-1}	£66 tCO_2e^{-1} (DECC non-traded carbon price, 2018) £459.80 ha^{-1}	£20,415
Climate Regulation	Carbon storage below ground (soil, t c ha-1)	Soil carbon*** = 109.4 t ha^{-1} =4857.4 t C top 10 cm	No equivalent £ values	Not known
	Carbon storage (above ground tC ha^{-1}	Variable with season, no long-term store		£0
Pollination	Habitat for pollinating insects	44.4 ha	£29.14 ha^{-1} #	£1,294
Water quality	Sediment trapping	0.8 m^3 ha^{-1}	£13.83 m^{-3}##	£491
Air quality	Removal of atmospheric pollutants	No data		
Natural Hazard Regulation	Flood storage (above ground)	44.4 ha	£197###	£8,746
Biodiversity	Species-rich habitats – high diversity and rare species.	44.4 ha	£499 ha^{-1}###	£22,156
Cultural history	Strong 'sense of place' and social history	44.4 ha of historic landscape	£203.4 ha^{-1}*#	£9,013
Aesthetic	Enhancement of the landscape, intrinsic appeal	No data		
Recreation	Enjoyment of the outdoors	15,000 visitors yr^{-1}*	£500 ha^{-1} yr^{-1}	£22,200
Health		2 km of path with 50 m wide buffer either side = 20 ha	£433 ha^{-1}**##	£8,660

*Figures supplied by Natural England Site Manager, 2018. Hay yields of species-rich floodplain meadows range from 3.0-6.0 t ha-1 yr-1 (Gowing et al., 2002)
**http://www.fao.org/forestry/17111/en/
*** in top 10 cm of soil. FMP unpublished
# adapted from Breeze *et al.*, 2012
Broads Authority Sediment Management Strategy, 2007
Figure from Holzinger and Haysom, 2017, adapted from Christie *et al*, 2011
*# based on £1.82 per person per trip (Sen *et al*, 2014)
**## based on figures in Hölzinger & Haysom, 2017

Figure 12. North Meadow NNR, 44.4 ha of species rich, agriculturally productive, historically important, and highly visited floodplain meadow.

4.1.3. Case Study 3: The Nene Valley Nature Improvement Area (NIA) and the use of detailed mapping to assess benefits and identify opportunities

Natural capital and ecosystem services in the Nene Valley NIA were mapped in 2016 (Rouquette, 2016). This compared the ecosystem-service value of the NIA area to an area that included the NIA plus a 3 km buffer zone.

Habitats, change in land use (including a recorded 95% loss in 80 years of semi-natural grassland) and biodiversity were mapped (Figure 13). Provision of ecosystem services was mapped based on an EcoServ GIS toolkit developed by The Wildlife Trusts, with modifications to suit the area. Bespoke models were created and applied at a 10 m x 10 m resolution, covering 10 services, including the capacity to store carbon, provide noise abatement, local climate regulation, air purification, water flow, water quality, pollination, food production, tranquillity and accessible nature, along with the demand for those services. Financial values were applied to the ten services.

Overall, the area within the NIA delivered benefits worth £2,639 ha^{-1} compared to £1,769 ha^{-1} across the whole study area. The value of recreational visits far outweighed the value of other services provided by the Nene catchment. However, only a limited number of services were considered in terms of a monetary valuation.

The maps will be used for raising public awareness, and to facilitate land-use planning and ecosystem accounting. They will identify where land use should remain

as it is, and areas where a change in land use would be beneficial, for example close to watercourses, where measures can slow the flow of water, deliver biodiversity, improve water quality and provide other benefits at the same time.

Trade-offs were identified through the mapping process including between food production and all the other services. The study highlighted that the wider ecosystem services delivered through a variety of different land uses needs to be balanced against the maintenance of a strong rural economy and farmer livelihoods. The use of payments for ecosystem services was recommended as a way of facilitating both.

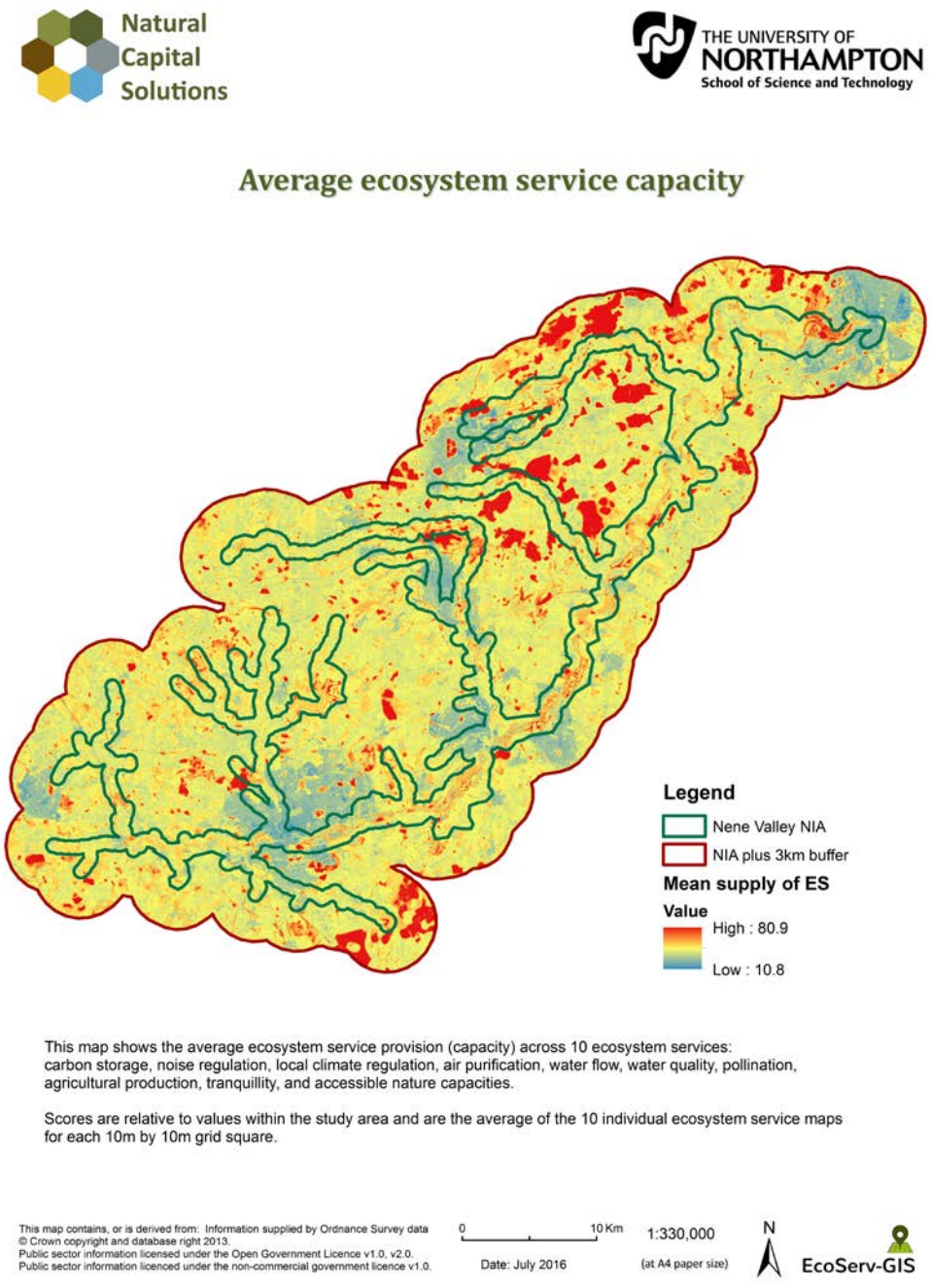


Figure 13. Overall supply of ecosystem services in the Nene Valley NIA plus a 3 km buffer zone (figure supplied by Jim Rouquette, Natural Capital Solutions).

5. Opportunity mapping for species rich grassland restoration

To determine how much more ecosystem service benefit could be gained if land use change was enacted in Welsh floodplains, an opportunity mapping exercise has been trialled, focussing on grasslands in particular.

As a pilot study, this has focussed on a single catchment (Wye catchment) within the mid-Wales NRW Operational area and has used various environmental data to predict which areas of the floodplain could realistically support more species rich grasslands. Opportunity mapping for woodlands and fens could also be undertaken following a similar method.

5.1. Method

A detailed GIS analysis of land use, Phase1 habitats, National Vegetation Classification (NVC; Rodwell, 1991 *et seq*.) community data, soils and designated sites for the River Wye catchment within the NRW mid-Wales operational area boundary was undertaken as follows:

Tributaries of the Wye were selected from the Ordnance Survey Open Rivers dataset[8] (Figure 14) and intersected with polygons in the previously established mid-Wales study area. The resulting layer (the Wye catchment Study area - Figure 15), covering approximately 98 km^2, was then used to clip data from the CEH land cover and Phase1 terrestrial habitat datasets, along with more detailed NVC data from the Phase 2 Lowland Grassland Survey of Wales (Stevens *et al*., 2010), focussing on communities of interest in the context of floodplains[9]. In the same way, boundary data were extracted from NRW's SAC and SSSI datasets and the National Soil Map (Rudeforth *et al*, 1984), through the NATMAP[10] GIS layer.

[8] https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-rivers.html
[9] NVC communities included in the study are MG4, MG5, MG8 and M22-M26.
[10] Cranfield University Soil Map 'Soils data © Cranfield University (NSRI) and for the Controller of HMSO, 2018' http://www.landis.org.uk/data/index.cfm

Figure 14. Main rivers in Wye catchment within mid-Wales operational area boundary.

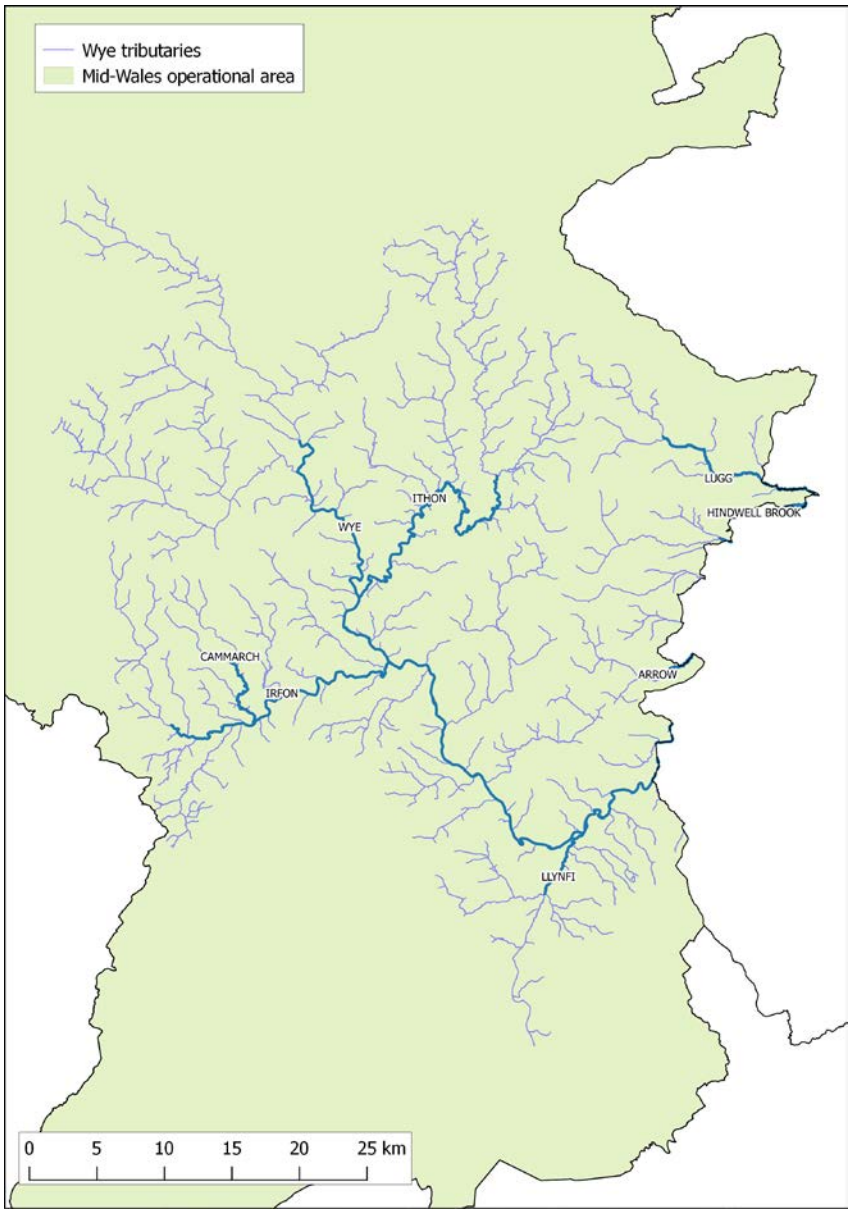
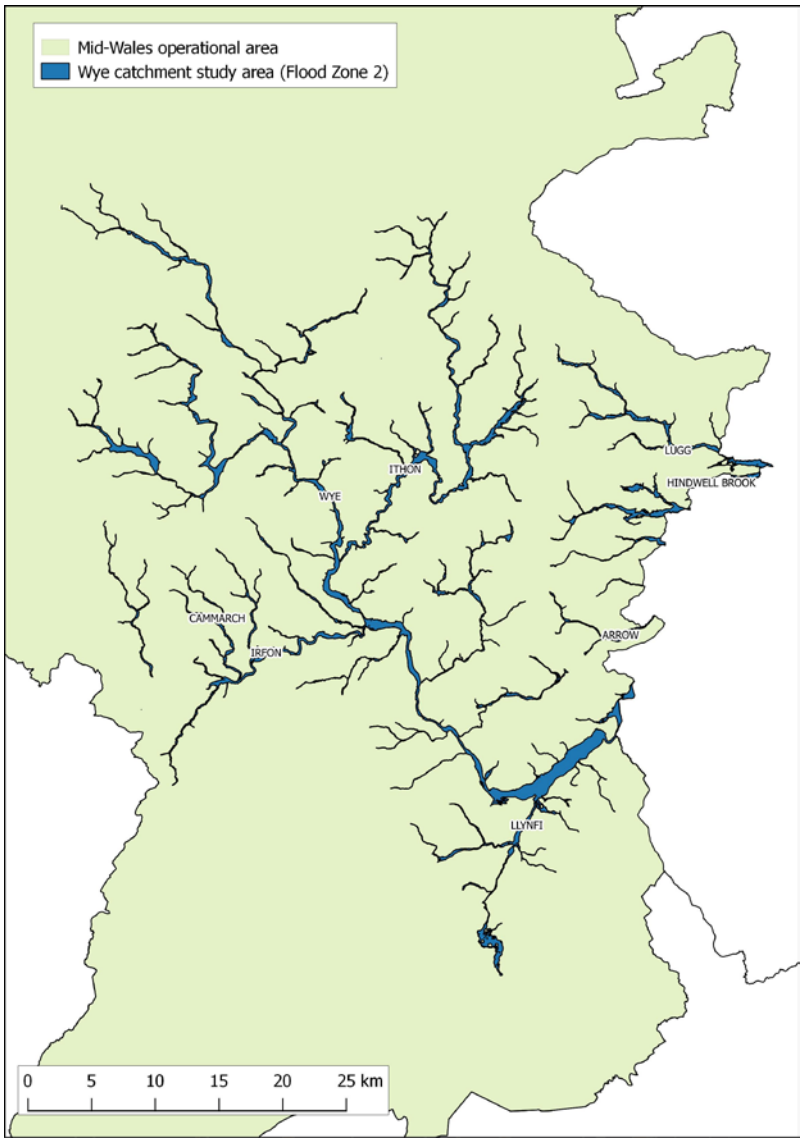


Figure 15. Wye catchment study area (flood zone 2)



Soil series polygons occurring within the Wye catchment study area were assigned a Hydrology of Soil Types (HOST) class (Boorman *et al.,* 1995). The HOST classes were then used to determine the potential hydrological suitability of each soil type for species-rich floodplain vegetation (Appendix 2). Polygons, including soils with HOST classes considered suitable for MG4, MG5, MG8 and M22 - M26 NVC plant communities (see Appendix 3 for full community names) were then selected and extracted to a new layer.

Area values were then generated for each dataset, extracted to Excel and used to calculate percentage cover for land use, Phase1 habitat types, NVC communities, suitable soil types and existing designated sites within the catchment study area.

5.2. Results

5.2.1. Land use and existing habitats

Land use and Phase1 habitat data within the Wye catchment follow the general pattern seen for the Welsh and mid-Wales study areas (Figures 16 and 17). Intensive land uses dominate, with improved grassland, arable and built up areas occupying between 65-70% of the total area. Woodland and freshwater are again the most extensive semi-natural habitat types. Area and percentage coverage for each land use and Phase 1 habitat type are shown in Tables 4 and 5.

Figure 16. CEH land use data within Wye catchment study area.

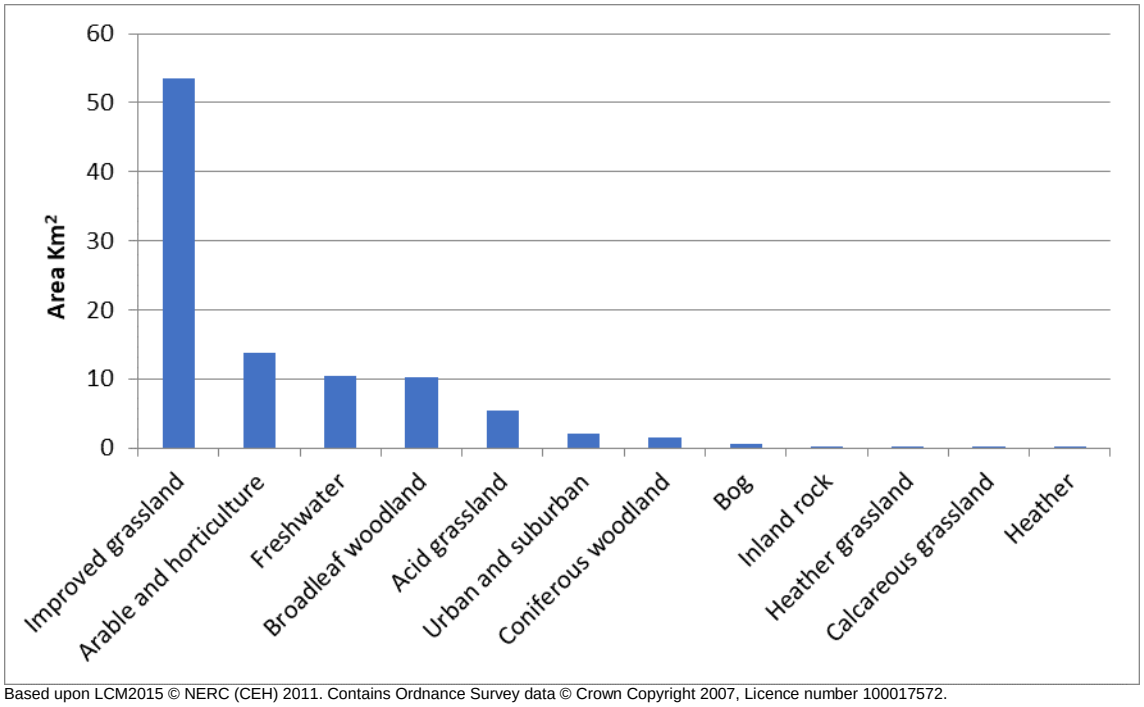


Figure 17. Phase1 habitats within Wye catchment study area.

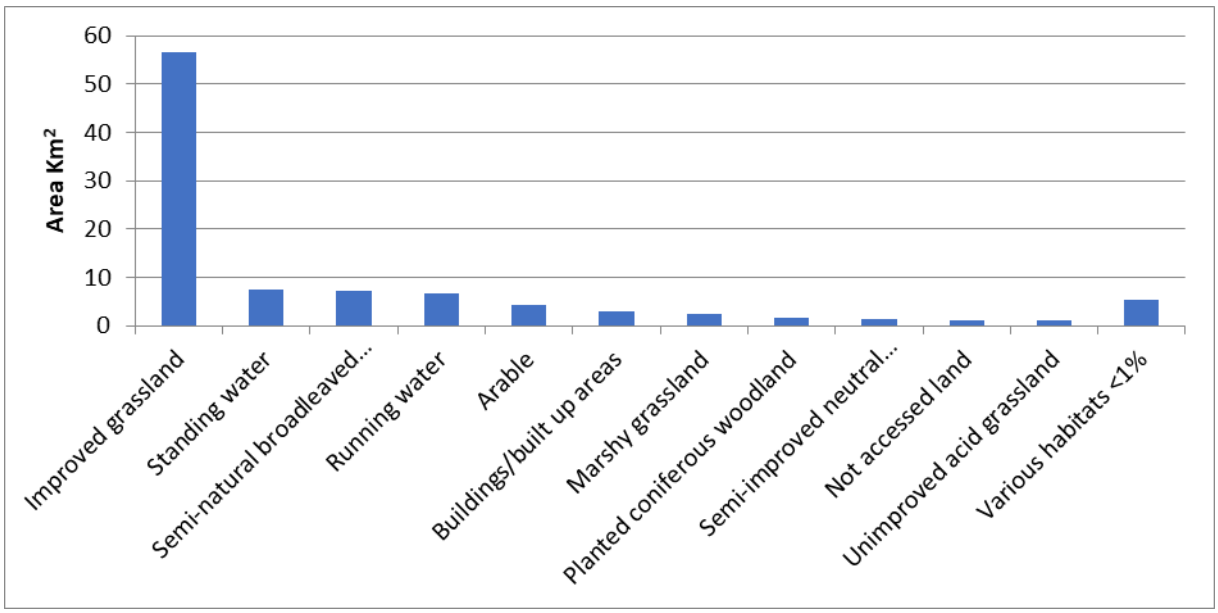


Table 12. Summary of CEH land use data within Wye catchment study area.

CEH landuse type	Area (sq km)	% cover
Acid grassland	5.47	5.58%
Arable and horticulture	13.76	14.05%
Bog	0.50	0.51%
Broadleaf woodland	10.27	10.48%
Calcareous grassland	0.07	0.07%
Coniferous woodland	1.52	1.55%
Freshwater	10.50	10.72%
Heather	0.02	0.03%
Heather grassland	0.11	0.11%
Improved grassland	53.54	54.68%
Inland rock	0.18	0.18%
Urban & suburban	2.00	2.04%
Total	**97.93**	**100.00%**

Table 13. Summary of Phase1 habitat data within Wye catchment study area.

Phase 1 habitat type	Area (sq km)	% cover
Improved grassland	56.56	57.76%
Standing water	7.38	7.54%
Semi-natural broadleaved woodland	7.28	7.43%
Running water	6.67	6.81%
Arable	4.14	4.23%
Buildings/built up areas	3.05	3.11%
Marshy grassland	2.30	2.35%
Planted coniferous woodland	1.58	1.62%
Semi-improved neutral grassland	1.32	1.34%
Not accessed land	1.14	1.17%
Unimproved acid grassland	1.10	1.13%
Various habitats <1%	5.40	5.51%
Total	**97.93**	**100.00%**

5.2.2. NVC communities

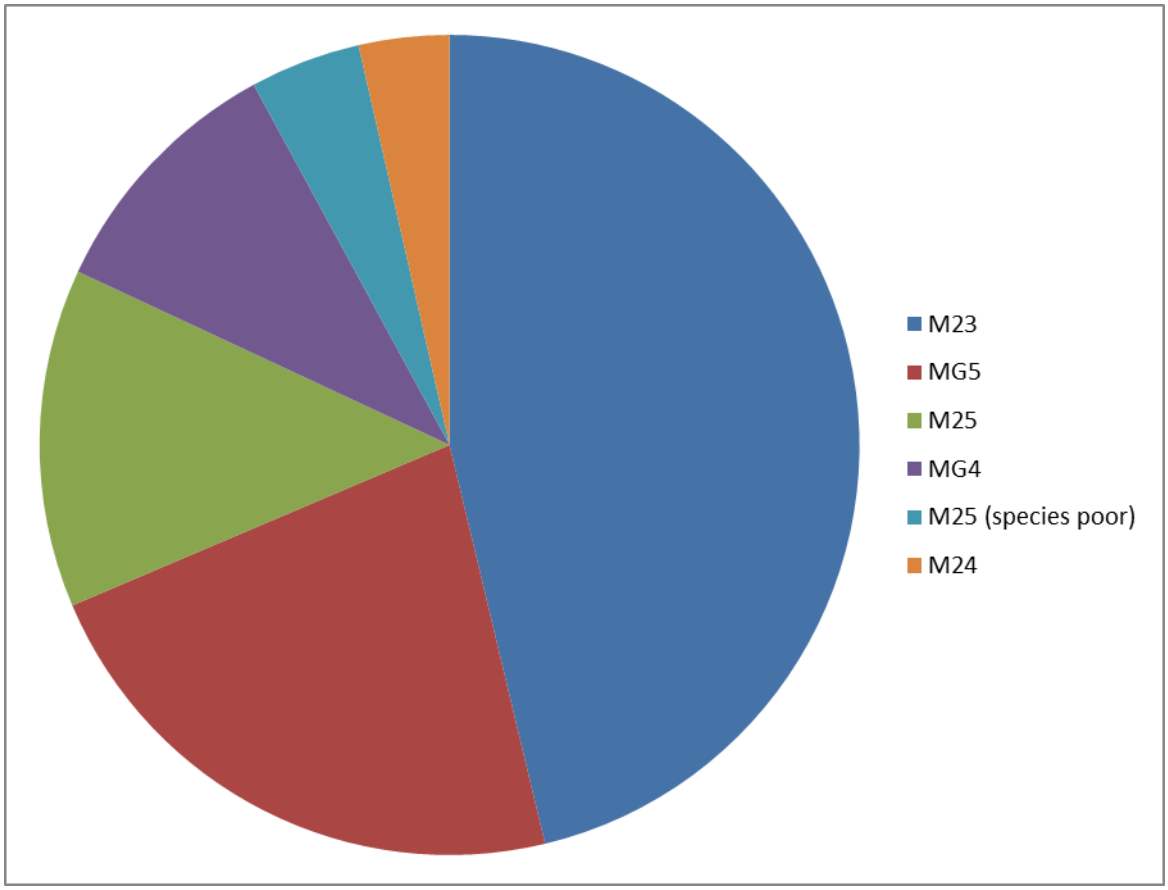
NVC data are available for sites surveyed during the Phase 2 Lowland Grassland Survey of Wales. The Phase 2 grassland sites include areas of higher quality grassland identified as worthy of more detailed survey, identified following the terrestrial Phase1 Habitat Survey of Wales (Blackstock *et al*., 2010), and covers approximately 1% (0.95 km^2) of the Wye catchment study area. A list of the NVC codes and Latin and vernacular names are found in Appendix 3.

M23 rush-pasture is the most extensive NVC community of interest within the Phase 2 grassland sites dataset, covering 0.19% (0.18 km^2), followed by MG5 neutral grassland (0.09%, 0.09 km^2). Of the two principal species-rich floodplain grassland communities, MG4 is very restricted, occupying just 0.04% (0.04 km^2) and the Phase 2 grassland survey dataset contains no polygons classified as MG8 within the Wye catchment study area. Areas and percentage coverage for MG4, MG5, MG8 and M22-M26 are shown in Table 6 and Figure 18.

Table 14. Summary of NVC data within Wye catchment study area

	Square km	% cover
Total Wye catchment study area	97.9	100
Area covered by NRW Phase 2 grassland sites (all)	0.9	0.92
M23	0.17	0.17
MG5	0.08	0.08
M25	0.05	0.05
MG4	0.04	0.04
M25 (species poor)	0.02	0.02
M24	0.01	0.01
MG8	0.00	0.00
M22	0.00	0.00
M26	0.00	0.00
Total area of target communities Wye catchment	**0.38**	**0.39**

Figure 18. NVC target communities recorded within Wye catchment study area (each segment represents the % cover of each grassland type identified in the NRW Phase 2 grasslands sites survey, out of a total area of 0.9 sq km, or 1% of the total Wye catchment area)



5.2.3. Designated sites

A total of 65 SSSIs intersect the Wye catchment, occupying 15.9% (15.59 km^2) of the total study area. Of these, 5 are also designated as SACs covering 10.46% (10.24 km^2). The River Wye SAC accounts for the large majority of the designated area within the catchment (covering 7.7 km^2). SACs and SSSIs intersecting the catchment study area are listed in Appendix 4.

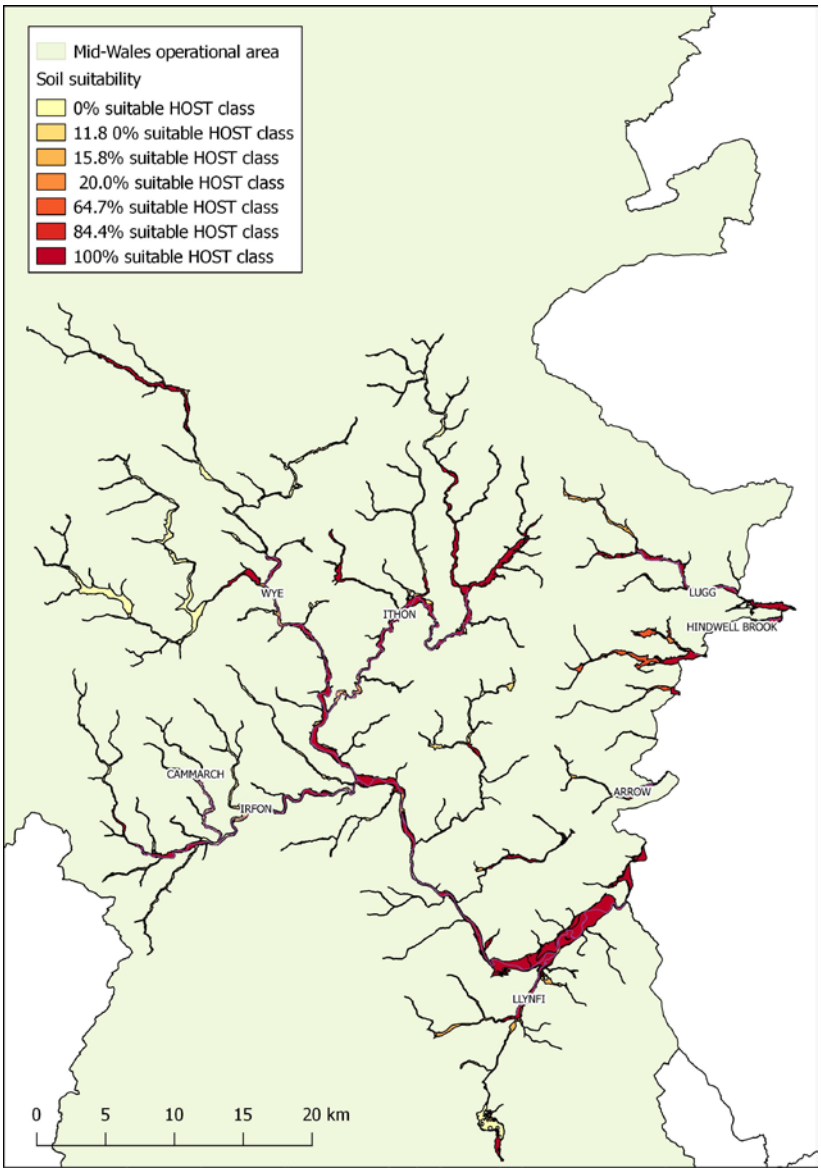
5.2.4. Soils

Soils determined to have some degree of suitability (very low suitability – high suitability) to support species-rich floodplain grasslands are present within approximately 70% of the Wye catchment study area. A breakdown of relative suitability and area coverage is shown in Table 7 and distribution illustrated in Figure 19.

Table 15. Coverage of soils potentially suitable for species-rich floodplain grasslands within Wye catchment study area.

% of suitable HOST classes within soil series	Area (km^2)	% cover
Unsuitable (0%)	29.41	30.03%
Very low suitability (<15%)	18.35	18.73%
Low suitability (<20%)	0.49	0.50%
Moderate suitability (<65%)	3.98	4.06%
High suitability (>80%)	45.70	46.67%
Total	**97.93**	**100.00%**

Figure 19. Distribution of soils potentially suitable for species-rich floodplain grasslands within Wye catchment study area.



6. Using multi-criteria decision analysis (MCDA) to prioritise sites for restoration

Selection of sites for the creation or restoration of species-rich floodplain grasslands is complex. Suitability of land is dependent on a variety of criteria including, but not limited to: soil hydrology and structure, existing habitat type, topography and land management history. Consideration of other factors may also be required, for example it may be desirable to target restoration effort to contribute to overall habitat connectivity or within land subject to agri-environment schemes.

GIS-based Multi-Criteria Decision Analysis (MCDA) is a useful tool for site selection and suitability analysis. Multiple criteria are assessed, combined and weighted to

allow evaluation and prioritisation of alternative decisions. Previous work undertaken by CEH used co-occurrence mapping of species within NVC communities and national databases of birds, plants and insects to identify and rank areas where restoration of coastal and floodplain grazing marsh could be targeted in England (Mountford *et al.,* 2006).

We have undertaken a similar method in order to use the data we have presented in a similar way, using the method described below.

6.1. Method

A trial of GIS-based MCDA was undertaken to identify potential sites for restoration of species rich floodplain grassland within the Wye catchment as follows:

Target NVC communities for restoration were selected (MG4, MG5, MG8 and M22-26) and criteria (both factors and constraints) likely to affect restoration success identified (as listed in Table 8). GIS vector datasets relevant to each criterion were then assembled or created, clipped to the previously established Wye catchment study area and assigned a suitability score (Figures 20 and 21).

Figure 20a. & b: a. Left: Vector layer showing co-occurrence of MG4 community constants generated from BSBI tetrad records (post 2000). B. Right: layer clipped to Wye catchment study area.

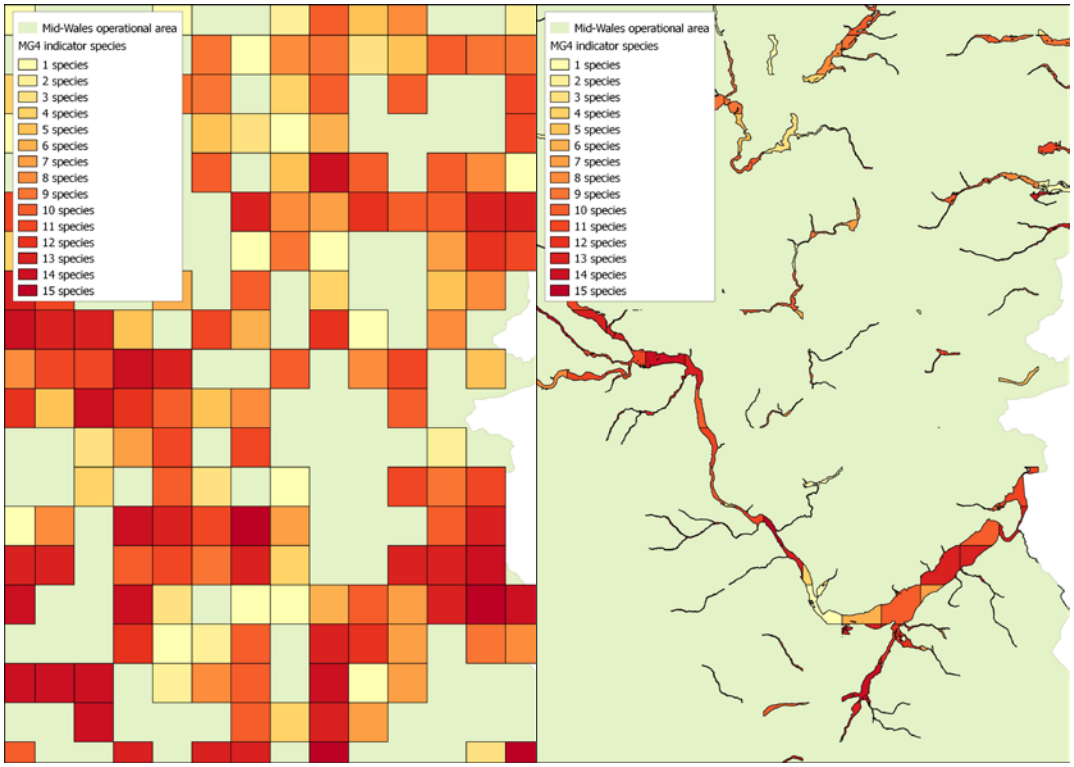
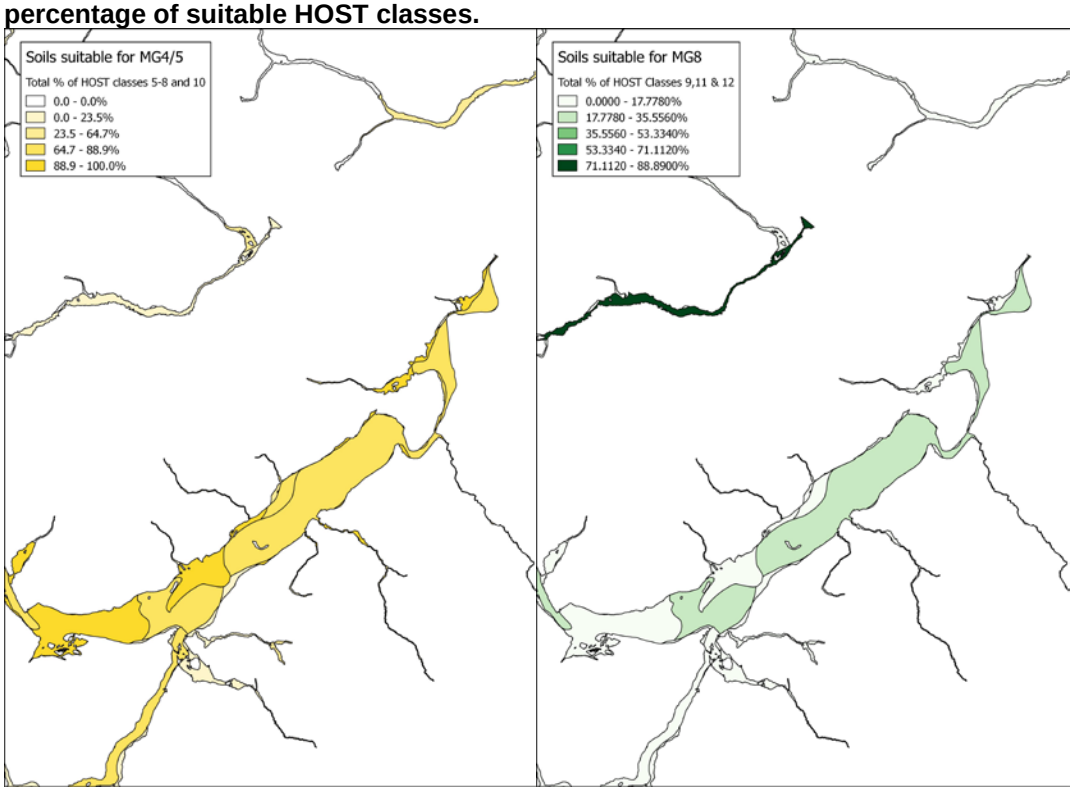


Figure 21a. & b: Layers showing suitability of soils for (a) MG4/5 and (b) MG8, based on total percentage of suitable HOST classes.



Each criterion vector was then rasterized and suitability scores were standardised to make comparison possible, and a weight assigned reflecting the relative importance of each factor. Criteria, suitability scores, and weightings used are shown in Table 8.

Table 16. Suitability analysis criteria for restoration of species-rich floodplain meadow communities.

Factors:	Description	Original criterion score	Standardized criterion score	Weighting	
Soil type and hydrology					
Soils potentially suitable for species-rich MG4 or MG5 sub-communities (dependent on calcium content)	Subset of national Soil Map data including total percentage of HOST classes 5-8 & 10 within soil series. 'Soil map © Cranfield University (NSRI) 2019 used with permission'	0 – 100%	0-1	35%	50%
Soils potentially suitable for less species rich MG4 or MG5 sub-communities (dependent on calcium content)	Subset of national Soil Map data including total percentage of HOST classes 13, 18 & 20 within soil series.	0 - 84.42%	0-1	15%	
Soils potentially suitable for species rich MG8, damp grassland or mires.	Subset of national Soil Map data including total percentage of HOST classes 9, 11 & 12 within soil series.	0 - 88.89%	0-1	50%	
Co-occurrence of NVC community constants.					
MG4	Species richness of NVC community constants (calculated from BSBI records post 2000).	1 – 15 species	0-1	15%	
MG5		1 – 11 species	0-1		
MG8		1 – 11 species	0-1		
M22		1 – 6 species	0-1		
M23		1 – 7 species	0-1		
M24		1 – 6 species	0-1		
M25		1 – 2 species	0-1		
M26		1 – 17 species	0-1		
Areas previously identified as priority for habitat restoration					
NRW Floodplain grassland inventory sites.	Sites >10ha previously identified as priority for floodplain grassland or mixed floodplain grassland/coastal grazing marsh restoration. (Dargie, 1998).	Data/no data	1	4%	
NRW Lowland grassland level 2	Sites previously identified as priority areas for conservation action:	Data/no data	1		

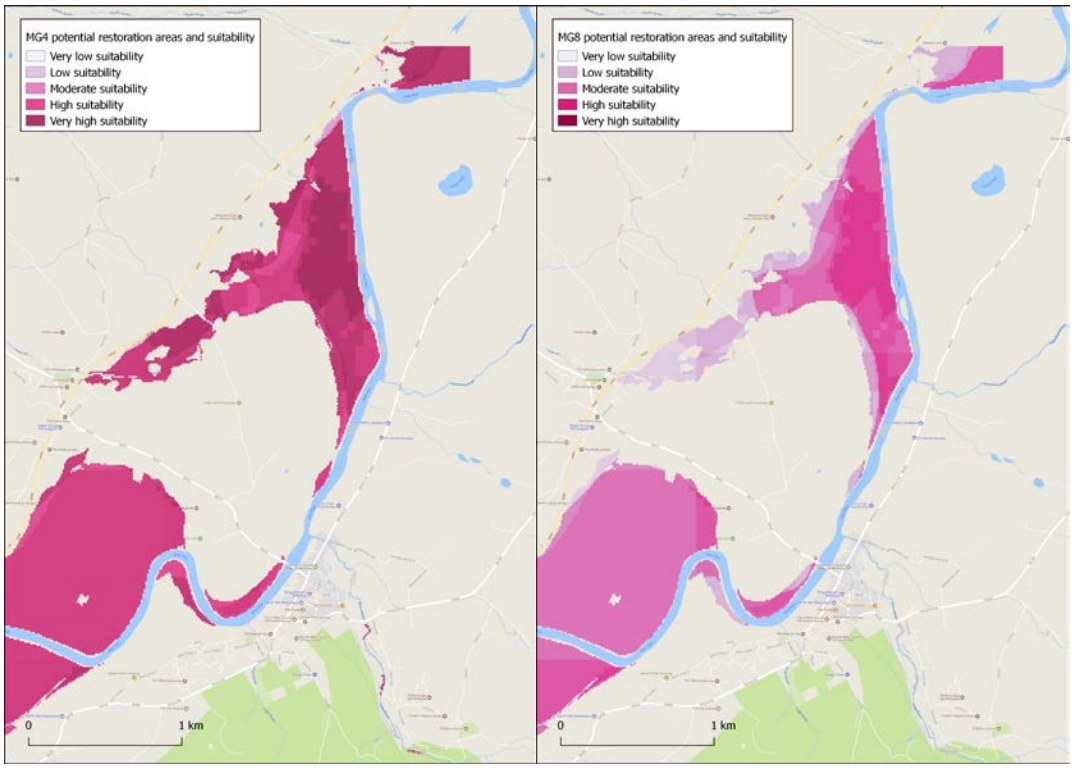
network sites	maintenance, restoration and expansion of grasslands (Latham *et al.*, 2013).			4%
Lowland wetland priority areas.	Sites previously identified as priority areas for targeted wetland conservation effort in Wales (Wales Biodiversity Partnership Wetlands Group, 2013).	Data/no data	1	4%
Floodplain reconnection potential.	Areas with potential for floodplain reconnection based on the premise that areas of low risk – using the Risk of Flooding from Rivers and Sea maps – which are in close proximity to a watercourse are likely to be poorly connected (Environment Agency 2018).	Data/no data	1	4%
Existing habitat type & suitability for restoration				
Broad habitat types	Habitats recorded by NRW terrestrial Phase1 habitat survey of Wales (1979-1999).	2: Suitable 1: Potentially suitable 0: Unsuitable.	0-1	15%
Potential influence over land management				
Glastir.	Areas under Glastir Advanced agreements 2012-2018.	Data/no data	1	4%
Constraints:	**Description**	**Original criterion score**	**Standardized criterion score**	**Weighting**
Areas of existing value				
Existing SAC	Existing designated sites within floodplain.	Data/no data	0 or 1	N/A
Existing SSSI		Data/no data	0 or 1	N/A
Existing NRW Phase2 grassland sites.	Phase2 grassland site boundaries.	Data/no data	0 or 1	N/A
Existing priority habitats	Glastir woodland creation sensitivity layer - priority habitats	Data/no data	0 or 1	N/A
Areas excluded from consideration				
Existing development	Buildings/built up areas from CEH and NRW Phase1 habitat survey data.	Data/no data	0 or 1	N/A

A weighted overlay analysis was then undertaken for each of the target communities using the raster calculator, with areas of constraint, e.g. existing development, masked to exclude them from the analysis.

6.2. Results

The set of maps produced illustrate the results of the analysis, indicating the relative suitability of areas for restoration of species-rich floodplain grassland. An example can be seen for MG4 and MG8 in Figures 22 a and b. All the maps are listed in Appendix 5. All data produced as part of this project are made freely available for download under the terms of the Open Government Licence from the LLe Geo-Portal for Wales: http://lle.gov.wales/catalogue/item/RiverWyeCatchmentWalesGrasslandCreationOpportunityMaps

Figure 22a and b: Example of output rasters showing potential restoration suitability for a) MG4 on left and b) MG8 on right.



The provision of these maps for use by a wide audience is currently being investigated.

6.3. Limitations

The above method is presented as an experimental trial for the targeting of resources for the restoration of species-rich floodplain grasslands. The value of the resulting maps as a tool for site selection is dependent on the accuracy of the data used in the analysis and would require ground truthing.

7. Applications in practice

Welsh floodplains provide a wide range of opportunities to deliver key principles and priorities set out in the Nature Recovery Plan for Wales (Welsh Government, 2015), and the Natural Resources Policy (Welsh Government, 2017). The latter recognises both the wide range of benefits Welsh natural resources provide to society, and the underpinning role played by biodiversity in ecosystem functioning. The case studies in Section 4.1 illustrate how nature-friendly management of floodplains can deliver a particularly wide range of benefits, notably for biodiversity, water storage and water quality.

The 2016 State of Natural Resources Report (SoNaRR) sets the baseline evidence base and assessment of Welsh natural resources and describes the loss of biodiversity in Wales. It highlights the need to maintain, enhance and restore floodplains and hydrological systems to reduce flood risk, and improve water quality and supply, in order to deliver ecosystem resilience and multiple delivery of benefits. The 2015 Nature Recovery Plan is aimed at addressing the underlying causes of biodiversity loss by placing nature at the heart of decision-making and by increasing the resilience of the natural environment.

Floodplain land managers and farmers need support in order to make decisions that deliver a wider range of services. Crucial to this ambition would be the formulation of a new environmental land-management scheme with a strong focus on floodplains.

This Evidence Review recommends a new agri-environment land management option specifically focussed on floodplains to ensure delivery of multiple benefits, as part of the changes to land-management support in Wales should Britain exit from the European Union.

To maximise benefits in floodplains, options should encourage:

- Reconnection of floodplains to rivers, allowing them to flood and drain naturally.
- Shift in land use from intensive to extensive agriculture, focussing on habitats that deliver multiple benefits.
- Manage grasslands to deliver more benefits as per Table 2.

This evidence review outlines a method by which habitats delivering the most benefits, yet still facilitating farming, could be targeted for re-creation.

8. Evidence gaps

This review offers a method that could be used to identify areas most suitable for the restoration or re-creation of species-rich grassland communities in floodplains. However, these areas are based on a modelling exercise and would require ground-truthing and testing. A survey is recommended that tests soil types and porosity in some of the areas identified as being suitable for species-rich grassland restoration, to check the accuracy of the use of the different HOST classes.

If this is found to be reliable, a similar method of identifying a site's potential for re-creation of other floodplain habitats, including wet woodland, could be undertaken. In this case, the consideration of sub-sections of habitat types, for example the extent of wet woodland as opposed to the category of 'broad leaved mixed and yew woodland' in floodplains is required to get a better understanding of the detail of extent of stocks of semi-natural habitats in floodplains.

Further research is required to look at biogeochemical processes (particularly carbon and water storage in soils) at the sub-habitat type level, as there are currently no data to effectively evidence differences.

Better understanding of the effectiveness of floodplain restoration for flood risk management has, amongst other things, been highlighted by the Environment Agency (2018) as part of a review on the evidence for benefits of natural flood management techniques.

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Appendix 1. Datasets used in the assessment

Datasets/reports			
Name	***Type***	***Source/Reference***	***Description***
NATMAP – National Soil Map	GIS Dataset	Cranfield University direct: http://www.landis.org.uk/data/index.cfm Soil map © Cranfield University (NSRI) 2019 used with permission	NATMAP vector is a vector dataset and is the most detailed of four versions of the National Soil Map. It is derived from the National Soil Map for England and Wales and is the product of sixty years of soil survey work in England and Wales.
Hydrology of soil types	Report	Boorman, D.B.; Hollis, J.M.; Lilly, A.. 1995 *Hydrology of soil types: a hydrologically-based classification of the soils of United Kingdom.* Wallingford, Institute of Hydrology, 146pp. (IH Report no.126)	Hydrology of Soil Types (HOST). 29 soil classes are grouped by hydrological properties, particularly their ability to transmit water both vertically and horizontally. HOST is used to estimate the Baseflow Index (BFI) and standard percentage runoff, from which low flow and flood statistics can be generated for ungauged catchments.
FMP Inventory	Excel spreadsheet	Floodplain Meadows Partnership direct	List of sites with extant MG4 & MG8
Vascular plant distribution.	CSV file	BSBI direct	Biological records of community constants for M22-26 and MG4, MG5 and MG8 from BSBI Atlas 2000.
Terrestrial Phase 1 Habitat survey.	GIS Dataset	NRW open access: http://lle.gov.wales/catalogue/item/TerrestrialPhase1HabitatSurvey/?lang=en	Phase 1 habitat survey of Wales (1979-1999).
An inventory and conservation review of coastal grazing marshes and floodplain habitats in Wales	Report	Dargie, T., Dargie, J. (1998). An inventory and conservation review of coastal grazing marshes and floodplain habitats in Wales. Stage 1:Inventory Dargie, T., Dargie, J. (2000). An inventory and conservation review of coastal grazing marshes and floodplain habitats in Wales. Stage 2 :Conservation review	Inventory & conservation review of coastal grazing marshes and floodplain habitats in Wales (1998 & 2000).
Grazing site boundaries	GIS Dataset	NRW - direct	Dataset resulting from above study.
Flood map: Flood Zone 2	GIS Dataset	NRW open access: http://lle.gov.wales/catalogue/item/FloodZ2/?lang=en	Flood Zone 2, which is NRWs best estimate of the areas of land between Zone 3 and the extent of the flood from rivers or the sea with a 1000 to 1 chance of flooding in any year. It includes those areas defined in Flood Zone 3.
Habitat networks	GIS Dataset	NRW open access: http://lle.gov.wales/catalogue/item/HabitatNetworks/?lang=en	This dataset provides an account of the work on connectivity and priority mapping in Wales and provides a basis for mapping connectivity. The output of the model is a series of

			mapping layers, known as core, focal and local networks. Together these provide a guide to overall habitat connectivity and can be interpreted in various ways to inform biodiversity action and environmental projects in general. Mapping is available for broadleaved woodland, heathland, unimproved grassland, fens and bogs, each (except woodland) in upland and lowland versions.
Ecological Connectivity and Biodiversity Prioritisation in the Terrestrial Environment of Wales	Report	Ecological Connectivity and Biodiversity Prioritisation in the Terrestrial Environment of Wales J. Latham, J. Sherry & J. Rothwell, 2013 CCW Staff Science Report No. 13/3/3	As above.
Lowland wetland priority areas	GIS Dataset	NRW/Wales Biodiversity Partnership (Wetlands Group) direct.	Priority areas for targeted conservation effort in Wales identified by Wales Biodiversity Partnership Wetlands Group.
Landcover Map 2015	GIS Dataset	CEH direct - https://www.ceh.ac.uk/services/land-cover-map-2015 **Acknowledgements** The following datasets have been used in the derivation of LCM2015 Vector (GB): Landsat-8 satellite imagery. Data available from the U.S Geological Survey. AWIFS satellite imagery © Antrix (2014), distributed by GAF AG, provided under COPERNICUS by the European Union and ESA, all rights reserved Mapping data reproduced by permission of Ordnance Survey on behalf of HMSO. © Crown Copyright 2007, Licence number 100017572. Digital elevation data © Intermap Technologies Inc. or its suppliers 2003. OS open data layers – Contains OS data © Crown copyright and database right (2015) National Forest Inventory (NFI) data provided by the Forestry Commission © Crown Copyright, courtesy Forestry Commission (2015), licensed under the Open Government Licence Boundaries from Welsh	LCM2015 is derived from satellite images and digital cartography and provides land cover information for the entire UK. Land cover is based on UK Biodiversity Action Plan Broad Habitats classes. It is used by government departments and agencies, county councils, charities and commissions, as well as environmental management bodies, consultancies and researchers. It has wide application in many sectors and is available in different formats to suit the requirements of users.

		Government, Department of Rural Affairs © Crown Copyright and database right and/or © third party licensors.	
Dudley Stamp Land Utilisation Survey 1933-1949.	GIS Dataset	NRW - direct	
OS Open rivers	GIS dataset	Ordnance survey – open access: https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-rivers.html	OS Open Rivers maps over 144,000 km of watercourses. These include freshwater rivers, tidal estuaries and canals.
Phase 2 lowland grassland veg & Phase 2 lowland grassland mospolys	GIS dataset	NRW - direct	NVC community polygons (incl. mosaics) covering NRW Phase 2 grassland survey sites.
Sites of Special Scientific Interest (SSSI)	GIS dataset	NRW open access: http://lle.gov.wales/catalogue/item/ProtectedSitesSitesOfSpecialScientificInterest/?lang=en	This spatial dataset contains the boundaries of Sites of Special Scientific Interest (SSSIs) in Wales
Special Areas of Conservation (SAC)	GIS dataset	NRW open access: http://lle.gov.wales/catalogue/item/ProtectedSitesSpecialAreasOfConservation/?lang=en	This spatial dataset contains boundaries of designated Special Areas of Conservation (SACs) in Wales.
Methods for targeting the restoration of grazing marsh and wet grassland communities at a national, regional and local scale.	Report	Mountford, J. O.; Roy, D. B.; Cooper, J. M.; Manchester, S. J.; Swetnam, R. D.; Warman, E. A.; Treweek, J. R.. 2006 Methods for targeting the restoration of grazing marsh and wet grassland communities at a national, regional and local scale. *Journal for Nature Conservation*, 14. 46-66	CEH study.

Appendix 2. Interpretation of HOST classes

HOST class	grassland type	DESCRIPTION
1	dry	Free draining permeable soils on chalk and chalky substrates with relatively high permeability and moderate storage capacity.
2	dry	Free draining permeable soils on 'brashy' or dolomitic limestone substrates with high permeability and moderate storage capacity.
3	dry	Free draining permeable soils on soft sandstone substrates with relatively high permeability and high storage capacity.
4	dry	Free draining permeable soils on hard but fissured rocks with high permeability but low to moderate storage capacity.
5	possible MG4/8 if in floodplain & calcareous	Free draining permeable soils in unconsolidated sands or gravels with relatively high permeability and high storage capacity.
6	possible MG4/8 if in floodplain & calcareous	Free draining permeable soils in unconsolidated loams or clays with low permeability and storage capacity.
7	MG4/8; M22/24/26/27 if calcareous	Free draining permeable soils in unconsolidated sands or gravels with groundwater at less than 2m from the surface.
8	MG4/8; M22/24/26/27 if calcareous	Free draining permeable soils in unconsolidated loams or clays with groundwater at less than 2m from the surface.
9	MG8/9/10/13; M27	Soils seasonally waterlogged by fluctuating groundwater and with relatively slow lateral saturated conductivity.
10	MG4/8; M22/24/26/27	Soils seasonally waterlogged by fluctuating groundwater and with relatively rapid lateral saturated conductivity.
11	MG8/9/10/13	Drained lowland peaty soils with groundwater controlled by pumping.
12	M22/23/24/25/26/27 depending on base status	Undrained lowland peaty soils waterlogged by groundwater.
13	MG7C/9/10/13	Soils with slight seasonal waterlogging from transient perched water tables caused by slowly permeable subsoil or substrate layers.
14	MG10/13	Soils seasonally waterlogged by perched water tables caused by impermeable subsoil or substrate layers.
15	upland grasses	Permanently wet peaty topped upland soils over relatively free draining permeable rocks.
16	dry	Relatively free draining soils with a moderate storage capacity over slowly permeable substrates with negligible storage capacity.
17	dry	Relatively free draining soils with a large storage capacity over hard impermeable rocks with no storage capacity.
18	MG7C/9/10/13	Slowly permeable soils with slight seasonal waterlogging and moderate storage capacity over slowly permeable substrates with negligible storage.
19	dry	Relatively free draining soils with a moderate storage capacity over hard impermeable rocks with no storage capacity.
20	MG7C/9/10/13	Slowly permeable soils with slight seasonal waterlogging and moderate storage capacity over impermeable clay substrates with no storage capacity.
21	MG7C/9/13	Slowly permeable soils with slight seasonal waterlogging and low storage capacity over slowly permeable substrates with negligible storage capacity.
22	dry	Relatively free draining soils with low storage capacity over hard impermeable rocks with no storage capacity.
23	MG7C/9/13	Slowly permeable soils with slight seasonal waterlogging and low storage capacity over impermeable clay substrates with no

		storage capacity.
24	MG7C/9/13	Slowly permeable seasonally waterlogged soils over slowly permeable substrates with negligible storage capacity.
25	MG9/13	Slowly permeable seasonally waterlogged soils over impermeable clay substrates with no storage capacity.
26	upland grasses	Permanently wet peaty topped upland soils over slowly permeable substrates with negligible storage capacity.
27	upland grasses	Permanently wet peaty topped upland soils over hard impermeable rocks with no storage capacity.
28		This soils type eroded peat is not mapped separately in England & Wales.
29	upland grasses	Permanently wet upland blanket peat.
98		lake
99		sea

Appendix 3. National Vegetation Classification – full nomenclature

NVC code	Vernacular	Latin
MG4	Burnet floodplain meadow	*Alopecurus pratensis-Sanguisorba officinalis* grassland
MG4a	Cock's-foot sub-community	*Alopecurus pratensis-Sanguisorba officinalis* grassland *Dactylis glomerata* sub-community
MG4b	Typical sub-community	*Alopecurus pratensis-Sanguisorba officinalis* grassland Typical sub-community
MG4c	Yorkshire Fog sub-community	*Alopecurus pratensis-Sanguisorba officinalis* grassland *Holcus lanatus* sub-community
MG4d	Creeping bent sub-community	*Alopecurus pratensis-Sanguisorba officinalis* grassland Agrostis stolonifera sub-community
MG5	Knapweed meadow	*Cynosurus cristatus-Centaurea nigra* grassland
MG8	Kingcup-carnation sedge meadow	*Cynosurus cristatus-Carex panicea-Caltha palustris* meadow
MG8a	Kingcup-carnation sedge meadow Burnet sub-community	*Cynosurus cristatus-Carex panicea-Caltha palustris meadow Sanguisorba officinalis* sub-community
MG8b	Kingcup-carnation sedge meadow Typical sub-community	Cynosurus cristatus-Carex panicea-Caltha palustris meadow Typical sub-community
MG8c	Kingcup-carnation sedge meadow Common sedge-lesser spearwort sub-community	*Cynosurus cristatus-Carex panicea-Caltha palustris meadow Carex nigra-Ranunculus flammula* sub-community
MG8d	Kingcup-carnation sedge meadow Kingcup-daisy sub-community	*Cynosurus cristatus-Carex panicea-Caltha palustris meadow Caltha palustris-Bellis perennis* sub-community
M22	Blunt-flowered rush-pasture	*Juncus subnodulosus-Cirsium palustre* fen meadow
M23	Sharp-flowered rush-pasture	*Juncus acutiflorus-Galium palustre* rush-pasture
M24	Meadow thistle fen-meadow	*Molinia caerulea-Cirsium dissectum* fen-meadow
M25	Purple moor-grass sward	*Molinia caerulea-Potentilla erecta* mire
M26	Hawksbeard fen-meadow	*Molinia caerulea-Crepis paludosa* mire

Appendix 4. Designated sites intersecting the Wye catchment study area

Designation	Site name
SAC	Coetiroedd Cwm Elan / Elan Valley Woodlands
SAC	Elenydd
SAC	Llangorse Lake / Llyn Syfaddan
SAC	Mynydd Epynt
SAC	River Wye / Afon Gwy (Wales)
SSSI	Afon Irfon
SSSI	Afon Llynfi
SSSI	Bach Howey Gorge
SSSI	Burfa Boglands
SSSI	Caban Lakeside Woodlands
SSSI	Cae Aber-Glanhirin
SSSI	Cae Pwll-Y-Bo
SSSI	Caeau Bryn-Du
SSSI	Caeau Clochfaen-Isaf (Clochfaen-Isaf Fields)
SSSI	Caeau Coed Mawr (Coedmawr Fields)
SSSI	Caeau Llwyn Gwrgan
SSSI	Caeau Troed-Rhiw-Drain (Troed-Rhiw-Drain Meadows)
SSSI	Carn Gafallt
SSSI	Cathedine Common Wood
SSSI	Cilcenni Dingle
SSSI	Ciliau
SSSI	Coed Aberdulas
SSSI	Coed Aberedw
SSSI	Coed Bryn-Person
SSSI	Coed Y Ciliau
SSSI	Coed Yr Allt-Goch
SSSI	Coedydd Glannau A Cwm Coel
SSSI	Colwyn Brook Marshes (North & South)
SSSI	Cors Cae'r Neuadd
SSSI	Crabtree Green Meadow
SSSI	Cwm Gwynllyn
SSSI	Cwm-Gwanon Dingle And Pasture
SSSI	Dolyhir Meadows
SSSI	Dolyhir Quarry
SSSI	Duhonw
SSSI	Elenydd
SSSI	Erwood Dingle
SSSI	Far Hall Meadow
SSSI	Glascwm And Gladestry Hills
SSSI	Gwaun Llwyn-Gwyn
SSSI	Gweunydd Camnant
SSSI	Gweunydd Coch-Y-Dwst

SSSI	Gweunydd Crychell
SSSI	Gweunydd Esgairdraenllwyn (Esgairdraenllwyn Pastures)
SSSI	Gweunydd Nant Y Dernol
SSSI	Ithon Valley Woodlands
SSSI	Llandeilo, Rhulen And Llanbedr Hills
SSSI	Llofft-Y-Bardd
SSSI	Llwyn-Cus
SSSI	Llymwynt Brook Pastures
SSSI	Llyn Syfaddan (Llangorse Lake)
SSSI	Maelienydd
SSSI	Marcheini Uplands, Gilfach Farm & Gamallt
SSSI	Moity And Garth Dingles And Fron Wood
SSSI	Mynydd Epynt
SSSI	New Castle Meadows
SSSI	Pwll-Y-Wrach
SSSI	Radnor Forest
SSSI	Rhagnentydd Gwy Uchaf / Upper Wye Tributaries
SSSI	Rhos Pant-Tyle
SSSI	Rhos Penrhiw
SSSI	Rhosydd Llanwrthwl
SSSI	River Ithon
SSSI	River Lugg
SSSI	River Wye (Lower Wye) / Afon Gwy (Gwy Isaf)
SSSI	River Wye (Tributaries) / Afon Gwy (Isafonydd)
SSSI	River Wye (Upper Wye) / Afon Gwy (Gwy Uchaf)
SSSI	Stanner Rocks
SSSI	The Wern, Rhosgoch
SSSI	Waen Rydd

Appendix 5. All output rasters showing potential restoration suitability for different vegetation communities.

M22 potential restoration areas and suitability
M23 potential restoration areas and suitability
M24 potential restoration areas and suitability
M25 potential restoration areas and suitability
M26 potential restoration areas and suitability
MG4 potential restoration areas and suitability
MG5 potential restoration areas and suitability
MG8 potential restoration areas and suitability

All data produced as part of this project are made freely available for download under the terms of the Open Government Licence from the LLe Geo-Portal for Wales: http://lle.gov.wales/catalogue/item/RiverWyeCatchmentWalesGrasslandCreationOpportunityMaps