Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

ERAMMP Technical Annex-105TA1: Wales National Trends and Glastir Evaluation

Emmett, B.A.[1], Anthony, S.[2], Arnett, J.[1], Bentley, L.F.[1], Bell, C.[1], Blaker, J.[1], Botham, M.[1], Bowgen, K.M.[3], Brentegani, M.[1], Campbell, H.[1], Chetiu, N.F.[1], Crossley, P.[1], Deacon, A.[1], Dhiedt, E.[1], Doeser, A.[1], Dos Santos Pereira, G.[1], Ebuele, V.[1], Feeney, C.[1], Fitos, E.[1], Garbutt, R.A.[1], Hunt, M.[1], Jarvis, S.G.[1], Keenan, P.[1], Kimberley, A.[1], Lord, W.[1], Macgregor, C.J.[3], Maskell, L.[1], Monkman, G.[1], Mondain-Monval, T.O.[1], Norton, L.[1], O'Neil, A.[1], Radbourne, A.[1], Reinsch, S.[1], Richardson-Jones, V.[1], Robinson, D.A.[1], Robinson, I.[1], Rowland, C.S.[1], Salisbury, E.[1], Scarlett, P.[1], Siriwardena, G.M.[3], Smart, S.M.[1], Tandy, S.[1], Thacker, S.[1], Wallace, H.[4], Waters, E.[1], Whitworth, E.[2], Williams, B.[1], Williams, G.[1], Williamson, J.L.[1] & Wood, C.[1]

[1]UK Centre for Ecology & Hydrology, [2]RSK ADAS Limited, [3]British Trust for Ornithology & [4]Ecological Surveys (Bangor)

Client Ref: Welsh Government / Contract C208/2021/2022
Version 1.0
Date: 04 April 2025

Funded by:
Llywodraeth Cymru
Welsh Government
Canolfan Ecoleg a Hydroleg y DU
UK Centre for Ecology & Hydrology

Version History

Version	Updated By	Date	Changes
1.0	PMO	04/04/2025	Publication

This report is available electronically at: **www.erammp.wales/105TA1**

Or by scanning the QR code shown.

Series Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

Title ERAMMP Technical Annex-105TA1:
Wales National Trends and Glastir Evaluation

Client Welsh Government

Client reference C208/2021/2022

UKCEH contact details Bronwen Williams
UK Centre for Ecology & Hydrology (UKCEH)
Environment Centre Wales, Deiniol Road, Bangor, Gwynedd, LL57 2UW
01248 374500
erammp@ceh.ac.uk

Corresponding author Bridget Emmett, UKCEH
bae@ceh.ac.uk

Authors Emmett, B.A.[1], Anthony, S.[2], Arnett, J.[1], Bentley, L.F.[1], Bell, C.[1], Blaker, J.[1], Botham, M.[1], Bowgen, K.M.[3], Brentegani, M.[1], Campbell, H.[1], Chetiu, N.F.[1], Crossley, P.[1], Deacon, A.[1], Dhiedt, E.[1], Doeser, A.[1], Dos Santos Pereira, G.[1], Ebuele, V.[1], Feeney, C.[1], Fitos, E.[1], Garbutt, R.A.[1], Hunt, M.[1], Jarvis, S.G.[1], Keenan, P.[1], Kimberley, A.[1], Lord, W.[1], Macgregor, C.J.[3], Maskell, L.[1], Monkman, G.[1], Mondain-Monval, T.O.[1], Norton, L.[1], O'Neil, A.[1], Radbourne, A.[1], Reinsch, S.[1], Richardson-Jones, V.[1], Robinson, D.A.[1], Robinson, I.[1], Rowland, C.S.[1], Salisbury, E.[1], Scarlett, P.[1], Siriwardena, G.M.[3], Smart, S.M.[1], Tandy, S.[1], Thacker, S.[1], Wallace, H.[4], Waters, E.[1], Whitworth, E.[2], Williams, B.[1], Williams, G.[1], Williamson, J.L.[1], Wood, C.[1]

Contributing authors & reviewers [1]UK Centre for Ecology & Hydrology, [2]RSK ADAS Limited, [3]British Trust for Ornithology & [4]Ecological Surveys (Bangor)

How to cite (long) Emmett, B.A., Anthony, S., Arnett, J., Bentley, L.F., Bell, C., Blaker, J., Botham, M., Bowgen, K.M., Brentegani, M., Campbell, H., Chetiu, N.F., Crossley, P., Deacon, A., Dhiedt, E., Doeser, A., Dos Santos Pereira, G., Ebuele, V., Feeney, C., Fitos, E., Garbutt, R.A., Hunt, M., Jarvis, S.G., Keenan, P., Kimberley, A., Lord, W., Macgregor, C.J., Maskell, L., Monkman, G., Mondain-Monval, T.O., Norton, L., O'Neil, A., Radbourne, A., Reinsch, S., Richardson-Jones, V., Robinson, D.A., Robinson, I., Rowland, C.S., Salisbury, E., Scarlett, P., Siriwardena, G.M., Smart, S.M., Tandy, S., Thacker, S., Wallace, H., Waters, E., Whitworth, E., Williams, B., Williams, G., Williamson, J.L., Wood, C. (2025). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)*. ERAMMP Technical Annex-105TA1: Wales National Trends and Glastir Evaluation. Report to Welsh Government (Contract C208/2021/2022) (UK Centre for Ecology & Hydrology Project 08435)

How to cite (short) Emmett, B.A., et al. (2025). ERAMMP Technical Annex-105TA1: Wales National Trends and Glastir Evaluation. Report to Welsh Government (C208/2021/2022) (UKCEH 08435)

Approved by Bridget Emmett (UKCEH)
James Skates (Welsh Government)

ABBREVIATIONS USED IN THIS REPORT

AES	Agri-Environment Scheme
ASPT	Average Score per Taxon
AWI	Ancient Woodland Indicators
BBMS	Butterfly Monitoring Scheme
BBS	Breeding Bird Survey
BGS	British Geological Survey
BOAT	Byway Open to All Traffic
BRC	Biological Records Centre
BTO	British Trust for Ornithology
CS	Countryside Survey
CS-DA & CS-LOW	Cattle & Sheep in the Lowland and Disadvantaged Area
CSM	Common Standards Monitoring
CS-SDA	Cattle & Sheep in the Severely Disadvantaged Area
EF	Emission Factors
EO	Earth Observation
ERAMMP	Environment and Rural Affairs Monitoring & Modelling Programme
ESA	Environmentally Sensitive Areas
EU	European Union
FPS	Farm Practices Survey
GA	Glastir Advanced
GB	Great Britain
GE	Glastir Entry
GHG	Greenhouse Gas
GIS	Geographic Information System
GMEP	Glastir Monitoring and Evaluation Programme
HAP	Habitat Action Plan
HEA	Historic Environment Asset
HNV	High Nature Value Farmland
IMP	Integrated Modelling Platform
JNCC	Joint Nature Conservation Committee
LCM	Land Cover Map
LiDAR	Light Detection and Ranging
LULUCF	Land Use, and Land Use Change and Forestry
LW	Living Wales
MA	Management Actions
NBN Atlas	National Biodiversity Network Atlas
NE	Natural England
NFI	National Forest Inventory
NFS	National Field Survey
NGO	Non-Government Organisation
NNR	National Nature Reserve
NPAP	National Peatland Action Programme
NRW	Natural Resources Wales
NTAXA	Number of Taxa
NVC	National Vegetation Classification
O/E WHPT	Observed Over Expected Walley Hawkes Paisley Trigg

Olsen P	Olsen Phosphorus
OS	Ordnance Survey
PYSM	Predictive System for Multimetrics
RDP	Rural Development Plan
RF	Random Forest
RSPB	Royal Society for the Protection of Birds
RUPP	Road Used as a Public Path
SAC	Special Areas of Conservation
SFS	Sustainable Farming Scheme
SLM	Sustainable Land Management
SNPA	Snowdonia National Park Authority
SOM	Soil Organic Matter
SoNaRR	State of Natural Resource Report
SSSI	Site of Special Scientific Interest
UK BAP	UK Biodiversity Action Plan
UKGHGI	The UK Greenhouse Gas Inventory
UKRI	UK Research and Innovation
VQI	Visual Quality Index
WATS	Welsh Archaeological Trusts
WEFO	Welsh European Funding Office
WFC	Whole Farm Code
WFD UKTAG	Water Framework Directive UK Technical Advisory Group
WFG	Well-being of Future Generations (Wales) Act 2015
WG	Welsh Government
WGRC-RDP	Welsh Government Rural Communities – Rural Development Programme
WLF	Woody Linear Features
WWII	World War II

CONTENTS

List of Figures

List of Tables

1 INTRODUCTION TO ERAMMP OBJECTIVES AND METHODS

Emmett, B.A.[1], Jarvis, S.G.[1], Monkman, G.[1] and Williams, B.[1]

[1]UK Centre for Ecology & Hydrology

The Environment and Rural Affairs Monitoring and Modelling Programme (ERAMMP) provides business-critical scientific evidence and analysis to the Welsh Government (WG) to support the development of policies and evaluate programme implementation in the agriculture and land use sector. The work involves three inter-related components of Monitoring, Expert Review and Integrated Modelling, and builds on the Glastir Monitoring and Evaluation Programme (GMEP) funded by the WG between 2012-16 which provided the essential building blocks on which ERAMMP has been developed and delivered between 2017-24.

Here we report on the latest results from the monitoring component of this work, which has involved the delivery of a National Field Survey (NFS), outputs from remote sensing technologies, interpretation of greenhouse gas (GHG) inventories and novel GHG emission modelling for peatlands and a repeat of the ADAS Farmer Practice Survey (FPS). The results enable reporting of National Trends for land use change; progress towards decarbonising agriculture and the role of restored peatlands in reducing GHG emissions; the impact of land management practices; and the state and change of the condition of Broad Habitats; Biodiversity (Vegetation, Pollinators and Birds); Soil health; Headwaters, Streamsides and Ponds; Landscape Features; Historic Environment Assets (HEAs); and Public Rights of Way (PROW). All of these reflect critical natural (and some cultural) resources which are heavily influenced by how we manage land and directly lead to a wide range of environmental, social and economic benefits.

The evidence provides foundational evidence for the State of Natural Resources Report (SoNaRR), several of the Well-being of Future Generations (Wales) Act 2015 (WFG) national indicators, evidence to the outcomes of the Glastir land management scheme and will also enable reporting of Sustainable Land Management (SLM) at the national scale and an impact evaluation of the Sustainable Farm Scheme (SFS) going forward. The data will also contribute baseline data with respect to other policy initiatives such as the new National Forest, 30 by 30 Biodiversity commitments and Net Zero.

1.1 Background to Glastir

Glastir is the land management scheme introduced by WG in 2012 as part of Axis 2 Welsh Government Rural Communities – Rural Development Programme (WGRC-RDP) to support farmers to manage their land to benefit the Natural Resources of Wales. The objectives of Glastir were:

- Combating climate change
- Improving water quality and manage water resources
- Improving soil quality and management
- Maintaining and enhance biodiversity
- Managing landscapes and historic environments
- Improving public access to the countryside

Additional outcomes (following the Welsh Audit Office (WAO) request to broaden the scheme outcomes) were:

- Improving number of farms undertaking action concerning climate change
- Improving diversification and efficiency of farms
- Improving profitability and wider sustainability

Glastir itself is a suite of individual schemes: (i) Glastir Entry, (ii) Glastir Advanced, (iii) Glastir Organic, (iv) Glastir Commons, (v) Glastir Small Grants, (vi) Glastir Woodland Creation and (vii) Glastir Woodland Restoration. All farms in the scheme, excluding Glastir Woodland Creation and Glastir Woodland Restoration, were also required to follow the Glastir Whole Farm Code (WFC).

1.1.1 Historical Schemes and Glastir

Glastir is just the latest of a history of land payment schemes in Wales which includes: Tir Cynnal (2005-13), Environmentally Sensitive Areas (ESA) (1987-2005), Tir Gofal (2000-15) and Glastir with the new future SFS going forward from 2026.

The presence of Tir Cynnal and Tir Gofal was included in the statistical modelling of some indicators. (See ERAMMP Technical Annex-105TA1S1: Wales National Trends and Glastir Evaluation. Supplement-1: Data Analysis Methods(Jarvis, et al., 2025) for methodological details.)

Tir Gofal ran between 2000 and 2015, sharing some overlap with Glastir (2012-24), and many options were directly equivalent. Tir Gofal imposed an obligatory suite of measures going beyond mandatory requirements for Good Agricultural and Environmental Conditions (GAEC) practice, and obligatory conservation and sustainable management of priority habit. Bespoke farm management plans were the core part of the scheme.

Tir Cynnal ran between 2005 and 2013. Participants were required to prevent loss of Biodiversity through protecting wildlife habitats (and have a minimum 5% of the farm area in a wildlife habitat). A Farm Resource Management Plan was required, specifying the actions required to remove environmental risks from their farm practices. For example, the use of fertilisers, manures and chemicals. Note that a lack of retained details on actual management undertaken limits the extent to which historical Tir Cynnal effects on environmental responses can be taken into account in contemporary analyses.

The area of land in land management schemes in Tir Cynnal and Tir Gofal was 646,700ha (33.2% of agricultural land). This increased to 783,800ha (40.2% of agricultural land) for Glastir. Land in Tir Cynnal and/or Tir Gofal intersected with Glastir over 423,800ha (54% of Glastir).

A total of 66% of Tir Cynnal and Tir Gofal therefore transferred into Glastir and 360,000ha (46%) of Glastir had not participated in previous schemes.

Table 1-1. Area and percentage of land under (i) Tir Cynnal and/or Tir Gofal, (ii) All Glastir and (iii) the intersection between Tir Cynnal and/or Tir Gofal, and Glastir. Percentage of Wales values calculated using NRW's operational area clipped to Ordnance Survey's mean high water spring limit. Percentage of agricultural land values calculated using WG's Survey of Agriculture and Horticulture: June 2023. All values derived from WFC areas or equivalent.

Schemes and scheme overlap	Area (ha)	% Wales	% Agricultural Land
Tir Cynnal and/or Tir Gofal	646,700	31.1	33.2
Glastir	783,800	37.7	40.2
Tir Cynnal and/or Tir Gofal, and Glastir	423,800	20.4	21.8
Tir Cynnal and/or Tir Gofal outside of Glastir	222,985	10.7	11.4
Glastir not in Tir Cynnal or Tir Gofal	360,000	17.3	19.5

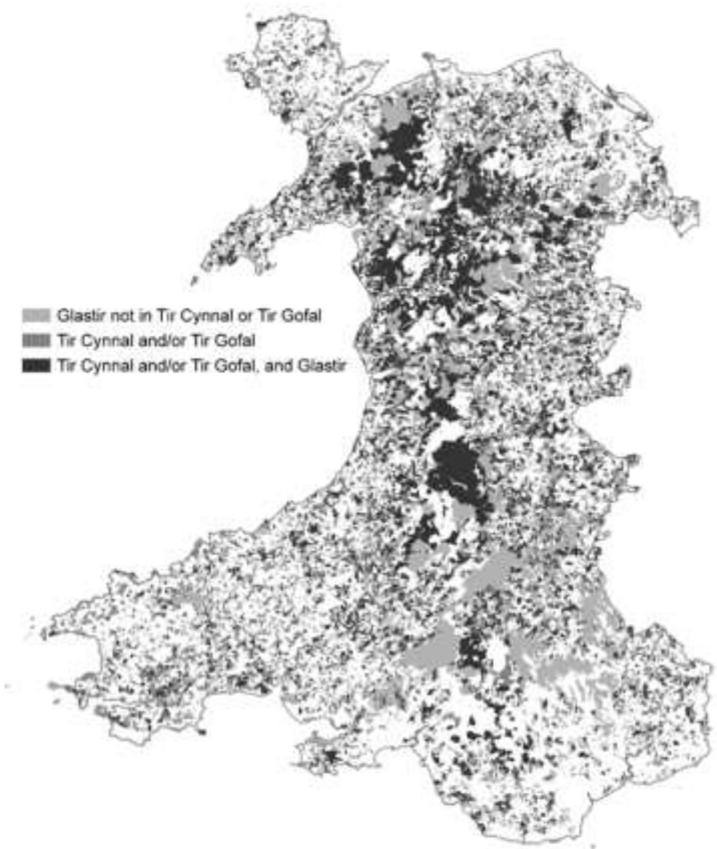


Figure 1-1. Intersections between scheme uptake extents for Glastir, Tir Gofal and/or Tir Cynnal.

1.2 Background to GMEP and ERAMMP

GMEP 2012-17 provided a comprehensive programme which established a baseline against which future assessments of Glastir would be made. The approach followed a well-tested and repeatable approach developed by UKCEH for their integrated monitoring programme Countryside Survey, which was enhanced to capture additional indicators of interest to the

WG. Previously, the approach has been used successfully to capture national-scale change across Wales (and GB) including a reduction in the length of managed Hedgerows, a reduction in plant species richness across Wales and an increase in Soil pH reflecting a reduction in pollution levels (Smart S. M., et al., 2009).

The GMEP report was published in 2017 (Emmett & team, 2017) and included evidence of National Trends by linking data to longer-term trends from past monitoring programmes which had used the same sampling and methodological approaches. Data presented in the report included analysis of data from a wide variety of sources including:

- GMEP NFS
- Monitoring programmes such as the UKCEH's Countryside Survey
- British Trust for Ornithology (BTO)/ Royal Society for the Protection of Birds (RSPB)/ Royal Society for the Protection of Birds (JNCC) Breeding Bird Survey (BBS) and Forest Research's (NFI)
- Biological Records Centre
- ADAS 2nd FPS
- Citizen science sources
- GHG inventories
- Outcomes from a suite of models which provided insight into the likely outcomes of Glastir.

In addition, the GMEP report included a comparison of the condition of land within the Glastir scheme relative to a national average which demonstrated that land coming into the scheme already had many characteristics which are considered to confer resilience such as better condition, diversity and connectivity relative to land outside of the scheme.

ERAMMP builds on this baseline GMEP report and focuses on National Trends and the impact of Glastir management options (excluding WFC – hereafter called Glastir management options) from 2013-16 and 2021-23. The approach takes into account the initial significant differences reported for land coming into the scheme versus the land outside of the scheme identified by GMEP.

For both National Trends and Glastir management options impact reporting, a range of environmental (and some cultural) resources are reported at different resolutions and classifications due to the nature of the resource and method of data collection.

Table 1-2. Reporting structure for environmental and cultural resources. White cells show resources reported (Y), light grey cells show partial report (Partial), and dark grey cells show resources not reported (No).

Environmental and Cultural Resources	All Wales	Asset Class	Broad Habitat	Some Priority Habitats
Plants	Y	Y	Y	Y
Pollinators	Y	Y	Y	Y
Birds	Y	Y	Partial	N
Topsoil	Y	Y	Y	
Headwaters, Streamsides & Ponds	Y	Y	N	Y
Landscape	Y	N	Y	N
Historic Environmental Assets	Y	N	N	N
Public Rights of Way	Y	N	N	N

Both GMEP and ERAMMP were developed to ensure compliance with the rigorous requirements of the European Commission's Common Monitoring and Evaluation Framework (CMEF) through the Rural Development Plan (RDP) for Wales.

1.2.1 Key Findings from GMEP and Priority Questions for ERAMMP

A core set of headline indicators were selected with our GMEP Advisory Group to create an accessible scorecard that spanned the six intended outcomes of Glastir and some additional WG priorities. The overall picture was a mixture of some clear areas of improvement, which could include a halt in historical declines and ongoing stability but also areas of concern where indicators showed an apparent increase in the number of indicators of decline or degradation over the last 10 years.

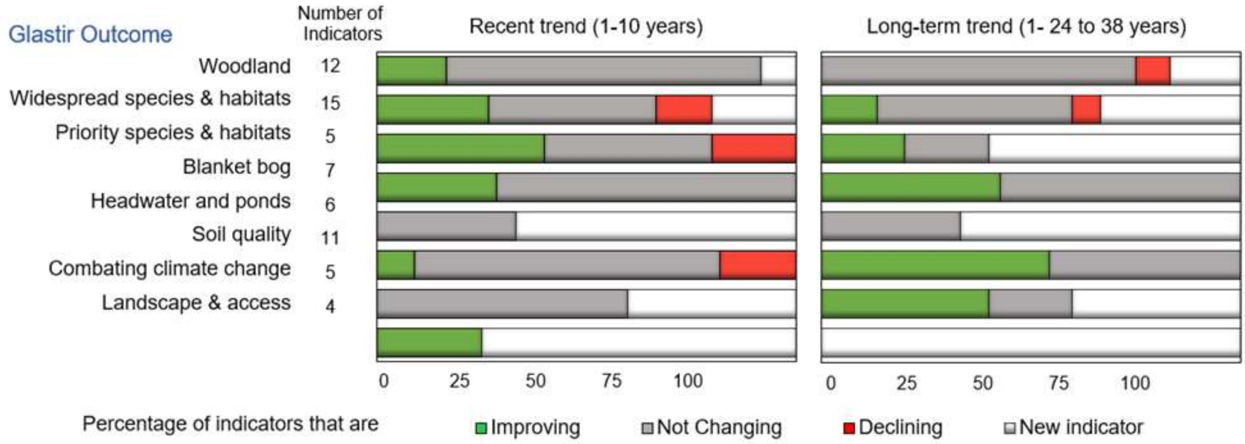


Figure 1-2. National Trends reported by GMEP 2017 expressed as the percentage of indicators across 6 Glastir objectives (Woodland, Biodiversity, Headwaters and Ponds, Soil, Climate change, Landscape and Access and 2 other WG priorities (Priority species and Blanket Bog) which had improved (green), were stable (grey) or had declined (red) over the short and long-term. Indicators were selected by the GMEP Advisory Group.

Whilst stability and/or a halt in an historical decline may not have been the improvement hoped for, it was emphasised that these findings did represent an important outcome within the context of ongoing climate change, air pollution and challenging economic conditions for the agriculture and land use sector.

The report also emphasised that land which had come into the Glastir scheme was of higher environmental quality with characteristics associated with greater resilience. This is critical when evaluating scheme outcomes to ensure any improvement identified is not falsely attributed to the scheme. The characteristics associated with resilience include extent, condition, diversity, connectivity and adaptability.

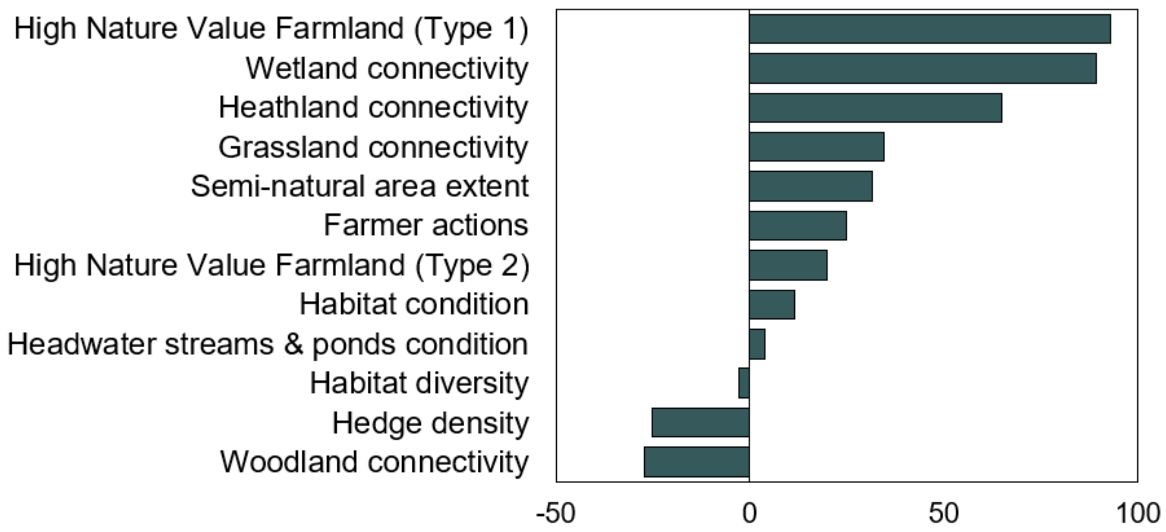


Figure 1-3. A comparison of land in Glastir compared to land across all Wales for metrics relating to resilience reported by GMEP 2017. Bars to the right of the central '0' line indicate a more positive value for that characteristic for land in scheme.

This finding demonstrated two important issues:

- Glastir payments have often, although not exclusively, been focussed on protecting and improving land which is already better in terms of environmental condition.
- Without the rigorous baseline captured in GMEP, there was a risk of potential false attribution of many positive outcomes to Glastir by the ERAMMP re-survey.

The findings of the ADAS FPS also highlighted that only 34% of farm managers had changed farm practices in response to Glastir Entry (GE) payments and therefore outcomes would reflect longer-term consequences of current management, driven in many cases by legacy agri-environment schemes (AES) (Anthony, Stopps, & Whitworth, 2017).

A range of GMEP modelling work reported in (Emmett & team, 2014) also concluded that many ecological responses can take decades to be achieved, therefore suggesting continuing payments may be required to realise intended outcomes. The modelling also suggested the impact for agricultural pollution to waters would likely be limited to a maximum of 4% to 11% reductions for losses to water bodies and 0% to 2% greenhouse for GHG emissions.

Finally, continued analysis of the GMEP baseline NFS data after the publication of the GMEP 2017 report (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022) also identified the importance of targeting and landscape context in defining the observed or modelled impact of management actions at a local level. Some of the biggest changes may be observed where land is most degraded. However, for some elements of biodiversity where dispersal is important, an improvement could be limited if the local area was surrounded by relatively depleted low condition land which hinders dispersal into the area.

Key questions for ERAMMP were agreed as:

- Are National Trends improving, staying the same or declining since the GMEP report in 2017?
- What is the evidence Glastir management options have contributed to Glastir achieving its objectives?
- Is there evidence of benefits of presence in previous AES schemes and/or landscape context impacting Glastir outcomes?

- How have Glastir management options contributed to the observed National Trends?
- Which specific management option types deliver most and should be considered for the SFS scheme?
- How do changes observed cascade through the ecosystem? Where do our current methods enable early alerts of improvement or degradation and what is the lag time for other components of the ecosystem? Can this help inform selection of indicators for SLM and SFS going forward?

1.3 Glastir Uptake

The impact of Glastir management options will depend on the extent, location and landscape context of management options paid for, their combination, and how well the actions are delivered. The last of these cannot be determined from the NFS and is not considered further but it should be noted that it may contribute to outcomes reported. The effect of combining individual options have also not been explored here but could be the subject of future analysis.

All data on the uptake and extent of Glastir management options and Glastir as a whole have been provided by WG and used to create a new spatial database upon which all analyses were dependent. This ensured a consistent data source was used for all data sources and provides a valuable resource for future analytical and survey work.

1.3.1 Area of Land Entering Glastir

The total land area in Glastir was 783,800ha which represents 38% of Wales (2,079,600ha) and 40% of agricultural land (1,948,000ha). However, in this report, the impacts of Glastir does not cover the whole area of land included the scheme. Instead, it focuses on management options targeted on improving Wales's Natural Resources in particular land parcels or areas within land parcels. These were embedded in a family of related schemes: (i) Glastir Entry, (ii) Glastir Advanced, (iii) Glastir Organic, (iv) Glastir Commons, (v) Glastir Small Grants, (vi) Glastir Woodland Creation and (vii) Glastir Woodland Restoration. Management option uptake across these schemes (overlaps excluded) covered an area of 495,148ha or 23.8% of Wales and 25.4% of land defined as agricultural land. This area excludes land which fell under the requirements of the WFC alone. The WFC covered a number of rules which were not allowed on a farm participating in the scheme (excluding Woodland Creation and Woodland Restoration). The impact of this additional area of WFC land could be the subject of future analyses if required however the priority by WG was for land where proactive action was being funded. Uptake of the Glastir Advanced scheme (including capital works) covered the largest area at 13.1% of agricultural land area, followed by Glastir Entry (10.4%) and Commons (6.7%).

Table 1-3. Uptake of Glastir management option areas by scheme and total area in Glastir which includes WFC area. Percentage of Glastir option uptake calculated from the sum of scheme option uptake areas with and without overlaps. Percentage of Wales values calculated using NRW's operational area clipped to Ordnance Survey's mean high water spring limit. Percentage of agricultural land values calculated using WG's Survey of Agriculture and Horticulture: June 2023. No data are shown as grey boxes.

**Note that Glastir Woodland Creation and Glastir Woodland Restoration (GWR) schemes do not intersect WFC or agricultural land but are given for comparison.*

Scheme	Area Across Wales (ha)	% of Scheme Excluding WFC	% Wales	% Agricultural Land
Glastir Advanced	254,400	37.7	12.2	13.1
Glastir Commons	129,800	19.2	6.2	6.7
Glastir Entry	203,300	30.1	9.8	10.4
Glastir Organic	81,660	12.1	3.9	4.2
Glastir Small Grants	60	<0.1	<0.1	<0.1
Glastir Woodland Creation	3,780	0.6	0.2	0.2*
Glastir Woodland Restoration	2,380	0.4	0.1	0.1*
Total	675,380	100	32.5	34.7
Total with no overlaps	495,148		23.8	25.4
Whole Farm Code	289,222		13.9	14.8
All Glastir	**783,800**		**37.7**	**40.2**

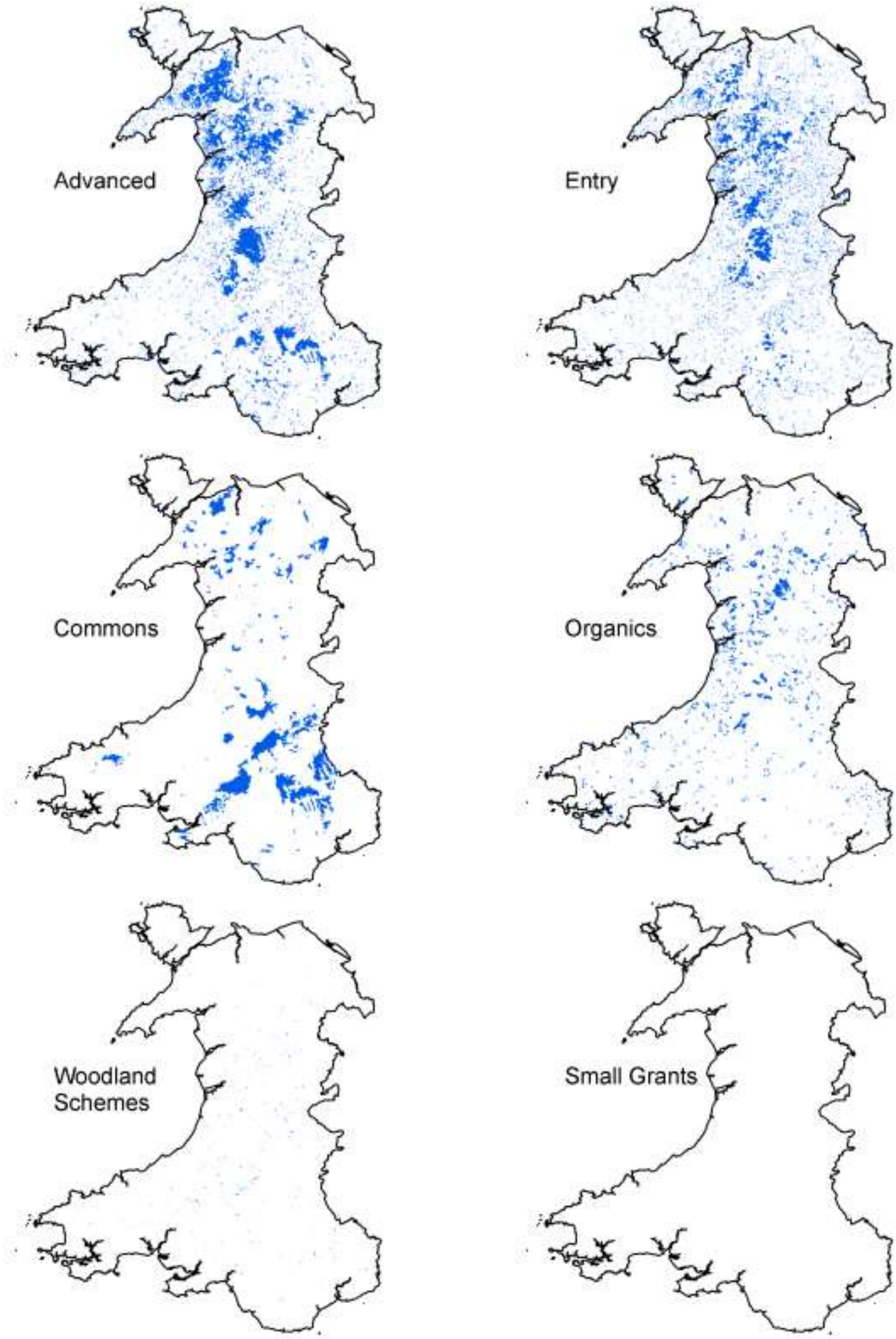


Figure 1-4. Glastir option uptake extents by scheme for 2012-24. The Glastir Small Grants did have uptake, but the extent sizes are too small to show at this resolution.

1.3.2 Individual Option Uptake

Across the Glastir schemes which had over 700 options (noting some option duplication between schemes), 211 options had uptake. However, the uptake area was dominated by fewer than 10 options, with just five options representing 62% of the area within Glastir (excluding WFC land). This is clearly seen in the cumulative distribution of option areas. Considering option counts – which may better represent linear actions such as Wildlife Corridors, Buffers and Hedgerows – the picture is very similar, with the same seven options coming top by both count and area, albeit in a different order. Note that options can overlap. The picture this data provides reflects the importance of large areas of semi-natural land and common which entered into the scheme but also the highly specific options required to cover many different priority habitats and features which often represent relatively small areas in the landscape.

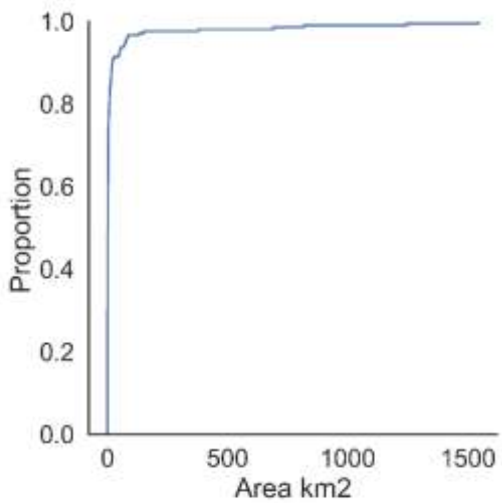


Figure 1-5. Accumulated distribution of the 211 options taken up by area across all Glastir schemes for all of Wales.

Table 1-4. Area in hectares (ha) of the top 5 area ranked Glastir management options taken up. The overlaps of the top 5 ranked options are given against all other up-taken options. Areas are given as a percentage of the total option uptake area (% Area All Uptake) and as a percentage of the land area of Wales (% Area Wales).

Subset	Area (ha)	% Area All Uptake	% Area Wales
All Glastir option uptake	495,150	100.00	24
Top 5 option uptake (total area)	309,690	62.55	15
All other option uptake (total area)	261,420	52.80	13
Top 5 option uptake overlapping other option uptake	75,960	15.34	4
Top 5 option uptake not overlapping other option uptake	233,730	47.20	11
Other option uptake only (no overlap with the top 5)	185,460	37.45	9

Table 1-5. The most popular Glastir management option uptake by count and area in hectares (ha). The area is given as a percentage of the total land area of Wales (% Wales). Options are ordered by descending land area. The top 4 options by count are indicated by an asterisk (*) and the top 8 options by area are shown in grey. Note that 'Additional Management Payment' options are restricted to land under a restricted set of qualifying options. Some options are better represented by length, not area or count.

Option	Option uptake count	Options uptake area (ha)	% Wales
411. Additional management payment – reduce stocking	6,509	154,600	7.4
41a. Grazing management of open country	6,119	124,500	6.0
Organic – Glastir organic interventions	24,763*	81,700	3.9
15. Grazed permanent pasture with no inputs	31,595*	69,000	3.3
15b. Grazed permanent pasture with low inputs	15,976*	37,900	1.8
19. Lowland marshy grassland	9,825	15,200	0.7
100. Woodland Stock Exclusion	18,076*	13,200	0.6
401. Additional management payment – mixed grazing	1,654	8,600	0.4
15c. Grazed permanent pasture with no inputs and mixed grazing	2,457	8,000	0.4
15d. Grazed permanent pasture with low inputs and mixed grazing	3,088	7,900	0.4
41b. Grazing management of open country with mixed grazing	573	7,400	0.4
40. Management of existing fence on stock excluded Woodland	6,954	2,800	0.1
133. Lowland marshy grassland (Advanced)	4,468	5,600	0.2
8a. Management existing Streamside corridor	4,186	245	<0.1
4. Simple Hedgerow management (on both sides)	3,977	182	<0.1

1.3.3 The Creation of Option Bundles for Analysis of National Field Survey Data

As 211 options were taken up, some form of aggregation was needed to simplify and target analysis. Option 'bundles' were therefore created. These are groups of options that have related aims and apply to a common habitat type. Bundles reduced the number of analyses to a manageable number and ensured that non-option counterfactual areas did not include coverage of other management aimed at a similar outcome. A list of bundles for WG to prioritise based the presence of the bundle to a meaningful extent within the 300 GMEP baseline survey squares using the approach outlined in (Alison, et al., 2021). This approach was required as even if a bundle was prioritised by WG, if it was not present in our survey sample, analysis of its effectiveness would not be possible. Once WG agreed a prioritisation list, survey squares for re-survey were selected according to the methodology outlined in (Alison, et al., 2021). The ERAMMP Technical Annex-105TA1S1: Wales National Trends and Glastir Evaluation. Supplement-1: Data Analysis Methods (Jarvis, et al., 2025) has a comprehensive list of bundles and options across schemes. The Table 1-6 lists the bundles with the option count within each bundle and a broad description of the type of options within each bundle. Different bundles have been used in different analyses depending on their relevance to a specific outcome but also their specific overlaps with the sample within a square. For example, Soil analysis required a bundle to sit directly on top of the Soil sampling locations whilst at the opposite end of the spectrum, for Birds a bundle had to be present anywhere on land for which we had permission to re-survey within the 1km survey square.

Table 1-7 provides bundle area or length in order of extent.

Table 1-6. List of bundles and the number of options in each bundle which were present in survey squares. Bundles were also subdivided; however, the use of these subdivisions is dependent on the various statistical analyses across indicators.

Bundle	Option Count	Option descriptions including associated small and capital grants which were taken up, were present in survey squares and included in bundles
01 Grazing Low/No Inputs	6	Low or no inputs on grassland with/without mixed grazing.
02 Habitat Management (General)	38	Specific by Broad Habitat and includes grazing management and mechanical Bracken controls.
03 Arable Management	16	Fallows, spraying, cover crops, red clover leys, headlands, margins, winter stubble, buffer zones; Unsprayed crop options dominate in the ERAMMP sample.
04 Hedge Management	11	Management including, laying, coppicing, fencing.
05 Woodland Stock Exclusion	3	Fencing for exclusion of stock dominated with a small amount of management of existing fence.
06 Woodland Management	54	Stock exclusion dominated with some significant *Rhododendron* control. All other actions (scrub clearance, re-stocking, coppicing, thinning etc.) were very small in area.
07 Hedge Management Advanced	2	Laying, planting, coppicing.
08 Habitat Management Advanced Reversions	16	Reversion actions for specific Broad Habitats including habitat creation, no grazing, no inputs, cutting and removal of invasives.
09 and 10 Habitat Management Peat and Heath	30	Analysed together as often overlapped.
11 Wildlife Corridors and Buffers	12	2m or 3m corridors by Streamsides including woody planting.
12 Woodland Creation	5	Mixed and native Woodland and Agroforestry.
13 Organic	1	Organic interventions.
14 Commons	4	Stocking levels and a closed winter period.
15 Habitat Management Advanced Birds	11	Diverse management options for particular targeted Bird species. (Note that there was insufficient sample to report on the effects of this bundle.)
16 Footpaths (PROW)	N/A	Stiles, gates and posts, hard surfacing, gates, bridges, seats, boardwalks.

Table 1-7. Glastir management option bundles in order of their uptake levels expressed as an area (hectares) and as percentage of land in Glastir and Wales. No relevant data are shown as grey boxes. Note that due to multiple options and bundles being present on the same land, the percentage of Glastir is > 100%.

Management Option Bundle	Area (ha)	Linear Option	% Glastir	% Wales
2. Habitat Management (General)	215,300		43.5	10.4
10. Habitat Management Heath/Peat	171,300		34.6	8.2
14. Commons	129,900		26.2	6.2
1. Grazing Low/No Inputs	110,500		22.3	5.3
13. Organic	81,700		16.5	3.9
6. Woodland Management	19,000		3.8	0.9
3. Arable Management	18,000		3.6	0.9
5. Woodland Stock Exclusion	16,000		3.2	0.8
8. Habitat Management Advanced Reversion to Grass	3,890		0.8	0.2
12. Woodland Creation	3,780		0.8	0.2
15. Habitat Management Advanced Birds	1,720		0.3	0.1
11. Wildlife Corridors	920	Yes	0.2	0.04
4. Hedge Management	530	Yes	0.1	0.03
16. Footpaths	200	Yes	0.04	0.01

1.4 The National Field Survey

The National Field Survey (NFS) is a structured systematic survey which captures co-located information in a carefully selected sample of locations across Wales covering the rural and peri-urban space (defined as <25% of sealed built-up area within a 1km square). The co-location of measurements is a response to the co-dependence and interaction of Natural Resources and the benefits they deliver within the landscape. This integrated approach to monitoring fulfils a key requirement of the Environment (Wales) Act 2016.

The units of sample area are 1km squares represents a compromise between relatively homogenous plot or field scale assessment to include broader landscape interactions whilst avoiding the complexity of landscape assessment, such as a catchment scale approach, which would be of variable extent and complexity. The use of catchments, whilst useful for many water monitoring programmes, would be problematic because they are highly variable in size across Wales, with many also crossing the border with England. Within the EU, a paired farm approach has often been adopted for AES monitoring. However, such approaches require close matching of in scheme and control (also called counterfactual) farms, which can be challenging as not many farms are directly comparable. Also, long-term maintenance of the management contract (as well as survey access) over time may be compromised as farms in scheme may opt out and/or 'control' farms may opt into scheme.

The NFS also emphasises long-term thinking by gathering fundamental evidence which can be combined into a range of different indicators as policy priorities change. The approach is also robust to, and can capture the effects of, land use change as survey squares are selected according to land class. Land classes are based on fundamental stable properties of Wales such as geology, climate and slope, rather than land cover/habitat which changes over time. All field measurements are collected using standardised published methodologies by professional surveyors and with associated independent assessment of quality control and assurance. The surveyors capture diversity and condition (and in some cases stock) of Broad Habitats including Woodland, Landscape Features such as Hedgerows, Streamsides and individual Trees, Vegetation, Soil, Water, HEA, Pollinators, Birds, PROW and Landscape Visual Quality using photography.

The potential to develop multiple indicators of habitat and resource condition and their spatial alignment (e.g. Vegetation, Soil and water quality with a single location or habitat) provides a rigorous approach to assessing the overall condition of the wider countryside which recognises the equal importance of different resources. This approach also provides an opportunity to identify the indirect impacts of Glastir management options beyond their primary intended target whether they are beneficial or result in a trade-off between one outcome and another.

Finally, it should be noted the NFS does not duplicate elements embedded within other national monitoring programmes that are already in place, e.g. monitoring of large water bodies by Natural Resources Wales (NRW) or forestry timber production embedded within the National Forest Inventory (NFI) by Forest Research. However, elements which are not present on those programmes, such as Headwaters and Ponds, and Woodland ground flora and Soils, are covered to provide added value. Whilst the inclusion of methods to capture Bird abundance and diversity uses the same methods as the BTO/RSPB/JNCC BBS the reason for its inclusion in GMEP was the novelty of targeting survey work towards the landscapes of interest for Glastir management option evaluation to inform about local-scale management effects (within survey squares) and the link to co-located Vegetation and Landscape change.

1.4.1 Selection of Survey Squares to Report National Trends

The NFS uses a structured, unbiased approach to the reporting of ongoing National Trends of widespread habitat, soil and landscape types across the rural and peri-urban landscape. A Nationally Representative population of 150 1km squares were sampled over a four-year period between 2013 and 2016. The squares were chosen by randomly sampling within assigned land classes to provide a good representation of widespread Broad Habitats and the wider countryside. The area surveyed in the GMEP baseline and ERAMMP for reporting National Trends represents 0.7% of Wales's land area. The number of squares needed to detect changes in National Trends for some common metrics was calculated using power analyses of past UKCEH Countryside Survey data. Whenever possible, the programme has used methods employed in past national surveys, such as Countryside Survey[1] and the

[1] http://www.countrysidesurvey.org.uk

Butterfly Monitoring Scheme[2], which enables short-term trends to be set within the historical context of changes resulting from past land management schemes and other drivers of change such as climate change and air pollution. Bird survey methods were revised from those of the BTO/JNCC/RSPB BBS (Heywood, et al., 2024) in order to provide better inference about Glastir management option responses at the field scale, as well as national population changes. Confidentiality of the square locations is maintained to reassure landowners that additional action by statutory authorities cannot be triggered and to prevent landowner fatigue by preventing un-authorised follow-up studies.

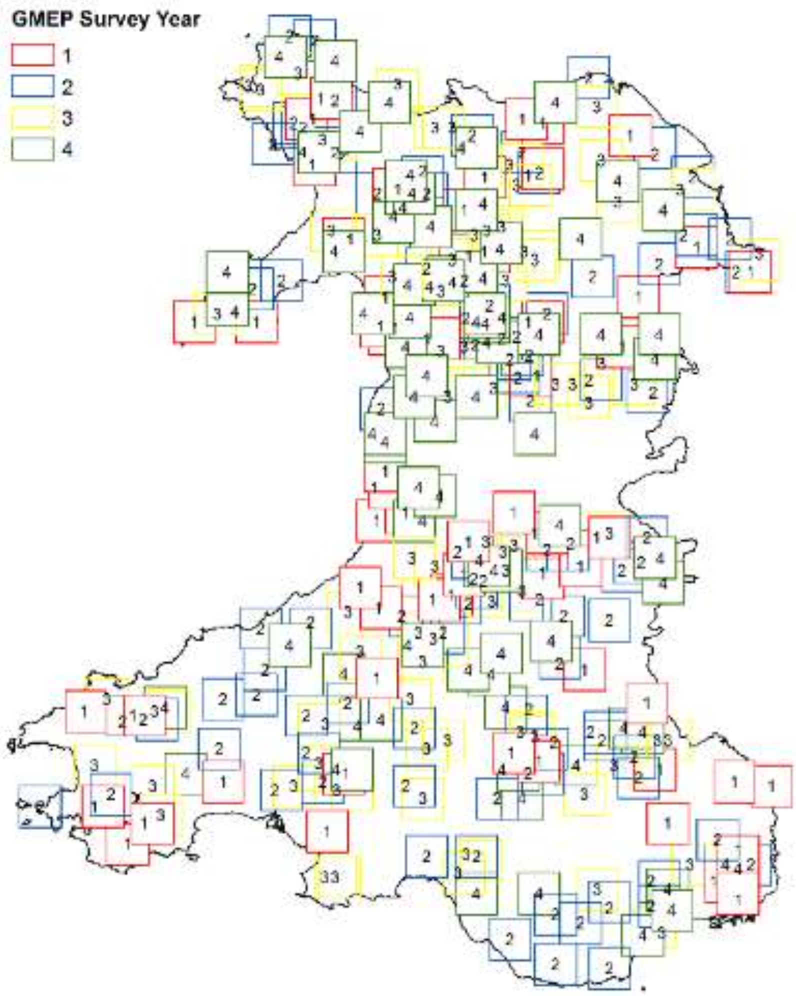


Figure 1-6. Distribution of GMEP 1km survey squares but enlarged and relocated within a 10km by 10km grid to protect locations.

[2] https://www.ceh.ac.uk/our-science/projects/uk-butterfly-monitoring-scheme

1.4.2 Selection of Survey Squares to Report Glastir Management Option Impacts

An additional set of 150 1km squares were selected to ensure that sufficient information on Glastir management options was captured in GMEP. These squares are not used for reporting National Trends as they are biased towards land targeted for payments by WG. They provide additional power for before and after comparisons for Glastir management options impacts only. Glastir management options payments were in general focussed on upland systems and on land where some Natural Resources were often (but not always) at a higher level than the national average (Emmett & team, 2017).

The selection of many squares for this purpose was carried out before the location of all land in scheme was fully known (i.e. in 2013-16) to ensure baseline conditions were not missed. Land was therefore selected according to the points-based system WG had used to prioritise payments by area. See (Emmett & team, 2017) for more details. Land with most points available to landowners was pooled and a representative sample selected. This approach can now be seen to have been successful as the land in the Glastir management options is double (22.2%) that of our Nationally Representative squares selected to report on National Trends and equivalent to that for All Wales (23.8%). It is interesting to note that our Nationally Representative sample had lower presence of Glastir management options than the national average, possibly indicating quite strong clustering spatially of Glastir management options.

Table 1-8. The area in hectares (ha) and percentage of land by area (% Area) with Glastir management option uptake across Wales within squares.

Square Area Type	Area (ha)	% Area
All Wales		
Glastir management options (excluding WFC)	495,148	23.8
All other land	1,584,500	76.2
In-square – In Glastir management options		
Nationally Representative squares	3,070	10.2
Glastir Targeted squares	6,650	22.2

Within this pooled set of all squares, Glastir Advanced is the most extensive scheme by area in Wales representing 61% of land in scheme in squares, followed by Glastir Entry (43%) and Commons (23%). This distribution is well matched to the distribution for scheme breakdown across Wales as a whole.

Table 1-9. Glastir management options uptake areas across Wales and within survey squares. Covers all 300 Glastir Targeted squares from any scheme option in any year. Percentage of totals in scheme also shown.

Scheme	Area in survey squares (ha)	% of Glastir schemes in survey squares	% of Wales
Glastir Advanced	5,887	60.6	12.0
Glastir Commons	2,255	23.2	6.1
Glastir Entry	4,139	42.6	9.6
Glastir Organic	2,204	22.7	3.8
Glastir Small Grants	0.4	<0.1 (0.004)	<0.1 (0.003)
Glastir Woodland Creation	65	0.7	0.2
Glastir Woodland Restoration	32	0.3	0.1

1.4.3 Delivery and Management of the ERAMMP National Field Survey Re-Survey

The budget was not available within the current ERAMMP contract to re-survey all 300 GMEP NFS squares for all previously sampled metrics, so a population of squares were selected to ensure WG priorities for reporting National Trends could be reported and that prioritised management bundles would be sufficiently captured for evaluation of Glastir management options. The approach taken is reported in (Alison, et al., 2021). A total of 247 squares were selected for re-survey of which 147 were from the Nationally Representative squares and 100 from the Glastir Targeted Survey. Only 225 were available for this report due to delays relating to COVID-19 which resulted in the survey extending into 2024 when the report was due. Overall, GMEP captured 1.4% of Wales by area whilst ERAMMP captured 1.1% (not taking into account the impact of land access permission to survey squares). The area captured for reporting National Trends was 0.7% in both surveys. Where permissions fell below 25% of a square a new square from the original GMEP NFS was selected).

A time and motion study revealed that ca. 50% of UKCEH survey time (except Pollinators and Birds which were delivered by the BTO), was taken up mapping and assigning habitat areas. It was decided that with the exception of Woodland mapping this would be stopped within the ERAMMP re-survey, with the intention going forward using satellite data to track change in habitat areas.

Other cost-saving measurement priorities were agreed with the ERAMMP Steering Group using an approach which highlighted uniqueness of data, relative costs (and efficiency of costs when combined with other measurements) and policy priorities. The result of this prioritisation exercise was:

Reduce or stop:

- A reduction in Bird and Pollinator effort to 60% of re-sampled squares and only two visits a year not three. In total 50% less effort.
- Stopping measurements of Soil Biodiversity using eDNA but with Soil samples taken and stored at -20°C for potential future Biodiversity and contaminant work.

- No Landscape Visual Quality Index work repeated but with photographs taken for possible future assessment and to maintain the long-term record.

Addition:

- Addition of Soil Erosion and degradation work using a combination of aerial photography and field verification approaches. Peat depth was also included.

1.4.4 The Impact of COVID-19 and the ERAMMP National Field Survey Response

The re-survey of NFS squares was planned for completion during 2020 and 2021. On the 23rd March 2020, the UK Government announced a national lockdown, ordering people to stay at home, restricting movement to all but essential workers. Initially, the NFS was postponed for 12 weeks. However, lockdown measures posed substantial challenges to conducting the NFS, especially in safeguarding the health and safety of ERAMMP staff, landowners, and rural communities. This, alongside social distancing requirements and practicalities of operating within lockdown restrictions, resulted in a full COVID-19 reset of the NFS, postponing the field survey into 2021, which sadly resulted in the cancellation of surveyor contracts.

The challenges continued into 2021 as Wales entered COVID-19 alert level 4 (stay at home lockdown measures) on the 20th December 2020 and field surveys could not proceed unless COVID-19 restrictions eased to alert level 3. At the request of WG, the permission process was postponed allowing for consultation with farming unions. With a more positive COVID-19 review published on the 19th February 2021, WG agreed the permission letters could be sent with an additional COVID-19 guidance document provided. The revised timetable reduced the allocated time for securing permissions by 50% and additional personnel were recruited to mitigate the condensed timeframe. Wales moved to alert level 3 on the 3rd May 2021. As Bird surveys have to be completed between April and June to correspond with springtime breeding activity, the Bird survey was postponed to 2022.

Table 1-10. Summary of ERAMMP NFS teams, their timing and duration.

Team	Month	Time of day	Surveyors per team	Number of visits	Average survey time per square (days)
Botanical (plants and Soil)	April - Sept	9am - 6pm	2	1	4
Freshwater	April - Sept	9am - 6pm	1	1	0.5
Woodland mapping, linear features, Soil Erosion and Historic Assets	June - October	9am - 6pm	1	1	2
Bird (territory mapping and Footpaths)	April - June	Early morning	1	2	2
Pollinator	July & August	9am - 6pm	1	2	1

To deliver the NFS, professional survey staff are recruited annually: UKCEH providing botanical, habitat mappers and Freshwater teams, and BTO the Bird and Pollinator teams. COVID-19 presented challenges in recruiting the required number of surveyors for the planned survey squares. Several mitigation options were implemented including running the survey over two years rather than one, making an exception to UKCEH policy to allow employment of sole traders on a self-employed basis, and contacting ERAMMP consortium organisations to enquire whether they had field surveyors available for inclusion into the survey teams. ADAS provided four survey staff in response to this appeal. Throughout the duration of the 2021 survey, field staff were required to test for COVID-19 weekly using rapid lateral flows tests. Survey training was also affected, with the majority being undertaken online rather than in person in 2021 and 2022.

Field surveys of this scale require an enormous amount of preparation, and gaining landowner permissions to access land was critical to secure a representative sample for analysis. As such, undertaking the NFS was reliant upon permission to access land being granted by landowners or tenants with management control. Maintaining a respectful and trusting relationship between ERAMMP and landowners was critical to the success of the NFS.

In total, 1,800 landowners have been contacted over the four-year period with an average of 75% granting access to their land for survey.

Table 1-11. Number of land managers contacted to request land access in the years 2021-24.

Year	2021	2022	2023	2024
Land managers contacted	657	554	517	72
Granted	477	450	372	56
Refused	71	81	117	14
No response	109	23	28	2

Overall, 247 1km survey squares have been surveyed by a team of professional surveyors in the years 2021 through to 2024.

1.4.5 The National Field Survey Sampling Approach

The basic unit of sampling for the NFS is a 1km square. Within these squares, a wide range of individual measurements are captured by highly trained surveyors who have three weeks of dedicated training covering all aspects of health and safety, biosecurity and survey methods. Quality Control is also carried out on a subset of squares using independent surveyors on a rolling basis to ensure surveyors are not drifting with respect to methodologies. Where possible, and contingent on past performance, surveyors are re-appointed from year to year. Quality Assurance of botanical survey is also independently reported in the field with other Quality Control and Assurance methods adopted for other elements of the survey, laboratory and for data analysis. (ERAMMP Technical Annex-105TA1S4: Wales National Trends and Glastir Evaluation. Supplement-4: Vegetation Quality Assurance (Deacon, Fitos, Prosser, & Wallace, 2025)).

Table 1-12. A summary of data collected and recorded by the ERAMMP NFS teams. All elements were delivered by UKCEH, except where noted for BTO and BGS,

Metric	Method
Vegetation	Species cover and Vegetation properties within 10 types of plot recorded. Plots include five permanent pre-selected random 200m^2 quadrats within each km square, and other plots which are both random and targeted to capture areas of conservation value, depending on complexity of square. Number of plots within square vary from a minimum of five random plots for very homogenous squares to 46 in very complex squares with high variability of habitats and complex mix of linear features.
Topsoil	Three 0-15cm topsoil cores taken within the five permanent random Vegetation quadrats. Soils are assessed from one of the cores for chemical and physical properties which include Organic matter content, pH, carbon, nitrogen and phosphorus content, volumetric water content, bulk density and porosity. The remaining two cores are archived – one dried and one frozen – the latter for repeating GMEP eDNA analysis if requested. Organic layer and Peat depth taken.
Soil Erosion	Erosion features are recorded and photographed within 200m circles of the five permanent random Vegetation quadrats. This information is used to ground-truth aerial imagery supplied by BGS.
Pollinators	Surveyors walk a fixed route along two 1km linear transects which are, nominally, 500m apart and 25m from the square boundary. Using Wider Countryside Butterfly Survey methodology, measurements recorded include counts of pollinating insects (identified to species where possible, or morphospecies groups for cryptic taxa, such as hoverflies), cover of flowering plants and weather conditions. The survey is repeated twice in July and August. This work was managed by BTO.
Birds	Surveyors walk within 200m of all areas of the 1km square with access permissions. Birds seen and heard, identified to species, are counted and mapped during two visits between 1st April and mid-July, along with the survey route followed. This work was managed by BTO. All data entered spatially post-visit via online forms from field maps.
Headwaters	One first- or second-order stream is surveyed within a 1km square. Measurements recorded include a River Habitat Survey, erosion assessment, counts of invertebrate and diatom species, chemical analysis of alkalinity, phosphates, dissolved nitrogen, pH and conductivity, calcium and non-purgeable Organic carbon.
Ponds	One Pond is selected for survey within the 1km square. A Pond is defined as a body of standing water 25m^2 to 2ha in area which usually holds water for at least four months of the year. Measurements recorded include physical characteristics, Wetland plant community and macroinvertebrate community.
Historic Environment Assets	A condition and threat assessment of up to eight HEAs per km square which have been pre-selected by CADW and the Welsh Archaeological Trusts.
Public Footpaths	Bird surveyors assess Footpath condition with respect to signage and accessibility, using a standard set of codes, considering any public Footpaths that they encounter on their survey routes.
Woodlands	Area of Woodlands mapped within the 1km square and attributes recorded using UK Broad and Priority Habitat classification including type of Woodland, dominant tree species, structure and size of tress, new planting and contextual information.

Individual and Veteran Trees	Individual trees greater than 50m apart are recorded. Up to 10 veteran trees (maximum two per species) are recorded. Species, size and condition measured.
Hedgerows	Up to 10 Hedgerows are recorded in each 1km square. Measurements include Hedgerow diversity, physical structure and condition, management and Streamsides understorey plant diversity in a subset of two Hedgerows per 1km square.
Landscape Photography	Photographs are taken looking North, South, East, West within four permanent random Vegetation quadrats, closest to the centre point of each quadrant of each 1km square. In GMEP, these were used to assess the public perception of Landscape Visual Quality Index. Change is not reported in ERAMMP but the images data are available should this be requested.

The result of this is a very large database of new ERAMMP re-survey measurements between 2021-24:

- 1,800 permission letters sent
- 1,355 (75%) custodians granted permission to survey
- 247 squares surveyed
- 15,456 photographs taken
- 5,580 botanical plots surveyed
- 73 Ponds and 111 streams surveyed
- 346 Historic Environment Assets (HEAs) surveyed
- 584km transect surveyed for Pollinators
- 2,522 Soil cores taken
- 1,808 Soil Erosion features surveyed

The original GMEP baseline database 2013-16 is even larger, representing all 300 NFS squares.

1.4.6 Capture of Land by the National Field Survey for Broad Habitats and Designated Land

Wales is dominated by Acid and Improved Grassland, which together represent 61% of total land cover (2,079,600ha). Both GMEP and ERAMMP surveys are therefore dominated by sampling in these habitats. In ERAMMP, the prioritisation of specific option bundles by WG has resulted in a higher number of sampling of relevant habitats for these management types relative to other habitats. That said, the large coverage for Improved Grassland was unintended and linked to its presence in surrounding targeted Peat areas. The area of land shown for GMEP and ERAMMP in Figure 1-7 reflects only land where permission was granted.

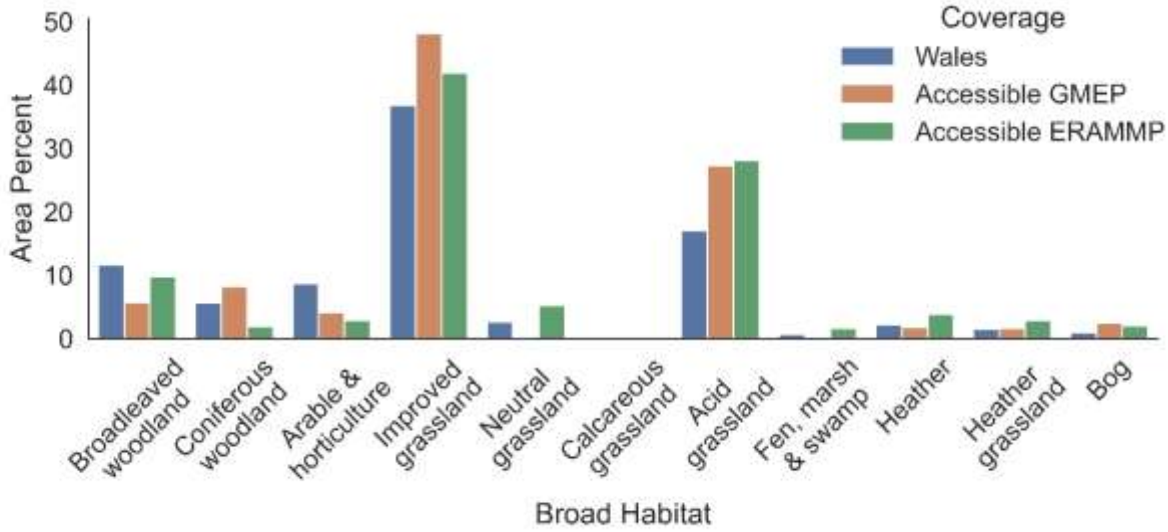


Figure 1-7. The percentage of land by Broad Habitat for Wales, and permissioned and sampled in GMEP and ERAMMP.

Wales has designated 29.5% of its land and some of this land has multiple designations (maximum 5). The NFS captures a greater proportion of this land relative to non-designated land (1.3% of land compared to 1.1% of all Wales) due to the stratification approach of the Nationally Representative sample and WG prioritisation for re-survey. This is particularly notable for National Parks.

Table 1-13. Designated land areas for all Wales and within squares which were re-surveyed in area and as a percentage. The area and percentage of designated land in scheme which was re-surveyed is also shown which was dependent on permissions received.

Designation	Wales		Land with permission to survey in-square		Land with permission to survey in-square (with Glastir options)	
	Area (ha)	Area %	Area (ha)	Area %	Area (ha)	Area %
Areas of Outstanding National Beauty	99,900	4.8	1,270	6.9	270	1.5
National Nature Reserves	22,500	1.1	250	1.4	170	0.9
National Parks	406,200	19.5	5,800	31.4	2,960	16.0
Special Areas of Conservation	127,400	6.1	1,550	8.4	1,080	5.9
Special Protection Areas	82,400	4.0	1,150	6.2	890	4.8
Sites of Special Scientific Interest	220,900	10.6	2,530	13.7	1,730	9.3
Natura 2000	148,300	7.1	1,930	10.5	1,430	7.7
All Wales	**612,900**	**29.5**	**8,200**	**44.4**	**3,940**	**21.3**

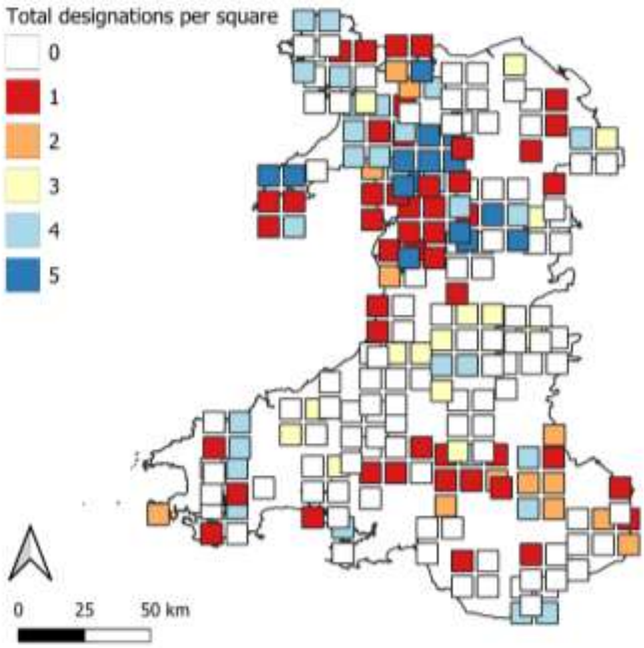


Figure 1-8. The overlap between NFS survey squares and designations but randomly shifted to protect locations. The overall picture however is correct.

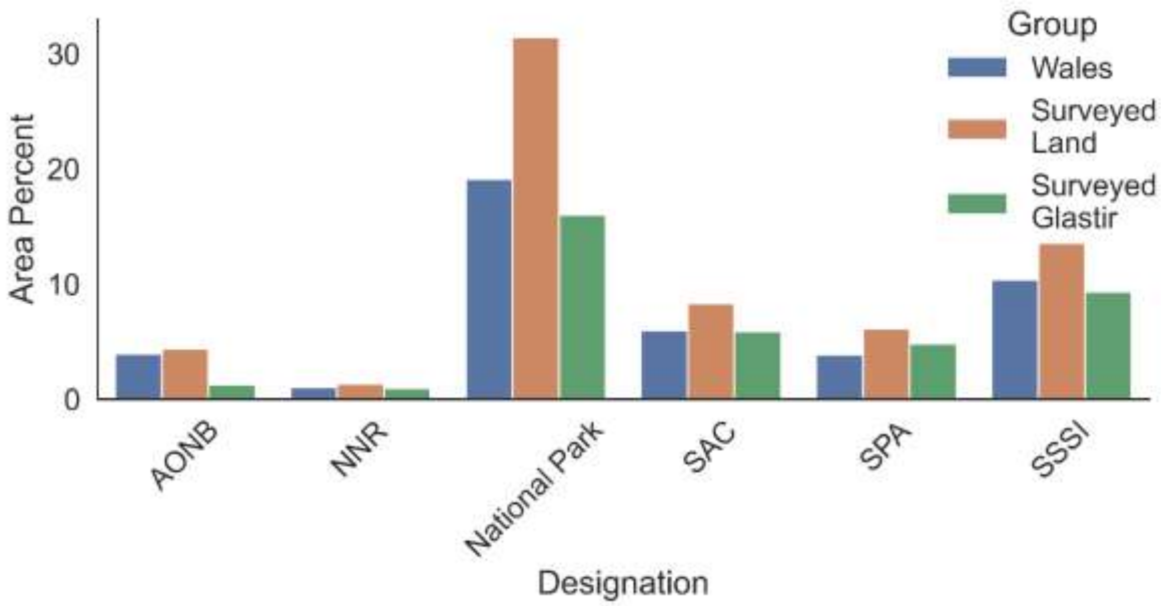


Figure 1-9. Percentage of designated land for Wales; for land in re-surveyed squares which had permission to survey (Surveyed Land); and for Surveyed Land with any Glastir management option uptake in any year (Surveyed Glastir).

1.4.7 Analysis of the National Field Survey Data

The key aim of the re-survey was to:

a) Quantify how the wider countryside of Wales had changed over the last 10 years since the GMEP survey and to place this within the context of longer-term historical trends where these were available primarily from UKCEH's Countryside Survey.
b) Report the impact of Glastir management options compared to land outside of Glastir, focussing on the evidence for delivery against Glastir objectives.
c) Integrate the findings to understand whether the trends reported for Glastir may have contributed to the overall national signal.

Therefore, two broad types of analysis were conducted in this report: a) analysis of National Trends using a Nationally Representative sample of squares; b) analysis of the effects of Glastir management options using the full population of Nationally Representative and Glastir Targeted squares. Critically, the same sampling approach was used for both analyses as part of the same monitoring programme, which means that; c) the contribution of Glastir to the National Trend can also be explored. Wales is unique in the UK (and we understand also within the EU) in combining national and AES monitoring in this way.

1.4.7.1 National Trends and Change in National Estimates

To understand the trends in indicators across Wales since the GMEP survey, we analyse National Trends using the Nationally Representative sample of squares. By ensuring we only use the representative sample we can be confident that trends are representative of Wales as a whole. To increase the detection levels of change of National Trends in Wales, WG invested in a 50% increase in the Nationally Representative 1km squares relative to the UKCEH Countryside Survey Wales 2007 (150 squares compared to 100 squares). There was only a small overlap between the two surveys to maintain their independence (25 squares). A total of 147 Nationally Representative squares were re-surveyed in ERAMMP and are reported here.

The analytical approach used in the GMEP report linked the Countryside Survey and GMEP datasets using a modelling approach; however, as we now have a complete re-survey of the new expanded population of squares following the ERAMMP re-survey, a decision was made to limit analysis for this report and all future analyses to this new, expanded population of 150 GMEP and ERAMMP squares. This means the national estimate has frequently changed relative to the values estimated from Countryside Survey and GMEP solely due to random effect of a different overall sample population. The key issue to note, however, is that a comparison of the ongoing trends between the two datasets is still valid as the fundamental sampling methods have been maintained. An example of this is illustrated below, where the overall national estimate has changed but a trend of a decline in an indicator has clearly been shown to have reversed, leading to a trend of recent improvement.

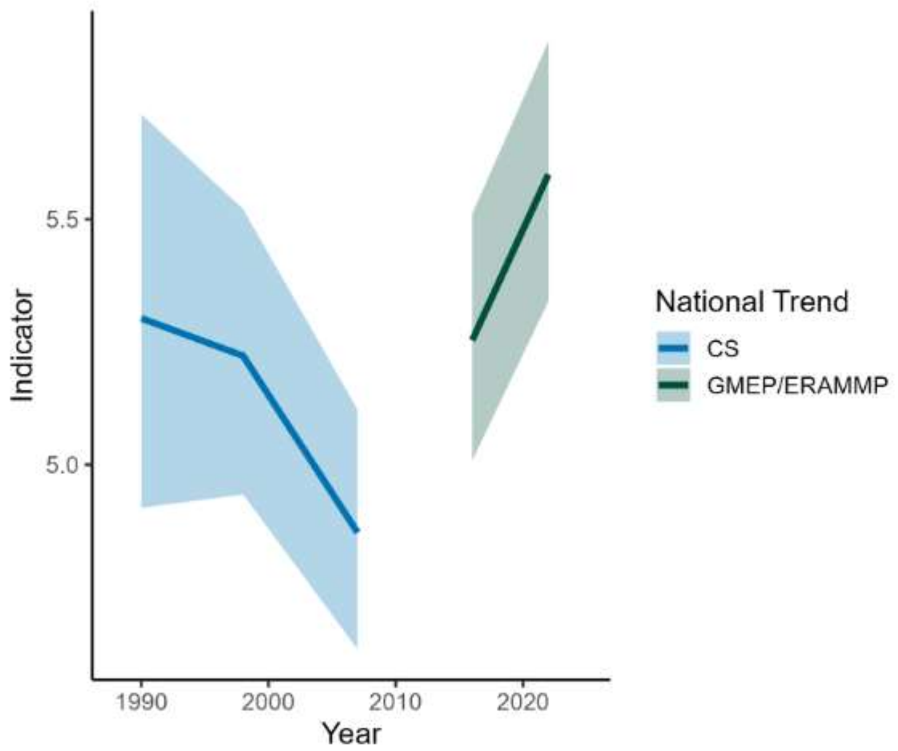


Figure 1-10. An example of a figure combining National Trends data from Countryside Survey (CS), GMEP (2013-16) and ERAMMP (2021-23) from a Nationally Representative sample. As methods of sampling and analysis between the three programmes have remained the same, the data provide robust evidence of a halt of a decline and switch to a stated of improvement in the hypothetical indicator.

1.4.7.2 Comparing Trends of Land In and Outside Glastir Management Options

Both the Nationally Representative and Glastir Targeted squares (225 squares in total) were used in the analysis to detect the impacts of Glastir management option bundles. See Section 1.3.3 for an explanation of the Glastir management option bundles approach.

With data from two time points available (the GMEP and ERAMMP survey periods) we are now able to look for impacts of Glastir management options on change in indicators over time. Previous reporting under GMEP was only able to look at spatial differences, i.e. if land which had entered the scheme was of higher environmental quality compared to the national average. If Glastir bundles are having a positive effect on indicators, then we would expect to see a more positive change over time under that Glastir bundle. If the indicator is declining outside of Glastir management options, then a positive Glastir management options effect can be observed as a lack of decline over time compared to the counterfactual. In the example below (A) we can see the indicator is stable where the Glastir bundle was absent (BundleX absent) but increasing where it was present (BundleX present).

For Birds whose populations within 1km squares cannot meaningfully be ascribed to individual habitat patches, proportions of habitat areas within surveyed areas (that were suitable for management for a given bundle and actually had such management) were used as continuous predictor variables. In these cases, results are presented comparing ‘high’ and ‘low’ Glastir management options coverage, derived from the statistical model results for the continuous predictors, as opposed to comparing scheme and non-scheme land. This is illustrated in figure (B) below.

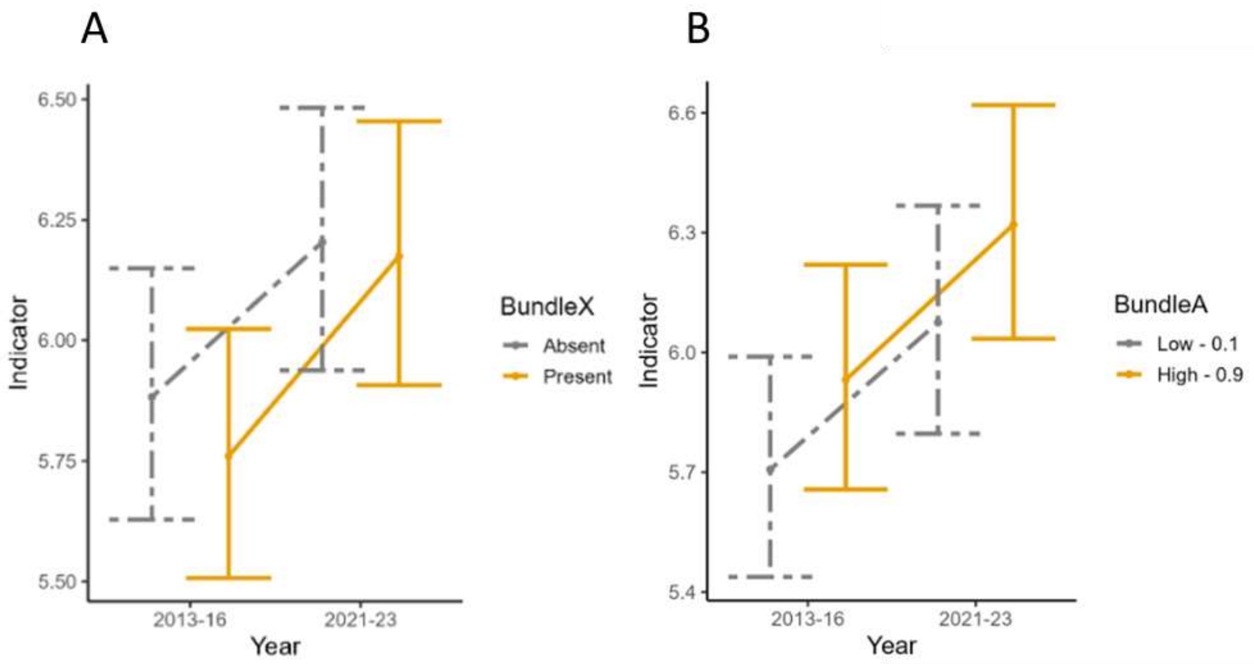


Figure 1-11. An example of the trends observed in: A) the presence and absence of a Glastir management options bundle from GMEP (2013-16) and ERAMMP (2021-23), and B) where Glastir presence in a square is High (>0.9) or Low (0.1) used for all Bird analyses.

1.4.7.3 Assessing the Influence of Glastir Management Options on Ongoing National Trends

The mean values provided by Nationally Representative and Glastir Targeted squares are different as the former is representative for Wales whilst the latter is biased towards areas with high Glastir uptake which were often of a more upland and peat-dominated nature. An example of the consequences of this is shown below where the mean for land in and out of scheme is, for this example, above the national mean.

This figure also illustrates the contribution of Glastir management options to National Trends, i.e. where Glastir management options are present there is an upward trend which is clearly more typical of that observed in the National Trend compared to where Glastir is absent. This suggests Glastir management options have contributed to the upward trend observed at a national scale.

Where this is not seen, and a Glastir management options trend does not mirror trends seen at a national scale, it suggests that uptake has not been of sufficient magnitude within our Nationally Representative set of squares to change the national picture. In an example like this, a positive trend for Glastir would not be reflected in the National Trend.

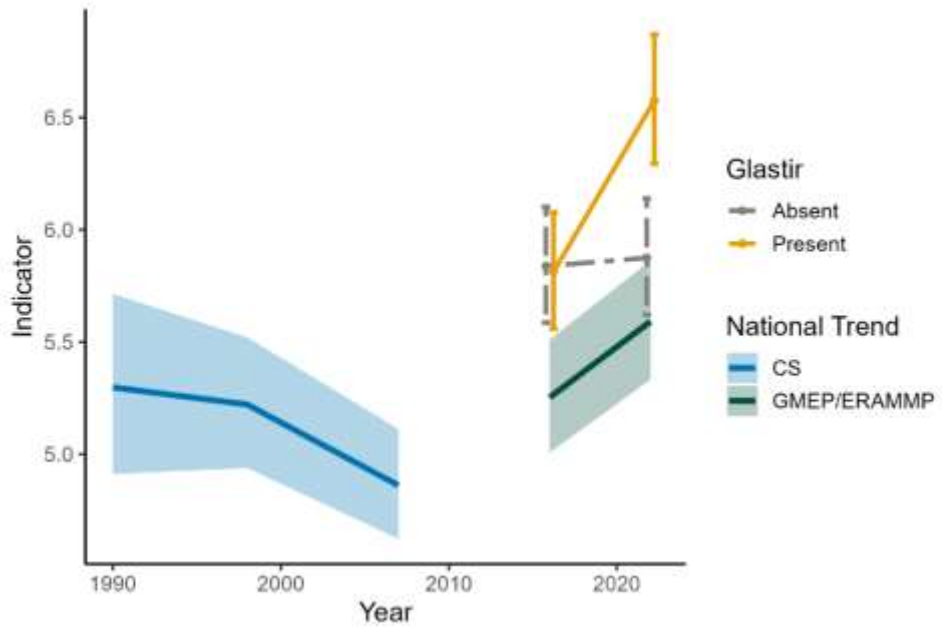


Figure 1-12. An example of a figure combining National Trends data from Countryside Survey (CS), GMEP (2013-16) and ERAMMP (2021-23) from a Nationally Representative sample and the sub-population of sample squares for assessing Glastir management options effects. This example shows there has been a historic decline in the National Trend which has now increased. The lines representing Glastir presence and absence suggests Glastir has most likely contributed to the observed increase in the National Trend. The blue and green shaded areas and vertical lines indicate the statistical uncertainty around the mean values.

1.4.7.4 Statistical Approaches Used for National Trends and Glastir Management Option Impact Analysis

For National Trend analyses we estimate the change in indicator values in each habitat of interest in the GMEP and ERAMMP surveys, and assess whether this change is significant. National Trend models are mixed effect models where survey (GMEP or ERAMMP) is the only fixed effect. The random effect structure varies between different indicators to account for differences in the structure of data collected. Estimates of mean indicator values are obtained for both time periods, along with an estimate of change.

For Glastir management options impact analysis, the various terrestrial and Freshwater responses require different statistical model structures for identification of Glastir management options bundle effects due to differences in the way the data are collected and differences in ecological processes. For example, Headwater streams may be influenced by Glastir options applied across the whole upstream catchment, but this is not the case for Soils where the spatial effect of Glastir will be very local and only relevant to a specific sampling site.

Table 1-14. Method of determining spatial relationships between field observations and Glastir bundles for different Natural Resources. Temporal relationships can be found in ERAMMP Technical Annex-105TA1S1: Wales National Trends and Glastir Evaluation. Supplement-1: Data Analysis Methods (Jarvis, et al., 2025).

Theme	Unit of Measurement	Spatial Glastir Definition
Biodiversity – Vegetation	Vegetation plot	A plot is 'in' a bundle if any actions associated with the bundle occur within a 100m radius buffer.
Biodiversity – Hedgerow	Hedgerow	Spatial buffer of 0.5m to overlay Glastir Hedgerow options on linear features.
Biodiversity – Birds	1km square	Glastir is summarised as the total area of land parcels within the survey square that are under an option in the focal bundle.
Biodiversity – Pollinators	Transect section or timed observation location	A transect or timed observation location is 'in' a bundle if any actions associated with the bundle occur within a 100m radius buffer.
Soils	Soil core	A plot is 'in' a bundle if any actions associated with the bundle intersect with the plot.
Soil Erosion	1km square	Aerial imagery approach used but ground-truthing undertaken within 200m radius of permanent random vegetation quadrats
Freshwaters – Headwaters	Upstream catchment	Glastir coverage (for a specific year) is quantified for the upstream catchment as the area affected by any-and-all actions within a given bundle as a percentage of the available area within the catchment.
Freshwater – Streamsides	Transect section (500m)	A transect is 'in' a bundle if any actions associated with the bundle occurred with a 100m radius of the surveyed transect.
Freshwaters – Ponds	Pond	A Pond is 'in' a bundle if any actions associated with the bundle occurred with a 100m radius of the recorded Pond sample point.
Historic Environment Assets	1km square	Glastir maximum area in-square to 2015.
Public Rights of Way	1km square	Glastir maximum area in-square to 2015.
Landscape Metrics/HNV	1km square	Glastir presence of any bundle within a 1km square.

Despite these differences, all Glastir management options analyses reported follow a core model structure. This term tells us whether the presence or area of a bundle of Glastir management options has changed the trajectory of the response between GMEP and ERAMMP surveys. All Glastir models follow this core structure allowing comparison of Glastir management options effects across all themes and habitats, despite differences in the type and scale of responses.

Some models consider additional contextual variables, which may also influence responses independently of Glastir. Most commonly, effects of historic AES (Tir Gofal and Tir Cynnal) are included in the models, although contextual variables are not used in all themes. The Glastir management options impact models are also mixed effect models, with the random effect structure differing between different types of indicators. The basic model structure is shown below, where (1|Unit) describes the varying random effect structures:

Indicator ~ Survey*Bundle1 + Survey*Bundle2 + ... + (1|Unit)

The key metric we report on is the interaction term Survey*Bundle, referred to as the Glastir management options effect. This interaction tells us whether each Glastir management options bundle has a positive effect on change in the indicator compared to the observations where the bundle is absent (the counterfactual population) or present at low levels. Where historic AES is included in models it is also included as a Survey*Historic AES interaction term, so we can compare change between surveys where historic AES was either present or absent. A full description of the analytical approaches is provided in the ERAMMP Technical Annex-105TA1S1: Wales National Trends and Glastir Evaluation. Supplement-1: Data Analysis Methods (Jarvis, et al., 2025).

1.4.7.5 Data Preparation, Quality Control and Assurance

Briefly below are described the data preparation, quality control and quality assurance approaches undertaken for each type of data collected prior to statistical analysis.

Vegetation

Data used in Vegetation analyses comes from (i) full census of Vegetation within Vegetation plots (different sizes and locations) and (ii) field mapping of woody features. Initially when data returns from the field, there is a series of checks such as ensuring all species identified, all mapped features checked, checking out species not recorded previously and adding trait data. Expert quality assurance exercises are also carried out that collect data for comparison to ensure consistency between surveys, which are reported in ERAMMP Technical Annex-105TA1S4: Wales National Trends and Glastir Evaluation. Supplement-4: Vegetation Quality Assurance (Deacon, Fitos, Prosser, & Wallace, 2025).

Indicators are derived from the raw Vegetation plot data using R scripts to calculate consistently across all years. These draw on existing lists of positive and negative indicators, non-native species etc. There is a lot of work required to collate the data and create an analysis dataset pulling in important contextual variables identifying repeat plots and ensuring that there are no duplicates or errors. Spatial mapping data is also very complex and requires sorting and collating. We need to have data on the permissions within a square to include how much land was surveyable for scaling up extent indicators, particularly for national estimates. Extraction of Glastir management options coverage was also a time-consuming analysis. For Vegetation plots, this was a 100m buffer around the plots and assembling of all the bundles that overlapped. For other elements (e.g. Hedgerows), a separate spatial analysis of options was carried out, and for some analyses we assembled percentage coverage of bundles within a 1km square. Within each analysis (e.g. Broad Habitat), the overlap between bundles and data was checked and the most appropriate bundles included in the model construction.

Pollinators

Data used in Pollinators analyses come from (i) transect surveys and (ii) timed observations in the field by expert surveyors. Both data types were subject to expert quality assurance to confirm accuracy and consistency of species identifications. All Pollinator records were standardised to the same level of taxonomic accuracy (species-level for butterflies, with records of unidentified individuals discarded; and functional group level for bees, hoverflies, and in the timed observation dataset, also interacting plants). Analysis combining cover of flowering plants and weather have not been possible for this report but will be included in future analysis as they provide important contextual information which can increase power of detection.

Birds

Data used in the Bird analyses came from the square-level field surveys carried out by expert surveyors. All data was subject to expert quality assurance to confirm accuracy of species identification given location and behaviour. The analysis used the maximum count of individuals per species across all surveys carried out in a year for each square. Given the high mobility of Bird species, the analyses were carried out at the square level rather than field level and this maximum number accounts for variable breeding season timings.

Soils

Data used in Soils analyses comes from: i) contextual data collected in the field by surveyors (e.g. Broad Habitat, Peat depth) and ii) metrics derived from the physical Soil cores (e.g. pH, carbon concentration). Both data types are subject to multiple rounds of expert quality assurance prior to analysis. Raw (directly from the labs) and derived data (calculated metrics) are screened independently by laboratory staff and expert analysts, taking into account the expected distributions of each indicator, known relationships between indicators and meta-data and the context of each Soil sample (Soil type and habitat), repeating laboratory analyses where necessary to ensure robust results. During sample processing, laboratory analyses are also repeated for one sample in each batch to ensure consistency. Standard Soils with known properties are also processed alongside monitoring samples to ensure accuracy. All derived metrics are calculated using a bespoke, automated process that ensures consistency across years, based on the laboratory data and field meta-data collected by the NFS. The locations of all sample points are inspected to ensure sufficient accuracy of sample site relocation over time, and a new identifier given to all samples to reflect this to be used in subsequent analyses. Plots that were not sufficiently accurately relocated are given a distinct ID to previous visits. At all stages of processing, checks are made to ensure sample traceability back to the original field record. For additional detail, please see ERAMMP Technical Annex-105TA1S7: Wales National Trends and Glastir Evaluation. Supplement- 7: Soil Health (Bentley, Reinsch, & Robinson, 2025).

Freshwaters

Data used in the Headwaters, Streamsides and Ponds analyses is derived from six distinct field survey methods, including the collection of data on-location and the collection of physical samples for species identification and water chemistry analysis. Samples are sent to external sub-contractors for the identification of species and calculation of some derived metrics. Additional metrics are calculated by UKCEH. All data (raw and derived) are subject to expect quality assurance by UKCEH, considering data accuracy, integrity and consistency, in addition to quality control performed by sub-contractors during sample processing. Sampling locations are also quality controlled, ensuring accurate relocation prior to analysis of change and the derivation of upstream catchments or areas of influence for the different feature classes.

Landscape

Analyses of landscape data were closely tied to the Vegetation analysis. Some of the metrics relied on field mapping data within a square, e.g. connectivity of Broadleaved Woodland. For this, the area habitat data was used to calculate Euclidean distance between Woodland patches, a larger number indicates lower connectivity. This analysis was also carried out using the woody linear dataset. There was no complete dataset for the coverage of nonwoody habitats because the field mapping was reduced to only woody mapping in ERAMMP, so we did some additional work to create a new habitat map using habitat allocation provided by surveyors and UKCEH LCM to fill in the gaps. This enabled calculation of metrics such as habitat diversity and the proportion of semi-natural habitat. Analyses were also carried out for all of Wales and this used UKCEH LCM from 2010 and 2021.

Footpaths

Footpaths and PROW data is collected during by the Birds survey by the Birds surveyors who observed and recorded the access condition and signage of Footpaths they were able to access and observe whilst surveying. PROW were validated by cross referencing with a PROW dataset provided by WG. The dataset underwent multiple validation and quality checking during each phase of its lifecycle prior to analysis. The length of Paths classified by access condition and signage were summed for each square and separately for GMEP and ERAMMP, and standardised to proportions within each square. The analysis used Glastir option uptake area to 2015 as a predictor for the Glastir effect analysis and the analysis was at square level. Bundles were unsuitable for inclusion in the model as they are primarily selected for their effects on ecological-centric indicators. Glastir effect and National Trends analyses used four distinct indicators which assess how the proportional length of the access classes differ. For further detail see the ERAMMP Technical Annex-105TA1S12: Wales National Trends and Glastir Evaluation. Supplement-12: Public Rights of Way (Monkman, 2025).

1.5 Limitations and Caveats of the Data and Approach

The GMEP and ERAMMP programmes, which have been operational over the last 10 years, represent the only integrated national monitoring and AES evaluation programme by any of the four nations in the UK. It has followed robust, well-tested, published methodologies; however, as with all monitoring programmes, some limitations and caveats should be highlighted:

National Trends:

- Whilst power analysis was completed to identify the number of squares needed to detect change in specific indicators at the national scale, and the square selection approach for the Nationally Representative sample is highly efficient, the sample for the GMEP baseline represents just 1.4% of the land of Wales. The re-survey for ERAMMP is 1.1%. This will limit power of detection, particularly for less common habitats and species.
- The purpose of GMEP and ERAMMP is not to report on rare and specialised species and habitats, but the ‘wider countryside’, which is critical if we want to create a diffuse landscape through which species can move as climate change extremes accelerate (as well as being important in its own right for a range of environmental outcomes). NRW has responsibility for reporting on the former, and GMEP and ERAMMP should be regarded as complementary. That said, some information is provided for the more common Priority Habitats (e.g. Blanket Bog) and priority species (e.g. priority Bird abundance), which collates the data collected on all priority Birds across the survey squares.
- Indicators selected for reporting all have highly variable spatial and temporal patterns. Some indicators are highly dynamic and may be fast to respond to inter-annual variability (e.g. Pollinator abundance), whilst others, such as Soil carbon and Vegetation condition, can be very slow. This variation does not make one indicator

less or more important, but should be taken into account when interpretating the results.

- Statistical significance has been used to provide confidence about trends reported. However, it should be noted it is possible to have strong confidence about a small absolute change, as well as low confidence in a large, apparent change. In addition, some indicators are of higher value than others in indicating current status as opposed to an early warning. Our experts have used their judgement in the ERAMMP Report-105: Wales National Trends and Glastir Evaluation report (Emmett & the ERAMMP Team, 2025) to help readers navigate these issues and to give an overall assessment as to the longer-term and short-term trends for individual habitats.

1.5.1 Glastir Management Options Impact

- Due to the large number of models required to assess all indicators across all themes, there is the potential for false positive and false negative results to be reported. Where these are thought to have occurred, they are highlighted; however, it is not possible to definitively identify false results so care should be taken in interpretation.
- The GMEP survey provides a unique baseline against which change can be tracked reducing the risk of false positives associated with better quality land coming into the scheme (Emmett & team, 2017). However, as this baseline was measured over a period of four years (2013-16), it is possible some change was already taking place on land which came quickly into the scheme, particularly for highly responsive indicators such as Pollinators. A precautionary approach has, however, been taken and it has been assumed that the baseline provides a true time zero status for all Glastir management options analysis.
- To evaluate Glastir management options bundle effects requires multiple difference-in-difference analyses, and when broken down by habitat type it is likely that power to detect these is variable across habitat/bundle combinations. Power is likely to be lower for bundles with lower uptake and for habitats with fewer observations, and will vary between indicators. Although a previous power analysis conducted during the design of the GMEP survey indicated that the number of squares monitored should be sufficient to detect trends and Glastir effects across Wales, it should also be noted that not all squares were re-surveyed in ERAMMP. In addition, the results of the previous power analysis do not guarantee sufficient power to detect effects once analysis is broken down into individual habitats and bundles.
- Analysis has included in some cases the potential legacy effect of past land management schemes, such as Tir Gofal and Tir Cynnal. There is a highly variable overlap between these historic schemes and land coming into scheme between difference habitats, e.g. there is low overlap for Improved Grassland but high overlap for Acid Grassland. This complexity requires further work, but it is highly likely that, in some cases, a ‘no detectable change’ of land in scheme compared to land out of scheme may be due to continuation of payments to land managers to maintain options from legacy schemes or from management practices which suit a particular farm business. For Birds, relevant active Tir Gofal management was included in bundle total areas that were associated with GMEP data.
- Recent trends over the last 10 years since GMEP are the focus of this report and, whilst longer-term trends are often included for comparison, these were well covered in (Smart S. M., et al., 2009), (Emmett, et al., 2010) and (Emmett & team, 2017) and other reports such as SoNaRR and State of Nature Reports, and are not repeated here in any depth.

- As for National Trends, a statistically significant result does not equate to the size of effect. Figures are included in the Glastir Impacts sections and ERAMMP Technical Annex-105TA1: Wales National Trends and Glastir Evaluation supplements to illustrate the magnitude of change together with the statistical significance.

Overall, the analysis presented here is a first initial exploration of the very extensive database that is now available. Many more in-depth analyses are possible to explore specific questions and more integrated thinking going forward.

1.6 Where to Find More Information, and Access GMEP and ERAMMP Data

All field manuals describing methods used in the NFS are published and available together with in-depth annexes of the analyses. The GMEP report and many other GMEP and ERAMMP reports are available on the ERAMMP website[3].

All summary GMEP data and associated metadata is also available on the UKCEH Environmental Information Data Centre[4].

ERAMMP data will be available September 2025.

All GMEP and ERAMMP data are owned by the WG. The locations are not made publicly available to protect locations to ensure survey land remains truly representative of national change and is not subject to special action by land managers. Application to use the data on licence can be made to the WG. Contact: data@gov.wales.

[3] https://erammp.wales
[4] https://catalogue.ceh.ac.uk/documents/5563266c-5bcf-4d1a-87d6-3e3ca72dc8a1

2 LAND USE AND FARM MANAGEMENT PRACTICES

Emmett, B.A. [1], Anthony, S. [2], Maskell, L. [1], Monkman, G. [1], Rowland, C.S. [1] and Whitworth, E. [2]

[1]UK Centre for Ecology & Hydrology and [2]RSK-ADAS

2.1 Introduction

Changes in National Trends and the impacts of Glastir management options will both be influenced by changes in land use which is the fundamental change in the primary purpose of a parcel of land (e.g. residential and industrial, agriculture, forestry and woodland, conservation etc) and the change of management practices within a particular land use. Here we have focussed on change in management practices on farms in Wales as this is the priority target of Glastir. Management practices reported include change in stock numbers, fertiliser use and overall diversity of the farming system.

The evidence of change for both land use and farm management practices cover the period 2010 to 2021-23 and exploit a range of data sources including satellite date, field data capture (i.e. the NFS) and social survey (i.e. the FPS). This evidence base provides critical underpinning evidence which is used to help interpret the results reported in the remainder of the report.

2.2 Land Use

Land use is one of the most profound changes which can impact on our Natural Resources. ERAMMP has used satellite data to estimate the National Trend of change in land use from 2010 to 2021 using an approach developed by UKCEH which has been producing land cover maps (LCMs) since 1990. These maps have been produced annually since 2017, with the 2022 and 2023 maps just recently published: (Marston C. , Morton, O'Neil, & Rowland, 2024); (Morton, Marston, O'Neil, & Rowland, 2024). This production of annual maps has been made possible due to advances in processing and satellite data by applying an automatically trained Random Forest classification algorithm to multi-temporal Sentinel-2 composite images (Carrasco, O'Neil, Morton, & Rowland, 2019) combined with a range of context layers. Context layers help the classifier to avoid spectral confusion between surfaces with similar spectra; for example, coastal sediment and Urban sealed surfaces have similar reflectance properties but can be separated using coastal proximity. UKCEH also produces a Land Cover® *Plus* series which includes Land Cover® *Plus®:* Crops (available annually since 2015); and Land Cover® *Plus®:* Fertiliser and Pesticides which estimate average agricultural chemical applications at 1km square scale over the interval of 2012 to 2017 (Jarvis, et al., 2020).

Only recently has change in landcover been possible from these UKCEH LCM. Previously, methodologies were continually being improved meaning maps were not directly comparable. A consistent approach has now been developed allowing more recent maps to be compared with lower resolution satellite data enabling historic changes to be compared in five-year intervals for the UK albeit at lower resolution than the more recent LCM (Rowland, Marston, Morton, & O'Neil, 2020). This work is funded by UKCEH through its National Capability and is provided here as part of the UKCEH co-funding element of GMEP/ERAMMP.

Going forward, the WG has invested in the development of Living Wales (LW). As this is a new satellite derived product change, change data will only be available from 2018 onwards so could not be used for this report. A comparison of the UKCEH LCM and LW current habitat maps and the GMEP habitat mapping from the NFS has been carried out and has been reported in-depth (Maskell, et al., 2023). In brief, the methodologies, purpose and classes of the approaches all differ, making comparison somewhat challenging. This is particularly true in upland areas where there is significant variation in habitat as many occur in mosaics with many areas a complex mix of transition zones. Assigning continuously varying surfaces into discrete categories can be difficult, especially for borderline cases. To overcome difficulties like this, field surveyors make judgements based on the presence or absence of indicator species but it is not possible to detect indicator species from space. Satellite-based habitat decisions are based purely on energy spectra and context. Spectra are determined by dominant cover with a specific pixel size (which has become smaller over time with higher resolution now possible). These interpretation differences almost certainly have significant effects when comparing field- and satellite-based information. It should be noted that neither approach is the ‘truth’. Both have strengths and weaknesses.

Issues of interest we explored using the UKCEH LCM include:

- Is the rate of Woodland planting meeting WG ambitions of 2,000ha/yr?
- Has the area of Semi-Natural Habitat increased due to habitat creation (WFG indicator No. 43)?
- Has there been a loss of Arable and Improved Grassland for agriculture?
- Has there been a loss of agricultural land to Urban expansion?

Headline findings are described below.

2.2.1 National Trends

- Satellite data indicates 6.8% of land changing land use over the 11-year period between 2010 and 2021. This is not visible on national maps and therefore results are also shown in figures and tables.
- Woodland cover represented 358,400ha / 16.9% of Wales in 2021. This includes all land where 10m pixels were dominated by a signal representing woody presence. The NFI reported 14.6% for Woodland >0.5ha in 2021. The difference between these two estimates will include the inclusion of small woody patches in UKCEH which is excluded from NFI but also other methodological differences.
- Woodland cover (Broadleaf plus Conifer and other woody features) increased between 2010 and 2021 by 23,600ha, representing a 7.0% increase. Broadleaved Woodland increased by 29,000ha (+16%) whilst Coniferous Woodland declined by 5,600ha (-4%). This is a rate greater than the WG new Woodland planting ambition of 2,000ha per year. Some methodological changes (i.e. pixel size lowering from 25m to 10m) may have contributed to this finding but it represents the only historical satellite data which is available. This is similar to an estimate from the NFI which uses a field-based approach which estimated a 5.2% increase of cover in Woodland > 0.5ha between 1998-2021 (Forest Research, 2023). This difference is likely to be within the detection limit of both approaches.
- Urban cover has increased by 28.6% (28,200ha) – an area greater than Woodland expansion during the same period. The majority has come from Improved Grassland
- When the overall loss of Improved Grassland 3% (23,000ha) is combined with a 24% loss of Arable land (25,900ha), there has been a 5% decrease (48,900ha) in the extent of the most productive land for agricultural production in Wales.
- There has been no net change in the area of Semi-Natural Habitat (which includes Broadleaf Woodland, Semi-Natural Grassland, Heathland and Wetland). A small increase from 878,800 hectares to 904,600 of +1.2% is within detection limits but is

included for completion. If Broadleaf Woodland is excluded to capture the area of change for non-woodland semi-natural land, again there has been no detectable change from 692,000ha to 688,600ha / -0.2%). In 2021, the area of Semi-Natural Habitat was 42.6% of Wales including Broadleaf Woodland and 32% excluding Broadleaf Woodland.

- These land use changes are broadly similar to changes seen at the GB scale.

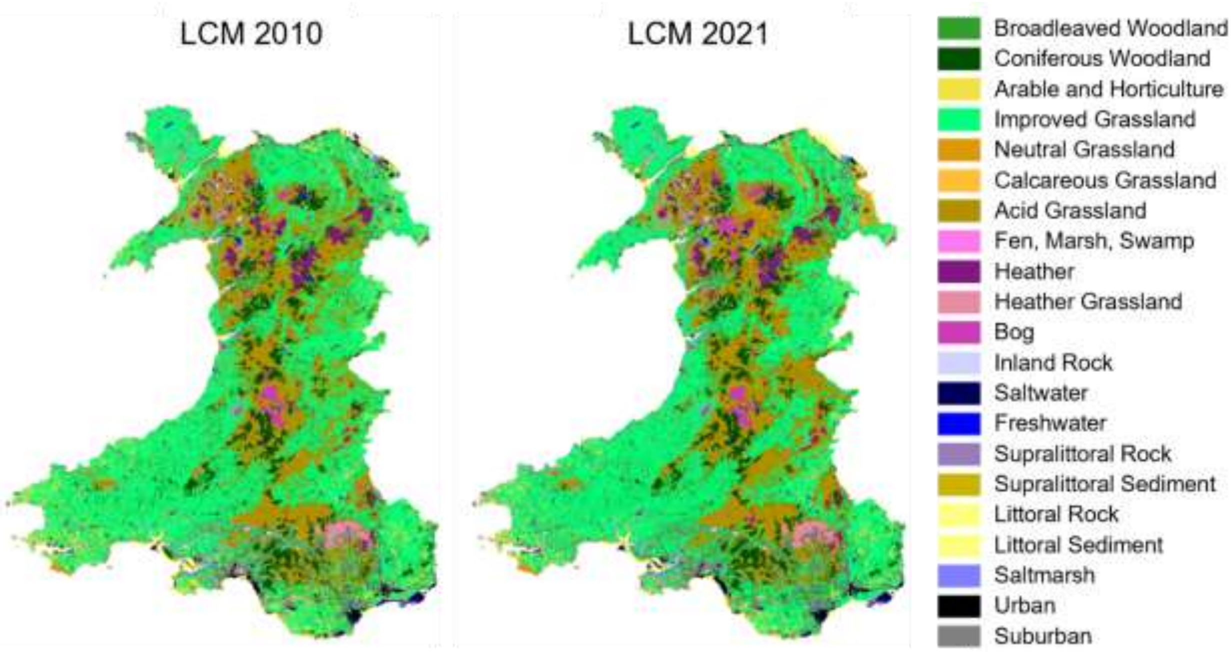


Figure 2-1. UKCEH LCM for 2010 and 2021.

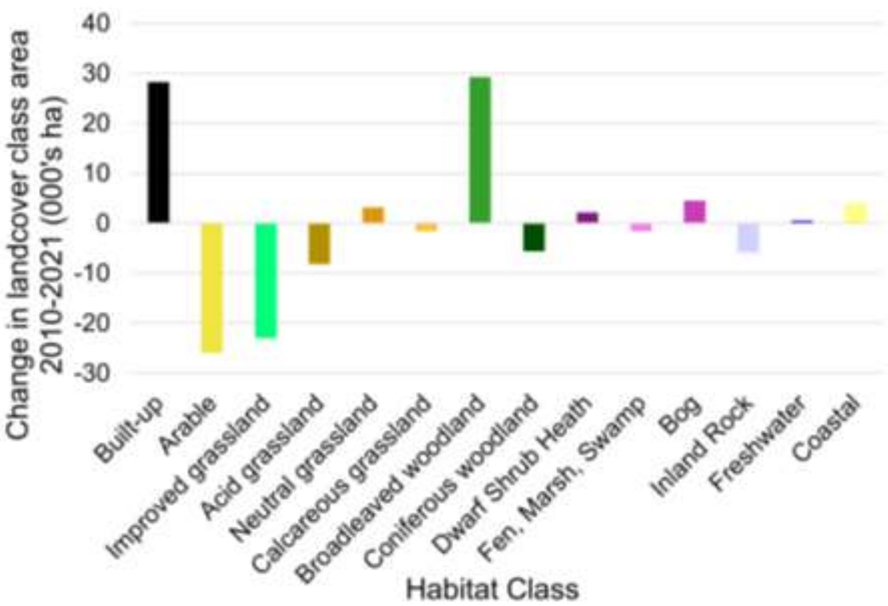


Figure 2-2. Change in land cover classes between 2010 and 2021 from the UKCEH LCM.

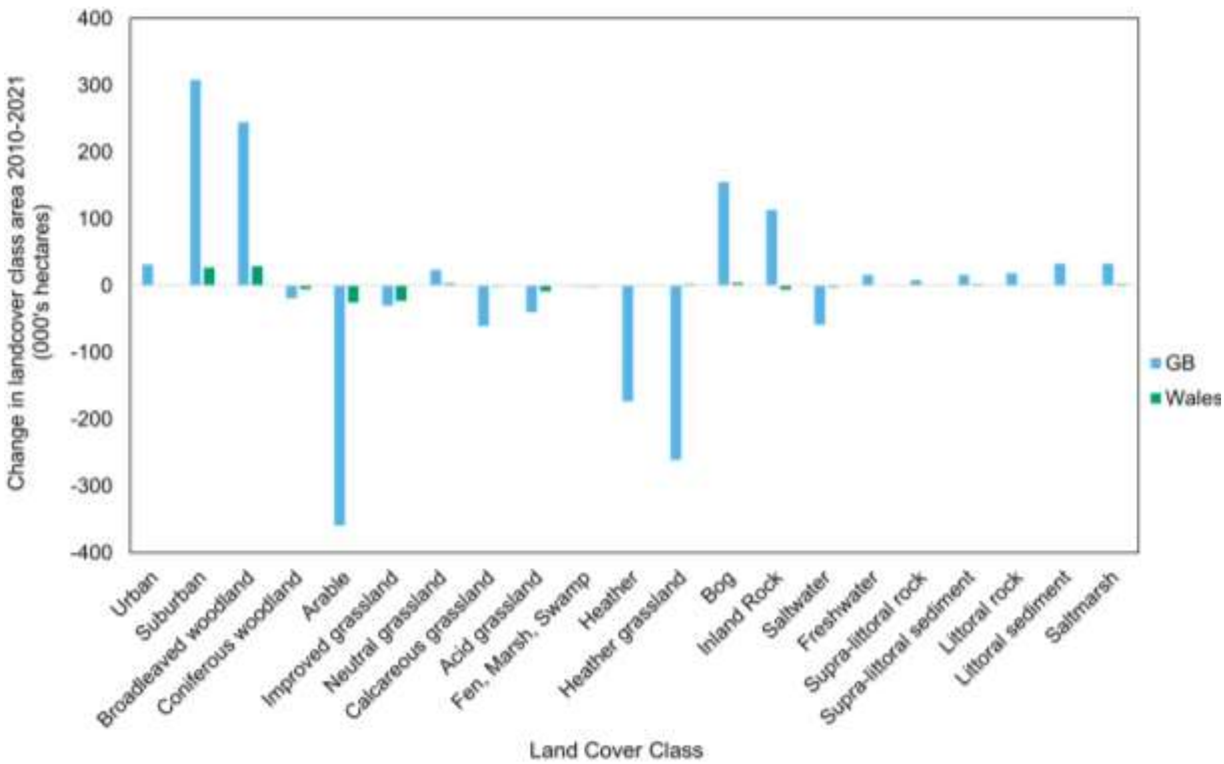


Figure 2-3. A comparison of change in land classes for Wales and GB 2010-21 (000's ha).

Table 2-1. Change in land use/habitat area (ha) as estimated by UKCEH LCM between 2010 and 2021 including the combined estimate of Semi-Natural Habitat with and without Broadleaf Woodland. The former is WFG National Indicator No. 43. The latter helps to identify change in non-woodland areas.

Land Use / Habitat Class	2010 (ha)	2021 (ha)	Change 2010 to 2021 (ha)
Arable	110,000	84,100	-25,900
Improved Grassland	876,300	853,300	-23,000
Acid Grassland	457,800	449,600	-8,200
Neutral Grassland	43,600	46,800	3,200
Calcareous Grassland	2,000	400	-1,600
Broadleaved Woodland	186,800	216,000	29,200
Coniferous Woodland	148,000	142,400	-5,600
Dwarf Shrub Heath	86,000	88,200	2,200
Fen, Marsh, Swamp	14,200	12,600	-1,600
Bog	15,900	20,400	4,500
Inland Rock	10,500	4,600	-5,900
Freshwater	9,500	10,000	500
Coastal	62,000	66,000	4,000
Built-up	98,500	126,700	28,200
Total	**2,121,100**	**2,121,100**	**Sum of +/- area = 143.6 (6.8% of Wales)**
Semi-Natural Habitat* with Broadleaf Woodland (WFG # 43_	**878,800**	**904,600**	**25,800 (+1.2% of Wales)**
Semi-Natural Habitat* without Broadleaf Woodland	**692,00**	**688,600**	**-3,400 (-0.2% of Wales)**

* All land excluding Arable, Improved Grassland, Coniferous Woodland, Freshwater and Built-up.

2.2.2 The Impact of Glastir on Land Use

Glastir made payments for options covering 23.8% (495,148ha) of Wales. A small number of these options were linked to creating land use change whilst the majority of options (ca. 490,000ha) were focussed on Habitat Management options which will impact on habitat condition but will not change land use categories as defined by the UKCEH LCM. This data originates from payments for Glastir management options from Rural Payments Wales (RPW). Not all of these changes will be detected by UKCEH LCM data as the small canopies of new Woodland and Hedgerows are unlikely to be picked. In summary, Glastir management options which will have contributed to land use change and habitat creation are:

- 3,780ha of Woodland Creation (+1.1% of 2010 area) of which 5ha was designated as agroforestry.
- 2,200km of new and restored Hedgerow.
- 992ha of peatland restoration (1.2% of peatland area) which has the potential to shift land use class, e.g. from Acid Grassland to Bog. (Note that peatland is not a land class in its own right.)
- 3,890ha of other habitat creation.

2.3 Change in Farming Practices in Wales

2.3.1 National Trends

Here we provide two sources of evidence relating to livestock numbers and fertiliser, which have the potential to have significant impact on habitat condition reported elsewhere in this report. These data have been selected as most Glastir management options taken up by area relate to the control or exclusion of grazing pressure and fertiliser use.

2.3.1.1 Livestock Numbers

Livestock are one of the primary influencers of habitat condition, the main source of ammonia emissions (which also contribute to particulate formation, PM2.5) and ruminants (Sheep & Cattle) contribute >60% (with manures, this increases to 75%) of agricultural GHG emissions in Wales.

For all of Wales, there is no consistent trend in total ruminant numbers between 2010 and 2023. Total sheep and lambs have increased by 450,333 animal / +5% since 2010 just before the start of Glastir from 8,244,162 to 8,694,495 in 2023. However, between 2010 and 2023, numbers increased to a maximum of 10,037,473 in 2017 suggesting the trends were unrelated to Glastir participation.

Numbers of cattle and calves decreased by 21,487 / -2% from their highest level in the same period from 1,138,127 in 2010 to the 1,116,640 in 2023.

All of these numbers are a decrease from historical highs in 1974 for cattle and calves and 1998 for sheep and lambs.

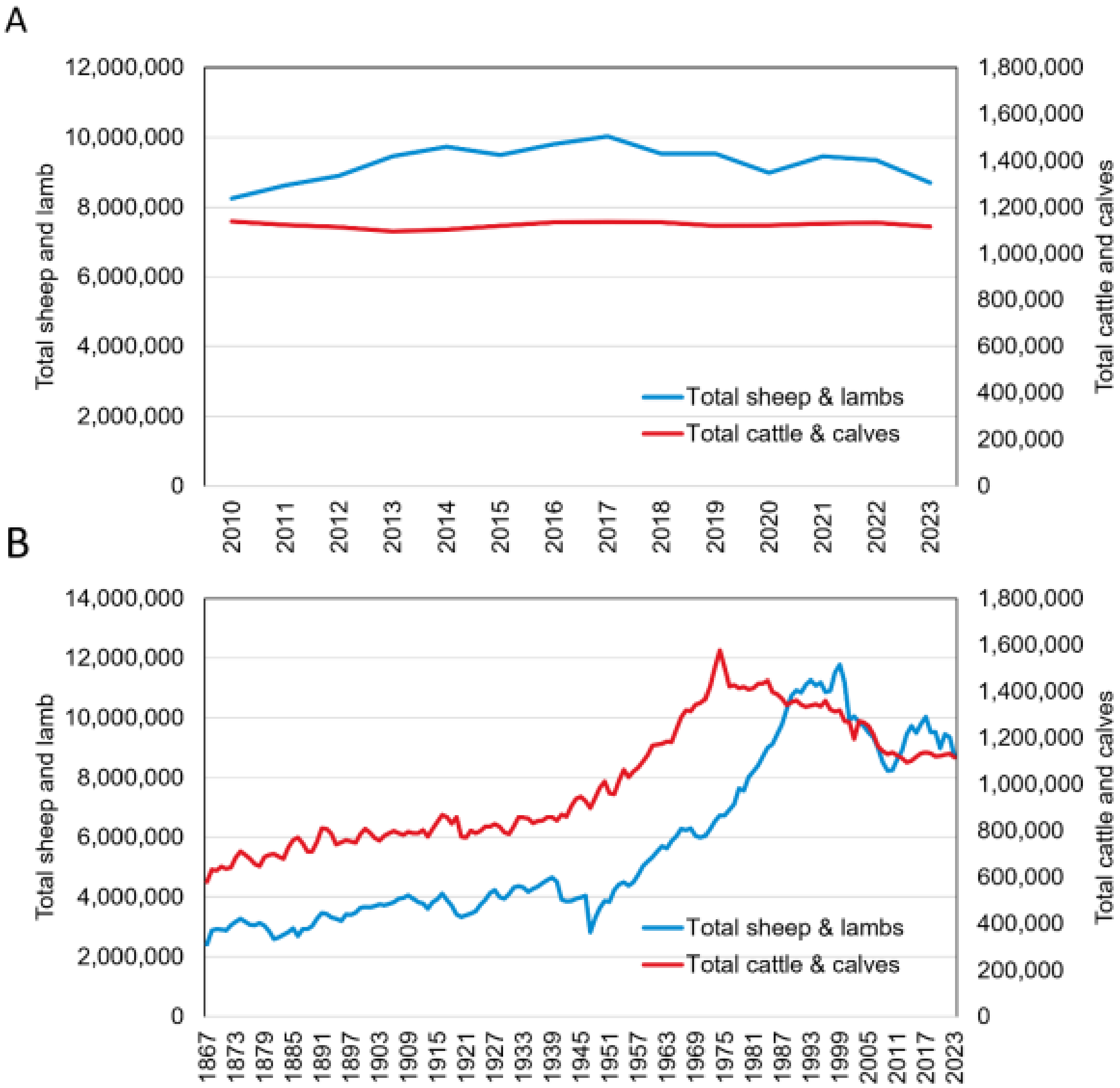


Figure 2-4. Trend in animal numbers since A) 2010 just before the launch of Glastir, and B) from 1867 (Survey of Agriculture and Horticulture: June 2023).

2.3.1.2 Fertiliser Use

Nitrogen (N) fertiliser use on Arable and Horticulture Land and Improved Grass are used by farm managers to support agriculture production as native soils do not contain sufficient nitrogen to support economic production levels on an annual basis. Nitrogen removed in crops and livestock needs to be replenished either by fertiliser use, although there is increasing interest in the use of legumes which have the capability to fix nitrogen out of the atmosphere to supply some of these needs in rotations, inter-cropping or herbal leys. If application rates are not matched to crop needs, there is a risk of eutrophication of soils and leaching to water bodies. Emissions of the GHG nitrous oxide from N fertiliser use also contributes to atmospheric nitrogen deposition together with ammonia release from animal wastes. These gases are transported away from the source on farm in the atmosphere and deposited across the landscape resulting in enrichment of all habitat types which can result in loss of native plants, many of which are adapted to low nutrient conditions. In 2021, it was estimated 99% of N-sensitive habitats in Wales (which is 44% of Wales) still received nitrogen deposition at rates which could cause eutrophication (Rowe, et al., 2023). This continued high rates of nitrogen deposition is known to result in a loss of plant diversity particularly those associated with open habitat and low growth forms with knock-on consequences for butterfly diversity (Hodgson, et al., 2014).

Since 2010 there has been a steady decline in the use of N fertiliser for crops and grassland across England and Wales by ca. 25% (DEFRA, 2024).

2.3.2 The Impact of Glastir on Farming Practices

2.3.2.1 Introduction to the Farmer Practice Survey

The ADAS FPS provided insights as to whether farm managers in the GE and GA schemes had changed their management practices away from the typical national picture. As background, a 1st FPS by ADAS focussed on the main effects of the previous Tir Cynnal and Tir Gofal schemes on farming practices (Anthony, et al., 2012). A 2nd FPS was commissioned by WG as part of GMEP was reported in depth in (2016-FPS; (Anthony, Stopps, & Whitworth, 2017) and the results summarised in (Emmett & team, 2014). This 2nd FPS established changes that were a direct response to Glastir, and specifically sought to collect information on changes in animal stocking rates and nutrient inputs on scheme entry that were neither explicit nor collected centrally as part of the scheme record keeping framework. The 2nd FPS also collected evidence for the persistence of behaviours from the earlier Tir Cynnal and Tir Gofal schemes (Anthony, Stopps, & Whitworth, 2017). The need for a repeat 3rd survey was identified as information provided by RPW on the number of holdings with ‘committed’ contract values under GE or GE elements identified that 45% of GA agreements did not begin until the year 2016 or later. The 2nd FPS used Glastir participation records that were complete as of October 2015 and therefore did not represent the maximum uptake of the GA scheme which was associated with more intensive effects on farm management. A 3rd FPS was therefore commissioned by WG.

This 3rd FPS used the same methodology and analysis approach where possible. It recorded changes occurring at the end of the scheme and provided a more robust assessment of the higher level of the scheme. The content and design of the survey is reported by (Anthony & Whitworth, 2023) and relied on comparisons between an in-scheme and non-scheme cohort of farms to infer effects.

A second objective of the 3rd FPS was to include additional questions to provide information on the social-capital and farm economic outcomes of Glastir participation in support of a parallel Socio-Economic Evaluation of Glastir study that was commissioned on a separate contract (No. C412/2021/2022-Glastir) under The Agriculture and Environmental Advice framework contract with ADAS. The survey therefore also collected information on climate change adaptation and the enhancement of farm business profitability, and perceived outcomes from Glastir participation on a range of farm economic objectives.

2.3.2.2 Farmer Practice Survey Design

The survey was designed by ADAS in consultation with the WG, project managers and stakeholders. Official approval of the questionnaire and final sample design was obtained from the Statistical Directorate by Richard Self on behalf of ADAS.
The survey was targeted at grazing livestock farms (Dairy, Cattle & Sheep) which account for the largest areas of managed land and fertiliser and manure nutrient inputs in Wales.
The survey questionnaire was designed to be a scripted telephone interview of 600 farms, taking up to 25 minutes to complete. The survey was translated into Welsh for those farmers

requesting this. The structure and flow of the survey were checked via a web implementation prior to the field work.
The survey questionnaire, introduction and privacy notices, are available in (Anthony & Whitworth, 2023).

2.3.2.3 Survey Sample

This 3rd FPS surveyed a total of 600 farms. The farms were stratified for analysis on the basis of participation in the Glastir Entry (GE (only)) and Advanced (GA or GE & GA) elements and on the basis of farm type. The farm types were distributed between Dairy ('DAIRY'), Cattle & Sheep in the Severely Disadvantaged Area (CS-SDA), and Cattle & Sheep in the Lowland and Disadvantaged Area (CS-DA & CS-LOW) of Wales (Anthony & Whitworth, 2023). The surveyed farms were also distributed by agricultural region and size (Standard Labour Requirement) in proportion to records in the Survey of Agriculture and Horticulture: June 2023, and according to records of participation in the preceding Tir Cynnal and Tir Gofal schemes. The latter was for consistency with the 2nd FPS, and a legacy effect of the preceding schemes was not expected. Farmers contacted to take part in the survey were given the opportunity to opt out. The overall refusal rate was 50%. However, the surveyed farm characteristics are representative of the background non-survey population of farms (Anthony & Whitworth, 2023).

The results presented in this summary are for the surveyed populations of farm types or an average for all farms that were surveyed. The survey achieved returns from 125 'DAIRY' farms, 226 CS-DA & CS-LOW farms and 249 CS-SDA farms, and was designed to maximise the detectable differences between survey strata. There was no attempt to raise the survey results to a representative national value that accounts for the relative numbers of each farm type. The surveyed farms managed a total area of 76,600ha, of which 55% was Improved Grassland and 6% was Arable land. Sole rights rough grazing accounted for 38% of the total land area. More than 1ha of Woodland was found on 64% of respondents' farms. For ease of interpretation, the summary of results presented in this section are generally based only on a subset of farms that were not registered Organic and had not participated in the Commons element of Glastir. It should be noted, the results from come the farm managers own assessment of management change as a consequence of Glastir participation.

2.3.2.4 Evidence of Management Change

31.1% of Glastir participants agreed or strongly agreed that they had 'changed my management of the farm', and 36.6% that they had made 'lasting changes to my farm management' (n 328). This is consistent with the findings from the 2nd FPS which identified that 34% of Glastir participants agreed there had been a change in farm management on joining the Entry scheme (Anthony, et al., 2016). This can be compared to the 61% of participants in the preceding Tir Cynnal and Tir Gofal schemes measured in the 1st FPS (Anthony, et al., 2012).

This suggests that payments may be continuing payments from previous schemes or paying for management that is already in place to maintain good practice. There were no statistically significant effects of farm type alone. Farms participating in the upper GA level of the scheme were more likely to agree (41.1% and 45.4%) than farms participating in GE (only) (18.5% and 28.7%). It was assumed that this reflects the increased requirements of management prescriptions and remuneration under GA. Of greater significance is that the number which agreed for GE decreased from 70% in the 2nd FPS to 46% in this 3rd FPS to the 'I have changed my management of the farm' statement. This is interpreted as evidence that any management changes did not persist after GE agreements came to an end as all GE only elements came to an end before or during the year 2019 (Anthony & Whitworth, 2023). In contrast, where respondents had participated in the GA element of the scheme, 79% of the scheme agreements were still live at the time of the survey, 11% had ended within the last three years, and 10% had ended more than three years ago.

2.3.2.5 Reported Scheme Payments

Overall, the survey average annual payment to farms in the GE (only) level of the scheme was £4,200, and for the GA or GE & GA level of the scheme was £11,230 (also including payments under the Woodland Management elements). This level of farm support was unlikely to result in changes in the broad approach to management but rather maintain existing practices. There was no relationship between the level of payment and self-reported management change which suggests farm managers did not conflate overall management of the whole farm with land embedded in the Glastir scheme. The payments information indicated that the level of farm support was unlikely to result in changes in the broad approach to management under the scheme, excepting the special case of support payments for conversion to Organic farming. ADAS also noted that the most popular of scheme options receiving payment under Glastir were for ‘grazed pasture – low/no inputs’ and Woodland Stock Exclusion, which together accounted for 35% to 40% of options taken up (Arnott, Chadwick, Harris, Koj, & Jones, 2019). As a high percentage (31%) of the Improved Grassland area in Wales already does not receive manufactured fertiliser (DEFRA, 2022), there is some risk of payment for practices already in place – so called ‘deadweight’ in negative scheme prescriptions (Rayment, Deane, Pieterse, & Parker, 2012). However, the ‘grazed pasture – no or low inputs’ went beyond restricting application of inputs. The classification of Woodland ecological condition in Wales has reported that only 24% of native Woodland stands were in unfavourable condition as a result of grazing pressure (Forestry Comission, 2020). (Scheme participation was therefore more likely to maintain existing practices rather than support large and detectable changes.

2.3.2.6 Change in Farm Economics

85% of respondents stated they had hoped that the scheme would ‘provide extra income to help the farm business remain viable or profitable’ and 75% stated that the scheme would ‘provide income stability’. ‘Compensation for the loss of income or increased costs of environmental work’ was cited by 67% of respondents, and ‘provision of capital investment to upgrade farm infrastructure’ was cited by 74% of respondents. Overall between 55-84% of scheme respondents stated their objectives regarding farm economics had been partly of fully realised.

2.3.2.7 Change in Social Outcomes

Overall, the combined GE and/or GA scheme respondents agreed or strongly agreed that they had made improvements in business resilience (40%), environmental motivation (45%), acquisition of sustainability skills (37%), and personal health and welfare (25%) as a result of scheme participation. The respondents that had participated in the higher GA level of the scheme were more likely to agree or strongly agree that they had made improvements compared to GE (only) by ca. 15%.

2.3.2.8 Woodland Management

34% of GE or GA respondents with a Woodland Management grant (46 respondents) had restored or created Woodland in the past three years. Of these, 93% stated that they would not have proceeded without grant support. Overall, 90% of the survey farms with Woodland actively managed their Woodland for one or more services. Respondents most frequently managed all or part of their Woodland for ‘wildlife habitat’ (70%), ‘livestock shelter’ (57%), ‘fuel or firewood’ (37%), ‘watercourse protection’ (44%) and ‘biosecurity’ (36%). Management for ‘carbon sequestration’ was reported by 30% of respondents.

The results were generally consistent with the 2nd FPS. Management for 'wildlife habitat' was marginally (+13%) more likely on farms participating in GA than non-scheme farms. The 2nd FPS had also found that Glastir participants were less likely to manage their Woodland for livestock shelter. The survey results were consistent with the popularity of the Woodland Stock Exclusion scheme option (Arnott, Chadwick, Harris, Koj, & Jones, 2019).

The WG's aim is to support the planting of 180,000ha of trees by 2050 to help meet Net Zero targets and achieve a wide range of environmental benefits (Welsh Government, 2021) (Welsh Government, 2023). More than 1ha of Woodland was found on 72% of the 'GE or GA' farms, and 59% of the non-scheme farms. The Glastir scheme provided grants for Woodland Creation and Restoration. However, relatively few survey respondents (11%) had received any form of grant for Woodland Management. This was partly a result of a targeting bias in the survey. Overall, 34% of GE or GA respondents with a Woodland Management grant had restored or created Woodland in the past three years. Of those, 93% stated that they would not have proceeded without grant support.

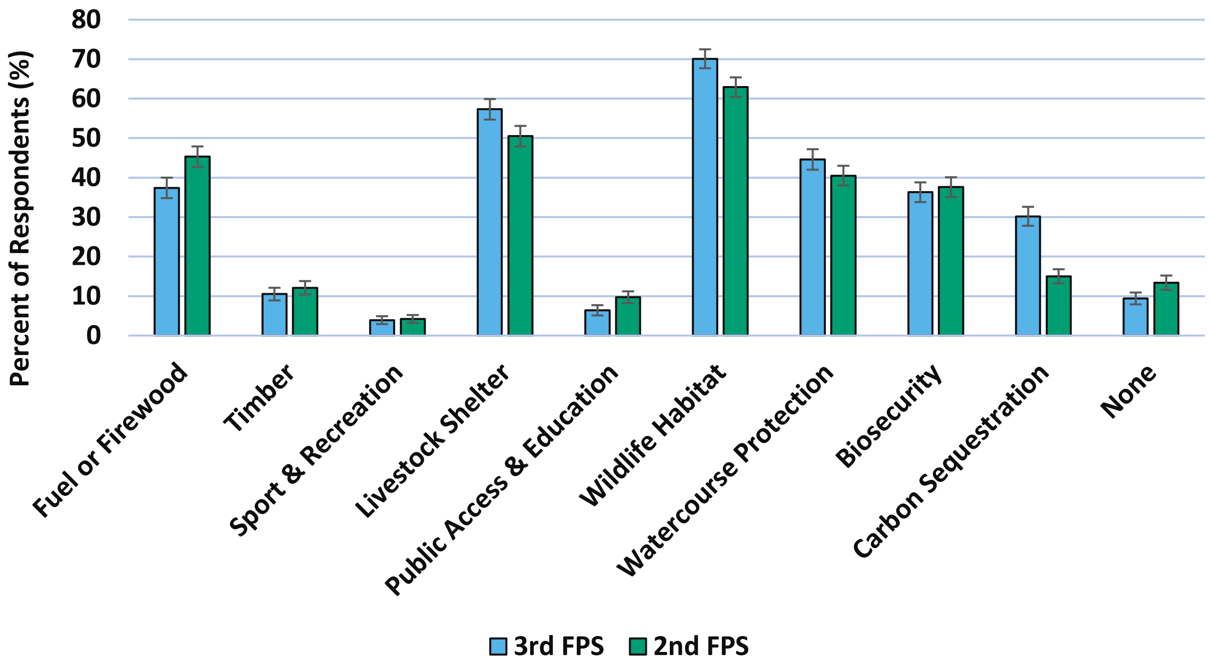


Figure 2-5. Percentage of survey respondents with Woodland actively managing part or all of the Woodland area for specific services in the 2nd (n 380) and 3rd (n 361) FPS.

2.3.2.9 Livestock Change

There were no differences between the Glastir and non-scheme survey respondents with respect to recent livestock changes over the last 3 years (where this was >10% of current stock number, i.e. disregarding small changes of herd size). The 2nd FPS reported a 3.9% decrease in breeding ewe numbers associated with entry to the scheme.

Overall, 27% of respondents reported a recent large decrease in the number of breeding ewes and 10% reported a large increase in the past three years. There was a similar pattern of change in the number of beef suckler cows, but more respondents reported a large increase in the number of dairy cows (19%) and finishing beef cattle (22%) than a large decrease (11% and 12% respectively). 'Changing input costs' was most often cited where numbers decreased closely, followed by 'environmental regulation' cited by 62% of respondents.

A low level of citation indicated little or no effect of end of scheme on animal numbers.

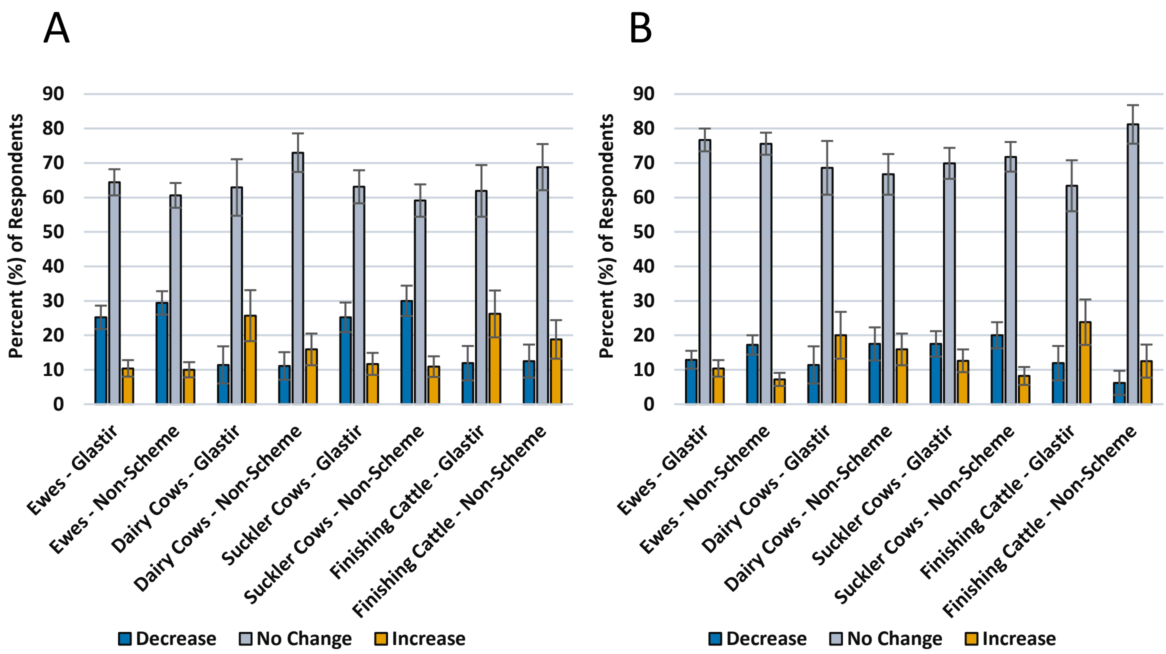


Figure 2-6. Percentage of survey respondents reporting a large (10%) increase or decrease in animal numbers in: A) the past three years, or B) planned for the next three years, for Glastir and non-scheme farms having the relevant animal type. Excludes Organic farms and those in the Glastir Commons scheme.

2.3.2.10 Fertiliser Change

Overall, there were no differences between Glastir and non-scheme respondents in response to changes in fertiliser use in the past 3 years. This contrasts to the 2nd FPS where a 8.5% reduction in nitrogen use and 9.4% reduction in phosphorus use on entry to the Glastir scheme.

Overall, 58% of respondents reported a large decrease in the application of nitrogen and 3% reported a large increase in the past three years (n 295). There was a similar pattern of change in the application of phosphate. The results reflected the trends in the British Survey of Fertiliser Practice 2023 (DEFRA, 2024). The vast majority (92%) of Glastir and non-scheme respondents cited an ‘increase in fertiliser cost’ as a contributing reason for change. ‘Existing scheme option requirements’ and ‘end of scheme option requirements’ were cited by only 10% and 7% of respondents respectively reporting some recent change in fertiliser use. There was no evidence that participation in the Glastir scheme was selective for farms having a different trend in manufactured fertiliser use from the national population of farms.

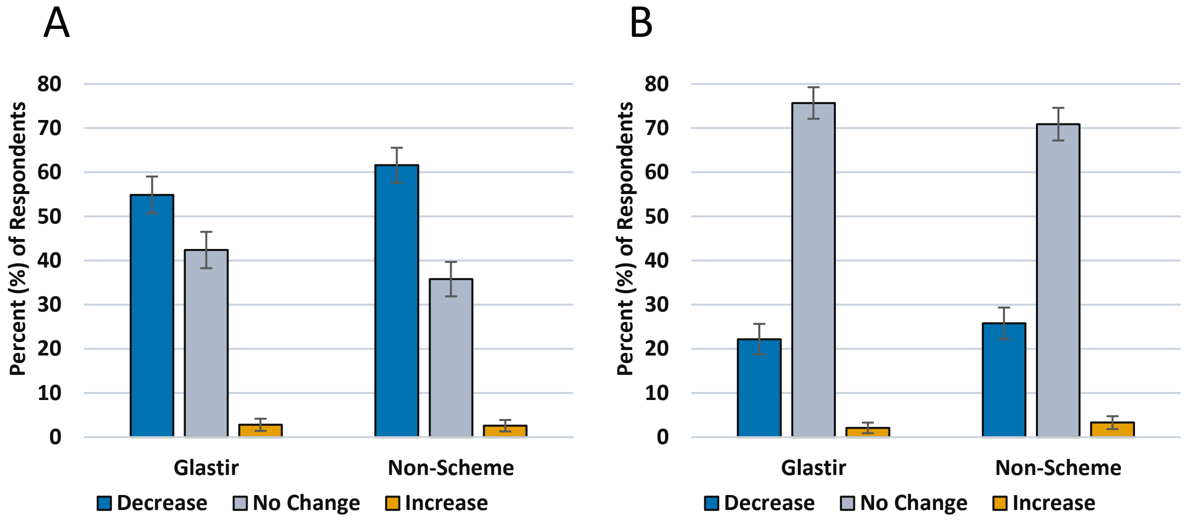


Figure 2-7. Percentage of survey respondents reporting a large (105%) increase or decrease in nitrogen fertiliser use in: A) the past three years, or B) planned for the next three years, for Glastir and non-scheme farms. Excludes Organic farms and those in the Glastir Commons scheme.

2.3.2.11 Climate Change Adaptation

Climate change projections for Wales of increased summer temperatures and winter rainfall present a business risk to farms vulnerable to events that are at present relatively infrequent. Between 9% and 40% of all farms had taken action to mitigate specific climate change threats in the past 3 years. The majority of actions were focussed on the management of heat stress. Overall, 40% of Dairy farms and 24% of Cattle & Sheep farms reported having taken action on heat stress. The results are similar to the 2nd FPS but with increased action to mitigate the threat of drought.

The average number of actions per farm in the 3rd FPS was 1.1 out of 6 possible actions. A high percentage of respondents took no action to adapt to climate change threats (49%), whilst others took multiple actions. 68% of farm managers in scheme had undertaken some action. The total number of actions carried out on the Dairy farm type (1.5) was significantly higher than on the Cattle & Sheep farm type (1.0).

Participation in the GE and/or GA element of Glastir contributed a significant additional +0.3 total actions per farm, and 68% of respondents who had taken one or more actions acknowledged some form of support by the scheme.

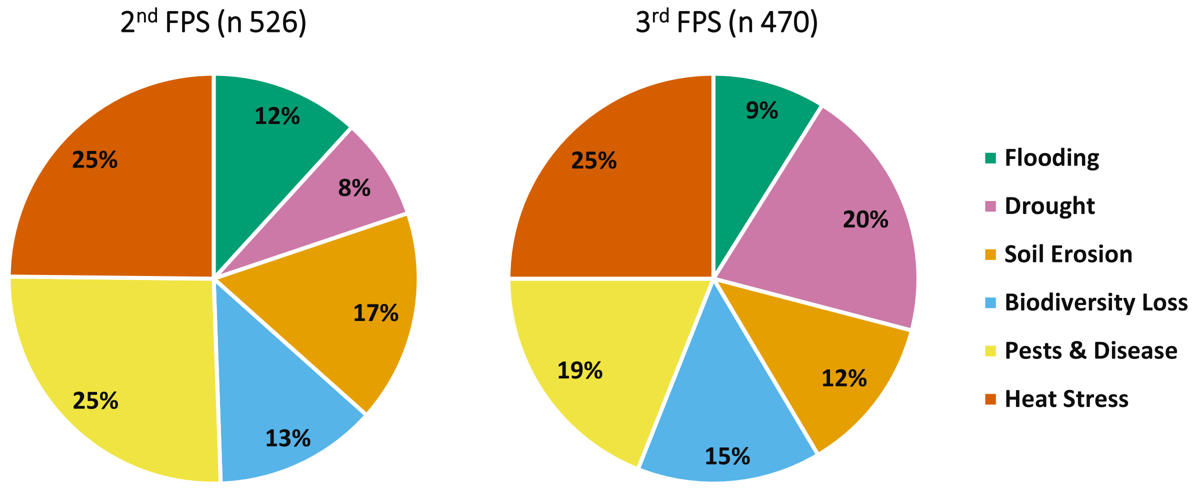


Figure 2-8. Share of the total number of actions taken by survey respondents for adaptation to climate change threats in the past three years, in the 2nd (n 526) and 3rd (n 470) FPS. Excludes Organic farms and those in the Glastir Commons scheme.

2.3.2.12 Business Improvement

Participation in the GA element of Glastir contributed a significant additional +0.6 total actions per farm to improve aspects of the farm business. Participation in the GE or GA elements contributed to a marginal increase (+9%) in the percentage of farms taking action on 'diversification'. 63% of respondents who had taken one or more actions acknowledged some form of support by the scheme. This sits within the wider context of between 16-83% of farms having taken actions to improve aspects of the farm business in the past three years.

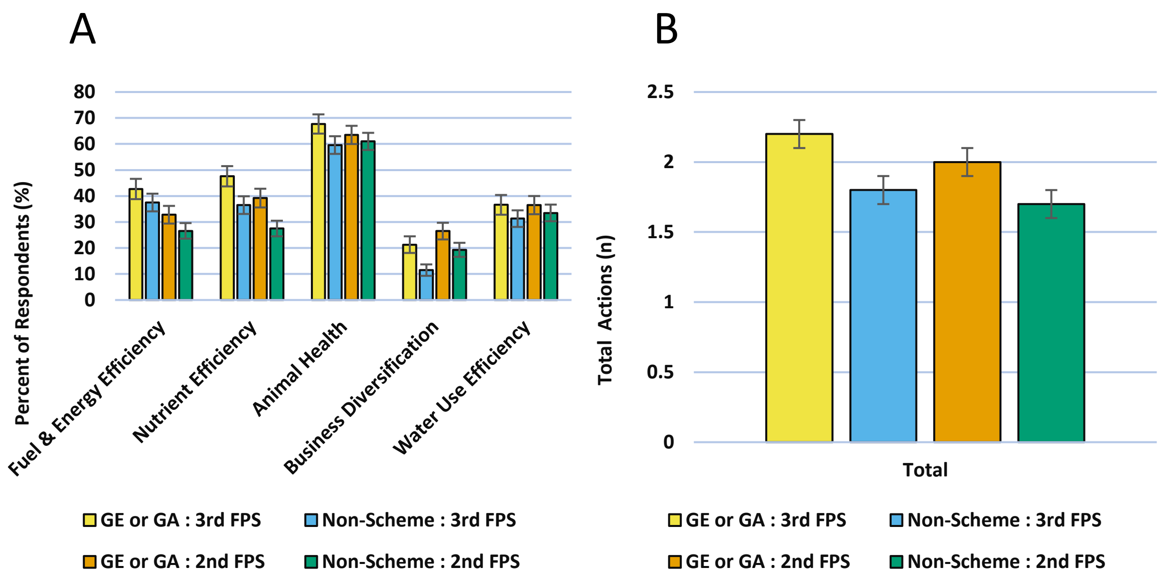


Figure 2-9. A) Percentage of Cattle & Sheep farms carrying out action for improvement of the farm business in the past three years, and B) the total number of actions taken, in the 2nd and 3rd FPS. Excludes Organic and the Glastir Commons scheme.

2.3.2.13 Change in Nutrient Management

Participants in the GE or GA element of the Glastir scheme were more likely to have completed a Nutrient Management Plan (NMP) than non-scheme farms. There was also a continuing legacy effect of participation in Tir Cynnal on the completion of a NMP despite the time passed since the scheme ended. For tested Soil nutrient status, only 11% were more likely to carried this out if in GE or GA compared to non-scheme farms. Participants with an NMP had carried out an additional +1.0 total nutrient management actions out of a possible five, but there was no direct effect of the GE or GA on the total number of actions.

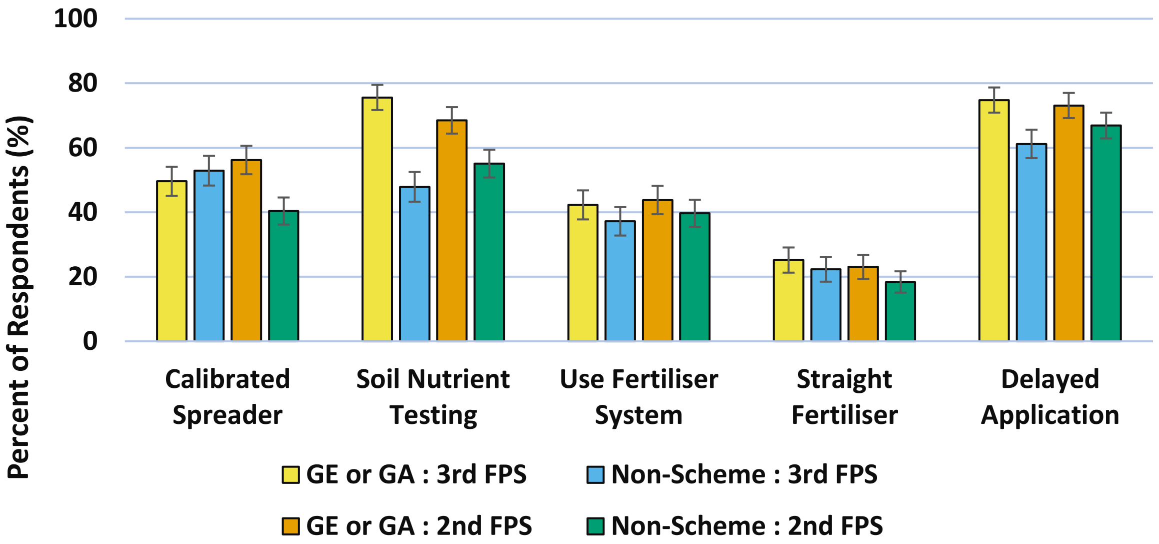


Figure 2-10. Percentage of Cattle & Sheep farms carrying out individual actions for improved nutrient management in the past three years.

2.3.2.14 Change in Manure Management

Participants in the GE or GA element of Glastir were 10% more likely to have filled in a Manure Management Plan than non-scheme farms and have carried out an additional +1.0 total manure management actions out of a possible 10, and there were a total +0.3 total actions for participation in GE or GA for all farm types.

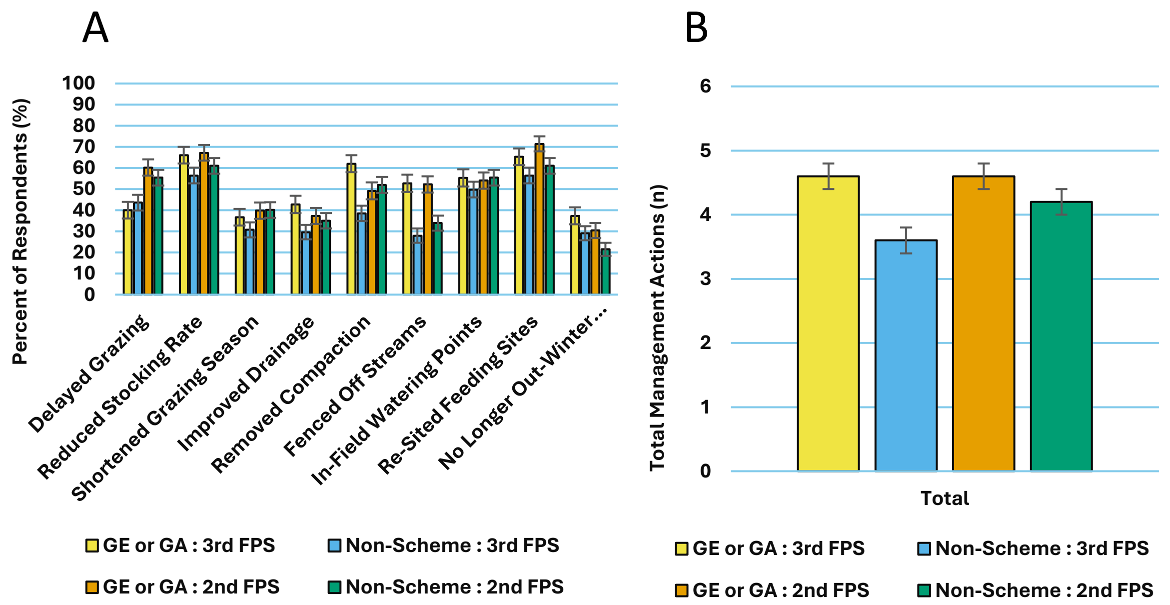


Figure 2-11. A) Percentage of Cattle & Sheep farms carrying out individual actions for Improved Grassland Soil management in the past three years, and B) the total number of actions taken in the 2nd and 3rd FPS (of those having Improved Grassland, and not being registered Organic or having participated in the Commons scheme).

2.4 The contribution of Glastir to National Trends of Land Use and Farming Practices

Overall, there been change in 6.8% of land use across Wales, mostly unconnected to the Glastir scheme. Glastir management options will have contributed an additional ca. 1% of future land use change due to Woodland Creation which is not yet detectable by satellites.

Across Wales, there has been fluctuations but no consistent trend in ruminant animal numbers but a consistent decline in the use of fertiliser for farms in and out of scheme. The majority of Glastir management options have focussed on limiting grazing pressure and fertiliser use by area, and the FPS indicates this has primarily supported the maintenance of current practices as there no evidence that animal numbers and fertiliser use are different in scheme compared to outside of the GE and GA schemes in the last 3 years and relatively small changes on entry to the scheme. These changes are not apparent in the national statistics. Changes in practices on farms in Glastir schemes are more likely for Arable and Woodland land use categories, however these are relatively small in area relative to grassland categories which dominate in Wales. Glastir management option uptake levels were also low for these Asset classes and so the signals were unlikely to be detectable in the national statistics.

2.5 Future Opportunities

The WG has invested in LW and a LiDAR (Light Detection and Ranging) survey which will provide the main remote sensing data sources for changes in land use going forward. UKCEH are also committed to maintaining their family of LCMs as they provide both historical context and use a common approach enabling a comparison of change from across the UK as well as developing their new high-resolution (< 3m) land cover product.

Repeating the ADAS FPS has been shown to be invaluable to track farm manager actions in response to payments. It is particularly important the same structure and questions were included to ensure links to previous surveys were possible. This approach should be maintained in any future surveys.

3 BROAD HABITATS

Emmett, B.A.[1], Bentley, L.F.[1], Bowgen, K.M.[2], Doeser, A.[1], Jarvis, S.G.[1], Kimberley, A.[1], Macgregor, C.J.[2], Maskell, L.[1], Mondain-Monval, T.O.[1], Reinsch, S.[1], Robinson, D.A.[1] and Siriwardena, G.M.[2]

[1]UK Centre for Ecology & Hydrology and [2]British Trust for Ornithology

The NFS has captured a wide range of evidence which can provide an overall picture of how individual Broad Habitats are changing over time and how the uptake of Glastir options is contributing to that change. These Broad Habitats come together to create the varied and complex landscapes we see across Wales. This section brings together evidence presented in the Biodiversity, Soil, Freshwater, Land Use and Management Practices and Landscape and HNV sections under the individual Broad Habitat headings to present a more integrated assessment and support the reporting requirements of SoNaRR for both National Trends and the impacts of Glastir management options. Birds and Freshwaters are reported for the four Asset Classes as a whole (i.e. Woodland, Mountain Moor and Heath, Semi-Natural Grassland and Enclosed Farmland) as this better reflects the scale of influence on these two resources. It should be noted that the population used for the reporting of Glastir outcomes extends beyond the Nationally Representative sample used to report National Trends. The impact of Glastir is reported as the change in land in-scheme compared to the change in land out-of-scheme except for birds where the relationship between indicators with relevant management measures is reported. More information, data tables and figures for the results summarised here can be found in the Habitat Supplement.

Going forward, further analysis will be required to provide a more in-depth analysis of the results presented here. In particular, this should include analysis to better understand drivers of change, evidence of spatial variability (e.g. identification of hotspots of improvement or decline) and more granular analysis (e.g. for individual species known to be at risk). This report is a first step to providing the fundamental evidence base to report on the success of the Glastir management options to meet the scheme objectives and overall progress in meeting WG broader environmental targets and ambitions.

3.1 Woodlands

The evidence from the NFS captures ongoing change in the condition of established Woodland over the period 2013-16 and 2021-23. Hedgerows are traditionally considered part of the Enclosed Farmland Broad Habitat although they are known to also provide important connectivity between individual patches of Woodland. The evidence of change is reported by two Broad Habitat classes: i) Broadleaved, Mixed and Yew Woodland and ii) Coniferous Woodland, for Vegetation, Pollinators and Soil and by the Woodland Asset Class as a whole for Birds and Freshwaters.

The impact of Glastir management option payments is also reported. This evidence is reported as the impact of a bundle of options which included the following options, which are expected to be relevant to Broadleaved Woodland:

- Woodland Creation
- Woodland Stock Exclusion
- Woodland Management

This approach captures land where any of these options have been included and will maximise detection of any change. Specific options can be tested at a later date where this is of interest. In contrast to Woodland Management, the creation and total cover of Woodland and woody features creation and their connectivity are more efficiently estimated by satellites rather than the NFS but are reported here for completeness.

Going forward, the WG has an ambition to plant 2,000ha of Woodland every year to help create a new National Forest. The WG commissioned ERAMMP to review the potential benefits and disbenefits of Woodland Creation, Woodland expansion and managing under-managed Woodland, to provide an evidence base to inform the development of this new National Forest for Wales. The review covered issues such as the potential contribution of new Woodland for climate change mitigation, Biodiversity and ecosystem services including societal benefits and the Welsh economy (Beauchamp, et al., 2020). This evidence is not repeated here but provides valuable supporting information across a wide range of Woodland-related topics.

3.1.1 Background

The Broadleaved, Mixed and Yew Woodland Broad Habitat includes stands of native and non-native Broadleaved trees scrub, yew (*Taxus baccata*) and can also contain Coniferous species up to 80% cover (Jackson, 2000). Structurally, the GMEP/ERAMMP habitats key identifies Woodland as ‘consisting of over 25% canopy cover of trees and shrubs, over a metre high’. Broadleaved, Mixed and Yew Woodland may be ancient or recent Woodland and may be semi-natural with natural regeneration or planted. Scrub Vegetation is included within this habitat, although some species are excluded (e.g. *Ulex gallii* and *Ulex minor* are classified in the Dwarf Shrub Heath Broad Habitat). Within the Broadleaved Woodland Broad Habitat there are a number of Priority Habitats including Wood Pasture and Parkland, lowland Mixed Deciduous, Wet Woodland, upland Oakwood and upland Mixed Ash.

Coniferous Woodland includes stands of Coniferous species (with the exception of *Taxus baccata*) where Coniferous species exceed 80% cover. As with Broadleaved, Mixed and Yew Woodland, it is classified through the Broad Habitats key where canopy cover is greater than 25% and Vegetation height greater than 1m. In Wales, there are no native Coniferous Forest types, with the exception of juniper scrub. It should also be noted that, where land is under a Coniferous management cycle, if trees had been felled, we tried to classify according to the dominant Vegetation that was actually present i.e. not Woodland if canopy cover was less than 25%. Other surveys (e.g. the NFI) would record that to be part of the forest cycle and classed as forest. Whilst many Coniferous stands are single species, the rides, fire breaks and other linear elements of managed Woodland provide habitat for a variety of species.

Many Woodlands in Wales are under-managed (Beauchamp, et al., 2020) leading to long-term declines in plant species richness. This may occur from successional processes operating unchecked, reducing structural heterogeneity, e.g. losing rides and glades, and excluding light-loving species. For Woodlands, this will result in a loss of plant species which favour high light conditions and an increase in canopy height. We assess this change in plant species composition using the Ellenberg scoring system. In brief, most plant species across Europe including the UK have been scored for a wide range of ecological requirements including light (Ellenberg light), nutrient levels (Ellenberg Nitrogen (N) fertility), acidity (Ellenberg reaction) and moisture (Ellenberg moisture) using the Ellenberg scoring system (Ellenberg, et al., 1991). They were adapted to the UK by (Hill, Roy, Mountford, & Bunce, 2000). Essentially, the higher the score the more a plant species favours that ecological condition. For example, a high Ellenberg (N) fertility score indicates that the plant has a preference for highly fertile conditions, and high moisture indicates a plant most suited to moist and wet habitats. Thus, in Woodlands, the under-management and successional conditions are indicated by a decreased Ellenberg light score for the ground flora community as a whole.

Historically, efficient capture of acidic and nitrogen deposition by tree canopies, particularly the evergreen canopy in coniferous plantations which is present all year, has interacted with the high base cation use of plantation forestry to acidify both Soils and Freshwaters and also increase nitrogen concentrations. Trends in Soil acidity and nitrogen level (and plant indicators of high nutrient conditions) are therefore of particular importance in this Broad Habitat. Over-grazing also contributes to increased fertility, which in turn influences the Vegetation structure and overgrowth of ground flora so we include both the Ellenberg reaction (acidity) and (N) fertility scores in our analysis.

Species richness indicators include total species richness of the ground flora, the richness of Ancient Woodland Indicator (AWI) plants (these may be associated with lower light levels, but there will be a trade-off where excess growth of fertile plants excludes AWI also and nectar plant richness. We also included the cover of invasive species, this includes all non-native species (including *Rhododendron*) and additionally, bramble (*Rubus fruticosus agg.*). Here we analyse NFS data from the large (200m^2) botanical survey plots and the small 4m^2 plots nested within these larger plots. Large plots are more suitable for the size of species in this habitat, small plots are more comparable to analyses in other habitats.

Habitat preferences of the Bird species that contribute to the indicators of change in Woodland are broader than the Woodland categories that are being considered for ERAMMP. Therefore, all Woodland habitats were combined for all Bird indicators into the Woodland Asset Class. Woodland Birds have declined, at UK level, since the 1970s, with similar patterns believed to have occurred in Wales. Particular pressures have been a reduction in Woodland Management reducing the diversity in Broadleaved Woodland structure, and therefore habitats for Birds, and increased browsing pressure from deer especially, significantly reducing understorey and field layer structure. Six indicators were investigated in these analyses: abundance of Woodland Bird species (indicator) and abundance of Woodland Bird species (guild), plus four general indicators for priority Bird species and the three dietary guilds (granivorous and invertebrate- and vertebrate-eating Bird species). The indicator uses the policy-led standard list of species from (Burns, et al., 2023) and so is consistent with national monitoring, whilst the guilds follow an extended list of species from (Siriwardena, Henderson, Noble, & Fuller, 2019) providing a more complete representation of the Bird community that uses Woodland habitats as well as key dietary preferences. The priority Bird species list consists of all Section 7 species from the Environment (Wales) Act 2016. Glastir effects compare predictions for the situation where Glastir covered 90% of a nominal surveyed Woodland area, compared to 10% coverage. This approach was needed due to the mobile nature of Birds, which will use multiple, individual habitats across a landscape, as opposed to being associated with individual fields or parcels.

Pollinators are important ecologically and, within this diverse group, butterflies also have high aesthetic value, i.e. they contribute positively to human perception of the environment. Several Pollinator indicators are considered here in order to capture a range of properties of the community, for its own sake, and to capture its role in ecosystem function and the provision of the pollination service (i.e. metrics capturing the overall abundance of Pollinators), their diversity and the range of ecological functions that they deliver (driving the range of flowers being pollinated). From GMEP results, (Alison, et al., 2021) found that, compared with Improved Grassland (the dominant habitat in Wales), Pollinator abundance was consistently higher in Woodland, especially Broadleaved Woodland. They estimated that Hedgerows could contribute up to 21% of hoverfly abundance in agriculturally improved habitats, with Woodland (and other semi-natural habitats) contributing similarly, potentially enhancing the pollination ecosystem service for nearby relevant crops.

Soils were sampled from 0-15cm; this is considered to be the most dynamic component of the Soil profile but is a less robust indicator of overall change in Woodland Soils due to the deep-rooting nature of many trees. In Woodlands, topsoil carbon content is more reflective of ground flora, litter inputs, disturbance and management than overall carbon trends. Bulk density is highly linked to Soil Organic Matter (SOM) content but is also responsive to changes in weather, climate and management (e.g. use of Woodlands for stock shelter), where increased topsoil bulk density may indicate compaction. Topsoil pH and nitrogen concentration reflect Soil properties needed for healthy Soil function and Vegetation health, and changes in these indicators can be indicative of changes to Vegetation, climate, nutrient deposition rates and management change. Many native Woodlands in Wales have plants which naturally are nutrient poor and acidic. Ongoing acidic and nitrogen air pollution may be of concern where there is Soil acidity above that naturally occurring and raised nutrient conditions favour more competitive species particularly in the ground flora.

With respect to Headwaters and Ponds water quality where there is a high proportion of Woodland in the upstream catchment of the Headwaters or 100m area surrounding the Pond, historical concerns tend to be around acidification and nitrogen deposition due to the greater capture of acidic and nitrogenous pollutants by tree canopies.

Woodland connectivity is thought to improve the movement and dispersal of species across the landscape and overall improve condition for Woodland plants and some mobile taxa. However, some species with preference for open spaces will be disadvantaged. There is also likely to be a benefit of more connecting woody features for soil due to reduced management intensity and presence of deeper rooting vegetation reducing compaction and nutrient levels whilst increasing carbon. Some benefit to Freshwater is also likely if Woodland is positioned in the landscape such that it breaks connectivity between intensively managed land and water courses reducing rapid runoff of rainwater and the transfer of fertiliser, control chemicals and animal manures into Freshwater. An increase in Woodland connectivity is therefore a positive outcome although some disbenefits may occur for some species and there may also be issues associated with the risk of the spreading of disease and non-natives and invasive species.

3.1.2 National Trends

The UKCEH LCM has been used to track change of Woodland cover. Note that the WG-funded LW product does not have long-term data relevant to the start of the Glastir scheme so could not be used.

Table 3-1. Change in two Broad Habitats between 2010 and 2021 (ha) and for the Woodland Asset Class as a whole (ha and as a percentage of 2010 extent) as estimated by the UKCEH LCM.

Land Use / Habitat Class	2010 (ha)	2021 (ha)	Change 2010 to 2021 (ha) and (%) 2010
Broadleaved Woodland	186,800	216,000	29,200 (+16%)
Coniferous Woodland	148,000	142,400	-5,600 (-4%)
Total	**334,800**	**358,400**	**Sum of +/- area = +23,600 (+7.0%)**

In 2021, Woodland and woody features were estimated to cover 358,400ha or 16.9% of Wales with 10.2% representing Broadleaved Woodland and 6.7% as Coniferous Woodland. This had increased by 16% for Broadleaved Woodland but decreased by 4% for Coniferous Woodland since 2010, resulting in an overall increase of 23,600ha or 2,145ha/yr which is equivalent to an increase of 7% of Woodland between 2010 and 2021. This compares to an estimate of 310,000ha or 14.6% of Wales by the NFI in 2021 and an increase of 800 - 1,000ha/yr since 1998 and 2013-16 respectively. This difference can be explained in part by the different definitions of Woodland by the two monitoring programmes. The UKCEH LCM defines Woodland wherever woody species dominate a $10m^2$ satellite pixel. The NFI for the period uses a field survey approach and covers all forest and Woodland area over 0.5ha with a minimum of 20% canopy cover, or the potential to achieve it, and a minimum width of 20m so will include newly planted areas which the UKCEH will miss but excludes small woody features which UKCEH includes. This approach by the NFI has now changed and results are expected to be more compatible going forward. However, for now, both programmes agree Woodland cover has increased and there is perhaps a greater increase in small woody features due to the greater increase observed by the UKCEH LCM approach.

One surprising note of caution is that despite this increase in Woodland and woody linear features, Broadleaf Woodland connectivity has not increased across Wales suggesting a more spatially targeted approach will be needed going forward if this is an overall ambition for Wales. It should be remembered however this should be spatially targeted as whilst there are benefits of greater connectivity for many Woodland species, trade-offs can occur for species associated with open land such as Skylark and Lapwing (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022).

With respect to Woodland condition for Broadleaved, Mixed and Yew Woodland, there is a picture of relative stability. Both positive AWI and negative plant indicators (e.g. bluebells and wood anemone) remain stable with some improvement seen for other indicators such as a reversal of a long-term decline in total plant species richness. However, there is a successional trend embedded in the data which matches a GB-wide process of canopy growth and increased shading as Woodlands respond to a long-term decline of traditional management and widespread timber extraction at the end of World War II (Kirby, 2005). This is resulting in the observed longer-term decline in plant species which require higher light levels. An increase in topsoil bulk density (i.e. compaction) is not unique to this habitat and is likely to be linked to a more widespread driver of change, such as climate, although more work is needed to explore this widespread finding for 7 of the 10 Broad Habitats. With respect to Pollinators, three of the indicators are stable but the two indicators relating to butterflies (abundance and species richness) have declined. One issue to explore further is whether this is related to a loss of structural heterogeneity and more open areas due to under-management.

National Trends for Coniferous Woodland indicate these habitats are in a relatively stable condition. One positive outcome is an increase in Pollinator abundance. The reasons for this are not known and require integrated analysis with the Vegetation data to explore the species-level responses that drive it. Main areas of concern for Coniferous Woodland are an increase in Soil bulk density (i.e. compaction) and an increase in Vegetation Ellenberg (N) fertility index. The increase in bulk density signal is seen for most habitats and is not unique to Coniferous Woodland and may be related to climate change.

For the Woodland Asset Class as a whole, an overall trend of stability for Woodland Birds is observed but this will hide a wide variety of species-specific responses. For Headwaters and Ponds where data is weighted by the area of each Asset Class within the catchment (Headwaters) or 100m buffer area (Ponds), all indicators were stable.

3.1.2.1 Summary

Table 3-2. Summary of the long-term (pre-2007[5]) and recent (2013-16 to 2021-23) trends for Woodland Broad Habitats.

Asset Class and Broad Habitat	Long-term trend	Recent trend
Woodland		
Broadleaved, Mixed and Yew Woodland	Stable	Stable
Coniferous Woodland	Stable	Stable

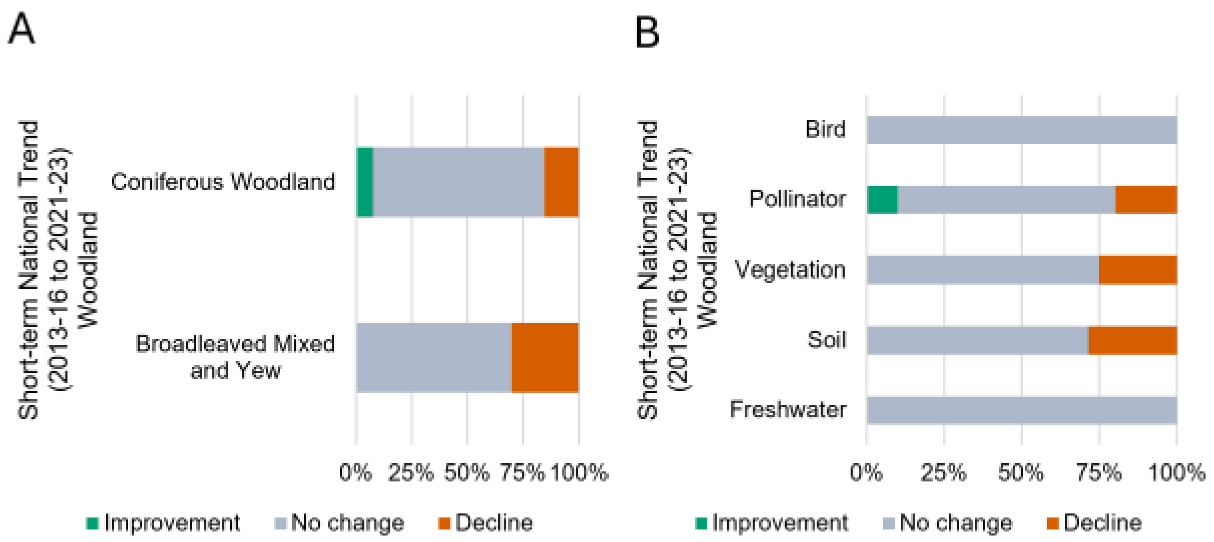


Figure 3-1. Short-term trends for the counts of indicators which have improved (green), stabilised (grey) or declined (red) for Woodland between 2013-16 and 2021-23 expressed as: A) counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only and B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators. All results are from Nationally Representative survey squares.

Positive Outcomes

All Woodland

- The area of Woodland has increased by 2,145ha/yr i.e. 7% between 2010 and 2021. This derives from an increase of 16% for Broadleaved Woodland and a decrease of 4% for Coniferous Woodland.
- No change seen in the National Trends for Woodland Bird Abundance (species and guild), in the context of previous, long-term declines in several woodland bird species at UK level (1970s and 1980s). Conversely, the national BBS suggests a slight decline between the GMEP and ERAMMP periods.

[5] Legacy schemes are of variable duration; the longest spans from 1978-2007 and shortest spans from 1998-2007.

- Water quality indicators where there is a high proportion of Woodland in the upstream catchment of the Headwaters or 100m area surrounding the Pond were stable.

Broadleaved Woodland:

- Connectivity remains stable.
- Total species richness is now stable after a period of decline.
- AWI plant species in remained stable in the recent survey period continuing the long-term stable trend. Negative plant indicators also remain stable.
- Nectar plant species richness was stable halting a decline in the longer term.
- Plants which favour high nutrient status as indicated by the Ellenberg score were stable.
- Pollinator abundance, functional group richness and generality of Pollinators are all stable.
- Topsoil nitrogen concentration and pH remained stable.

Coniferous Woodland

- Ground flora species richness, cover-weighted canopy height and AWI were all stable.
- Pollinator abundance increased with all other pollinator indicators remaining stable.
- Topsoil nitrogen concentration and pH remained stable.

Areas for Concern / Need for Further Action

All Woodland

- No specific concern and no further actions are needed but continued monitoring and investigation of potential wider impacts on woodland bird species across Wales for species of concern are important. Note that the summary metrics used here will tend to obscure species-specific variations in changes over time and it would be beneficial to examine the data at the species level. Note that Welsh birds have been monitored effectively only since 1994, but woodland species probably declined considerably before this time, on the basis that such declines were seen at the UK level.

Broadleaf Woodland

- Strong declines in plant Ellenberg light score appear to be ongoing. This is in an indicator of a loss of plants which require higher levels of light and is likely to be a response to long-term increase in canopy cover due to long-term under-management.
- There was an increase in the cover of non-native and invasive plant species in the botanical small plots, however, there was no significant increase in the large plots. There is a lot of variation in cover values which is likely to be why the large plots were not significant.
- Mean butterfly abundance and butterfly species richness declined.
- Topsoil carbon concentration declined significantly by 13% in the recent survey following a long-term period of gradual carbon accrual since 1978 to 2007, but there was no change in carbon density due to increased bulk density. This carbon may have been redistributed to lower horizons which is known to occur in Woodland systems.
- There has been an increase in topsoil bulk density of 15% which is indicative of compaction.

Coniferous Woodland

- There has been an increase in the cover of plants favouring high nutrient status i.e. Ellenberg fertility scores in the short-term.
  Topsoil bulk density increased by 34% in Coniferous Woodland, indicating greater soil compaction. This increase together with a stable topsoil carbon concentration led to a 15% increase in topsoil carbon density across Coniferous Woodlands in Wales, which is not indicative of carbon sequestration due to the confounding effect of change in bulk density.

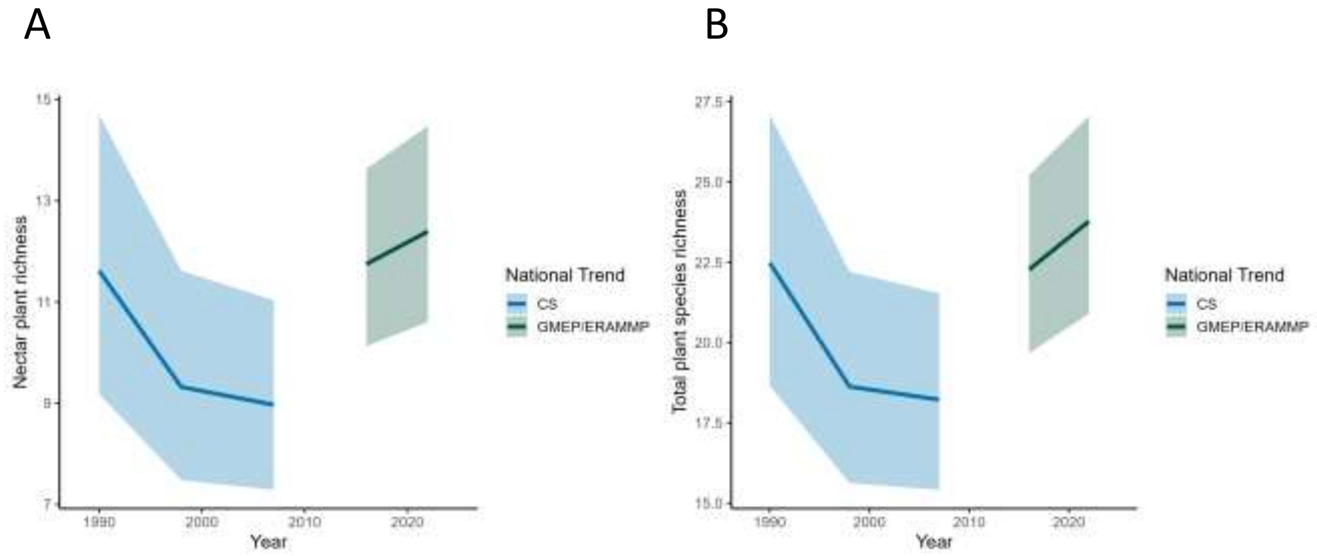


Figure 3-2. Long-term National Trends in Broadleaved, Mixed and Yew Woodland in large botanical plots for: A) nectar plant richness, and B) total species richness from Countryside Survey (CS) squares in Wales (1990-2007) and GMEP/ERAMMP (2013-16 to 2021-23) from Nationally Representative squares.

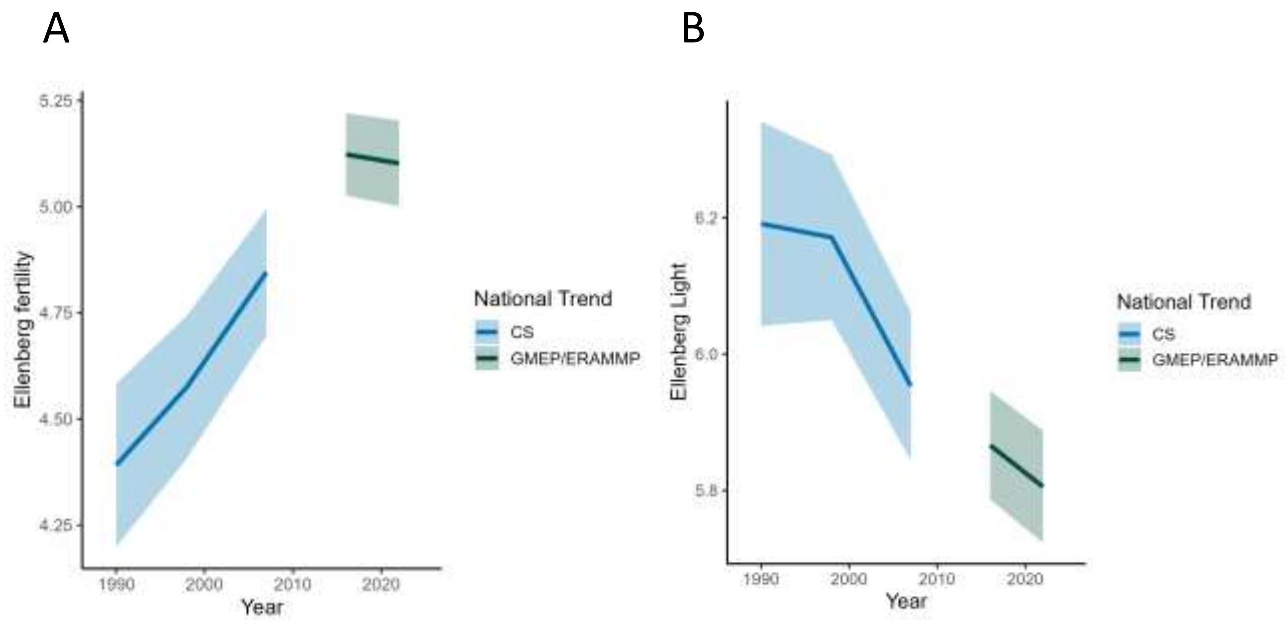


Figure 3-3. Long-term National Trends in plants which favour: A) high nutrient conditions (i.e. Ellenberg (N) fertility), and B) high light conditions (i.e. Ellenberg light scores) in small Broadleaved, Mixed and Yew Woodland plots from Countryside Survey (CS) squares in Wales (1990-2007) and GMEP/ERAMMP (2013-16 to 2021-23) from Nationally Representative squares.

3.1.3 Glastir Impact

Three Glastir options bundles were evaluated for Woodland within which a range of options were included. These bundles were: Woodland Creation (3,780ha of which 64.7ha was captured in the NFS) and was dominated by the option Enhanced Mixed Woodland in our survey squares; Woodland Stock Exclusion (16,000ha or which 244.4ha was captured in the NFS) and was dominated by stock exclusion with a minor component for management of existing fence in survey squares; and Woodland Management (19,000ha of which 359.8ha was captured in NFS) which was again primarily (60%) stock exclusion but included 22% of *Rhododendron* control in survey squares.

As the spatial location within an NFS square varies between the different indicators the relative importance of options and bundles can vary. However, for Woodland as a whole, stock exclusion clearly was the dominant option and bundle for all analyses.

All outcomes are reported for change relative to land outside of the Glastir scheme.

The amount of Woodland Creation resulting from Glastir option payments was 3,780ha represented 1% of Woodland cover observed in 2010. More Woodland was created outside of the scheme (6% of 2010 cover) indicating there are other mechanisms which are contributing to Woodland cover increases across Wales.

With respect to Woodland condition for Broadleaved Woodland and despite the relatively low uptake of Woodland options, the NFS has detected positive outcomes from the Glastir Woodland option bundles. This includes an increase in plant AWI and Soil carbon concentrations, and a reduction in Soil bulk density (i.e. compaction) and the Vegetation Soil fertility index with Woodland Management. Increases are also demonstrated for Woodland Bird species (indicator and guild) and invertebrate-eating species in response to Woodland Stock Exclusion. Five of the six indicators (the exception being vertebrate-eating Bird abundance) also increased in response to Woodland Management. It should be noted that composite indicators may obscure species-level responses, so the results would benefit from further analyses by species.

As the main difference between Woodland Stock Exclusion and Woodland Management bundles in the NFS squares at the spatial scale relevant for Birds is the uptake of the *Rhododendron* control option, it is possible this has particular benefits for Birds. The options covering Vegetation change in the Woodland Management bundle is more diverse and suggests value of a wider range of options beyond stock exclusion, including re-stocking, coppicing, invasive species management, rabbit guards and thinning all at low levels.

Overall, there was low retention of Woodlands from historic schemes into the Glastir scheme, but this probably represents a relatively low uptake of Woodland options overall. Despite this low overlap, some interesting legacy effects were detected. These included:

- An ongoing benefit for Vegetation with respect to ground flora species richness and nectar plants where historic schemes had been in place was observed.
- Benefits for Soil from historic AES were quickly lost for Soil carbon concentrations and bulk density benefits previously detected in response to legacy AES scheme now lost where Glastir options were not present. This was a relatively common occurrence as there were low rates of retention of Broadleaved, Mixed and Yew Woodland sites into the Glastir scheme.

This contrast in responsiveness to historic AES schemes between the Vegetation and Soils illustrates the long lag time and legacy effects in realising ecological benefits in the plant community but also the new finding of the very rapid response of Soils should land fall outside of enhanced management.

There were no reported impacts of Glastir options in Coniferous Woodland. This is not unexpected as no actions were targeted towards them.

The impact of Glastir options for Broadleaved Woodland is clearly one of the most positive Glastir outcomes for any Broad Habitat. This is likely to reflect well-established benefits from the Woodland Management involved, notably allowing understoreys to develop via the reduction of browsing, and management encouraging gap formation and variation in Vegetation structure (Fuller, Smith, Grice, Currie, & Quine, 2007), (Gill & Fuller, 2007). However, as the total area of uptake of Glastir Woodland options was relatively low, this improvement in habitat condition is not detected in the National Trend signal. Clearly, if more Woodland could be brought into a scheme, the benefits for Woodland condition could be high.

3.1.3.1 Summary

Table 3-3. Summary of the impacts of Glastir management option bundles on Woodland Asset Class as a whole and for the two individual Woodland Broad Habitats.

	Glastir management option bundles		
Asset Class and Broad Habitat	**Woodland Creation**	**Woodland Stock Exclusion**	**Woodland Management**
Woodland			
Broadleaved, Mixed and Yew Woodland	Some Improvement	Some Improvement	Some Improvement
Coniferous Woodland	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect

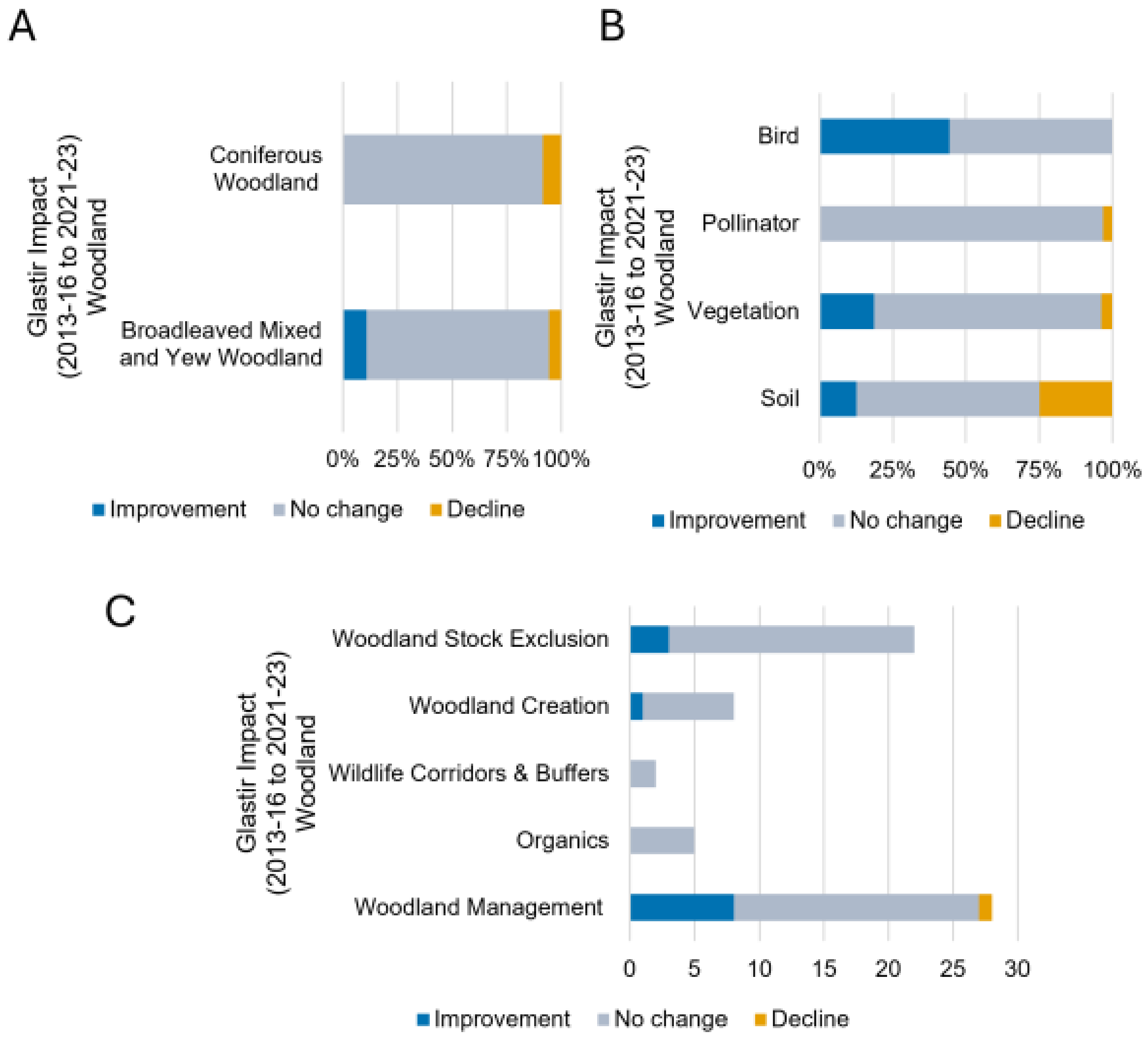


Figure 3-4. The impact of Glastir management options for the counts of indicators which have improved (blue), stabilised (grey) or declined (orange) for Woodland expressed as: A) counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only, B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators, and C) in response to individual Glastir option bundles as total count of tests carried out.

Positive Outcomes

All Woodland

- There was 3,780ha of new Woodland created in response to Glastir option payments which represents an increase of 1.1% of Woodland cover in 2010. This can be compared to a total increase for Wales of 7%. Agroforestry represented 5ha of this increase although it is likely more of the Woodland created would fit the definition of Agroforestry generally accepted.

- An increase in the abundance of woodland Bird species (indicator and guild) and invertebrate-eating birds in response to Woodland Stock Exclusion options.
- An increase in the abundance of woodland Bird species (indicator and guild), invertebrate-eating birds, granivorous birds and priority birds in response to Woodland Management.

Broadleaf Woodland

- AWI richness increased with Woodland Management relative to land outside of scheme.
- Glastir Woodland Management (in this case, all actions were Woodland Stock Exclusion) increased topsoil carbon concentration compared to Broadleaved, Mixed and Yew Woodland outside of scheme.
- Glastir Woodland Management decreased topsoil bulk density relative to land outside of Glastir, suggesting recovery from compaction. This runs counter to the National Trend where bulk density has increased by 15%, suggesting Glastir has reversed the compaction seen in the National Trend.

Coniferous Woodland

- None reported

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

All Woodland

- No impacts of Woodland Creation on Woodland Birds indicators were seen, although this may be due to length of time needed for Woodland Creation to be at the right stage for impacts to be seen being longer than the difference between current survey periods. This will be reassessed in future survey designs. Composite indicators may obscure species-level responses, so the results would benefit from further analyses by species.

Broadleaf Woodland

- There was no effect of Glastir Woodland Management on cover-weighted canopy height, plant Ellenberg light scores, nectar plant species richness, invasive and non-native species cover, and total ground flora species richness.
- There was no effect of Glastir Woodland Management on any Pollinator response indicator.
- Glastir Woodland Management had no significant impact on topsoil carbon density. The lack of response of topsoil carbon density may be due to increased Soil depth, which is not currently measured as part of the NFS.
- There was no effect of Glastir Woodland Management on topsoil nitrogen concentrations or pH

Coniferous Woodland.

- There was a significant negative effect of Woodland Management on pollinator abundance.

Impact of Historic AES

- Historic AES reduced cover-weighted height, increased nectar species richness and ground flora species richness. These are all a continued positive long-term legacy.
- Topsoil carbon concentration significantly decreased in sites with historic AES participation, converging on similar levels to those in land without historic AES

management, indicating that benefits of historic schemes have now been lost in Broadleaved, Mixed and Yew Woodland where these have not come into the Glastir scheme.

- Glastir Woodland Management and historic AES schemes did not affect topsoil pH in Broadleaved, Mixed and Yew Woodland, which remained stable in line with the National Trend.

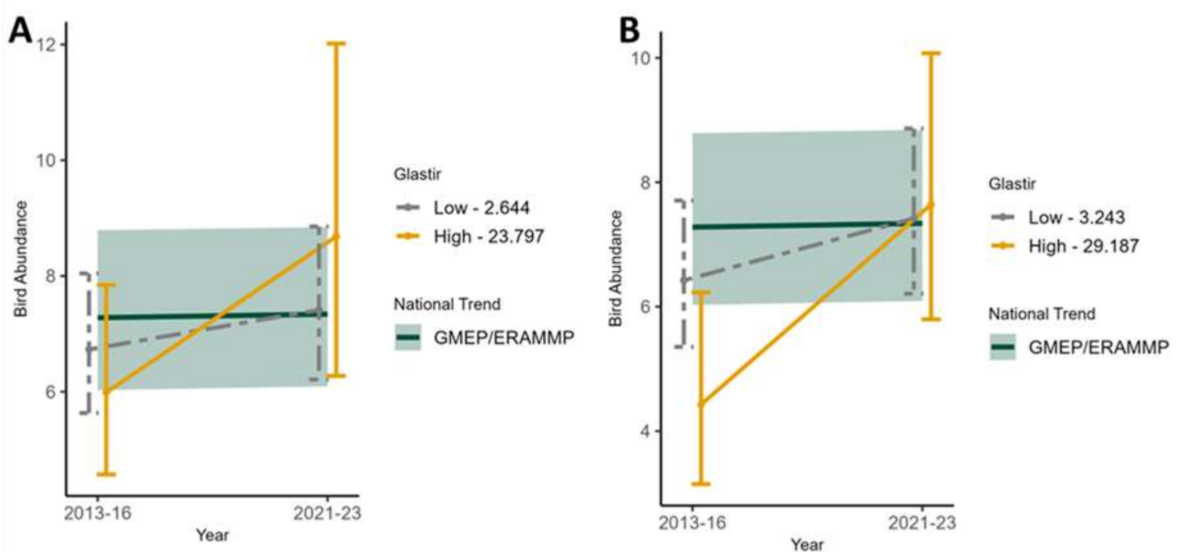


Figure 3-5. Trend in Woodland Bird indicator species abundance between 2013-16 and 2021-23 in all Woodland showing both National Trends and the effect of the Glastir management options of: A) Woodland Stock Exclusion, and B) Woodland Management where there was high or low coverage of Glastir management options in the NFS squares.

3.2 Mountain, Moor and Heath

Mountain, Moor and Heath (MMH) is a complex category which encompasses most of the iconic habitats of the Welsh uplands, including Dwarf Shrub Heath, Inland Cliff and Ledge habitats, Bog/Blanket Bog, Flush and Fen, and Montane habitats (Natural Resources Wales, 2020). The majority of Mountain, Moor and Heath occurs in the uplands, defined as land lying above the upper limit of agricultural enclosure. Mountain, Moor and Heath includes a proportion of the upland margins or ffridd, a distinct transition zone between intensively farmed lowlands and open hill habitats. Ffridd comprises a mosaic of habitats: heath, grassland, peatland, bracken, rock and Woodland (Blackstock, Howe, Stevens, Burrows, & Jones, 2010). Specific definitions for individual Broad Habitats are included below.

3.2.1 Background

Dwarf Shrub Heath is characterised by Vegetation where the cover of dwarf shrub species (e.g. heather, cross-leaved heath, bell heath) is > 25%. This also includes *Ulex gallii* and *Ulex minor*, but not *Ulex europaeus* which is classified to the Broadleaved Woodland habitat. It generally occurs on well-drained, nutrient-poor acid soils (Jackson, 2000). Dwarf Shrub Heath includes both dry and wet types, and can be found in the uplands and lowlands (including coastal habitats). Pressures on Dwarf Shrub Heath include burning, cutting, inappropriate grazing, recreational pressures and scrub encroachment. Climate change may lead to extreme weather conditions which will be an additional pressure. To assess vegetation condition, we use positive plant indicator species presence, initially collated from Common Standards Monitoring (CSM) species and refined from discussions with NRW specialists, and Dwarf Shrub Heath cover to indicate where we have ‘appropriate diversity’, i.e. the right species in the right place. We also use negative plant indicators and the ratio of Grass to Forb which can be linked to over-grazing and nutrient enrichment. Ellenberg (N) fertility and moisture are used to indicate change in underlying environmental conditions.

Bog covers Wetland that supports Vegetation consisting of Peat-forming species that receive water and mineral nutrients from rainfall rather than groundwater (Jackson, 2000). Peat depth should be greater than 0.5m. This habitat includes raised Bog and Blanket Bog Priority Habitats as well as topogenous and soligenous mires (e.g. Valley Mires). Blanket Bog is defined by the presence of acidophilous indicators such as *Sphagnum, Eriophorum vaginatum*, and water is likely to be at or near the surface. In other types of Bog, *Eriophorum vaginatum* is absent although other *Eriophorum spp.* may be present and may also include *Myrica gale, Narthecium ossifragum* and *Trichophorum* species. Modified Bog that includes impoverished Vegetation and lacks key indicators may be included, but where *Molinia* dominates it is likely to have been included in Acid Grassland (moorland grass). Pressures include inappropriate grazing, recreational pressures, encroachment of invasive native species (e.g. *Molinia*) and planting of Coniferous plantations. In addition, for many years they have been drained, resulting in loss of unique habitat specialists and species-poor habitats often dominated by *Molinia*. Grip blocking and restoration of natural function in Bogs has been occurring. Climate change also will impact on these habitats.

Blanket Bog is a Priority Habitat that is a subset of the Bog Broad Habitat. Others define Blanket Bog quite broadly as Wetland on deep peats, including the landscape context as well as species. It is defined in this survey by the presence of acidophilous indicators such as *Sphagnum* and particularly *Eriophorum vaginatum* and does not include species-poor rank Vegetation dominated by *Molinia*. Water is likely to be at or near the surface and Peat should be greater than 0.5m. It is rainfall fed and can be extensive in upland areas. As with Dwarf Shrub Heath, we use the presence of positive plant CSM species, Dwarf Shrub Heath cover and negative plant indicators to indicate where we have ‘appropriate diversity’, i.e. the right species in the right place. We also use Ellenberg (N) fertility to indicate fertility conditions particularly relating to nitrogen pollution and Ellenberg moisture to understand whether the underlying hydrological regime is changing.

Bracken is defined where Bracken is greater than or equal to 95% cover at the height of the growing season. It requires surveyors to predict Bracken cover. Bracken is not a desirable target habitat and itself tends to be a negative indicator in many other habitats. Total plant species richness can be used to indicate overall plant Biodiversity value. Soil indicators are also of general relevance here due to the ecosystem functions they confer.

Fen, Marsh, Swamp is a complex set of habitats but all have the common characteristic of being groundwater rather than rainfall fed and dominated by plants which favour high moisture status (i.e. they have a high Ellenberg moisture score). They can be found on Peat or mineral Soils and include the Priority Habitats Fen, Flush (lateral water movement), Reedbed and Purple Moor Grass Rush Pasture. Fen, Marsh, Swamp habitats do not include areas of dense soft rush (*Juncus effusus*) with no other Wetland species; these are likely to be recorded as Acid Grassland with rush as an accompanying attribute. Fen, Marsh, Swamp habitats can be found in the uplands and lowlands, and we have not split them by altitude. Similar pressures to other Mountain, Moor and Heath habitats occur here, including inappropriate grazing, drainage, impacts of climate change on sub-optimally managed habitats, eutrophication from runoff and atmospheric deposition.

Purple Moor Grass and rush pastures occur on poorly drained, usually acidic soils in lowland areas of high rainfall. Purple Moor Grass *Molinia caerulea,* and rushes, especially sharp-flowered rush *Juncus acutiflorus*, are usually abundant. Key indicator species associated with Purple Moor Grass and rush pastures include *Carum verticillatum*, *Cirsium dissectum*, *Platanthera chlorantha* and *Achillea ptarmica.* The term 'marshy grassland' is used within Glastir, and we have used the Priority Habitat Purple Moor Grass Rush Pasture as a surrogate for marshy grassland. Pressures on Purple Moor Grass Rush Pasture include inappropriate grazing, drainage and eutrophication.

Inland Rock includes both natural and artificial exposed rock surfaces where these are almost entirely lacking in Vegetation. It includes inland cliffs, ledges and caves, screes, quarries and quarry waste. The Priority Habitats included within this Broad Habitat are Limestone Pavement (of geological and biological importance with Vegetation rich in vascular plants, bryophytes, ferns and lichens), Inland Rock outcrop and Scree habitats characteristic of high altitudes, (coastal cliff and ledge habitats are excluded as they form part of the maritime cliffs and slopes Priority Habitat). Screes are typically dominated by *Cryptogramma crispa* and other ferns, lichens and bryophytes. Calaminarian grassland includes a range of semi-natural and anthropogenic sparsely vegetated habitats on substrates characterised by high levels of heavy metals such as lead, chromium and copper, or other unusual minerals. Pressures on Inland Rock include inappropriate grazing, eutrophication primarily from nitrogen deposition leading to loss of species richness. Indicators include Ellenberg (N) fertility and reaction (pH), total species richness as well as CSM positive indicators.

Soil indicators are as described for Woodland. Most Broad Habitats in Mountain, Moor and Heath have soil which is nutrient poor and acidic. Ongoing acidification and nitrogen air pollution may be of concern where this leads to reduced acidity below that naturally occurring and raised nutrient conditions favouring more competitive species. Compaction and erosion due to over-grazing may also be a concern as is loss of Soil carbon.

Pollinator metrics considered here match those used for Woodland. Pollinators largely depend on plant diversity and Vegetation quality, so the pressures on them will follow those described for Vegetation.

Headwaters and Ponds Freshwater quality for Mountain, Moor and Heath as a whole is defined where there is a high proportion of Mountain, Moor and Heath in the upstream catchment of the Headwaters or 100m area surrounding the Pond. Historical concerns tend to be around acidification and nitrogen deposition due to the low nutrient and specific acidity requirements of many plant species. Levels of sediment may also be a concern, linked to access of animals to, and poaching of, Streamsides which can also increase the risk of transfer of pathogens into the water bodies from animal waste.

As for freshwaters, Birds use landscapes at large spatial scales and cut across habitat patches, so their data were at the broad Asset Class level. Since the bulk of relevant habitat in the sample will be in upland areas, analyses are then conducted only for upland Bird indicators. Six upland Bird indicators were investigated in these analyses: abundance of upland farmland Bird species (indicator) and abundance of upland Bird species (guild), plus four general indicators for priority Bird species and the three dietary guilds (granivorous-, invertebrate- and vertebrate-eating Bird species). The indicator follows a policy-led, standard list of species from (Burns, et al., 2023), whilst the guilds follow an extended list of species from (Siriwardena, Henderson, Noble, & Fuller, 2019) and aim to cover wider ranges of habitat and dietary preferences in an upland context than are reflected by upland farmland alone, as well as key dietary preferences. The priority Bird species list consists of all Section 7 species from the Environment (Wales) Act 2016. Long-term pressures on upland Birds cut across various Broad Habitats within the relevant landscapes include grazing pressure from sheep reducing Vegetation cover and diversity, and climate change causing drying and decline of peatland habitats. Afforestation in some areas has facilitated the spread of predators, with negative effects particularly on some ground-nesting species.

3.2.2 National Trends

The UKCEH LCM indicates small changes in areas of four of the more widespread Mountain, Moor and Heath Broad Habitats for which it is possible to estimate area extent using satellite methodologies. However, it is likely that these changes may be within the estimation error of the approach for the less extensive habitats. For Mountain, Moor and Heath as a whole there was no significant overall change in extent. In 2021:

- Dwarf Shrub Heath represented 4% of land use in Wales. This is an increase of 3% since 2010. Bog represents 1% of Wales, an increase of 28%. This latter result may reflect restoration but also the difficulties of attributing satellite images to this Broad Habitat.
- Changes in other MMH Broad Habitat are within detection limits of the satellite approach. Fen, Marsh, Swamp covered 1% of Wales and Inland Rock represented 0.2% of land cover in Wales.

Overall the change in extent between 2010 and 2021 was within the detection limits of the satellite approach,

Table 3-4. Change in the extent (ha) of four Broad Habitat types within Mountain, Moor and Heath Asset Class between 2010 and 2021 and in the Mountain, Moor and Heath Asset Class as a whole (ha and as a % of 2010) estimated by the UKCEH LCM.

Land Use / Broad Habitat	2010 (ha)	2021 (ha)	Change 2010 to 2021 (ha) and (%) 2010
Dwarf Shrub Heath	86,000	88,200	2,200 (+3%)
Fen, Marsh, Swamp	14,200	12,600	-1,600 (-11%)
Bog	15,900	20,400	4,500 (+28%)
Inland Rock	10,500	4,600	-5,900 (-56%)
Total	**126,600**	**125,800**	**Sum of +/- area = -800 (-0.6%)**

With respect to habitat condition, there is an overall picture of stability for Dwarf Shrub Heath, which occurs in both the lowlands and uplands and includes coastal heaths. Cover of dwarf shrub species (which defines the habitat with a requirement for 25% cover or over) remained stable as did all Pollinator indicators. Positive outcomes include a recent shift to plants which favour less nutrient-rich conditions, suggesting reduced flow of nutrients into the habitats either from the atmosphere (e.g. nitrogen deposition) or flowing in from adjacent land or improved management. This will benefit this typically nutrient-poor habitat. A trend for a decrease in negative plant indicators is also observed. One area of concern is a reversal of the previous recovery from acidification, with Soil pH now at levels not seen since 1970s. This pattern of increased Soil acidification in unmanaged land is seen across GB and has been linked to drier conditions.

Most indicators for Bogs suggest stability in this habitat, with one critical exception of a decline in the bog-building plant *Sphagnum* which is a fundamental keystone species for Bogs. As the overall index for plants which favour high moisture is stable, the driver behind this fall in *Sphagnum* abundance is unclear. It may be *Sphagnum* is more sensitive than other plants to changing patterns in rainfall possibly linked to greater sensitivity to nitrogen deposition and acidic conditions as the decline was observed concurrently with a decrease in Soil pH.

As for the Bog Broad Habitat, Blanket Bogs remained relatively stable with the critical exception again of a decline in the bog-building plant *Sphagnum* as for Bogs as a whole. As the overall score for plants which favour high moisture is stable, the driver behind this fall in *Sphagnum* abundance is unclear. It may be more sensitive than other plants to changing patterns in rainfall.

It is a mixed story for Bracken, with no change in Vegetation indicators but an increase in Soil bulk density (i.e. compaction).

For Fen, Marsh, Swamp, there are some areas of concern for this habitat, with a significant decrease in total plant species richness, an increase in the Grass:Forb ratio [6](a negative indicator) and a decrease in the Ellenberg moisture score. Butterfly abundance and species richness have also declined.

There are early indicators of a decline in the condition of Purple Moor Grass Rush Pasture (Marshy Grassland) after a period of stability. This is indicated by an increase in the Grass:Forb ratio and a decline in plants which favour high moisture status (i.e. Ellenberg moisture scores) which are both negative indicators for this Priority Habitat.

There is a low sample size for Inland Rock, but the data available has identified this habitat is showing a decline in overall plant species richness. Pollinator indicators are stable.

National Trends of six Upland Bird indicators are stable. This is a more positive pattern than is apparent from the national BBS. ERAMMP is likely to sample upland habitats better than BBS because volunteer observers are harder to find in the uplands which the BBS relies on. However, note that the summary metrics used here will tend to obscure species-specific variations in changes over time and it would be beneficial to examine the data at the species level. Several important upland farmland species, such as Curlew, remain at historically low levels and Glastir has not supported a population recovery.

Headwaters are generally which are dominated by MMH upstream are stable but with an increase in sensitive macroinvertebrate taxa suggesting some improvement.

3.2.2.1 Summary

Table 3-5. Summary of the long-term (pre-2013) and recent (2013-16 to 2021-23) trends for Mountain, Moor and Heath Asset Class as a whole and for individual Broad Habitats.

Asset Class and Broad Habitat	Long-term trend	Recent trend
Mountain, Moor and Heath		
Dwarf Shrub Heath	Stable	Stable
Bog	Stable	Of concern
Blanket Bog	Improved	Of concern
Bracken	Declined	Stable
Fen, Marsh, Swamp	Declined	Declined
Marshy Grassland	N/A	Of concern
Inland Rock	N/A	Of concern

[6] Grass:Forb ratio describes the relationship between grasses and forbs, a higher score indicates that there is more grass cover which is undesirable, and the aim is to increase forb richness of these grasslands. A high cover of grass in relation to the abundance of forbs can indicate intensive management impacts, e.g. high grazing intensity, nutrient enrichment from atmospheric nitrogen deposition.

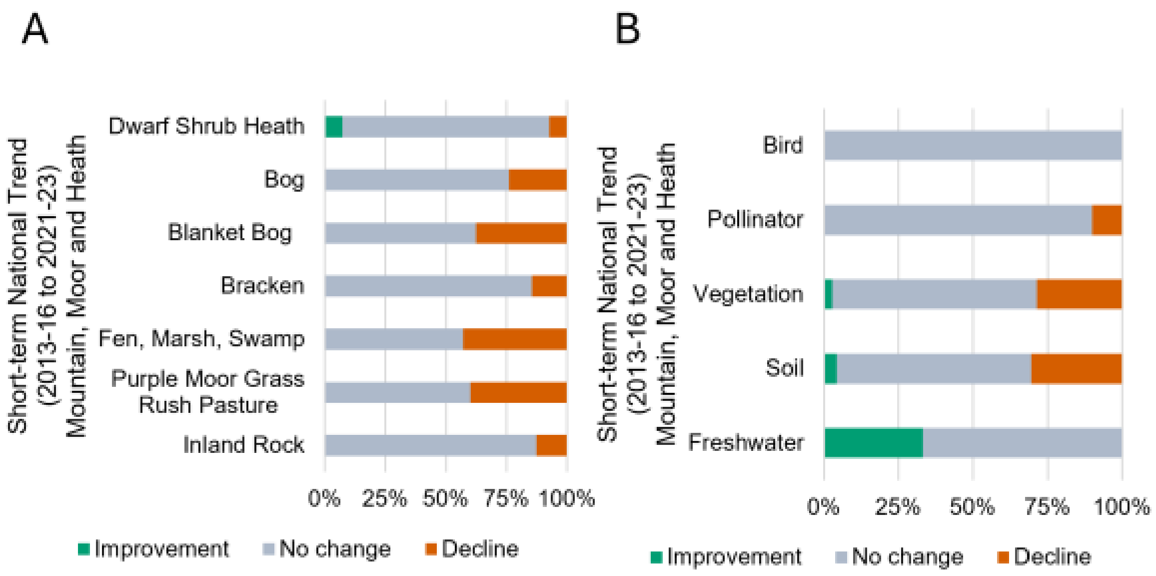


Figure 3-6. Short-term trends for the counts of indicators which have improved (green), stabilised (grey) or declined (red) for Mountain, Moor and Heath between 2013-16 and 2021-23 expressed as: A) counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only and B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators. All results are from Nationally Representative survey squares.

Positive Outcomes

- A decrease in negative plant indicators in Dwarf Shrub Heath and a shift to plants which favour less nutrient-rich conditions, suggesting reduced flow of nutrients into the habitats either from the atmosphere (e.g. nitrogen deposition) or flowing in from adjacent land or improved management.
- Vegetation indicators have remained stable in Bracken.
- All Pollinator indicators have remained stable in Dwarf Shrub Heath, Bog and Inland Rock.
- National Trends of the six upland Bird indicators are stable. This is a more positive pattern than is apparent from the national BBS. ERAMMP is likely to sample upland habitats better than BBS, because volunteer observers are harder to find in the uplands which ERAMMP does not rely on.
- Soil carbon and nitrogen concentrations in all MMH Broad Habitats have remained stable.
- Headwaters dominated by MMH are generally stable but with an increase in sensitive macroinvertebrate taxa, suggesting some improvement.

Areas for Concern / Need for Further Action

- There has been a recent increase in Soil acidity (i.e. pH has decreased) back to levels measured in 1978 when Soils experienced high levels of acidic deposition in Dwarf Shrub Heath.
- In Bogs, and Blanket Bogs, *Sphagnum* cover has declined by 10% and topsoil acidity has increased.
- Soil compaction increased in Bracken by 15%.
- In Fen, Marsh, Swamp, the Grass:Forb ratio of Vegetation (a negative indicator) increased, total plant species richness and numbers of plants favouring high moisture

levels declined. Soil compaction increased by 27%. Mean butterfly abundance and species richness both declined.

- There has been a recent decline in total plant species richness in Inland Rock.

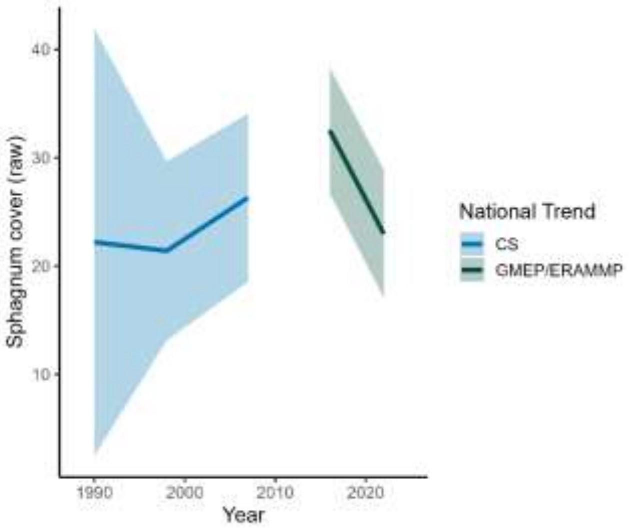


Figure 3-7. Long-term National Trends in Sphagnum cover in Bog from Countryside Survey (CS) squares in Wales (1990-2007) and GMEP/ERAMMP (2013-16 to 2021-23) from Nationally Representative squares.

3.2.3 Glastir Impact

As the spatial location within an NFS square varies between the different indicators, the relative importance of Glastir option bundles tested varied. For Vegetation, bundles used included the Habitat Management bundle which contained options for grazing management of open country, additional management payments for stock reduction and stock management, Bracken control and some habitat-specific actions. We also analysed the Grazing Low/No Inputs management bundle and the Commons bundle. For Soils, the Glastir impact on Dwarf Shrub Heath was tested using the Habitat Management bundle, Organics and Commons bundles, and presence in historic AES. The Habitat Management bundle was dominated by actions on 'Additional Management Payment – reduced stocking' and 'Grazing management of open country'. The Organics bundle contained the action on 'Glastir Organic interventions', and the Commons bundle was covered by the action 'Commons management of options combined'.

Glastir bundles had no positive impact for the Dwarf Shrub Heath Broad Habitat. No benefits were observed for all Vegetation and topsoil indicators in response to all Glastir bundles tested. A negative outcome for Commons management was observed for butterfly species richness, with other indicators all with no change.

For Bog, no impact of Glastir was detected for bundles tested, with one exception where Bog acidification was accelerated with the Habitat Management bundle i.e. a negative outcome.

In Blanket Bog, the Commons bundle increased Dwarf Shrub Heath cover, plant positive indicators and *Sphagnum* cover – all positive effects.

In Bracken, Grazing Low/No Inputs management was found to increase total plant species richness – a positive outcome. However, the Grazing Low/No Inputs bundle increased the Grass:Forb ratio of the Vegetation – a negative effect.

In Fen, Marsh, Swamp, plants which favoured high nutrient conditions (i.e. Ellenberg (N) fertility score) increased under Habitat Management and there was also increased Grass:Forb ratio with Commons management. Both are negative indicators. Grazing Low/No Inputs increased topsoil pH. There was no impact of Organic management on Vegetation condition.

There was little evidence Glastir has improved the Priority Habitat Marshy Grassland, with no change in all plant indicators. No change was also detected for Inland Rock for Vegetation or Pollinator indicators.

No change in Birds associated with upland Birds was detected with Habitat Management of Mountain, Moor and Heath.

3.2.3.1 Summary

Table 3-6. Summary of the impacts of Glastir option bundles on Mountain, Moor and Heath as a whole and for individual Broad Habitats.

	Glastir management option bundles			
Asset Class and Broad Habitat	**Habitat Management**	**Grazing Low/No Inputs**	**Commons**	**Organic**
Mountain, Moor and Heath	Low/No detectable effect	Low/No detectable effect	Minimal improvement with some trade-offs	Low/No detectable effect
Dwarf Shrub Heath	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Bog	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Blanket Bog	Low/No detectable effect	Low/No detectable effect	Some Improvement	N/A
Bracken	Low/No detectable effect	Some Improvement	Minimal improvement with some trade-offs	N/A
Fen, Marsh, Swamp	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Marshy Grassland	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Inland Rock	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect

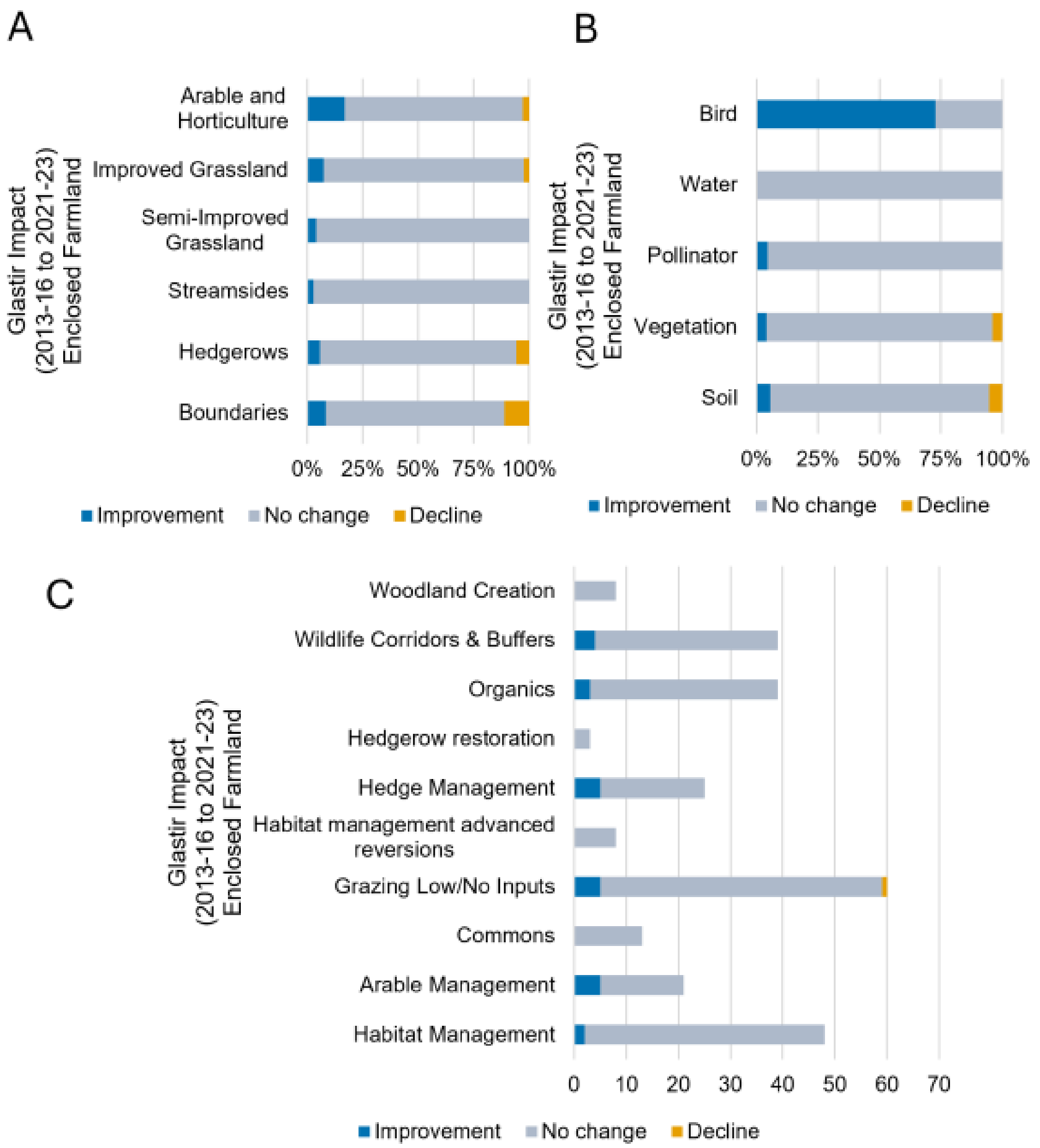


Figure 3-8. The impact of Glastir management options for the counts of indicators which have improved (blue), stabilised (grey) or declined (orange) for Mountain, Moor and Heath expressed as: A)counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only, B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators, and C) in response to individual Glastir option bundles as total count of tests carried out.

Positive Outcomes

- Ellenberg (N) fertility decreased in Bog and Blanket Bog subject to Habitat Management.
- There were several positive outcomes for Blanket Bog on land under Commons management including increased *Sphagnum* cover, Dwarf Shrub Heath cover and positive plant indicators.
- Grazing Low/No Inputs management increased plant total species richness in Bracken.
- Commons management increased topsoil carbon concentration compared to areas without Commons management in Bracken.
- Grazing Low/No Inputs management significantly increased topsoil pH in Fen, Marsh, Swamp.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- There were no significant changes in the Vegetation or topsoil indicators for any Glastir bundles for Dwarf Shrub Heath, Purple Moor Grass Rush Pasture (Marshy Grassland) or Inland Rock.
- In Bogs, the Habitat Management bundle (primarily consisting of reduced stocking density) showed a greater increase in topsoil acidity than those without Glastir option uptake. There was no measurable impact on topsoil carbon or nitrogen concentrations, carbon density or bulk density in Bogs.
- There was a significant increase in Grass:Forb ratio (a negative indicator) with Habitat Management and Commons management in Bracken.
- In Fen, Marsh, Swamp, plants which favoured high nutrient conditions (i.e. Ellenberg (N) fertility score) increased under Habitat Management. There was no impact of Organic management on Vegetation condition. There were increases in the Grass:Forb ratio (a negative indicator) with Commons management.
- Glastir bundles had no effect on Pollinator indicators in any Broad Habitat tested with one exception: butterfly species richness declined where Commons management was applied for Bogs – a negative outcome.
- Glastir bundle Habitat Management had no effect on Bird indicators with one exception: there was a small decline in vertebrate-eating Birds with Habitat Management. It is important to understand which specific vertebrate-eating species are driving the negative association with Glastir and whether this shows a genuine negative effect of certain options or a chance correlation with an unforeseen background influence.

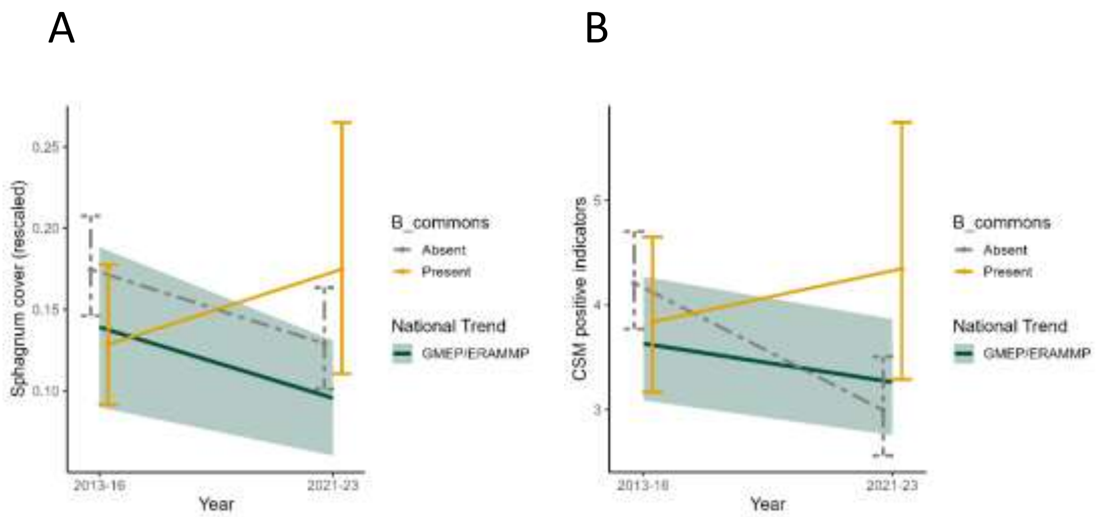


Figure 3-9. Trends between 2013-16 and 2021-23 in Blanket Bog showing both National Trends and effect of: A) Sphagnum cover (rescaled from 0 to 1), and B) positive plant indicators (CSM) with the Commons bundle.

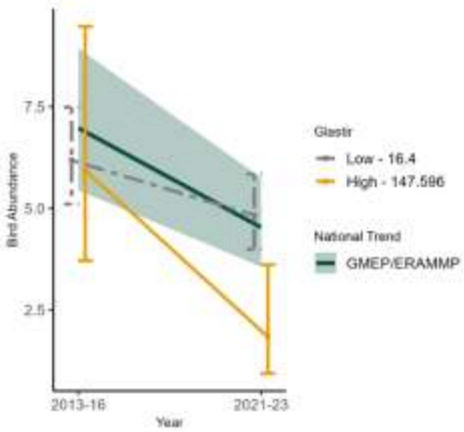


Figure 3-10. Trend in vertebrate-eating Bird species abundance between 2013-16 and 2021-23 in Mountain, Moor and Heath showing both National Trends and effect of uptake of Habitat Management is low or high in proportion to specific bundle coverage maximums.

3.3 Semi-Natural Grassland

Semi-Natural Grassland is a mix of grassland types including Unimproved Neutral Grassland, Calcareous Grassland and Acid Grassland. High levels of grazing and impacts of atmospheric acidic and nitrogen deposition are two important pressures on this Asset Class.

3.3.1 Background

Unimproved Neutral Grassland from GMEP analysis has been re-defined to exclude Semi-Improved Neutral Grassland. In (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022) plots were assigned using their National Vegetation Classification class. Here we used the Priority Habitat Hay Meadow to signify high-quality Unimproved Grassland, hence the sample size is quite low (see ERAMMP Technical Annex-105TA1S1: Wales National Trends and Glastir Evaluation. Supplement-1: Data Analysis Methods (Jarvis, et al., 2025)). These habitats consist of traditionally managed lowland hay meadows and pastures in which grasses such as *Cynosurus cristatus*, *Festuca rubra*, *Agrostis capillaris* and *Anthoxanthum* *odoratum* typically occur in a species-rich sward with a high cover of associated herbs. Cover of grass species and clover are usually less than 50%. Typically, rich in forb species with frequent low soil pH (i.e. high acidity), lowland meadow indicators include *Lathyrus pratensis*, *Lotus corniculatus*, *Leucanthemum vulgare*, *Primula veris*, or flood meadows indicators include *Caltha palustris*, *Sanguisorba officinalis*, *Filipendula ulmaria* and *Alopecurus pratensis*. It also includes upland hay meadow, *Anthoxanthum odoratum – Geranium sylvaticum* grassland. Pressures on this habitat include intensification of use, e.g. application of fertilisers, over-grazing and fragmentation. As this habitat is high quality and targeted for conservation, positive and negative plant species richness have been used to measure condition. Ellenberg (N) fertility indicates plant response to changing nutrient conditions, which may be a pressure here, and total species richness enables comparison to other less high-quality habitats. This habitat is sensitive to grazing pressure which will be linked to a decrease in plant CSM species, and an increase in Grass:Forb ratio and Soil compaction (both negative indicators). Grass:Forb ratio describes the relationship between grasses and forbs, a higher score indicates that there is more grass cover which is undesirable, and the aim is to increase forb richness of these grasslands. A high cover of grass in relation to the abundance of forbs can indicate intensive management impacts, e.g. high grazing intensity, nutrient enrichment from atmospheric nitrogen deposition. Soil compaction impacts on plant root growth and potentially resilience to drought, and can cause rapid rainfall runoff into water courses increasing peak flows. The habitat is also particularly sensitive to acidic deposition due to its limited Soil buffering capacity.

Calcareous Grassland is a Broad Habitat characterised by Vegetation dominated by grasses and herbs on shallow soils rich in bases (calcium carbonate), pH 5-6. Calcareous Grassland is a relatively uncommon habitat in Wales (and in Britain as a whole). Because the habitat type is so scarce and unevenly distributed, it is not well sampled by this survey. Hence, we do not have sufficient Vegetation data to analyse Calcareous Grassland. Results based on limited Pollinator data are, however, presented.

Acid Grassland is dominated by grasses and forbs on a range of Soils derived from acidic bedrock, sands and gravels, or shallow Peat. It can consist of fine grasses in generally dry situations, e.g. *Agrostis curtisii*, *Festuca ovina* and *Anthoxanthum odoratum* on brown podzolic Soils. This Broad Habitat also includes moorland grass dominated by coarser grass species (*Nardus* or *Molinia*), usually occurring in a moorland setting but also present within lowland heath landscapes. Dwarf shrubs and peatland species may be frequent but are usually less than 25% cover and are never dominant. The results for Vegetation are split into the Priority Habitats lowland Dry Acid Grassland and upland Acid Grassland as underlying conditions are so different. Results presented are for both unless otherwise stated. This habitat is sensitive to grazing pressure which will be linked to a decrease in plant CSM species, and an increase in Grass:Forb ratio and Soil compaction (both negative indicators) as for Unimproved Neutral Grassland. The habitat is also particularly sensitive to acidic deposition due to its limited Soil buffering capacity. The majority (79.2%) of sites applying Glastir options were also participants of historic AES. Glastir management options present may be serving to maintain and preserve past improvements.

Pollinators largely depend on plant diversity and Vegetation quality, so the pressures on them will follow those described for Vegetation, although upland grassland is always likely to be species-poor, relative to lowland habitats.

For Birds, results presented are relevant to all Broad Habitats within the Semi-Natural Grassland Asset Class, with the exception of Acid Grassland for which a different set of indicators have been used. Due to the known resolution of habitat preferences of the species in the relevant indicators and the similarity of management measures for different grassland types, all Semi-Natural Grassland habitats analyses are combined together for each of lowland and upland contexts. Tests to detect Glastir management option outcomes consider the Bird indicators that are not specific to habitats are reported here but can be considered to be relevant to all Semi-Natural Grassland (i.e. including Acid Grassland) as the Glastir bundles apply across both upland and lowland grass. Semi-Natural Grassland is typically a patchy habitat in the lowlands, forming part of Bird habitat, as opposed to supporting populations alone. However, its value has been affected and is threatened by the same factors that are relevant to Vegetation.

3.3.2 National Trends

Broad Habitat change in extent in Semi-Natural Grassland was assessed using the UKCEH LCM (Martson, Rowland, O'Neil, & Morton, 2022). It indicated a decrease in Acid Grassland extent of 2% in 2021 relative to 2010. Acid Grassland represented 21% of land use cover of Wales in 2021. Unimproved Neutral Grassland represented 2% of land cover of Wales in 2021. This presented a 7% increase from 2010, although this is likely to be within the detection limits of the satellite data and approach. Calcareous Grassland represented < 0.1% of Wales's land use in 2021. Change data are not reported due to small areas involved. Overall change was within detection limits for this Asset Class.

Table 3-7. Change in the extent (ha) of three Broad Habitat types within the Semi-Natural Grassland Asset Class and for the Semi-Natural Grassland Asset Class as a whole (ha and as a percentage of 2010) between 2010 and 2021 estimated by the UKCEH LCM.

Land Use / Broad Habitat	2010 (ha)	2021 (ha)	Change 2010 to 2021 (ha) and (%) 2010
Acid Grassland	457,800	449,600	-8,200 (-2%)
Unimproved Neutral Grassland	43,600	46,800	3,200 (+7%)
Calcareous Grassland	2,000	400	N/A
Total	**503,400**	**496,800**	**-6,600 (-1.3%)**

No change was detected in lowland farmland Bird indicator species, which showed no significant difference in abundance between the survey periods of GMEP and ERAMMP. There is some suggestion that the abundance of grassland Bird species (guild) may have declined, continuing a long-term reported trend by the BBS for abundance of grassland Bird species (indicator).

There are early signs of a decline in Acid Grassland condition after a longer-term period of stability with an increase in the Grass:Forb ratio (a negative indicator), a decline in some Pollinator indicators and an increase in topsoil acidity, although there has been a slight reduction in Ellenberg (N) fertility.

There are a few early warning signs of an onset of decline in condition of Unimproved Neutral Grassland habitat. This includes a decline in overall plant species richness, Pollinator and mean butterfly abundance. Positive and negative plant species indicators, butterfly species richness and functional group richness however currently remain stable.

Most Pollinator indicators, which are the only results presented for Calcareous Grassland, show a decline.

3.3.2.1 Summary

Table 3-8. Summary of the long-term (pre-2013) and recent (2013-16 to 2021-23) trends for Semi-Natural Grassland as a whole and for individual Broad Habitats.

Asset Class and Broad Habitat	Long-term trend	Recent trend
Semi-Natural Grassland		
Unimproved Neutral Grassland	Stable	Of concern
Calcareous Grassland	N/A	Of concern
Acid Grassland	Stable	Of concern

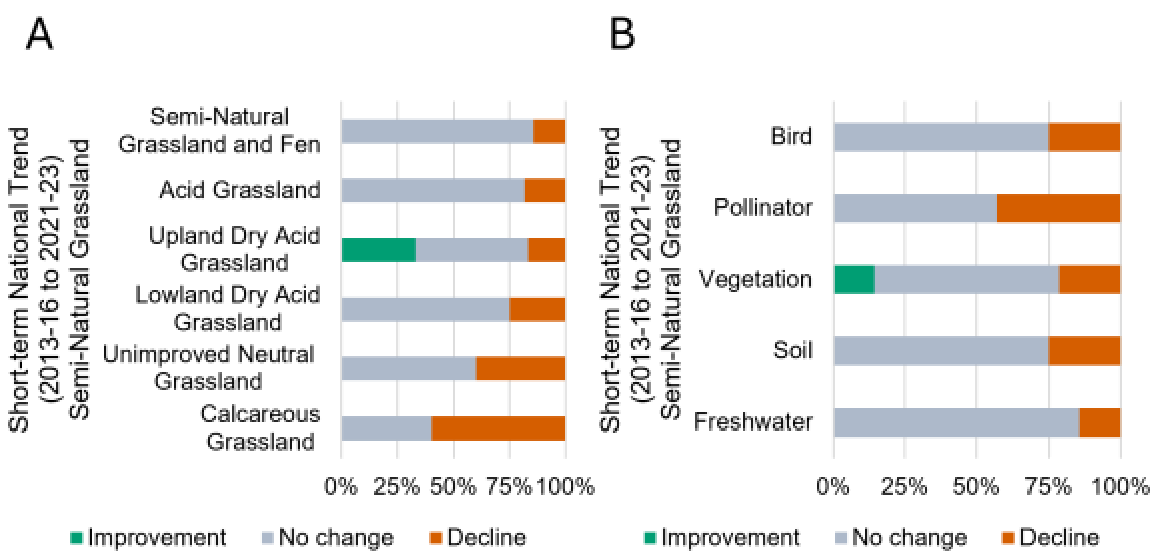


Figure 3-11. S Short-term trends for counts of indicators which have improved (green), stabilised (grey) or declined (red) for Semi-Natural Grassland between 2013-16 and 2021-23 expressed as: A) counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only and B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators. All results are from Nationally Representative survey squares.

Positive Outcomes

- Unimproved Neutral Grassland: Both positive and negative CSM plant species remain stable. Plants which favour high nutrient status (i.e. Ellenberg (N) fertility scores) and acidic conditions (i.e. Ellenberg reaction scores) have remained stable. Butterfly species richness and functional group richness were stable.
- Calcareous Grassland: Indicators for Pollinator functional group richness and the generality (range) of ecological functions Pollinators deliver are stable.
- Acid Grassland: Plant positive indicators are stable. There has been a slight reduction in Ellenberg (N) fertility in upland Acid Grassland. Functional group richness and generality of Pollinators are stable. Topsoil carbon and nitrogen concentrations and compaction remained stable in Acid Grassland.
- Semi-Natural Grassland overall (excluding Acid Grassland): The lowland farmland Bird abundance indicator showed no significant recent decline (unlike the national BBS).

Areas for Concern / Need for Further Action

- Unimproved Neutral Grassland: There has been a decline in total plant species richness. Pollinator abundance and mean butterfly abundance show significant declines.
- Calcareous Grassland: Pollinator abundance, mean butterfly abundance and butterfly species richness have all shown declines.
- Acid Grassland: The Grass:Forb ratio has increased which indicates a decline in condition in both lowland Dry Acid Grassland and upland Acid Grassland. There has been a slight reduction in Ellenberg moisture. Mean butterfly abundance has declined. Pollinator abundance and butterfly species richness also tended towards decline but were marginally non-significant. Topsoil pH has significantly decreased in Acid Grassland, which is in line with wider trends for GB.
- Semi-Natural Grassland overall (excluding Acid Grassland): A decline in the abundance of grassland Bird species (guild) was observed. It is important to understand which specific grassland Bird species are driving the negative guild trend nationally.
- Upland farmland: Upland Farmland Bird species (indicator) which is of particular relevance for Acid Grassland was stable.

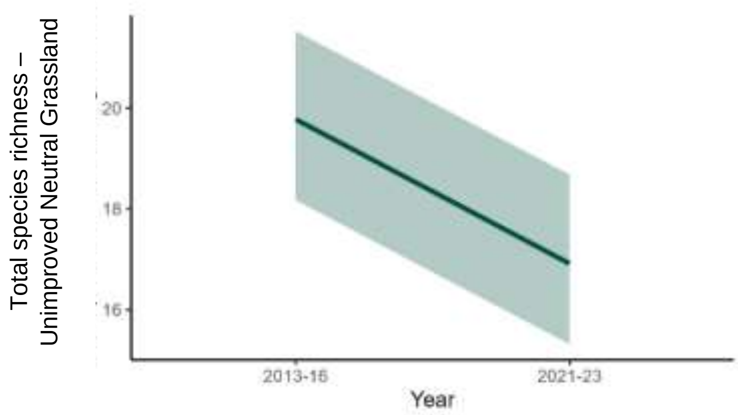


Figure 3-12. Trend between 2013-16 and 2021-23 in plant total species richness in Unimproved Neutral Grassland from Nationally Representative survey squares.

3.3.3 Glastir Impact

Few effects of Glastir management options were detected for the two Broad Habitats in Semi-Natural Grassland for which there was sufficient data. The most significant exception was an increase in positive plant indicators with Habitat Management for Unimproved Neutral Grassland. A reduction in the Grass:Forb ratio (a negative indicator) with Habitat Management for Acid Grassland also suggests some improvement, however other Vegetation indicators show no response.

Despite high uptake of reduced stocking density in Acid Grassland, no improvement in Soil condition was observed including no change for Soil compaction. No response for any Pollinator indicators was reported.

For Semi-Natural Grassland as a whole, there were small declines in the abundance of priority, granivorous and invertebrate-eating Bird species in response to Grassland Management (General). This may be driven by specific Bird species, for which additional work would aid in understanding whether these patterns are likely to reflect real negative effects of Glastir or chance associations with other, unforeseen, background associations. However, the effects involved were small in magnitude, so are unlikely to have an important effect on national populations.

The overall lack of any significant response may be due to options maintaining management levels from previous AES. However, benefits from the continued application of these actions which can take decades to emerge could have been expected.

3.3.3.1 Summary

Table 3-9. Summary of the impacts of Glastir option bundles on Semi-Natural Grassland as a whole and for individual Broad Habitats.

	Glastir management option bundles					
Asset Class and Broad Habitat	**Habitat Management**	**Grazing Low/No Inputs**	**Habitat Management (General Grassland)**	**Habitat Management (Peat/Heath)**	**Organic**	**Commons**
Semi-Natural Grassland	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Unimproved Neutral Grassland	Some improvement	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Calcareous Grassland	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Acid Grassland	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect	Low/No detectable effect
Semi-Natural Grassland Bird	N/A	Some improvement	Small decline	N/A	N/A	N/A
Upland Farmland Bird	N/A	Low/No detectable effect	Low/No detectable effect	N/A	N/A	N/A

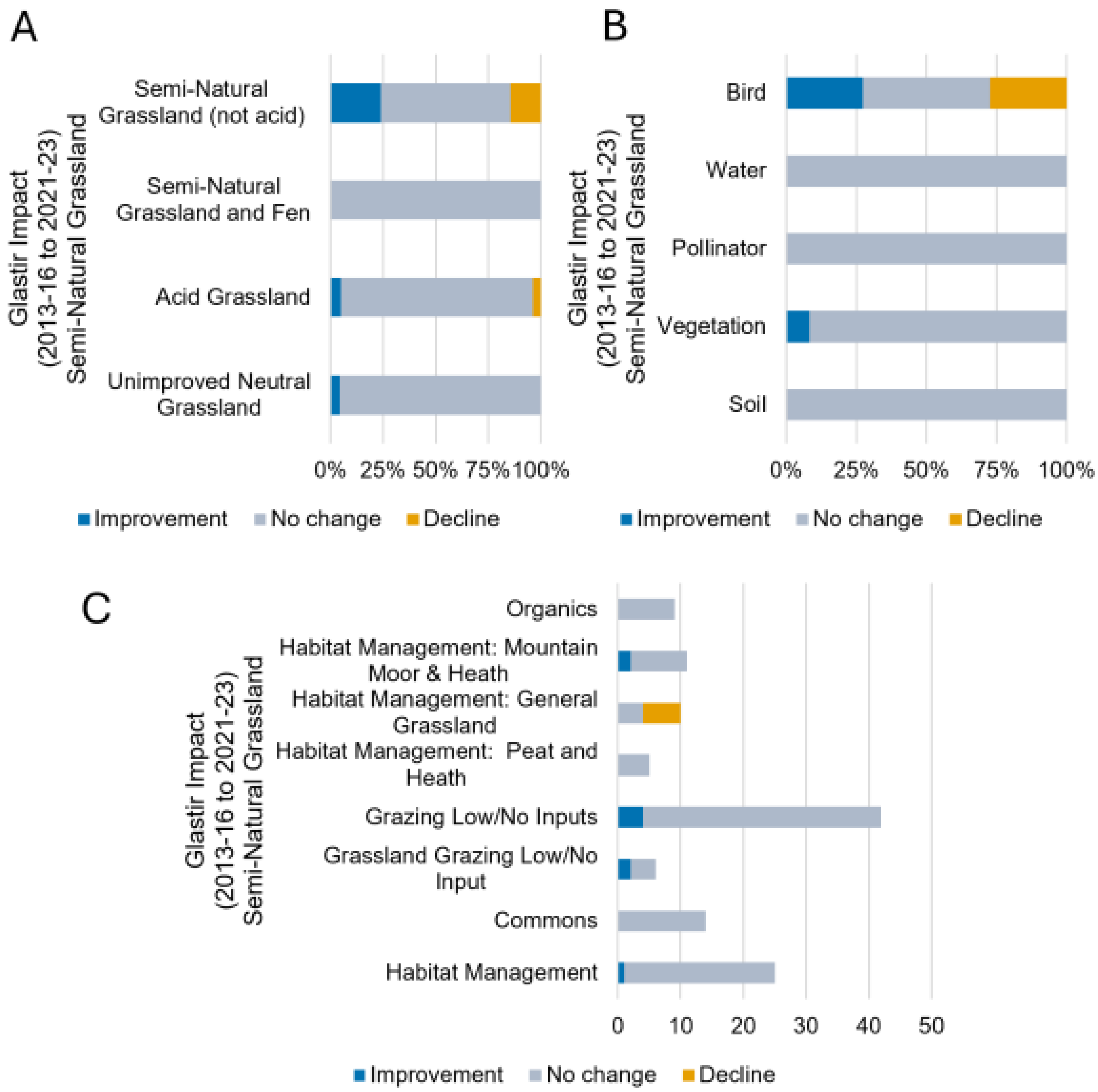


Figure 3-13. The impact of Glastir management options for the counts of indicators which have improved (blue), stabilised (grey) or declined (orange) for Semi-Natural Grassland expressed as: A) counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only, B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators, and C) in response to individual Glastir option bundles as total count of tests carried out.

Positive Outcomes

- Unimproved Neutral Grassland: There was an increase in positive plant indicators with Habitat Management. None was reported for Pollinators.
- Acid Grassland: Grass:Forb ratio (a negative indicator) decreased with Habitat Management.
- Semi-Natural Grassland as a whole (excluding Acid Grassland): Grazing Low/No Inputs management showed small but positive impacts on population change for lowland farmland Bird species, grassland guild species, and invertebrate- and vertebrate-eating species.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Unimproved Neutral Grassland: There were no significant Glastir effects for Pollinators and only one for Vegetation, but note there was a low sample to analyse.
- Calcareous Grassland: There was no response for any Pollinator indicators.
- Acid Grassland: There was no effect of Habitat Management (General) on topsoil carbon concentrations in Acid Grassland as seen in Semi-Improved Grassland and Broadleaved, Mixed and Yew Woodland, despite a high uptake of 'reduce stocking density' options. There were no significant effects of Glastir management on most Vegetation indicators. There was no effect of Glastir on Pollinator indicators.
- For Semi-Natural Grassland as a whole: There were small declines in priority, granivorous and invertebrate-eating species in response to in Grassland Habitat Management (General). This may be driven by specific Bird species, for which additional work would aid in understanding whether these patterns are likely to reflect real negative effects of Glastir, or chance associations with other, unforeseen, background associations. However, the effects involved were small in magnitude, so are unlikely to have an important effect on national populations. For Acid Grassland specifically, there was no change in the abundance of upland farmland Bird species (indicator).

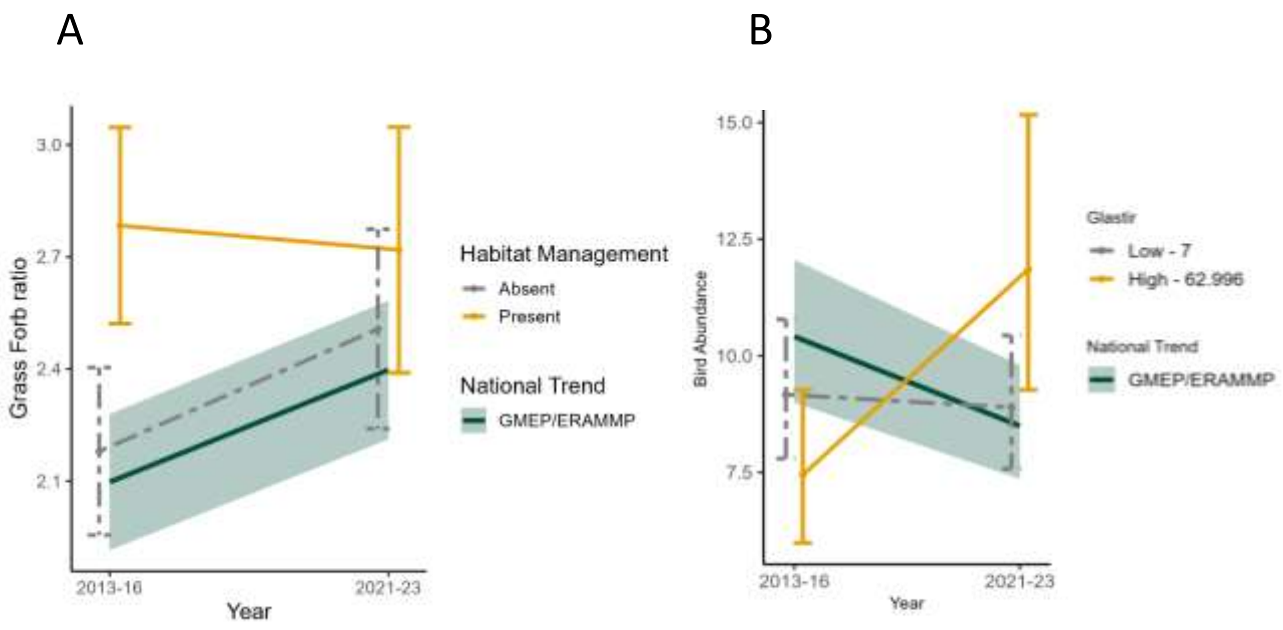


Figure 3-14. Trends in A) Grass:Forb ratio between 2013-16 and 2021-23 in Acid Grassland showing both National Trends and effect of Habitat Management, and B) grassland guild Bird abundance between 2013-16 and 2021-23 in Semi-Natural Grassland showing both National Trends and effect of uptake of grassland Grazing where Low/No Input management is low or high in proportion to specific bundle coverage maximums.

3.4 Enclosed Farmland

Enclosed Farmland comprises a wide mix of different Broad Habitats where the majority of land is managed primarily for food production. The soils are naturally the most productive in Wales. Whilst the management aims to maximise production, a number of important refugia provide space for native wildlife and some traditional management approaches, such as using a wall or Hedgerows as field boundaries, whilst also providing important landscape and cultural values. Increasingly the potential of linear features, such as field margins, riparian strips as well as the greater use of trees within the intensive agricultural landscape to support native species, increase connectivity in the landscape, and capture carbon is being realised and encouraged as part of schemes such as Glastir. Their value in improving resilience for crops with respect to heat stress for animals, control of pests and disease is being tested as is the potential for so called 'regenerative' agricultural practices which include reduced tillage and reduced use of synthetic fertilisers to improve resilience and overall sustainability of the farm system. The Organic method of production also has greatest relevance for this Asset Class, and transfer into that approach has been supported by the Glastir scheme.

3.4.1 Background

Arable and Horticultural habitats include ploughed land, land planted with crops and annual/early successional with open ground habitats. It may also be used to define some types of field margin, uncropped strips usually cultivated each year; and wild bird seed cover e.g. kale, quinoa and pollen and nectar mixes usually with a high proportion of legumes. Vegetation indicators for Arable habitats include annual forbs, and positive and negative Arable indicators which can be characteristic of species-rich Arable plant communities. In Improved Grassland, Ellenberg (N) fertility is likely to be high in these habitats.

Improved Grassland is an extensive Broad Habitat comprising low botanical quality grassland with high grazing value used as pasture, silage or occasionally hay. Intensively managed agricultural grasslands include ecologically impoverished swards usually dominated by rye grass (*Lolium perenne*), often with varying amounts of *Cynosurus cristatus, Holcus lanatus* and *Poa trivialis*. The diversity of flowering plants is characteristically low, consisting of white clover (*Trifolium repens*), dandelions (*Taraxacum officinale agg.*), creeping buttercup (*Ranunculus repens.*), docks, thistles and nettles. Separation of Improved from Semi-Improved Grassland has been done by separating habitats with greater than 25% cover of *Lolium perenne* and clover and assigning them to Improved Grassland. Increasing the plant species richness of the sward is an aim to increase Biodiversity so we have included total plant species richness as an indicator. We have also used positive and negative plant species richness. As Improved Grassland is not a habitat of conservation importance, the indicators came from discussions with NRW and it is the same list as used for Semi-Improved Grassland. Grass:Forb ratio describes the relationship between grasses and forbs, a higher score indicates that there is more grass cover which is undesirable and the aim is to increase forb richness of these grasslands. A high cover of grass in relation to the abundance of forbs can indicate intensive management impacts, e.g. high grazing intensity and nutrient enrichment. High fertility and low sward diversity are characteristics of these habitats, so improvement will likely also require reduction in fertility as indicated by Ellenberg (N) fertility scores.

Semi-Improved Grassland occurs on circum-neutral soils. It includes enclosed and managed grassland such as pastures, a range of grasslands which are inundated with water periodically, permanently moist or even waterlogged grassland, where the Vegetation is dominated by grasses, and tall and unmanaged grassland. It has been distinguished from the Improved Grassland above by a lower percentage of rye grass (*Lolium perenne* and *L. multiflorum*) and white clover (<25%). It also does not include high-quality neutral grassland such as upland and lowland hay meadows. Semi-Improved Grassland is of slightly higher botanical quality than Improved Grassland, with less domination by *Lolium perenne* and white clover. Increasing species richness of the sward is still desirable, and we have included total plant species richness as an indicator as this is more comparable across habitats, although we have also used the positive and negative plant species richness from a list created by discussions with NRW. The Grass:Forb ration and the Ellenberg (N) fertility ratio are also used as described for Improved Grassland.

The term ‘woody linear features’ (WLFs) has been used to account for the very large diversity of WLFs to be found in the countryside including everything from a traditionally managed Hedgerow to a planted avenue of trees or a line of old scrub which may at one time have been a managed Hedgerow. WLFs fall into two broad categories based on the extent to which the trees within them take their natural shape.

- ‘Natural shape’ means unhindered/unmanaged growth for at least a decade. Where trees take their natural shape, the feature will essentially be a line of trees or scrub.
- Where trees/scrub has been managed relatively recently, the WLF will fall into the Hedgerow category.

Most of the analyses presented are on Hedgerows as the managed component for which specific Glastir options have been created. These have been put into two bundles for Hedgerow Management and Restoration. Boundary plots are also analysed as a group. These are linear features including fences, walls, Hedgerows and grass strips. Understanding the condition of these features is important as they can play an important role as a refuge for species lost from the wider countryside, and they may also improve connectivity for some species and have been used as Buffers. Finally, the age, number and condition of individual trees, including veteran trees, are reported. Again, these can provide valuable refugia for many different taxa.

Hedgerow condition assessment depends on recording Hedgerow ‘attributes’, based on thresholds from the UK Habitat Classification (UKHAB) Steering Group to indicate whether a particular Hedgerow is in ‘favourable condition’. These attributes include:

- Structural only; height >1m, width of the woody component >1.5m, cross-sectional area (height x width) >3m, the degree of intactness of the Hedgerow canopy, vertical gappiness 5m wide, the height above ground at which the canopy starts 1m
- Structural and undisturbed ground >2m adjacent to the Hedgerow (all land).
- Structural and margins (width of perennial herbaceous Vegetation >1m).
- Undisturbed ground >2m adjacent to the Hedgerow (on Arable land only).

The percentage of plots meeting these condition thresholds is then calculated. Individual elements of structural condition including Hedgerow height and width have also been analysed along with changes in management type (% of length). For all linear plots including Hedgerow, Boundaries and Streamsides, the total species richness of the understorey has been analysed, along with the number of AWI and nectar plant species. This enables tracking of changes in plant diversity. By also analysing Ellenberg (N) fertility and light score, we hope to understand why changes are happening, i.e. is it due to increased fertility or changes in successional processes resulting in shading (and lower light scores) changing the type of species that might succeed?

Soil indicators are only available for Arable and Horticulture and Improved Grassland Broad Habitat classes. All indicators are of relevance here as intensive management practices, including fertiliser use, machinery, poaching by animals, and tillage, may lead to nutrient levels above crop needs resulting in eutrophication of Soil, rivers and coastal water; compaction and erosion which impact crop rooting depth (and thus resilience to drought), rapid runoff and sediment transfer to rivers and coastal waters; and loss of organic matter which affects carbon storage and habitat suitability for soil biota including a hugely diverse microbiome. All of these indicators may also be affected by more general processes such as climate change and atmospheric nitrogen deposition.

Pollinators largely depend on plant diversity and Vegetation quality, so are largely dependent on the semi-natural habitats that are peripheral to production Arable, such as Hedgerows, and their condition, although mass-flowering crops (in particular) can provide flushes of resources. Non-crop Arable plants are particularly important as food plants and nectar sources, so agricultural practices that restrict their availability constitute particular pressures. In Improved Grassland, dense, homogeneous swards provide few resources, although species like clovers will support some Pollinators. Rich and diverse peripheral habitats, such as Hedgerows, Boundaries and Streamsides within Enclosed Farmland landscapes, will support larger and more diverse Pollinator communities.

Six Bird indicators were investigated for this Asset Class: abundance of lowland farmland Bird species (indicator) and abundance of Arable species (guild), plus four general indicators for priority Bird species and the three dietary guilds (granivorous, and invertebrate- and vertebrate-eating Bird species). The indicator follows the policy-led standard list of species from (Burns, et al., 2023), whilst the Arable guild indicator represents a list of species selected for an ecological association with this habitat derived from (Siriwardena, Henderson, Noble, & Fuller, 2019). Siriwardena also provides the species lists for the key dietary guilds. The priority Bird species list consists of all Section 7 species from the Environment (Wales) Act 2016. Arable habitats are localised in Wales, but support a distinct Bird community that is not found elsewhere. They are threatened by long-term trends in agriculture towards simplification (loss of Arable to grass in the Welsh context), greater cropping efficiency reducing the availability of seed and invertebrate food resources associated with non-crop plants and declining condition of peripheral habitats like Hedgerows. Semi-Improved Grassland could not be separated from Improved Grassland in terms of Bird habitat preferences, so results for this habitat should be considered to be covered here. For Hedgerows, Boundaries and Streamsides, relevant Bird indicators are analysed with respect to the Glastir bundles for Hedge Management and Streamsides (which dominated the options considered for Wildlife Corridors). Some Glastir bundles focus on these features (e.g. Wildlife Corridors), whilst other Glastir Bundles that reduce inputs or grazing density may have indirect effects on them via impacts on adjacent land.

Enclosed Farmland contains habitats most likely to change in condition because their management is so intensive and dynamic in response to a range of economic, technological and policy drivers.

3.4.2 National Trends

With respect to extent of Broad Habitats within Enclosed Farmland, Arable and Horticultural represented 4% of land cover of Wales in 2021. This was a decrease of 24% compared to 2010. Improved Grassland represented 40% of land use in Wales in 2021 according to the UKCEH LCM. This was a 3% decrease in cover from 2010. There is no satellite data available from UKCEH LCM to indicate change of Semi-Improved Grassland. Overall there was a loss of 48,900 ha or 5% of the most productive farmland in Wales between 2010 and 2021.

Table 3-10. Change in the extent of two Broad Habitats within the Enclosed Farmland Broad Habitat Asset Class and for the Enclosed Asset Class as a whole (ha and as a % of 2010) between 2010 and 2021 estimated by the UKCEH LCM.

Land Use / Broad Habitat	2010 (ha)	2021 (ha)	Change 2010 to 2021 (ha) and % of 2010
Arable	110,000	84,100	-25,900 (-24%)
Improved Grassland	876,300	853,300	-23,000 (-3%)
Semi-Improved Grassland	N/A	N/A	N/A
Total	**986,300**	**937,400**	**-48,900 (-5%)**

There was no change in indicators of Vegetation condition in the Arable and Horticultural Broad Habitat. Several topsoil indicators indicate a decline in Soil condition with a decrease in topsoil carbon concentration, an increase in bulk density (i.e. compaction), and a four-fold increase in the number of sites with phosphorus concentrations which risk leaching to water courses. These all indicate potential risks for Soil health, associated risks for Freshwater quality and reduced carbon sequestration. Abundance of Arable Bird species (guild) also showed a significant decline.

Whilst there were some signs of positive improvement in Improved Grassland such as an increase in positive plant indicator richness, a reduction in Ellenberg (N) fertility and stability of Pollinator indicators, a decline in several Soil health indicators is of major concern as is a decline in the abundance of grassland Birds (guild). For example, Soil pH remains below that suitable for production for 72% of all sites and there has been an average of 15% increase in Soil phosphorus concentrations and three-fold increase in sites where levels risk Soils being a point source of pollution to water courses. Topsoil bulk density has also increased. Going forward, with support from satellite information, a separate category of leys should be included to capture land moving between Arable and pasture systems. Currently this is known to affect a minimum of 14% of all Arable and Improved Grassland sites. This is likely to be an underestimate of the number of leys in Wales as fields may have switched between visits but have returned to the original state at the time of the survey. Satellite image analysis will enable leys to be separately reported going forward. This is important as they are likely to have intermediate trends compared to Arable or Improved Grassland and are therefore currently increasing variability and thus reducing detection limits in both Arable and Improved Grassland. WG does not currently capture this information through the Farm Business Survey.

There are some early indicators of a decline in the condition of Semi-Improved Grassland after a period of stability. Whilst the number of negative plant indicators decreased and Pollinator indicators were stable, total plant species richness declined together with an increase in the Grass:Forb ratio (a negative indicator). Topsoil bulk density (an indicator of Soil compaction) also increased.

Overall, there was a marginal signal of improvement of Hedgerow extent and condition with an increase in length of new and restored hedges, an increase height, width and woody species richness. Both Hedgerow height and width are important for Hedgerow condition, ensuring a greater area of habitat for wildlife as well as storing higher amounts of carbon so taller, wider Hedgerows have many benefits. Changes in woody species richness are most likely to occur if there is a significant increase in Hedgerow extent or restoration resulting from the planting of multi-species Hedgerows. Although we did not find evidence of a large uptake of Glastir restoration options, these could be implemented outside of Glastir.

A higher percentage of Hedgerow woody diversity plots were in good condition according to UKHAB criteria. This is due mostly to improvements in structural condition with increased height. There is no evidence that this is related to Glastir management options, although the survey overlap with Glastir management options was not high particularly for restoration actions. Although Hedgerow condition had improved, over half of Hedgerows surveyed still failed to reach both good structural and margin condition criteria.

Ground flora species richness and nectar plant richness declined in Hedgerows. A decrease in species richness likely reflected the increased dominance of species that can tolerate shady/eutrophic conditions as indicated by the decreased Ellenberg light score.

When analysing all Boundary plots together, the trend previously observed of succession along linear features appears to have been stabilised in these habitats. At the same time there has been a decline in species richness and nectar plants. There was no change however in positive plant indicators.

Unlike Boundaries where the successional trend may have been stabilised, results from Streamsides suggest a shift to more shade-tolerant species as the canopy closes, favouring a gradual colonisation of slow dispersing AWI species but not yet at a rate to offset loss of more light-demanding species.

Lowland farmland Bird indicator species showed no recent change in abundance. However, the abundance of grassland and Arable Bird species (guilds) showed significant declines.

3.4.2.1 Summary

Table 3-11. Summary of the long-term (pre-2013) and recent (2013-16 to 2021-23) trends for Enclosed Farmland as a whole and for individual Broad Habitats.

Asset Class and Broad Habitat	Long-term trend	Recent trend
Enclosed Farmland		
Arable and Horticulture	Declined	Declined
Improved Grassland	Of concern	Of concern
Semi-Improved Grassland	Stable	Of concern
Hedgerows	Declined	Improved
Individual Trees	N/A	Stable
Boundaries	N/A	Improved
Streamsides	N/A	Of concern

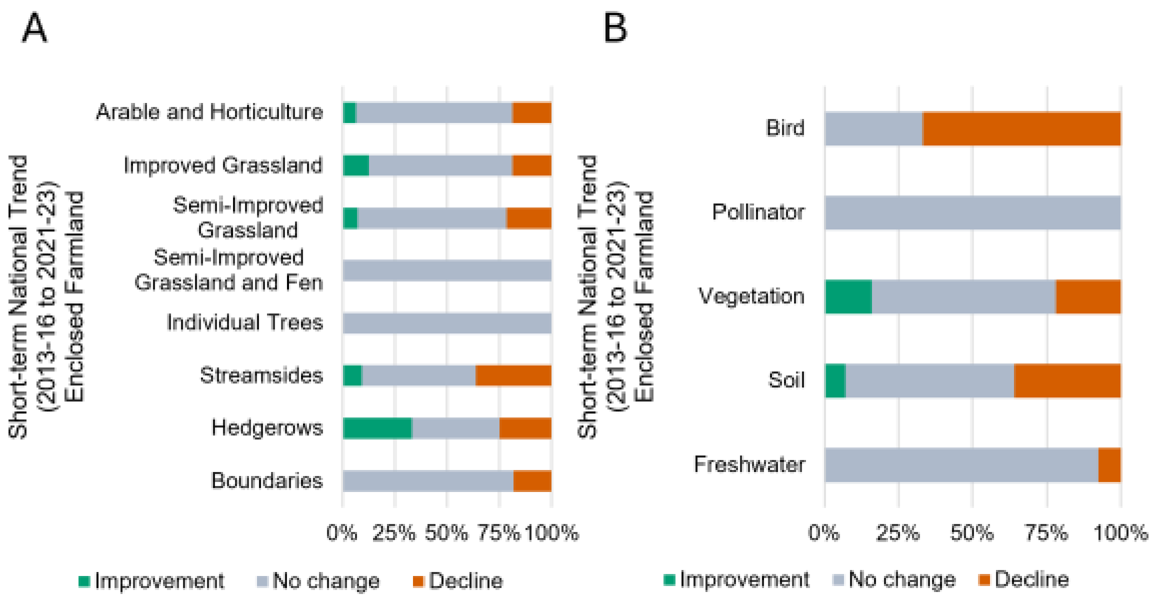


Figure 3-15. Short-term trends for the counts of indicators which have improved (green), stabilised (grey) or declined (red) for Enclosed Farmland between 2013-16 and 2021-23 expressed as: A) counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only and B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators. All results are from Nationally Representative survey squares.

Positive Outcomes

- Arable and Horticulture: There was no significant change for plant indicators and Pollinators. Soil N levels have decreased, and Soil Olsen P levels have remained stable and within the range suggested for biomass production in Arable and Horticultural land. However, note the increased number of sites with high P levels.
- Improved Grassland: There has been an increase in positive plant indicator richness reversing a long-term decline. This may be associated with a decrease in Ellenberg (N) fertility score, however Soil analyses have remained stable suggesting a lag or other drivers of this Vegetation change. Although there has been no increase in total plant species richness, a previously reported decline (1990-2007) has been stabilised at a higher level. Pollinator abundance, mean butterfly abundance and generality of Pollinators are stable. There was no change in lowland farmland Bird indicator (species). Topsoil carbon and nitrogen concentrations in Improved Grassland remain stable. Topsoil acidity (pH) is now stable in Improved Grassland after a long-term increase. Topsoil acidity remains within the optimal range of pH for mesotropic grassland (pH 5 to 7).
- Semi-Improved Grassland: There has been a decrease in negative plant indicators. Positive plant indicators have remained stable. Pollinator functional group richness increased. All other Pollinator indicators remained stable. Topsoil carbon and nitrogen concentrations in Semi-Improved Grassland remained stable across Wales. The national average topsoil pH is now stable in Semi-Improved Grassland after a period of recovery from acidification but remains within the optimum pH for mesotropic grasslands (pH 5 to 7).
- Hedgerows: There is an improvement in Hedgerow condition overall (based on UKHAB condition measures), increased Hedgerow length of 2,200km (includes

restored), height (94%) and width (+9%) and increased woody species richness (+6%) in Hedgerows. Hedgerow management has remained stable in the short term. There was no significant change in AWI in Hedgerows.

- Individual trees: The age structure of individual trees is progressing – there are more older trees for some species, e.g. ash and oak. There has been no change in the total number of trees per square.
- Veteran trees: there have been some condition changes, more epiphytes, slightly less of the canopy live, more hollow trunks, and more trees are pollarded.
- Boundaries: Plants that favour high light conditions and positive plant indicators have stabilised after a decline in the longer-term data. Canopy height has also stabilised after a long-term increase. Increasing trends for Ellenberg (N) fertility and Ellenberg reaction seem to have stabilised more recently in Boundary plots.
- Streamsides: Positive plant indicators and Ellenberg (N) fertility have stabilised from a long-term decline.

Areas for Concern / Need for Further Action

- Arable and Horticulture: Arable topsoil carbon concentration has significantly decreased by 8% (3g kg^{-1}) which is in line with the magnitude of change observed in the long-term trend in Arable and Horticultural land in Wales from 1978 to 2007. The decrease in Soil carbon concentration suggests a potential overall loss of topsoil carbon stock from Arable Soils. The number of sites which were potential point sources of phosphorus leaching (i.e. where Olsen P > 60mg P kg^{-1}) increased from 4% of Arable sites in 2013-16 to 16% of Arable sites in 2021-23 – a four-fold increase. 8% of the new sites identified in 2021-23 were under grassland management in 2013-16, suggesting a ley management. 18% of Arable Soils exceed the threshold of bulk density (i.e. compaction) for well-functioning mineral Soils in 2021-23 (>1.3g cm^{-3}) The abundance of Arable Bird species (guild) declined. It is important to understand which Arable Bird species are driving the guild-level decline in the National Trend, but this is likely to reflect an ongoing, well-known trend at UK level in this Bird community, as is shown by the analogous indicator from the national BBS for lowland farmland Birds.
- Improved Grassland: 72% of Improved Grassland had a topsoil pH below 6 in 2021-23, identified as a trigger point to grassland productivity on mineral Soils (down from 75% in 2013-16). Topsoil Olsen P increased by 15.6% to an average of 24.7mg P kg^{-1} in Improved Grassland. This typical value is well below the critical threshold of 60mg P kg^{-1} associated with leaching. It is also within the range of 16-25mg P kg^{-1} suggested for biomass production in Improved Grassland. However, potential point sources of phosphorus leaching in Improved Grassland (i.e. where Olsen P > 60mg P kg^{-1}) has approximately tripled from 5.4% of sites in 2013-16 to 17.1% of sites in 2021-23. Topsoil bulk density (i.e. compaction and a negative indicator) has significantly increased in Improved Grassland by 6% from 2013-16 to 2021-23. There has been a decline in grassland Bird abundance (guild). This reflects an established pattern of change among lowland farmland Bird species at the UK level, although the analogous index for 2021-23 data showed no change, whilst the BBS indicator declined.
- Semi-Improved Grassland: The Grass:Forb ratio increased, which is a negative plant indicator. There was also a decline in total plant species richness. This trend is reversed where there was HNV Farmland Type 2 within the 1km survey square. This suggests decline in this habitat is more likely where land is isolated, e.g. from potential seed sources. Topsoil bulk density, which is an indicator of compaction, has significantly increased in Semi-Improved Grassland by 13%.

- Hedgerows: There has been a decline in nectar rich plants and ground flora plant species richness. There is increased shading as indicated by canopy height and a decline in Ellenberg light score.
- Boundary plots: There has been a decline in nectar rich plants and reduction in overall plant species richness.
- Streamsides: There has been a decline in nectar rich plants and overall plant species richness. There is increased shading as indicated by canopy height and a decline in Ellenberg light score.

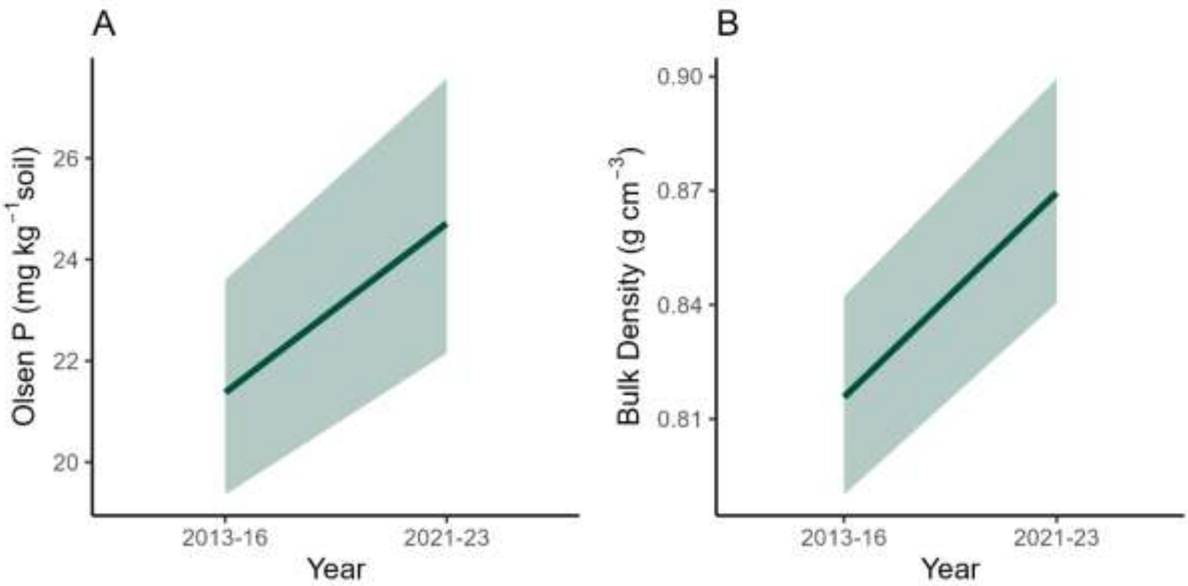


Figure 3-16. Trend in Improved Grassland topsoil for: A) Olsen P concentration, and B) bulk density between 2013-16 and 2021-23 from Nationally Representative survey squares.

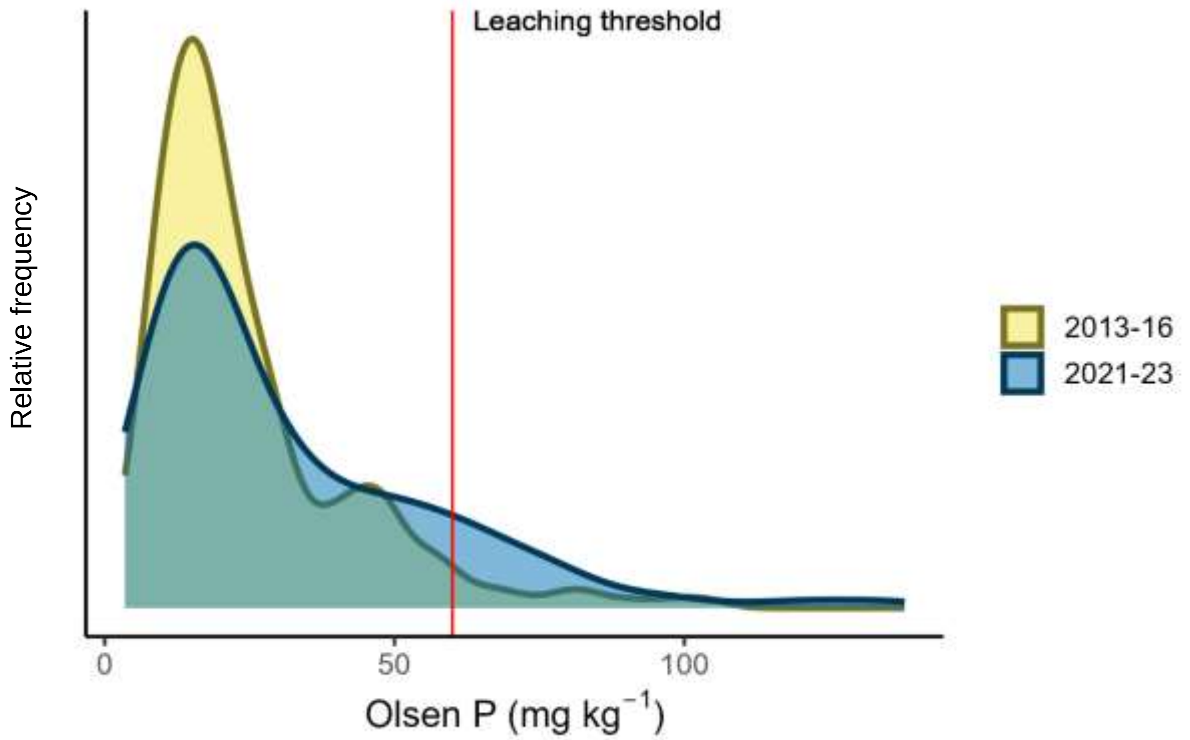


Figure 3-17. A three-fold increase in Improved Grassland sites now exceeding the threshold for phosphorus leaching from 2013-16 to 2021-23 from Nationally Representative survey squares. This is an increase from 5% to 17% of all sites.

.

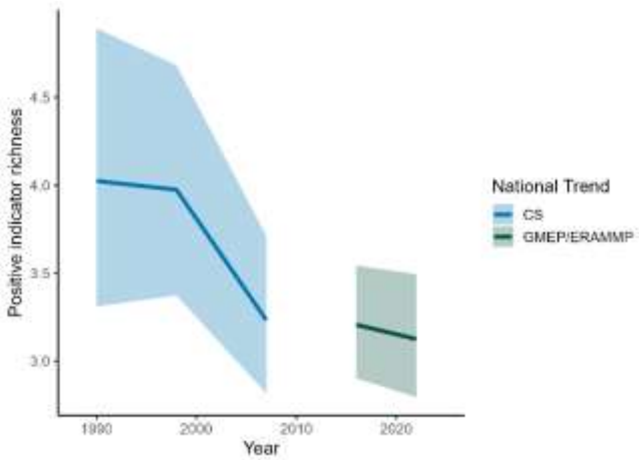


Figure 3-18. Long-term National Trends in plant positive indicators (CSM Indicators) in Semi-Improved Grassland from Countryside Survey (CS) squares in Wales (1990-2007) and GMEP/ERAMMP (2013-16 to 2021-23) from Nationally Representative survey squares.

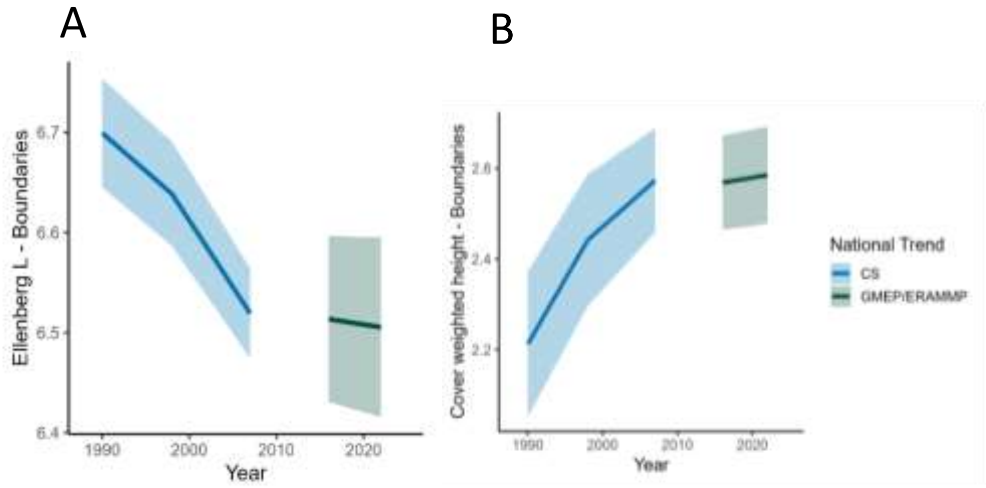


Figure 3-19. Long-term National Trends in: A) plant species preferring high light conditions (i.e. Ellenberg light (L) in boundaries), and B) cover-weighted canopy height on boundaries from Countryside Survey (CS) squares in Wales (1990-2007) and GMEP/ERAMMP (2013-16 to 2021-23) from Nationally Representative survey squares.

3.4.3 Glastir Impact

Arable and Horticulture: For Vegetation, Glastir options on Arable habitats included Arable Management options (such as cover crops, margins, unsprayed root crops, retaining winter stubbles) and Glastir Organic management. There was no impact of these Glastir management options on indicators of Vegetation condition. There was an improvement in Pollinator abundance where Glastir Organic was applied and butterfly species richness where Arable Management options were applied. For Soils, Glastir impacts on Arable and Horticultural Soils was not assessed due to very low Glastir action uptake on Arable and Horticultural land. Arable-associated Bird species, priority Bird species, and invertebrate- and vertebrate-eating species all responded positively to Arable Management options.

Improved Grassland: Glastir management option bundles analysed for Vegetation change included the Habitat Management bundle and Grazing Low/No Inputs. There were also some plots subject to Organic management. For Soils, Glastir impacts on Improved Grassland were assessed using the Arable Management bundle, the Grazing Low/No Inputs management bundle, and the Organic bundle. The effect of presence in historic AES schemes was assessed too. Glastir has not resulted in any detectable improvements in Soil or Vegetation condition in Improved Grassland. The single example of a benefit of Glastir was observed for Organic, which was positive for butterfly abundance and butterfly species richness. Surprisingly, Grazing Low/No Inputs (primarily ‘Grazed permanent pasture with Low/No Inputs’ which reduced nutrient and pesticide inputs) had no effect on Soil nutrient concentrations. A positive impact of Grazing Low/No Inputs management is seen for the lowland farmland Bird species indicator, grassland Bird species (guild) and invertebrate- and vertebrate-eating Bird species.

In general, in-scheme land was of better quality, e.g. has higher total plant species richness and lower number of plants which require high nutrient status (i.e. Ellenberg (N) fertility score). This suggests targeting of payments on land that was in better condition and may also mean that limited response is expected over time if quality on scheme entry is already high and/or options are not sufficiently transformative.

The presence of historic AES and landscape context, i.e. the presence/absence of HNV Farmland 1 and 2 in the surrounding 1km square, were not found to have any significant influence on Vegetation. Note the contrast to Semi-Improved Grassland and Acid Grassland, where benefits were observed.

Finally, it is worth noting, uptake of Glastir in Improved Grassland has been low compared to membership of historic AES. Of the 131 sites sampled for Soil that were members of historic AES, only 19 (15%) applied Glastir options between 2013-16 and 2021-23. Glastir options were also implemented on sites that had no membership of prior schemes. For Soils, land which was part of historic AES schemes have seen significant faster declines in Soil carbon concentrations than sites that were not part of schemes. This suggests that the benefits of historic management have been short-lived and were not maintained by subsequent schemes. This illustrates the lack of permanence of Soil carbon which should be considered as part of future Net Zero plans.

Semi-Improved Grassland: The impact of Glastir options on Vegetation was assessed for Semi-Improved Grassland using the bundle Habitat Management which included grazing management of open country and reduced stocking additional payments. There were also some Organic interventions. For Soils, the impact of Glastir on Semi-Improved Grassland was assessed using the Habitat Management bundle, Grazing Low/No Inputs management bundle, and the Organic bundle. The impact of the presence in historic AES schemes was assessed too. There were no effects of Glastir options on Vegetation indicators and few impacts on Soil, with the exception of increased topsoil carbon concentration with the Habitat Management (General) bundle. Evidence of continued benefits from historic AES schemes are detected with declines in Grass:Forb ratio (a negative indicator) and topsoil nitrogen concentrations.

3.4.3.1 Summary

Table 3-12. Summary of the impacts of Glastir option bundles on Enclosed Farmland as a whole and individual Broad Habitats.

<table>
<tr><th rowspan="2">Asset Class and Broad Habitat</th><th colspan="8">Glastir management option bundles</th></tr>
<tr><th>Habitat Management</th><th>Arable Management</th><th>Grazing Low/No Inputs</th><th>Wildlife Corridors</th><th>Organic</th><th>Commons</th><th>Hedge Management</th><th>Woodland Creation</th></tr>
<tr><td colspan="9">Enclosed Farmland</td></tr>
<tr><td>Arable and Horticulture</td><td rowspan="6">Low/No detectable effect</td><td>Some improvement</td><td></td><td rowspan="3">Low/No detectable effect</td><td></td><td rowspan="6">Low/No detectable effect</td><td rowspan="3">Low/No detectable effect</td><td rowspan="6">Low/No detectable effect</td></tr>
<tr><td>Improved Grassland</td><td rowspan="5">Low/No detectable effect</td><td>Some improvement</td><td>Some Improvement</td></tr>
<tr><td>Semi-Improved Grassland</td><td rowspan="4">Low/No detectable effect</td><td rowspan="4">Low/No detectable effect</td></tr>
<tr><td>Hedgerows</td><td rowspan="2">Some Improvement</td><td rowspan="2">Some Improvement</td></tr>
<tr><td>Boundaries</td></tr>
<tr><td>Streamsides</td><td></td><td></td></tr>
</table>

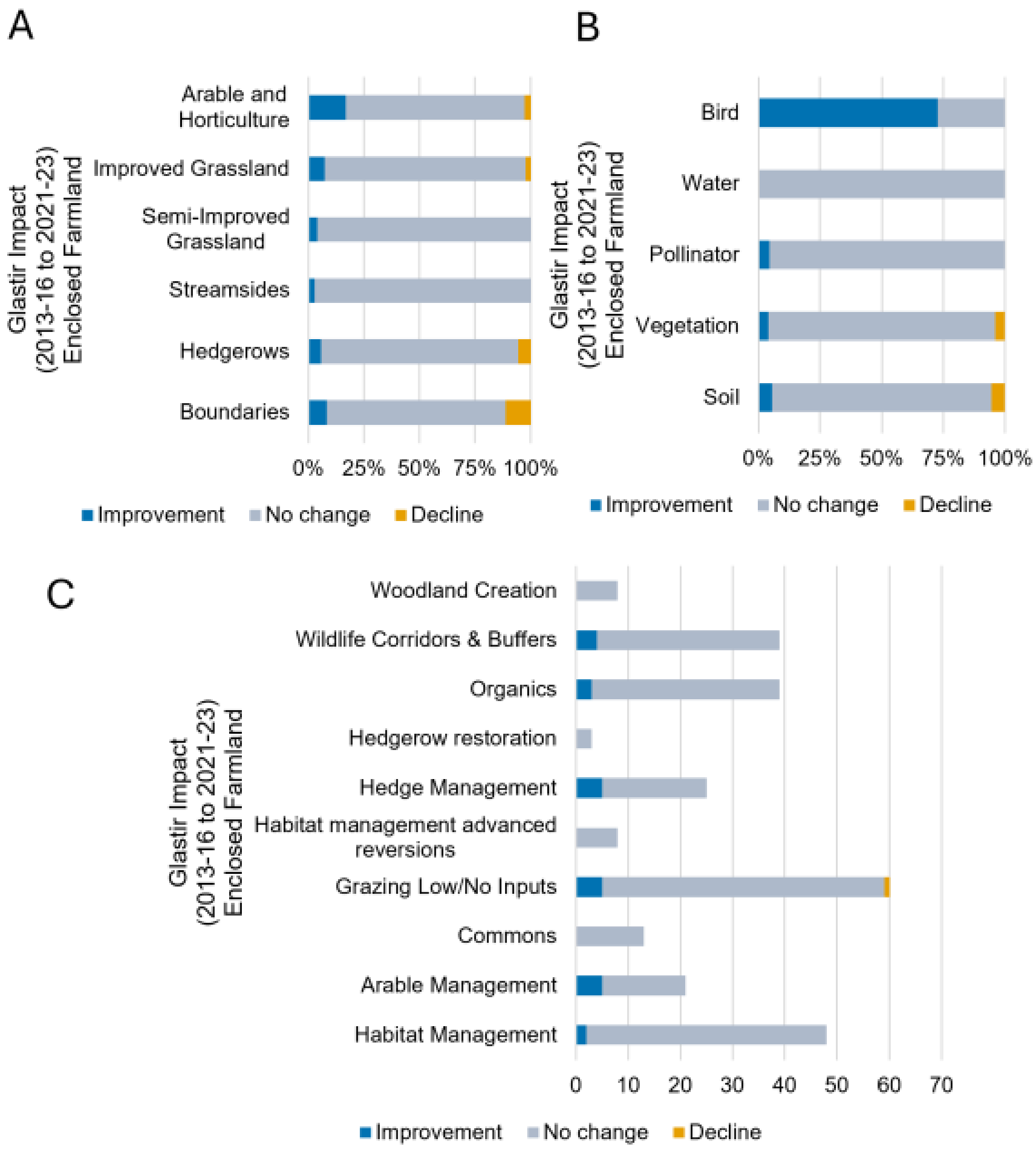


Figure 3-20. The impact of Glastir management options for the counts of indicators which have improved (blue), stabilised (grey) or declined (orange) for Woodland expressed as: A) counts as a percentage of total indicators within each individual Broad Habitat to control for different number of indicators, for vegetation, soil and pollinators only, B) counts as a percentage of total indicators within each Natural Resource to control for different number of indicators, and C) in response to individual Glastir option bundles as total count of tests carried out.

Positive Outcomes

- Arable and Horticulture: Pollinator abundance has increased where Glastir Organic was applied. Butterfly species richness has increased where Arable Management options were applied. All Bird indicators tested but one (granivorous Bird guild) showed positive population change responses to Glastir Arable Management. The

Arable Glastir options in survey squares were dominated by unsprayed crop options; these are most likely to benefit insectivorous Birds.

- Improved Grassland: Mean butterfly abundance and butterfly species richness increased where Glastir Organic management was applied. Bird abundances showed increases for four indicators with Grazing Low/No Inputs management: lowland farmland Bird species, grassland Bird species (guild) and invertebrate- and vertebrate-eating Bird species.
- Semi-Improved Grassland: The Habitat Management bundle (primarily reduced stocking density) increased topsoil carbon concentration, counter to the stable National Trend for Semi-Improved Grassland. These options were applied on land that had below-average topsoil carbon concentration and has brought it up to the national average.
- Hedgerows: Hedgerow condition positively increased with Hedge Management (this is based on the percentage of plots meeting condition criteria, so not statistically confirmed). There were positive responses from most Bird indicators to Hedge Management, as well as to Wildlife Corridor and Buffers management. Actual option coverage indicates that the latter pattern involved responses to Streamside management.
- Boundaries: Grazing Low/No Inputs bundle had a positive effect on total ground flora species richness on Boundary features.
- Streamsides: There was a reduction in plant negative indicators on Streamsides with the Wildlife Corridor Management bundle.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Arable and Horticulture: There were no effects of Glastir on Vegetation indicators. Granivorous Bird species showed no effect of Glastir Arable Management options, despite the latter being the principal element of Glastir that should nominally benefit this group.
- Improved Grassland: No impact of Glastir was detected for indicators of Vegetation condition. The Glastir Grazing Low/No Inputs management bundle is associated with a decrease in topsoil carbon concentration. The Glastir Grazing Low/No Inputs management bundle (primarily ‘Grazed permanent pasture with Low/No Inputs’ which reduced nutrient and pesticide inputs) did not affect topsoil nitrogen or Olsen P concentrations in Improved Grassland. This may be explained by the results of the ADAS FPS which show little difference in fertiliser application levels between Glastir and non-Glastir land. Land with Glastir options in the Arable Management bundle were below average Soil condition for Improved Grassland, likely reflecting the effect of ley rotation into Arable Management on topsoil carbon concentrations.
- Semi-Improved Grassland: There were no significant Glastir options effects for indicators of Vegetation condition. There were no significant positive individual bundle effects on Pollinator indicators. There was no change in Soil indicators other than for carbon concentration for Habitat Management.
- Hedgerows: There were no significant effects of Hedge Management, Hedge Restoration, Wildlife Corridors or Woodland Creation on length or width of Hedgerows. Hedge Management also had no effect on woody species richness or ground flora species richness of Hedgerows.
- Individual Trees: There was no effect of Glastir on the number of individual trees.
- Boundaries: There were no other effects of Glastir option bundles in addition to those positive outcomes noted above.
- Streamsides: There were no other effects of Glastir option bundles in addition to those positive outcomes noted above.

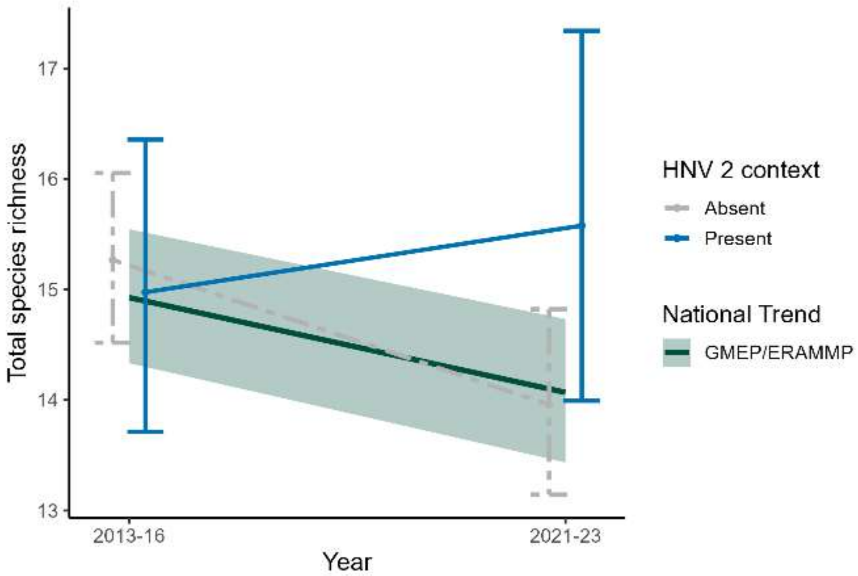


Figure 3-21. Trend in total plant species richness between 2013-16 and 2021-23 in Semi-Improved Grassland showing both National Trend and where HNV Farmland Type 2 (i.e. heterogeneous land with high habitat diversity) as context is present or absent.

4 BIODIVERSITY

Maskell, L.[1], Bowgen, K.M.[2], Macgregor, C.J.[2], Bentley, L.F.[1], Doeser, A.[1], Hunt, M.[1], Jarvis, S.G.[1], Kimberley, A.[1], Mondain-Monval, T.O.[1], Siriwardena, G.M.[2], Smart, S.M.[1], and Wood, C.[1]

UK Centre for Ecology[1] and Hydrology and British Trust for Ornithology[2]

To help inform the next SoNaRR report, a request was made by NRW that all Biodiversity evidence was collated from across the different habitats and resources to provide National Trends. In addition, WG is still obliged to provide evidence as to the impact of Glastir on land in scheme as the EU provided funding for Glastir. Both are reported in this chapter.

It should be noted that the population used for the reporting of Glastir outcomes extends beyond the Nationally Representative sample used to report National Trends. The impact of Glastir is reported as the change in land in-scheme compared to the change in land out-of-scheme except for birds where the relationship between indicators with relevant management measures is reported. It should also be noted that all analyses reported for both National Trends and Glastir impacts will primarily capture the most common habitat components and soil types as they are designed to assess national status, and are not intended to exhaustively capture or represent the condition of rare or more biodiversity-rich areas.

4.1 Introduction

A high-level overview summary of changes in Vegetation, Pollinator and Bird indicators between the GMEP 2013-16 and ERAMMP surveys 2021-23 is presented below. This is followed by three sections outlining the individual National Trend and Glastir Impact data for Vegetation, Pollinators and Birds.

Biodiversity in Headwaters and Ponds is reported in Section 8 Freshwater. Biodiversity in Soil was reported by GMEP (Emmett & team, 2017) (George P. , et al., 2019) but was not repeated at WG request as there is currently no agreement in the soil community as to how high level indicators of change are linked to soil function. Soil samples however were collected and archived in both dried and frozen -20 ^{o}C formats for potential future analysis should this be required.

4.1.1 National Trends

- Out of numerous tests to report National Trends for over 20 habitats for Vegetation, more than 50% indicated no detected change of indicators suggesting stability. Only 11 positive outcomes were reported overall with the remainder being negative outcomes. (Note that some increases ‘+’ in the table are for negative indicators so do not suggest positive outcomes, and some ‘-’, such as for fertility, are actually positive. The table footnote always indicates where these are present).
- There was no improvement in Woodland Vegetation Biodiversity indicators, although there was also no decline, and most long-term trends show stability or a halted decline. However, the cover of non-native and invasive species increased, which is a negative indicator.
- National Trends for all Wales across all habitats indicate a 9% decrease in total plant species richness, but the number of positive indicator species has remained stable as reported in 2017, following as historic decline.

- National Trends for all Wales combining data across all habitats suggests that all Pollinator indicators were stable, probably reflecting the overall stability in geographically dominant habitats including Improved Grassland, and Mountain, Moor and Heath. Butterfly abundance fell in five habitats and Butterfly species richness fell in three habitats.
- There was no detected change in the abundances of priority Bird species, upland farmland Bird indicator species, lowland farmland Bird indicator species and Woodland Bird indicator species. Among the four habitat guilds of Bird species identified, Woodland Bird guild species and upland Bird guild species showed no change whilst Arable and Grassland Bird abundance declined.
- The three dietary Bird guilds considered showed varied patterns: an increase for seed eaters, no significant change for invertebrate eaters and a decline for vertebrate eaters.

4.1.2 Glastir Impact

- When habitats were examined individually for Vegetation, most tests showed no effect of Glastir bundles. There was a positive effect of Glastir on All Wales Total plant species richness halting the decline seen in the National Trends, but no effect of all Glastir options for the remaining four high-level Vegetation indicator analyses combining across all habitats for Wales as a whole.
- The few positive Glastir impacts for plants from numerous tests were: an increase in AWI for Woodland Management in Broadleaved Woodland; a decrease in Ellenberg (N) fertility for Bog and Blanket Bog with Habitat Management; increases in Dwarf Shrub Heath cover, CSM positive indicator species and *Sphagnum* cover with Commons management in Blanket Bog; an increase in total plant species richness in Bracken in response to the Grazing Low/No Inputs; an increase in positive indicators in Unimproved Neutral Grassland; a reduced Grass:Forb ratio in response to Habitat Management bundle in Acid Grassland; increased Total species richness in Semi-Improved Grassland with Commons; improved Structural Condition in Hedgerows with Hedgerow Management; increased plant species richness in Boundaries for Grazing Low/No Inputs; and a reduction in plant negative indicators in Wildlife Corridors bundle.
- When habitats were examined individually for Pollinators, most tests showed no effect of Glastir bundles. Exceptions were: a positive effect of Arable Glastir management on butterfly species richness in Arable and Horticultural land; a positive effect Glastir Organic management on butterfly abundance in Arable areas and butterfly species richness in Improved Grassland. However, Glastir was associated with reduced Pollinator abundance over time for Woodland Management in Broadleaved Woodland and with reduced butterfly species in Dwarf Shrub Heath for the Commons options bundle. (It should be noted that for Pollinators, responses to management might be faster than for other indicators, so it is possible that they occurred with the first years of Glastir management prior to some baseline assessments by GMEP 2013-2016.
- In contrast to Vegetation and Pollinators, Glastir management was clearly a positive influence on a wide suite of Bird indicators with the one exception of Habitat Management of Semi-Natural Grassland, which requires further exploration. Specific results suggest that relevant Glastir management were: a positive effects on Birds in Arable, Woodland, Improved Grassland and Hedgerow habitats, albeit only to slow overall rates of decline, rather than to halt or to reverse them.

4.2 Vegetation

An ongoing homogenisation (i.e. fewer overall plant species in communities which are dominated by a small group of species) of the countryside has been happening in the longer term due to a wide range of direct and indirect drivers across GB (Carey, et al., 2008). Nitrogen deposition in particular was highlighted in the National Ecosystem Assessment (Natural Capital and Ecosystem Assessment Programme, 2022) due to its eutrophying impact benefitting taller and more competitive plant species at the expense of many native plants although grazing pressure and now climate change will all be contributing.

Vegetation Indicators

A range of indicators are reported to capture the many different elements of Vegetation which capture overall condition. This includes positive and negative indicator species, as well as other indicators which provide information as to the pressures and intermediate changes which will, in the longer term, change condition, such as nutrient and light levels.

These indicators include:

- Indices relating to fertility, moisture, light and acidity status (Ellenberg scores) (Ellenberg, et al., 1991), (Hill, Roy, Mountford, & Bunce, 2000). An increase in fertility and acidity scores are considered negative indicators. Light levels are particularly important for Woodlands where an increase may indicate improved management in Broadleaved Woodland. High moisture scores are positive for wet habitats such as Bog and Fen, Marsh, Swamp. A decline could indicate early stages of climate change and/or continued effects of historical drainage.
- The Grass:Forb ratio which indicates increases in conditions which favour grass species at the expense of flowering plants (forbs). This is often linked to high grazing pressure and fertility levels. This is a negative indicator for all habitats for which it is included.
- Species richness indicators:
    - Total plant species richness: this has been calculated for some habitats where higher numbers of species are a positive indicator, e.g. Improved and Semi-Improved Grassland. In others, particularly low nutrient habitats, an increase in overall richness may not be a good thing if the incoming species are indicative of eutrophication and disturbance. So instead, we use presence of positive indicator species.
    - Positive indicator richness or ‘appropriate diversity’: where a species is representative of the habitat in good condition. Indicators were initially collated from CSM species and then refined from discussions with NRW specialists. AWI are plant species particularly prevalent in Ancient Woodland and therefore indicative of good Woodland and woody feature (e.g. Hedgerow) condition. They may be associated with lower light levels but there will be a trade-off where excess growth of fertile plants excludes AWI.
    - Vegetation indicators for Arable habitats: this includes annual forbs in addition to positive and negative Arable indicators.
    - Nectar plant richness: plant species that provide a nectar source for pollinating insects.
    - Negative indicator species richness: this is the presence of species known to be associated with loss of condition. As such increases are negative.
- Dwarf Shrub cover and *Sphagnum* cover are recognised as particularly positive elements linked to good condition within Dwarf Shrub Heath, Bog and Acid Grassland habitats.

- Cover of Non-native and invasive species for most habitats, where non-native species are from a list of neophytes, alien casuals, alien hybrids and where native status is unclear using plantATT (Hill, Preston, & Roy, 2004). In Broadleaved Woodland we included bramble (*Rubus fruticosus agg.*) and *Rhododendron* cover also.
- Woodland connectivity is thought to improve the movement and dispersal of species across the landscape and improve overall condition for Woodland plants and mobile taxa. An increase in Woodland connectivity is therefore generally a positive outcome for species associated with Woodland. Some other species which favour open land may be disadvantaged.
- There is a suite of indicators specific to Hedgerows. Hedgerow condition assessment depends on recording Hedgerow 'attributes', based on thresholds from the UKHAB Steering Group to indicate whether a particular Hedgerow is in 'favourable condition'. These attributes include structural condition of Hedgerow height, width, woody species richness, gappiness, distance to margin, changes in management type (% of length).

4.2.1 National Trends

Positive Outcomes

- Hedgerow height, width, length and woody diversity have increased, along with the percentage in favourable condition.
- In Improved Grassland, there has been an increase in Positive plant indicator richness alongside a decrease in Ellenberg (N) fertility score, reversing a long-term decline. Although there has been no increase in Total plant species richness, a previously reported decline (1990-2007) has been stabilised at a higher level.
- There have been declines in fertility in Dwarf Shrub Heath and Upland Dry Acid Grassland.
- There have been declines in Negative plant indicators in Semi-Improved Grassland.
- Some habitats that had previously shown signs of declining condition now show signs of stability (i.e. no further change). For example, both Ground flora species richness and Nectar plant richness in Broadleaved Woodland now show stability, although Ellenberg light scores have continued to decrease, possibly indicating under-management.

Areas for Concern / Need for Further Action

- This list is long and indicates the need to reduce pressure from nitrogen pollution, eutrophication from fertilisation and grazing pressure. The first signs of climate change are also potentially being observed, e.g. a decline in *Sphagnum* cover on Bogs and Blanket Bog.
- In Bogs and Blanket Bogs, many indicators remained stable including: Positive and Negative plant indicator species, Ellenberg (N) fertility and moisture. However, this was offset by the worrying decline of the keystone bog building plant *Sphagnum*.
- Although in many habitats there is stability in some indicators, there are usually declines in others. For instance, in Unimproved Neutral Grassland there was no change in fertility or positive and Negative plant indicators, whilst Total species richness declined.
- In the Broad Habitat Fen, Marsh, Swamp and the Priority Habitat Purple Moor Grass Rush Pasture (Marshy Grassland) habitats, fertility and positive indicators were stable. However, other indicators showed negative trends with a significant decrease in Ellenberg moisture scores and an increase in Grass:Forb ratio (a negative indicator

of condition signalling the increase of grasses at the expense of flowering plants) in both habitats and a decrease in Total plant species richness in Fen, marsh Swamp.
- In Acid Grassland, Positive plant indicators are stable, and there has been a slight reduction in Ellenberg (N) fertility in upland Acid Grassland. However, the Grass:Forb ratio has increased which indicates a decline in condition in both lowland Dry Acid Grassland and upland Acid Grassland, and there has been a slight reduction in Ellenberg moisture.
- Results were mixed for Semi-Improved Grassland. As mentioned above, there has been a decrease in Negative plant indicators and Positive plant indicators have remained stable, however, the Grass:Forb ratio increased and there was a decline in Total plant species richness. Interestingly, this trend was reversed where there was HNV Farmland Type 2 within the 1km survey square. This suggests that decline in this habitat is more likely where land is isolated, e.g. from potential seed sources.
- Declines in Vegetation condition along linear features: Hedgerows, Boundaries and Streamsides. These include a decrease in Nectar rich plants and the Total species richness of ground flora, likely to be a result of increased shading as indicated by increased canopy height (Streamsides) and decreased Ellenberg light scores (Streamsides and Hedgerows), although there has also been an increase in AWI species on Streamsides.
- There has been a very small increase in the number of Non-native species across habitats. In Broadleaved Woodland the cover of Non-natives and bramble had increased, and Non-native species richness increased on Streamsides.

4.2.2 Glastir Impact

Positive outcomes

- A halt in the decline of Total plant species richness when combining all habitats with Glastir management options across Wales.
- An increase in AWI with Woodland Management/Stock Exclusion in Broadleaved Woodland;
- An increase in connectivity (without linear features) of Broadleaved Woodland with Woodland Creation;
- An increase in Total plant species richness in Bracken in response to the Grazing Low/No Inputs;
- A reduction in Ellenberg (N) fertility with Habitat Management in Bog and Blanket Bog;
- Positive outcomes on land under Commons management in Blanket Bog including: increased *Sphagnum* cover; Dwarf Shrub Heath cover and Positive plant indicators with the Commons bundle;
- Increased positive indicators in Unimproved Neutral Grassland with Habitat Management;
- Increased Total plant species richness in Semi-Improved Grassland with Commons;
- Increased total plant species richness in Boundaries for Grazing Low/No Inputs, and a reduction in plant negative indicators in Streamsides with the Wildlife Corridors bundle.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Most tests identified no effect of Glastir management option bundles on Vegetation Indicators. The positive outcomes reported above were a small minority of tests carried out (note some '+' in the table are of increases in negative indicators). In addition, at a national level, land in scheme showed no overall change in four of the five headline Vegetation indicators tested across all habitats for all Wales compared to land out-of-scheme.

- The importance of landscape context was explored by GMEP and found to be critically important in explaining the response of some Vegetation due to, for example, proximity of seed sources (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022). A start on this analysis has been made using HNV Farmland as a useful integrating factor of environmental condition of surroundings for Semi-Natural Land.

Table 4-1. Long-term and short-term trends in Vegetation indicators (including Woodland). where '=' no significant change, '+/-' significant at p =< 0.05, and '++/--' significant at p =< 0.01. Long-term trends in indicators for Wales were extracted from (Smart S. M., et al., 2009). No data are shown as grey boxes. Results are linked back to reporting categories used in the GMEP report (2013-16) to help connect to the previous more aggregated approach requested by WG.

Asset Class	Broad Habitat	Indicator	Long-term analysis using CS data 1978/1990-2007	Mean 2013-16	Mean 2021-23	Short-term analysis using GMEP 2013-16 to 2021-23
GMEP Category: Woodland						
Woodland	Broadleaved	Ellenberg (N) fertility large plots*	=	4.82	4.81	=
		Broadleaved connectivity no linears	=	0.88	0.87	=
		Broadleaved connectivity with linears		0.94	0.93	=
		AWI small plots	=	1.85	1.79	=
		AWI large plots	=	4.33	4.46	=
		Ground flora total species richness large plots	-	22.3	23.8	=
		Nectar plant species richness large plots	-	11.7	12.4	=
		Ellenberg light small plots	--	5.87	5.81	--
		Ellenberg light large plots	=	5.87	5.83	=
		Invasive and non-native species *Rhododendron*, bramble large plots (rescaled 0 to 1)*	=	0.21	0.27	=

		Invasive and non-native species *Rhododendron*, bramble small plots (rescaled 0 to 1)*	=	0.16	0.22	++
		Cover-weighted ground flora canopy height small plots	+	2.69	2.43	--
	Coniferous	Ellenberg (N) fertility*	=	3.67	3.87	+
		Ground flora species richness	=	12.89	14.1	=
		Cover-weighted canopy height	=	0.64	0.77	=
		AWI	=	2.17	2.56	=
GMEP Category: Habitat Land						
Mountain, Moor and Heath	**Dwarf Shrub Heath**	CSM positive indicators	=	2.47	2.66	=
		CSM negative indicators*	=	2.37	1.97	=
		Ellenberg (N) fertility*	=	2.72	2.57	--
		Ellenberg moisture	=	6.06	6.01	=
		DSH cover	=	35.08	36.72	=
	Bog	CSM positive indicators	=	3.53	3.17	=
		CSM negative indicators*	=	0.16	0.17	=
		Ellenberg (N) fertility*	=	2.07	2.10	=
		Ellenberg moisture	=	7.2	7.19	=
		Sphagnum cover	=	32.55	22.98	--
		Sphagnum rescaled 0 to 1	=	0.18	0.12	--
		DSH cover	=	14.39	14.36	=
	Blanket Bog	CSM positive indicators	=	3.63	3.26	=
		CSM negative indicators*	=	0.14	0.20	=
		Ellenberg (N) fertility*	=	2.02	2.05	=
		Ellenberg moisture	=	7.21	7.19	=
		Sphagnum cover	=	32.81	21.71	--
		Sphagnum cover (rescaled 0 to 1)	=	0.17	0.12	--
		DSH cover	=	0.13	0.14	=

	Bracken	Grass:Forb ratio*	=	1.13	1.35	=
		Total plant species richness	=	7.89	7.92	=
		Ellenberg (N) fertility*	=	4.21	4.17	=
	Fen, Marsh, Swamp	CSM positive indicators	=	9.29	8.78	=
		Total species richness	=	13.44	12.43	-
		Grass:Forb ratio*	=	0.14	0.78	++
		Ellenberg (N) fertility*	=	3.98	4.02	=
		Ellenberg moisture	=	7.14	7.04	--
	Purple Moor Grass Rush Pasture (Marshy Grassland)	Grass:Forb ratio*	=	0.24	0.99	++
		CSM positive indicators	=	3.36	3.29	=
		Total plant species richness	=	14.86	13.98	=
		Ellenberg (N) fertility*	=	3.91	3.88	=
		Ellenberg moisture	=	7.1	7.0	--
	Inland Rock	Ellenberg (N) fertility*	=	4.04	3.69	=
		Ellenberg reaction	=	4.56	4.58	=
		CSM positive indicators				
		Total species richness	=	7.96	5.74	-
Semi-Natural Grassland	Unimproved Neutral Grassland	CSM positive indicators		2.23	1.57	=
		CSM negative indicators*		6.00	6.26	=
		Ellenberg (N) fertility*		4.36	4.55	=
		Total plant species richness		19.78	16.91	-
	Calcareous (Lowland and Upland)					
	Lowland Dry Acid Grassland	Grass:Forb ratio*		0.48	1.66	++
		CSM positive indicators		1.67	0.89	=
		Ellenberg (N) fertility*		3.70	3.23	=
		Ellenberg moisture		5.19	5.61	=

	Upland Dry Acid Grassland	Grass:Forb ratio*	=	2.1	2.4	++
		CSM positive indicators	=	0.86	0.90	=
		CSM negative indicators*	=	1.40	1.22	=
		Dwarf Shrub Heath cover (rescaled)	=	0.07	0.08	=
		Ellenberg (N) fertility*	=	3.13	3.05	-
		Ellenberg moisture	=	6.04	5.99	-
GMEP Category: Improved Land						
Enclosed Farmland	Improved Grassland	Total plant species richness	-	10.06	10.26	=
		Grass:Forb ratio*	=	1.52	1.63	=
		CSM positive indicators	--	0.83	1.99	++
		CSM negative indicators*	=	3.06	3.24	=
		Ellenberg (N) fertility*	=	5.48	5.39	-
	Semi-Improved Grassland	Grass:Forb ratio*	=	0.94	1.44	++
		CSM positive indicators	=	3.21	3.13	=
		CSM negative indicators*	=	2.80	2.33	--
		Ellenberg (N) fertility*	=	4.74	4.68	=
		Total species richness	=	14.93	14.07	-
GMEP Category: Arable						
Enclosed Farmland	Arable and Horticultural	Ellenberg (N) fertility*	=	6.30	6.39	=
		Total species richness	=	9.49	8.66	=
		Arable forbs	=	1.87	1.79	=
		Arable positive indicators	=	0.12	0.09	=
		Arable negative indicators*	=	1.87	1.75	=
GMEP Category: Priority Habitats						
Enclosed Farmland	Hedgerows	Ellenberg (N) fertility*	=	5.8	5.8	=
		Ellenberg light	=	6.12	6.05	--
		Ground Flora species richness	=	19.49	17.8	-
		AWI richness	=	2.18	2.04	=
		Nectar plant richness	=	12.87	11.98	-
		Woody diversity	=	5.52	5.83	+
		National estimates of	-	50.5	52.7	+

		Hedgerow length (thousands of km)**				
		Mean length per square (m)	=	3,337.87	3,067.07	=
		Hedgerow width (m)	=	2.10	2.29	+
		Hedgerow height (m)	=	1.87	2.03	+
		Hedgerow management : laying and coppicing, newly planted, cutting				=
		% Hedgerow in favourable condition		47.8	50.1	+
	Individ-ual Trees	Total number of trees (mean per square)		28.14	26.74	=
	Boundaries	Ellenberg (N) fertility*	++	5.15	5.15	=
		Ellenberg reaction	++	5.58	5.57	=
		Ellenberg light	--	6.51	6.51	=
		All species richness	-	16.57	15.84	--
		Nectar species	=	8.15	7.70	--
		AWI species	=	0.95	0.96	=
		CSM positive species	-	8.64	8.53	=
		CSM negative species*	=	11.50	11.13	=
		Canopy height	++	2.57	2.58	=
		Non-native species cover*	=	0.27	0.27	=
		Non-native species richness*		0.14	0.15	=
	Streamsides	Ellenberg (N) fertility*	+	4.97	5.00	=
		Ellenberg reaction	+	5.42	5.4	=
		Ellenberg light	--	6.33	6.23	-
		All species richness	--	20.48	19.41	--
		Nectar species	-	10.15	9.22	--
		AWI species	=	2.26	2.43	=
		CSM positive species	--	11.62	11.26	=
		CSM negative species*	-	10.89	10.44	=

		Canopy height	++	2.64	2.79	++
		Non-native cover rescaled 0 to 1*	=	0.14	0.14	=
		Non-native richness*	+	0.21	0.29	+
All Wales	All Habitats	Ellenberg (N) fertility*	++	4.40	4.35	=
		Total plant species richness	--	11.0	10.1	--
		CSM positive plant species richness	--	6.50	6.46	=
		Non-native species richness*	=	0.09	0.11	++
		Non-native cover (rescaled 0-1)*	++	0.02	0.03	=

* These are all negative indicators so a '+' indicates a decrease in condition.

** Includes new and restored Hedgerows

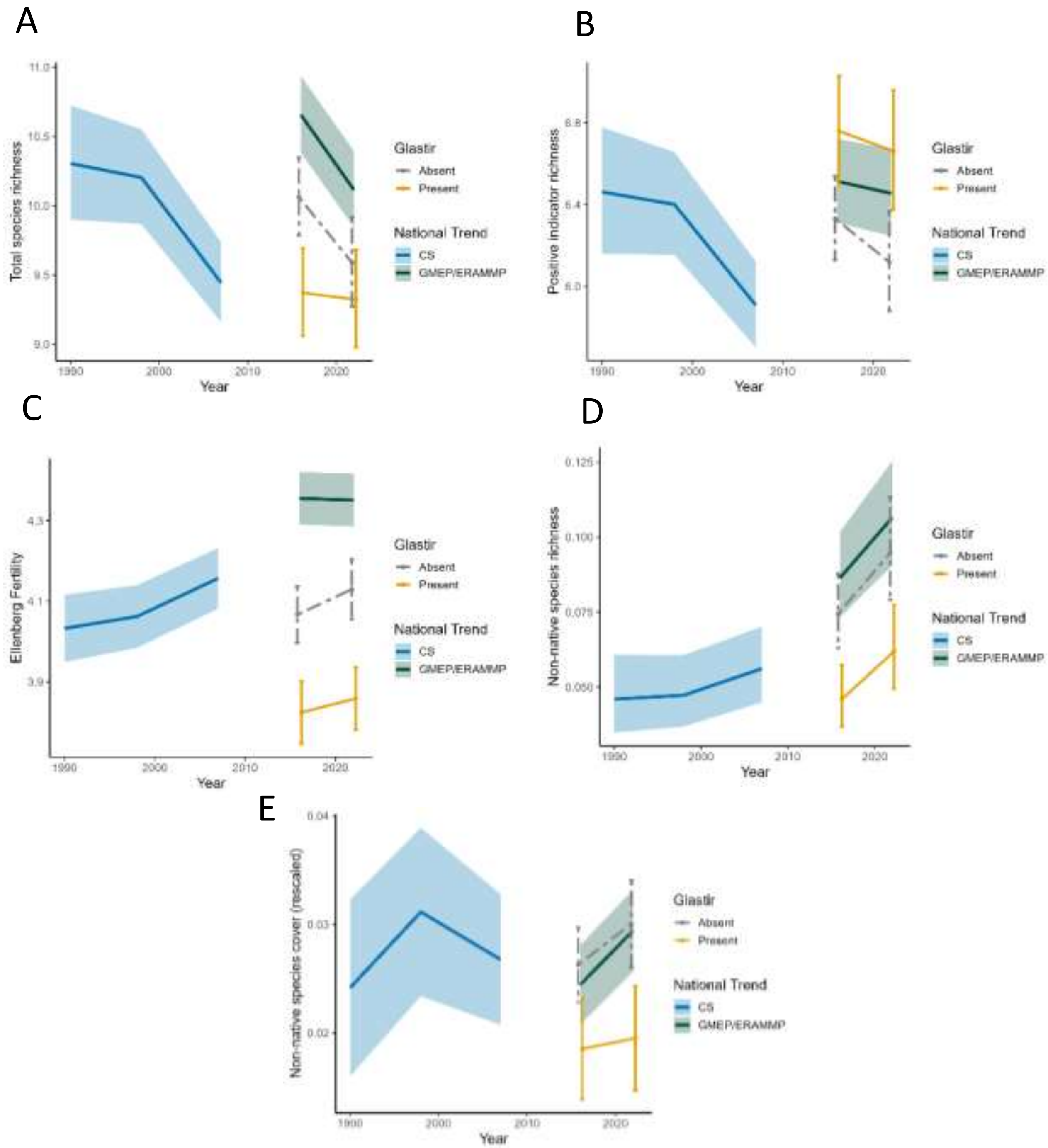


Figure 4-1. National Trends between 2013-16 to 2021-23 and impacts of Glastir in: A) Total plant species richness, B) CSM Positive plant indicator richness, C) Ellenberg (N) fertility with Glastir (in/out), D) Non-native plant species richness with Glastir (in/out), and E) Non-native plant species cover. (Analysis of non-native species included linear plots.)

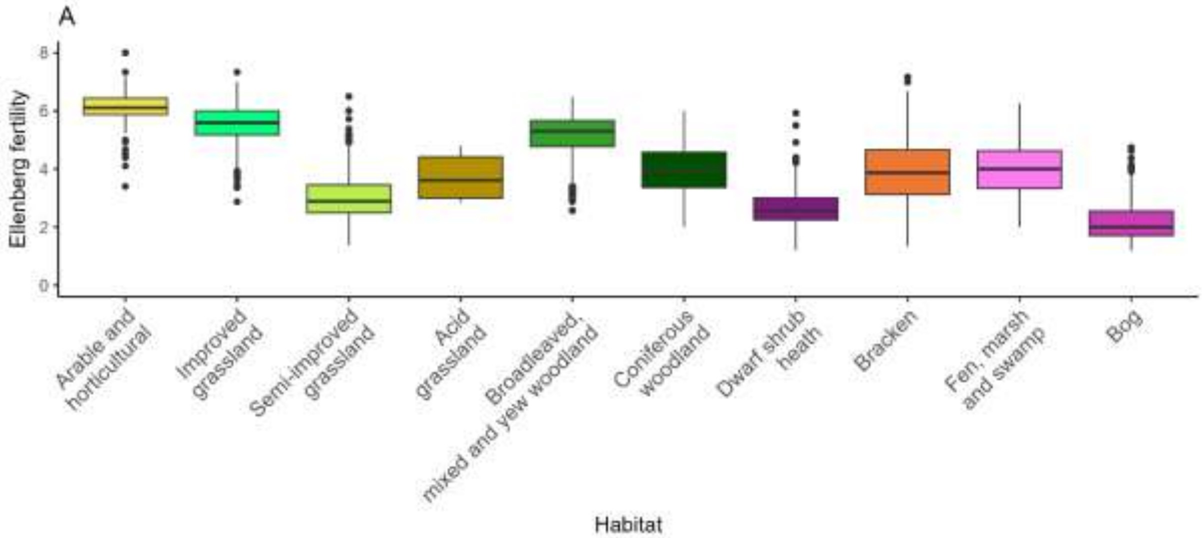


Figure 4-2. The difference in Ellenberg (N) fertility across different habitat classes in 2021-23.

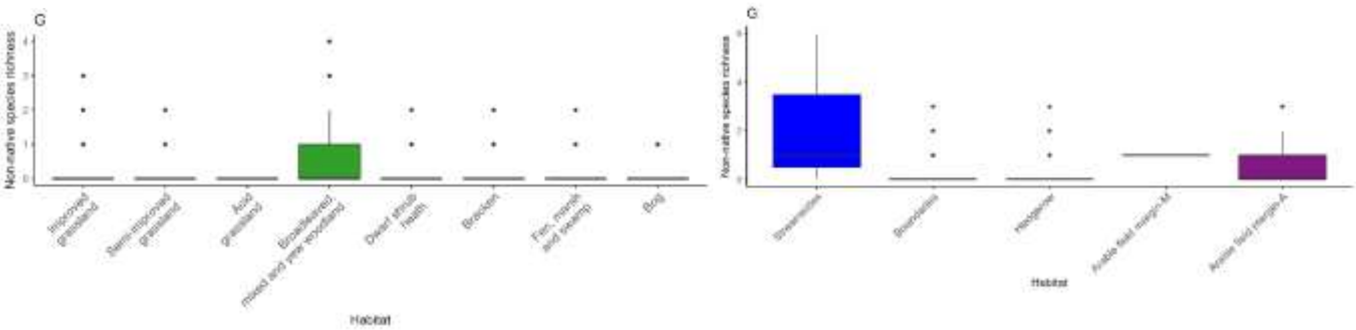


Figure 4-3. The difference in Non-native plant species richness (calculated across all habitats including linear habitats e.g. Streamsides, Boundaries, etc.) across different habitat classes in 2021-23.

Table 4-2. The impact of Glastir management option bundles on Vegetation 2013-16 to 2021-23 by Asset Class and Broad Habitat where '=' no significant change and '+/-' significant at p =< 0.05, and '++/--' significant at p =< 0.01. No data are shown as grey cells.

Asset Class	Broad Habitat	Indicator	Grazing Low/No Inputs	Grassland Grazing Low/No Inputs	Habitat Management	Habitat Management: General Grassland	Arable Management	Hedge Management	Hedgerow Restoration	Woodland Stock Exclusion	Woodland Management	Habitat Management Mountain, Moor & Heath	Wildlife Corridors and Buffers	Woodland Creation	Organic	Commons	Context: HNV	All Glastir
Woodland	Broadleaved, Mixed and Yew Woodland	Ellenberg (N) fertility large plots*								=	=							
		Ellenberg light large plots								=	=							
		Ground flora species richness large plots								=	=							
		AWI large plots								=	+							
		Cover-weighted ground flora canopy height small plots								=	=							
		Nectar plants large plots								=	=							
		Non-native *Rhododendron* and Bramble cover large plots*								=	=							
		Connectivity (no linears)									=		=	++				
		Connectivity (linears)							=		=		=	=				

Mountain, Moor and Heath	Dwarf Shrub Heath	Ellenberg (N) fertility*		=								=				=		
		Ellenberg moisture		=								=				=		
		Dwarf Shrub Heath cover		=								=				=		
		CSM positive species		=								=				=		
		CSM negative species*		=								=				=		
	Bog	Ellenberg (N) fertility*		=								--				=		
		Ellenberg moisture		=								=				=		
		Sphagnum cover		=								=				=		
		Dwarf Shrub Heath cover		=								=				=		
		CSM positive species		=								=				=		
		CSM negative species*		=								=				=		
	Blanket Bog	Ellenberg (N) fertility*		=								--				=		
		Ellenberg moisture		=								=				=		
		Sphagnum cover		=								=				+		
		Dwarf Shrub Heath cover		=								=				+		
		CSM positive species		=								=				++		
		CSM negative species*		=								=				=		

	Bracken	Ellenberg (N) fertility*		=								=				=		
		Grass:Forb ratio*		=								+				=		
		Total species richness		+								=				=		
	Fen, Marsh, Swamp	Ellenberg (N) fertility*	=									+			=	=		
		Ellenberg moisture	=									=			=	=		
		Grass:Forb ratio*	=									=			=	+		
		Total plant species richness	=									=			=	=		
		CSM positive species	=									=			=	=		
	Purple Moor Grass Rush Pasture (Marshy Grassland)	Ellenberg (N) fertility*	=									=			=	=		
		Ellenberg moisture	=									=			=	=		
		Grass:Forb ratio*	=									=			=	=		
		Total species richness	=									=			=	=		
		CSM positive species	=									=			=	=		
	Inland Rock	Ellenberg (N) fertility	=		=											=		
		Ellenberg reaction	=		=											-		
		Total plant species richness	=		=											=		
Semi-Natural Grassland	Unimproved Neutral Grassland	Ellenberg (N) fertility*		=		=												
		Ellenberg reaction		=		=												
		Total plant species richness		=		=												
		CSM positive species		=		+												

		CSM negative species*		=		=												
	Acid Grassland	Ellenberg (N) fertility*		=		=										=		
	Acid Grassland	Ellenberg moisture		=		=										=		
	Acid Grassland	DSH cover		=		=										=		
	Acid Grassland	Grass:Forb ratio*		=		-										=		
	Acid Grassland	CSM positive species		=		=										=		
	Acid Grassland	CSM negative species*		=		=										=		
Enclosed Farmland	Arable and Horticulture	Ellenberg (N) fertility*					=								=			
Enclosed Farmland	Arable and Horticulture	Total plant species richness					=								=			
Enclosed Farmland	Arable and Horticulture	Arable forb count					=								=			
Enclosed Farmland	Arable and Horticulture	Arable positive indicators					=								=			
Enclosed Farmland	Arable and Horticulture	Arable negative indicators*					=								=			
Enclosed Farmland	Improved Grassland	Ellenberg moisture		=	=										=			
Enclosed Farmland	Improved Grassland	Total plant species richness		=	=										=			
Enclosed Farmland	Improved Grassland	CSM positive species		=	=										=			
Enclosed Farmland	Improved Grassland	CSM negative species*		=	=										=			
Enclosed Farmland	Improved Grassland	Grass:Forb ratio*		=	=										=			

	Semi-Improved Grassland	Ellenberg (N) fertility*		=	=											=	=	
		Grass:Forb ratio*		=	=											=	=	
		CSM positive species		=	=											=	=	
		CSM negative species*		=	=											=	=	
		Total plant species richness		=	=											=	+	
	Hedgerows	Height						=										
		Length (mean per square)						=					=					
		Width						=					=					
		Ground flora species richness						=										
		Woody species richness						=										
		AWI						=										
		Nectar plant richness						=										
		Width						=										
		Structural condition						+										
	Boundaries	Ellenberg (N) fertility*	=					=					=					
		Ellenberg reaction	=					=					=					
		Ellenberg light	=					=					=					
		Total plant species richness	+					=					=					
		AWI species richness	=					=					=					
		Nectar species	=					=					=					
		CSM positive species	=					=					=					
		CSM negative species*	=					=					=					
		Canopy height	=					=					=					

	Streamsides	Ellenberg (N) fertility*	=		=								=					
		Ellenberg reaction	=		=								=					
		Ellenberg light	=		=								=					
		Total plant species richness	=		=								=					
		Nectar species	=		=								=					
		AWI species	=		=								=					
		CSM positive species	=		=								=					
		CSM negative species*	=		=								--					
		Canopy height	=		=								=					
All Wales	In Glastir Scheme Only relative to land outside of scheme	Ellenberg (N) fertility*																=
		Total plant species richness																+
		CSM positive species																=
		Non-native species richness																=
		Non-native cover (rescaled 0-1)																=

* These are all negative indicators so a '+' indicates a decrease in condition.

4.3 Pollinators

Pollinators are important ecologically and, within this diverse group, butterflies have particular cultural importance, reflecting aesthetic appreciation by humans (Snaddon J L, 2007). Several Pollinator indicators are considered here in order to capture: properties of the community; to capture its role in ecosystem function and the provision of the pollination service, i.e. metrics capturing the overall abundance of Pollinators; and community diversity and the range of ecological functions delivered (driving the range of flowers being pollinated).

In common with other elements of Biodiversity, various Pollinator taxa are believed to have undergone considerable, long-term declines, although structured monitoring has only been in place at UK level for a few years, making GMEP/ERAMMP a unique programme (and meaning that there are no long-term data to provide historical context here). A range of issues are likely to have affected Pollinator numbers, such as habitat simplification in farmland reducing the availability of key resources such as nest sites, and the general decline in floral diversity as herbicides have become more efficient having a cumulative effect on weed seed banks, hence ultimately affecting species that depend on the plants that grow from the seed. Pesticide effects on non-target species have also been a problem, as has intensification and other loss of Semi-Natural Grassland and meadow habitats. A range of Glastir options in Grassland, Arable and Woodland aim to provide resources for Pollinators, such as by re-creating historical land use in Grassland and delivering new nectar resources in Arable and Grassland habitats.

An in-depth analysis of pollinator abundance and distribution between habitats type, habitat diversity, Hedgerows and Woody Linear Features and flower cover was published from the GMEP baseline data (Alison, et al., 2021). Findings included: Pollinator abundance was consistently higher in Cropland and Broadleaf Woodland. For mining bees and two hoverfly groups, abundance was at least 1.5× higher in woodland ecosystems than elsewhere. Hedgerows and Woody Linear Features contributed abundance in agriculturally improved habitats of up to 14% for honeybees and up to 21% for hoverflies. Increasing floral provision in areas where existing flower cover was low could increase abundance prioritising wild over managed species.

Pollinator Indicators

- Pollinator abundance: the combined sum across all Pollinator species of the peak count per species, for each transect section.
- Mean Butterfly abundance: the mean across all butterfly species of the peak count per species (including zeroes), for each transect section.
- Butterfly species richness: the total number of butterfly species recorded across all visits, for each transect section.
- Functional group richness: the total number of Pollinator functional groups recorded across all visits, for each transect section. Bees and hoverflies were recorded in the field to functional group level already (honeybees, bumblebees, mining bees, leafcutter bees; aphid-eaters, plant-eaters, detritivores). For butterflies, taxonomic subfamilies were used as proxies for functional groups, since closely related butterfly species often tend to share similar life-histories, habitat requirements and/or larval host-plants.
- Generality of Pollinators: the mean number of plant species visited per Pollinator species, for each timed observation location.

4.3.1 National Trends

Positive Outcomes

- Across habitats, Pollinator indicator results indicated an overall picture of stability in most habitats. There was an increase in Pollinator abundance in Coniferous Woodland.
- National Trends combining data across all habitats suggest that all Pollinator indices were stable, probably reflecting the overall stability in geographically dominant habitats including Improved Grassland, and Mountain, Moor and Heath.

Areas for Concern / Need for Further Action

- Butterfly abundance fell in five habitats and species richness also fell in three of those habitats: there were declines in both Butterfly abundance and species richness in Fen, Marsh, Swamp, in Calcareous Grassland and in Broadleaved, Mixed and Yew Woodland. Then, there were declines in Pollinator abundance in Calcareous Grassland and Unimproved Neutral Grassland, and in butterfly abundance in Acid Grassland.

4.3.2 Glastir Impact

Positive outcomes

- There was a positive effect of Arable Glastir management on Butterfly species richness in Arable and Horticultural land. Similarly, Butterfly abundance and Butterfly species richness were positively affected by Organic management in Improved Grassland.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Considering the full range of tests conducted for Pollinators, with respect to the relevant Glastir management in individual habitats, there were only six significant results. Three of these showed positive relationships and three negative ones. Overall, therefore, it cannot be concluded that Pollinator metrics have improved due to Glastir. Rather, against a background of declines over time in some metrics, there has largely been no detectable effect.
- Further analyses of the data are recommended to investigate the relationships between specific management types and particular taxa that are most likely to respond, as opposed to generalised option bundles and broad metrics. These tests should be more sensitive and facilitate the detection of Glastir effects, if they exist. This should also include the data collected on cover of flowering plants and climate at the same time as Pollinators were assessed as these can provide important co-variate information.
- The importance of landscape context was explored by GMEP and found to be critically important in explaining variability in Pollinator responses (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022). This should also be the focus of future analysis.
- For Pollinators, responses to management might be faster than for other indicators, so it is possible that they occurred within the first years of Glastir management and would be detected as different absolute levels of indicators, rather than different changes in indicators. However, half of the patterns of this type were detected for Commons management, which was not the strongest test available due to sample sizes. All five of these results and four of the five involving Woodland Management or Woodland Stock Exclusion were also negative, suggesting that indicator levels were consistently lower where Glastir was applied, and a land selection bias, rather than a rapid, positive response to Glastir.

Table 4-3. Long-term and short-term trends in Pollinator indicators, where '=' no significant change, '+/-' significant at p =< 0.05, and '++/--' significant at p =< 0.01. No data are shown as grey boxes. Habitat categories not shown had insufficient data to support analyses. Results are linked back to reporting categories used in the GMEP report (2013-16) to help connect to the previous more aggregated approach requested by WG.

Asset Class	Broad Habitat	Indicator	Mean 2013-16	Mean 2021-23	Short-term analysis using GMEP 2013-16 to 2021-23
Woodland	**Broadleaved, Mixed & Yew Woodland**	Pollinator abundance per site	32.66	29.44	=
		Mean number of individuals per butterfly species per site	0.31	0.17	-
		Species richness of butterflies	3.45	2.64	--
		Functional group richness of Pollinators	5.20	5.26	=
		Generality of Pollinators	1.85	1.61	=
	Coniferous Woodland	Pollinator abundance per site	22.92	35.1	+
		Mean number of individuals per butterfly species per site	0.15	0.13	=
		Species richness of butterflies	2.24	2.07	=
		Functional group richness of Pollinators	4.37	4.96	=
		Generality of Pollinators	1.83	1.94	=
Mountain, Moor and Heath	**Dwarf Shrub Heath**	Pollinator abundance per site	16.23	12.77	=
		Mean number of individuals per butterfly species per site	0.14	0.09	=
		Species richness of butterflies	2.63	1.53	=
		Functional group richness of Pollinators	3.58	3.07	=
		Generality of Pollinators	1.71	1.54	=
	Bog	Pollinator abundance per site	10.21	11.86	=
		Mean number of individuals per butterfly species per site	0.12	0.09	=
		Species richness of butterflies	1.56	1.69	=
		Functional group richness of Pollinators	2.48	3.12	=
		Generality of Pollinators	1.31	1.30	=
		Pollinator abundance per site	17.29	17.13	=

	Fen, Marsh, Swamp	Mean number of individuals per butterfly species per site	0.31	0.14	--
		Species richness of butterflies	3.41	1.97	-
		Functional group richness of Pollinators	4.25	4.08	=
		Generality of Pollinators	1.71	1.47	=
	Inland Rock	Pollinator abundance per site	9.35	6.34	=
		Mean number of individuals per butterfly species per site	0.12	0.05	=
		Species richness of butterflies	1.62	0.90	=
		Functional group richness of Pollinators	3.46	1.62	=
		Generality of Pollinators	1.83	1.78	=
Semi-Natural Grassland	**Unimproved Neutral Grassland**	Pollinator abundance per site	49.35	20.92	-
		Mean number of individuals per butterfly species per site	0.53	0.15	-
		Species richness of butterflies	3.93	2.63	=
		Functional group richness of Pollinators	6.38	5.51	=
		Generality of Pollinators			
	Calcareous Grassland	Pollinator abundance per site	105.64	55.14	--
		Mean number of individuals per butterfly species per site	1.26	0.31	--
		Species richness of butterflies	10.20	4.72	-
		Functional group richness of Pollinators	9.24	8.01	=
		Generality of Pollinators	2.37	1.62	=
	Acid Grassland	Pollinator abundance per site	20.41	21.39	=
		Mean number of individuals per butterfly species per site	0.15	0.08	-
		Species richness of butterflies	2.18	1.48	=
		Functional group richness of Pollinators	3.58	2.90	=
		Generality of Pollinators	1.26	1.33	=
Enclosed Farmland	**Arable and Horticultural**	Pollinator abundance per site	36.12	39.65	=
		Mean number of individuals per butterfly species per site	0.39	0.20	=
		Species richness of butterflies	3.71	3.35	=
		Functional group richness of Pollinators	5.36	5.67	=

		Generality of Pollinators	1.54	1.73	=
	Improved Grassland	Pollinator abundance per site	20.41	21.39	=
		Mean number of individuals per butterfly species per site	0.19	0.16	=
		Species richness of butterflies	2.82	2.44	=
		Functional group richness of Pollinators	4.47	4.75	=
		Generality of Pollinators	1.68	1.60	=
	Semi-Improved Grassland	Pollinator abundance per site	21.81	24.51	=
		Mean number of individuals per butterfly species per site	0.24	0.19	=
		Species richness of butterflies	2.95	2.60	=
		Functional group richness of Pollinators	4.47	4.93	=
		Generality of Pollinators	1.60	1.52	=
All Wales	**All Habitats**	Pollinator abundance per site	18.76	18.93	=
		Mean number of individuals per butterfly species per site	0.17	0.13	=
		Species richness of butterflies	2.60	2.19	=
		Functional group richness of Pollinators	4.20	4.39	=
		Generality of Pollinators	1.59	1.52	=

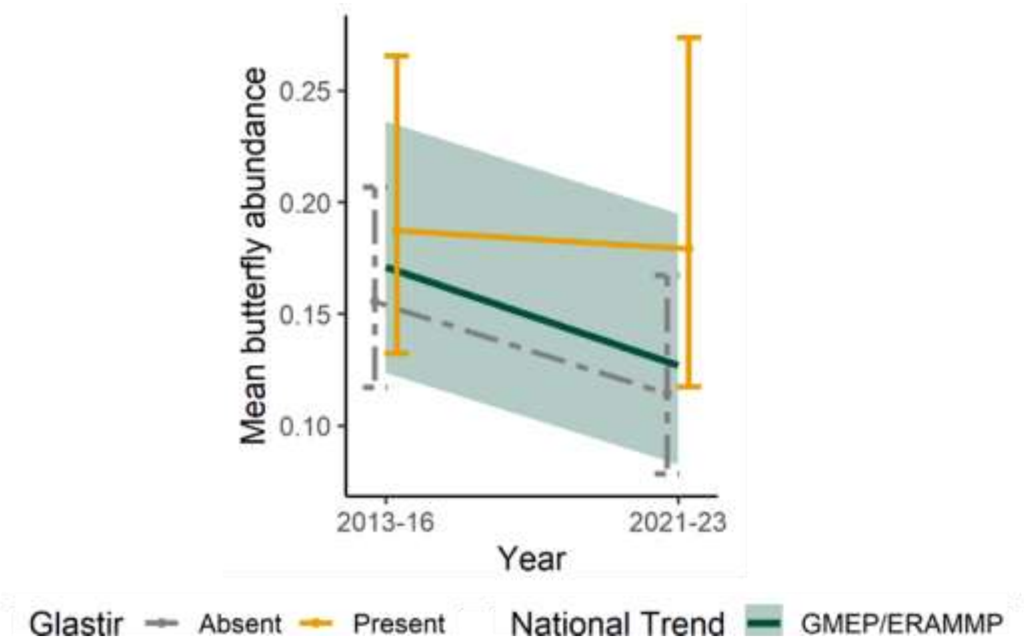


Figure 4-4. National Trend and the effects of Glastir management options on mean Butterfly abundance per species for all Wales. Mean Butterfly abundance was positively affected by Organic management only.

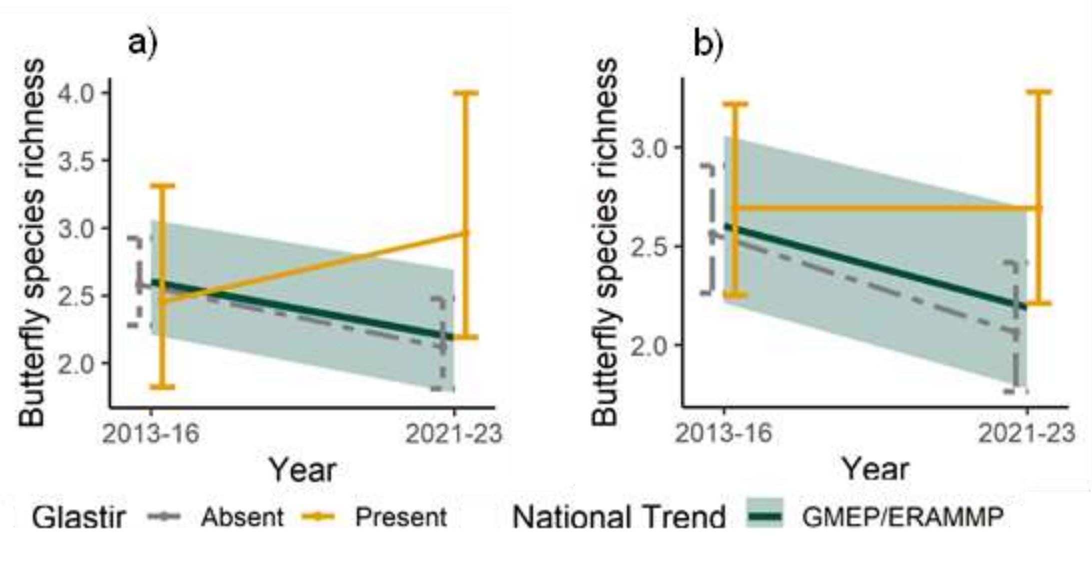


Figure 4-5. Effects of Glastir management on Butterfly species richness for all Wales. Butterfly species richness was positively affected by: a) Arable Glastir management in Arable and Horticultural land, and b) Organic management in Improved Grassland only.

Table 4-4. Glastir analysis for Pollinator indicators. Glastir management bundles assessed for effects on indicators are shown, where '+' significant positive effect, '-' significant negative effect, '++/--' strong response, and '=' no detectable effect. No data are shown as grey boxes.

Asset Class	Broad Habitat	Indicator	Grazing Low/No Inputs	Habitat Management	Arable Management	Hedge Management	Woodland Stock Exclusion	Woodland Management	Hedge Management Advanced	Habitat Management Peat & Heath	Wildlife Corridors and Buffers	Woodland Creation	Organic	Commons	All Glastir
GMEP Category: Woodland															
Woodland	Broadleaved, Mixed and Yew Woodland	Pollinator abundance per site				=	=	=					=		
		Mean number of individuals per butterfly species per site				=	=	=					=		
		Species richness of butterflies				=	=	=					=		
		Functional group richness of Pollinators				=	=	=					=		
		Generality of Pollinators				=	=	=					=		
	Coniferous	Pollinator abundance per site				=	=	--							

		Mean number of individuals per butterfly species per site				=	=	=							
		Species richness of butterflies				=	=	=							
		Functional group richness of Pollinators				=	=	=							
		Generality of Pollinators													
GMEP Category: Habitat Land															
Mountain, Moor and Heath	**Dwarf Shrub Heath**	Pollinator abundance per site	=	=		=				=			=	=	
		Mean number of individuals per butterfly species per site	=	=		=				=			=	=	
		Species richness of butterflies	=	=		=				=			=	--	
		Functional group richness of Pollinators	=	=		=				=			=	=	
		Generality of Pollinators	=	=						=			=		
	Bog	Pollinator abundance per site		=						=			=		

		Mean number of individuals per butterfly species per site		=						=			=		
		Species richness of butterflies		=						=			=		
		Functional group richness of Pollinators		=						=			=		
		Generality of Pollinators		=						=					
	Fen, Marsh, Swamp	Pollinator abundance per site		=									=	=	
		Mean number of individuals per butterfly species per site		=									=	=	
		Species richness of butterflies		=									=	=	
		Functional group richness of Pollinators		=									=	=	
		Generality of Pollinators		=									=		
	Inland Rock	Pollinator abundance per site		=						=					

Semi-Natural Grassland		Mean number of individuals per butterfly species per site		=						=					
		Species richness of butterflies		=						=					
		Functional group richness of Pollinators		=						=					
		Generality of Pollinators		=											
	Unimproved Neutral Grassland	Pollinator abundance per site	=	=											
		Mean number of individuals per butterfly species per site	=	=											
		Species richness of butterflies	=	=											
		Functional group richness of Pollinators	=	=											
		Generality of Pollinators													
	Acid Grassl	Pollinator abundance per site	=	=		=				=			=	=	

		Mean number of individuals per butterfly species per site	=	=		=				=			=	=	
		Species richness of butterflies	=	=		=				=			=	=	
		Functional group richness of Pollinators	=	=		=				=			=	=	
		Generality of Pollinators	=	=						=			=		
GMEP Category: Arable															
Enclosed Farmland	Arable and Horticulture	Pollinator abundance per site			=						=		+		
		Mean number of individuals per butterfly species per site			=						=		=		
		Species richness of butterflies			++						=		=		
		Functional group richness of Pollinators			=						=		=		
		Generality of Pollinators			=						=		=		
GMEP Category: Improved Land															
Enclosed Farmland	Improved Grassland	Pollinator abundance per site	=	=		=			=		=	=	=	=	
		Mean number of	=	=		=			=		=	=	+	=	

		individuals per butterfly species per site													
		Species richness of butterflies	=	=		=			=		=	=	++	=	
		Functional group richness of Pollinators	=	=		=			=		=	=	=	=	
		Generality of Pollinators	=	=		=					=		=		
	Semi-Improved Grassland	Pollinator abundance per site	=	=		=			=		=	=	=	=	
		Mean number of individuals per butterfly species per site	=	=		=			=		=	=	=	=	
		Species richness of butterflies	=	=		=			=		=	=	=	=	
		Functional group richness of Pollinators	=	=		=			=		=	=	=	=	
		Generality of Pollinators	=	=		=					=		=		
GMEP Category: All Wales															
All Wales	**In Glastir Scheme Only relative to land**	Pollinator abundance per site													=
		Mean number of individuals per butterfly species per site													=

		Species richness of butterflies													=
		Functional group richness of Pollinators													=
		Generality of Pollinators													=

4.4 Birds

Birds are high in the food chain and so a good proxy for general environmental health, and a range of Glastir options were designed wholly or partly to benefit them, notably in respect of Bird communities that have shown significant declines over recent decades. At policy level, these are captured by indicators collating trend information for sets of species that are associated with specific habitats or landscapes: lowland farmland, upland farmland and Woodland. These are based on ongoing, national monitoring via the BTO/JNCC/RSPB BBS (see ERAMMP Technical Annex-105TA1S6: Wales National Trends and Glastir Evaluation. Supplement-6: Birds Section 2 *(Siriwardena & Bowgen, 2025)*). GMEP and ERAMMP added to evidence provided from the BBS via more detailed square-level data supporting local and national inference, and co-location with monitoring of other targets. The national indicator variables can be produced as summaries of species-level Bird data from ERAMMP, along with bespoke summary metrics for the total abundance of priority species (to show patterns among the most threatened species), overall Bird diversity (an index that will indicate variation in community composition) and guild-level summaries collating data for Birds with different broad diets (seeds, invertebrates and vertebrates) and habitat preferences. The latter should represent broader environmental conditions affecting the dietary components and habitats involved. Arable, pastoral and Woodland habitat preference guilds provide clearer associations with the habitats involved than the official indicator species sets.

Whilst Bird surveys were conducted for all 300 squares in GMEP, funding restrictions limited the possible sample size in ERAMMP to a total of 149, selected as having greater proportions of the square area with permitted, surveyable land area in GMEP and larger numbers of Glastir-relevant Bird and Pollinator species detected.

Glastir effects were tested considering whole squares and the proportions of the areas of habitat relevant to categories of Glastir management, instead of a Glastir in/out comparison, because Birds are mobile and use their environment at larger scales than that of Glastir option patches. To separate Glastir effects from those of landscape components with which the options were associated, areas of the background land covers for each Glastir category were included as controls. Glastir option design and intended mechanisms of effect will be different for Birds associated with different habitats, so habitat types and their associated Glastir management were tested separately. This also means that simple tests combining all Glastir options and considering all species together would not make sense ecologically.

Glastir effect results are presented in summary form, with simplified tables covering all tests that were conducted and the tests with larger, significant effects being shown graphically.

More detailed results are tabulated and graphs illustrating all statistically significant findings (i.e. including small and large effects) are presented in the ERAMMP Technical Annex-105TA1S2: Wales National Trends and Glastir Evaluation. Supplement-2: Broad Habitat Results *(Emmett, et al., 2025)*.

Bird Indicators

Unlike other indicator groups in ERAMMP, Birds do not readily map onto specific habitat types because they are typically highly mobile and use the landscape at large spatial scales, i.e. across multiple habitat patches in typically patchy Welsh landscapes. For example, it is not meaningful to consider Bird populations in Semi-Natural Grassland. Moreover, Birds that benefit from, say, Woodland Management may well actually be recorded in the field in an adjacent habitat. Hence, coverage of Habitat Management effects on Birds is achieved here via Bird ecology (habitat use), rather than spatial associations with specific habitats or locations of management. The rationale is that Birds recorded in a survey square that use a given habitat type may benefit from management of the habitat, so provide a metric for that benefit.

Two approaches were used to select Bird indicators. First, the average trend metrics that are used at UK and Wales policy level, as calculated from BTO/JNCC/RSPB BBS data, were both calculated for the BBS and analogues constructed from ERAMMP field survey data. The standard indices take pre-calculated National Trends of annual index values for each species on standard lists of species that have a notional association with the focal habitat and take a geometric mean of the indices (which are standardised to a common initial value). In GMEP/ERAMMP, counts in each of the two survey periods were similarly standardised and combined, controlling for surveyed area in survey squares. A further indicator simply summed the abundances of priority Bird species, a diverse set, but one that is closest to conservation policy priorities. Note that the latter is not an established policy-level indicator.

The second approach was to combine the abundances of species more explicitly using ecological knowledge of (a) habitat use and (b) breeding season diet. This led to overlapping lists of species that share ecological characteristics that are hypothesised potentially to lead to common responses to environmental variation, supporting the summing of their local abundance into a coherent indicator. These are expected to be stronger, ecologically, than the national indicators.

The national indicator set comprised:

- Woodland Birds (BBS Woodland Bird Indicator)
- Lowland farmland Bird abundance indicator
- Upland farmland Bird abundance indicator
- Total abundance of priority Bird species

Habitat preference indicators were:

- Total abundance of Woodland guild Bird species
- Total abundance of Arable guild Bird species
- Total abundance of upland guild Bird species
- Total abundance of grassland guild Bird species

Diet metrics were:

- Total abundance of invertebrate-eating Bird species
- Total abundance of vertebrate-eating Bird species
- Total abundance of granivorous (seed eating) Bird species

The national indicators and habitat-specific metrics were tested against management in individual, relevant Asset Classes and/or habitats, whilst the diet classes and priority Birds were tested in all habitats for all management variables.

4.4.1 National Trends

Positive Outcomes

- Bird diversity (comparing between the two survey periods) changed little in absolute terms over time, although mean diversity was significantly lower in ERAMMP than GMEP. This could be explained by the movement of rarer species into Wales given the changes in the climate and/or rarer species becoming more common.
- Priority Bird species (Section 7 of the Environment (Wales) Act 2016), upland farmland Bird indicator species, lowland farmland Bird indicator species and Woodland Bird indicator species showed no significant difference in abundance between the two survey periods. However, this is certain to mask species-level variation and needs to be considered in the context of the use of composite indicators that combine species with varied ecologies and influences on habitat use and demography.
- Among the four habitat guilds of Bird species identified, Woodland Bird guild species and upland Bird guild species showed no significant differences in abundance between the two survey periods.
- Among the three dietary guilds considered, there was an increase in seed eaters and no significant change for invertebrate eaters.

Granivorous seed-eating Bird species are an established conservation priority across the UK, with particular concerns arising from declines and lack of food resources in Arable farmland. The evidence for an increase between GMEP and ERAMMP may therefore be encouraging. However, the guild variable included both target and non-target (e.g. woodpigeon) species for conservation, so a breakdown to species-level results would be needed to interpret directly with respect to conservation targets. There is also no evidence that this has been driven by an effect of Glastir.

Areas for Concern / Need for Further Action

- Arable and Grassland Bird species showed significant declines between GMEP to ERAMMP.
- There was a decline in the dietary guild index for vertebrate eaters.
- Independently of ERAMMP, national monitoring from the BBS, based on a random sample of 1km squares across Wales, provides data on widespread species from 1994 onwards. Analyses of the data producing the standard indices for Woodland, lowland farmland and upland farmland show patterns of shallow increase or stability, ongoing decline and fluctuation but broad stability, respectively, from 1994 to 2023 (BTO, unpublished).

Declines in Arable and pastoral farmland species are not unexpected, reflecting National Trends that have been detected from ongoing national reporting, although no such decline in vertebrate eaters has been reported before. However, all of these patterns need to be investigated further and disaggregated by species in order to understand likely drivers in the context of the relationships between species and habitats. In general, it would be valuable to extract GMEP-ERAMMP changes for all individual species to review where the inference possible from monitoring scheme data can be enhanced. Another useful addition would be to construct combined population change models with the dataset of random 1km square counts in Wales that are available from the UK BBS. This could both enhance monitoring inference by increasing statistical power and contribute more reliable Bird abundance data to the Integrated Modelling Platform element of ERAMMP.

The slight reduction in diversity that was detected indicates that Bird community composition overall has changed but cannot readily be interpreted as positive or negative for conservation targets. This is because the latter are constructed with respect to species' abundances and diversity indices can increase, for example, if new species arrive, rare species become more common or numerically dominant species decline. Therefore, the pattern again argues for further exploration of the data at the species level.

Table 4-5. Long-term and short-term trends in Bird indicators, where '=' no significant change, '+/-' significant at p =< 0.05, and '++/--' significant at p =< 0.01. No data are shown as grey boxes. Results are linked back to reporting categories used in the GMEP report (2013-16) to help connect to the previous more aggregated approach requested by WG.

Asset Class	Broad Habitat	Indicator	Long-term analysis using BBS data 1994-2013	Mean 2013-16	Mean 2021-23	Short-term analysis using GMEP 2013-16 to 2021-23
GMEP Category: Woodland						
Woodland	All Woodland	Abundance of Woodland Bird species (indicator) – BBS	+	118.2	108.5	
		Abundance of Woodland Bird species (indicator)		7.279	7.340	=
		Abundance of Woodland Bird species (guild)		7.646	7.266	=
GMEP Category: Habitat Land						
Mountain, Moor and Heath	Upland Farmland	Abundance of upland farmland Bird species (indicator) – BBS	=	103.0	89.2	
		Abundance of upland farmland Bird species (indicator)		8.190	8.099	=
		Abundance of upland Bird species (guild)		4.536	4.357	=
GMEP Category: Improved Land and Arable						
Enclosed Farmland	Lowland Farmland	Abundance of lowland farmland Bird species (indicator) – BBS	-	81.4	70.5	
		Abundance of lowland farmland Bird species (indicator)		7.589	7.227	=

	Improved Grassland	Abundance of grassland species (guild)		10.413	8.497	--
	Arable and Horticultural	Abundance of Arable species (guild)		9.895	8.626	--
GMEP Category: All Wales						
All Wales	**All Habitat**	Priority Bird abundance		6.025	6.037	=
		Granivorous Bird species		5.350	6.652	++
		Invertebrate-eating Bird species		7.846	7.320	=
		Vertebrate-eating Bird species		6.973	4.531	--

Footnote:

Priority Bird Species – Species present on the Section 7 list from the (Environment (Wales) Act (2016) Section 7)

Upland Farmland Bird Indicator Species – Species on the upland farmland Bird indicator list from (Noble & Barnes, 2023)

Lowland Farmland Bird Indicator Species – Species on the farmland Bird indicator list from the UK Biodiversity Indicators report (Burns, et al., 2023)

Woodland Bird Indicator Species – Species on the Woodland Bird indicator list from the UK Biodiversity Indicators report (Burns, et al., 2023)

Upland Bird Guild Species – Taken and updated from (Siriwardena, Henderson, Noble, & Fuller, 2019)

Arable Bird Guild Species – Taken and updated from (Siriwardena, Henderson, Noble, & Fuller, 2019)

Grassland Bird Guild species – Taken and updated from (Siriwardena, Henderson, Noble, & Fuller, 2019)

Woodland Bird Guild Species – Taken and updated from (Siriwardena, Henderson, Noble, & Fuller, 2019)

Granivorous Bird Species – Taken and updated from (Siriwardena, Henderson, Noble, & Fuller, 2019)

Invertebrate-eating Bird Species – Taken and updated from (Siriwardena, Henderson, Noble, & Fuller, 2019)

Vertebrate-eating Bird Species – Taken and updated from (Siriwardena, Henderson, Noble, & Fuller, 2019)

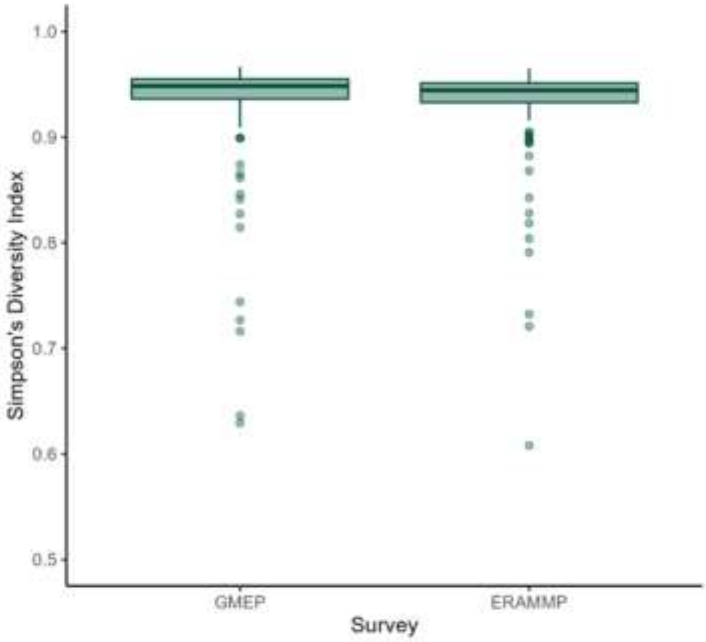


Figure 4-6. Comparison of diversity of Bird species in squares between GMEP and ERAMMP. Simpson's Diversity Index identifies a significant difference between the means (p=0.02053, W=6,296) with ERAMMP lower than GMEP.

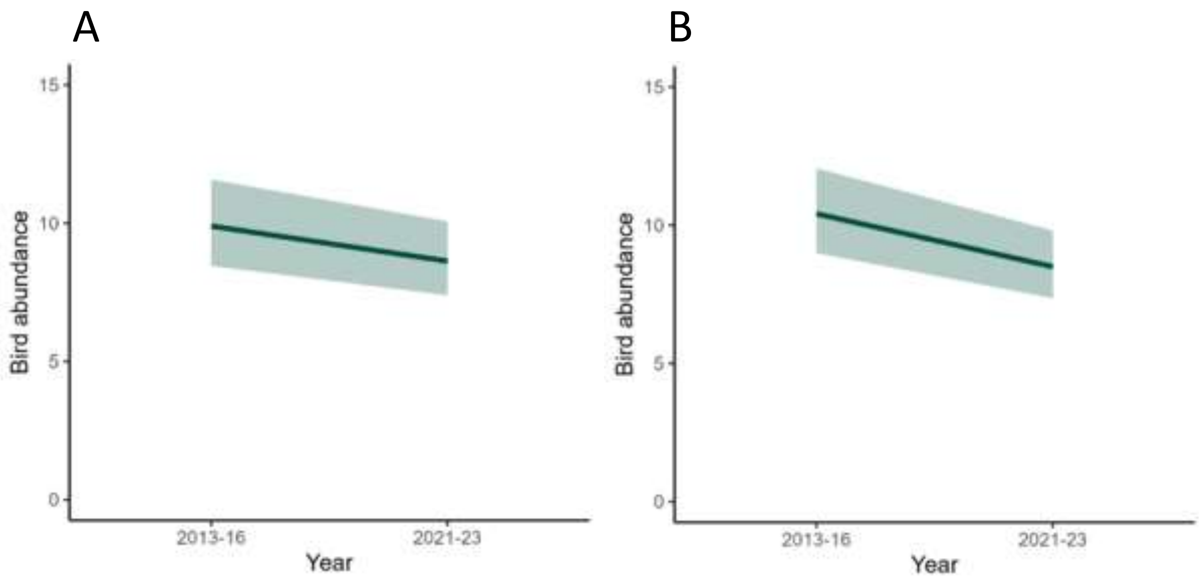


Figure 4-7. National Trend in Bird abundance between GMEP and ERAMMP across the two farmland habitat indicators that gave rise to significant results, for species found in the: A) Arable Bird guild, and B) grassland Bird guild.

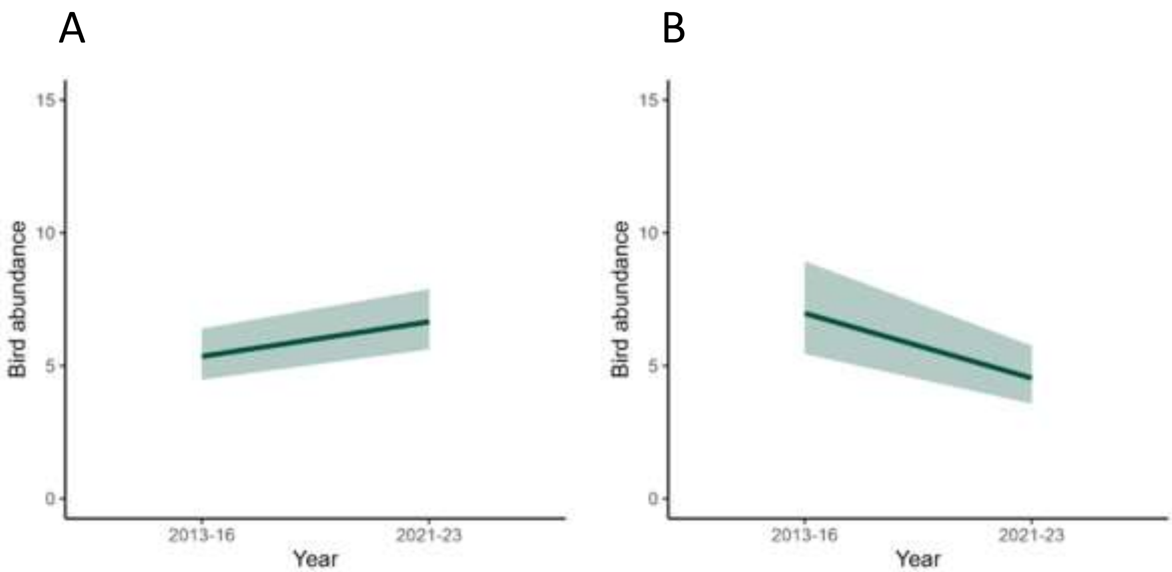


Figure 4-8. National Trend in Bird abundance between GMEP and ERAMMP across two diet indicators that gave rise to significant results, for species found in the: A) granivorous guild, and B) the vertebrate-eating guild.

4.4.2 Glastir Impact

Approach Taken for Birds

- There is no meaningful definition of 'land in Glastir' for Birds that has a counterfactual for comparison: (a) Birds use the landscape at a larger spatial scale than that of most Glastir options and (b) options can be beneficial for some species and not others, so the same land can be both effectively managed and unmanaged at the same time. For an over-arching measure of scheme effect, it therefore does not make sense to try to compare 'in' and 'out' land, or to extract a trend in the former alone.
- Instead, the full range of relevant tests conducted can be examined; complete Glastir success overall would be shown by all potential effect metrics showing positive relationships with relevant management measures. In practice, with broad indicators and broad management bundles, where the likely effects a priori are variable and statistical power is unknown, such clear results are unlikely.
- In total for Birds, 68 Glastir effect tests are reported. Of these, 31 (46%) showed no significant relationship, seven (10%) a significant negative effect (consistent with Glastir being deleterious for the species involved) and 30 (45%) a positive effect. Even allowing for spurious results from multiple testing, this suggests a clear balance towards positive effects of Glastir, and an overall role in reducing rates of Bird decline in Wales, albeit without a sufficiently large effect to reverse those declines.

Overall Patterns

ERAMMP shows no clear trend in Woodland Bird populations, whilst the national BBS suggests a shallow decline in the same period. This difference probably just reflects sampling variation, noting that the significance of the BBS trend has not been tested. This pattern is in the context of long-term declines in Woodland Birds (since the 1970s) and the clear balance towards positive effects of Glastir on relevant Bird indicators suggests that the scheme may have prevented further declines, although it is important to note that the effects are small. The principal management option involved in these patterns was Woodland Stock

Exclusion, which is consistent with a known, well-established mechanism that understorey structure is critical in driving Woodland Bird abundance.

Upland farmland Birds have declined according to the BBS, but ERAMMP, which samples uplands better, suggests stability. There were no detectable effects of Glastir on Bird abundance in the most relevant habitat class (Mountain, Moor and Heath), except that vertebrate-eating species showed a very small negative effect. It is likely that AES management in uplands that involves Vegetation change will act more slowly on ecological responses than that in lowlands, because growth is slower. There was also no effect of Acid Grassland management on upland farmland Birds in ERAMMP.

The long-term National Trend in lowland farmland Bird abundance has been one of consistent decline, and this pattern in the BBS is also shown in the indicator metric in ERAMMP. Positive effects of Glastir management would then suggest that the scheme has slowed the rate of decline. The relevant tests of Glastir effects involve lowland Semi-Natural Grassland, Improved Grassland, Arable Management, Hedgerow and Streamside options.

Among lowland grassland species, grassland grazing/input management tended to have positive effects on several Bird indicators, whereas Habitat Management of grassland tended to be negative. The former management could be relevant to Semi-Natural and Improved Grassland habitats, whereas the latter is explicitly for Semi-Natural Grassland. Hence, the results suggest that Glastir management of the more intensive management has been more successful. This may be because there is more capacity for change in Improved Grassland, whereas management of Semi-Natural habitat may have failed to address declines that have been occurring in areas where these habitats are found.

In Arable habitats, all Bird indicators showed either positive or no detectable effect of Glastir. The management predominantly involved unsprayed crops, so the results support a positive role for the expected enhancements to invertebrate food supplies for breeding Birds (and granivorous species abundance was one indicator that did not respond).

Hedgerow and Streamside management both had only positive or no detectable effect on changes in Bird abundance, as revealed by the various indicators. Enhanced Hedgerows provide better nest sites, improved food resources and more cover, so the results suggest that Glastir has provided some or all of these resources successfully and, hence, support more positive population change. Streamside management is likely to have more limited and localised benefits, but linear scrub and uncropped open areas are likely to provide benefits, especially in terms of food resources.

Overall, Glastir management shows clear patterns in support of positive effects on a wide suite of the Bird indicators tested here, with the only exception being Habitat Management, as applied to (lowland Semi-Natural) Grassland. Clearly, the latter pattern requires further exploration, but the habitats involved do not cover large proportions of Wales and therefore cannot affect large proportions of the breeding Bird community. The other results suggest that relevant Glastir management has had positive effects on Birds in Arable, Woodland, Improved Grassland and Hedgerow habitat contexts, albeit only to slow overall rates of decline, rather than to halt or to reverse them.

It should be noted, however, that the broad species groups and Glastir management bundles used here make disentangling specific ecological mechanisms difficult and further analyses are recommended, considering the dominant species and their likely relationships to the most common Glastir management that is likely to have affected them. Such analyses would also allow the use of more targeted counterfactual approaches and could, hence, more confidently exclude potential confounding factors.

Positive Outcomes

- A clear balance towards positive effects of Glastir on relevant Bird indicators suggests that the scheme may have prevented further declines in Woodland.
- Upland farmland Birds have declined according to the BBS, but ERAMMP, which samples uplands better, suggests stability.
- Positive effects of Glastir management would suggest that the scheme has slowed the rate of decline in lowland farmland Birds.
- Among lowland grassland species, grassland grazing/input management tended to have positive effects on several Bird indicators.
- In Arable habitats, all Bird indicators showed either positive or no detectable effect of Glastir.
- Hedgerow and Streamside management both had only positive or no detectable effect on changes in Bird abundance.
- Overall, Glastir management shows clear patterns in support of positive effects on a wide suite of the Bird indicators tested here, with the only exception being Habitat Management, as applied to (lowland Semi-Natural) Grassland.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- There were no detectable effects of Glastir on upland Bird abundance, except that vertebrate-eating species showed a very small negative effect.
- The long-term decline in lowland farmland Birds has continued and, whilst Glastir may have slowed the decline, it has not reversed this pattern.
- Habitat Management of Semi-Natural Grassland tended to have negative effects, the only element of Glastir tested that appeared to perform badly for Birds, but probably only covers a small proportion of important habitat for Birds but requires further investigation.
- The broad species groups and Glastir management bundles used here make disentangling specific ecological mechanisms difficult and further analyses are recommended, considering the dominant species and their likely relationships to the most common Glastir management that is likely to have affected them.

Table 4-6. Glastir analysis for Bird indicators. Glastir management bundles assessed for effects on indicators are shown, where '+' significantly positive effect, '-' significantly negative effect, '++/--' strong response, and '=' no detectable effect. No data are shown as grey boxes.

Asset Class	Broad Habitat	Indicator	Grassland Grazing Low/No Inputs	Habitat Management: General Grassland	Arable Management	Hedge Management	Woodland Stock Exclusion	Woodland Management	Habitat Management Mountain, Moor & Heath	Wildlife Corridors and Buffers	Woodland Creation	All Glastir
GMEP Category: Woodland												
Woodland	All Woodland	Priority Bird species					=	+			=	
		Woodland Bird indicator species					+	++			=	
		Woodland Bird guild					+	++			=	
		Granivore Bird guild					=	+			=	
		Invertebrate-eater Bird guild					++	++			=	
		Vertebrate-eater Bird guild					=	=			=	
GMEP Category: Habitat Land												
Mountain, Moor and Heath	All Mountain, Moor and Heath	Priority Bird species							=			
		Upland farmland Bird indicator species							=			
		Upland Bird guild							=			
		Granivore Bird guild							=			
		Invertebrate-eater Bird guild							=			

		Vertebrate-eater Bird guild							--			
Semi-Natural Grassland	Semi-Natural Grassland (not acid)	Priority Bird species	=	--								
		Lowland farmland Bird indicator species	++									
		Grassland Bird guild	++	=								
		Granivore Bird guild	=	--								
		Invertebrate-eater Bird guild	++	--								
		Vertebrate-eater Bird guild	++	=								
	Acid Grassland	Priority Bird species	=	--								
		Upland farmland Bird indicator species	=									
		Upland Bird guild	=	=								
		Granivore Bird guild	=	--								
		Invertebrate-eater Bird guild	++	--								
		Vertebrate-eater Bird guild	+	=								
GMEP Category: Arable												
Enclosed Farmland	Arable	Priority Bird species			++							
		Lowland farmland Bird indicator species			=							
		Arable Bird guild			++							
		Granivore Bird guild			=							

		Invertebrate-eater Bird guild			++							
		Vertebrate-eater Bird guild			++							
GMEP Category: Improved Land												
Enclosed Farmland	**Improved Grassland**	Priority Bird species	=									
		Lowland farmland Bird indicator species	++									
		Grassland Bird guild	++									
		Granivore Bird guild	=									
		Invertebrate-eater Bird guild	++									
		Vertebrate-eater Bird guild	+									
GMEP Category: Arable and Improved Land												
Enclosed Farmland	**Hedgerows, Boundaries & Streamsides**	Priority Bird species				=				++		
		Lowland farmland Bird indicator species				++						
		Arable Bird guild				++						
		Granivore Bird guild				+				=		
		Invertebrate-eater Bird guild				++				++		
		Vertebrate-eater Bird guild				++				++		
All Wales	**In Glastir Scheme Only relative to land**											

4.5 Spatial targeting for improving Biodiversity outcomes

In ERAMMP Report-43 (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022), an in-depth analysis of some elements of the original GMEP baseline data was carried out to provide guidance on how to optimise management interventions in future AES schemes. The occurrence of ecological and spatial contextual thresholds was clearly identified which can help to guide spatial targeting to maximise benefits derived from: hedge creation; increased flower cover; grassland extensification; and habitat diversity creation for plants, insects and pollinators and birds.

Key messages

Hedge creation

- New hedge creation where current cover is low (< 100h/ha) will result in more increases for insects; more bird abundance; but deliver lower plant species richness in hedge ground flora.

Flower cover

- Any increase in flower cover in farmland creates a net benefit for insect abundance. Most benefit is seen where current cover is currently (< 5%) although increases are seen up to 60% cover.

Grassland extensification

- Extensification payments will have most benefit for plant species richness where surrounding habitat diversity is low.
- Habitat diversity payments will help to sustain ongoing high plant diversity levels where habitat diversity is high.

Landscape heterogeneity, diversity and extensification (often linked to resilience)

- Habitat diversity up to 1.5 habitats in 1 km squares will benefit plant species richness but benefits are for generalist species with declines likely for plant specialists.

This is an area which deserves more investigation to optimise AES outcomes going forward in addition to greater exploration of the potential role of previous AES schemes in influencing outcomes, including where and when past improvements are maintained or lost, if land falls out of schemes, and where ecological lags need to be accounted for.

The overall message is ultimately there are often winners and losers when land management is changed. Therefore, spatial targeting to support specific taxa and ecosystem outcomes is essential if unintended consequences are to be avoided. Payments to create a mix of landscape types has most benefits for a mix of taxa including those required by specialist taxa. Decisions also have to be made whether the priority for future payments is to maintain, i.e. protect, land in good environmental condition where further improvement (often an objective for AES schemes) may be limited, or improve land with lower environmental quality where improvement can often be more clearly demonstrated and also provide a more connected and better quality landscape through which species can more easily move, or both.

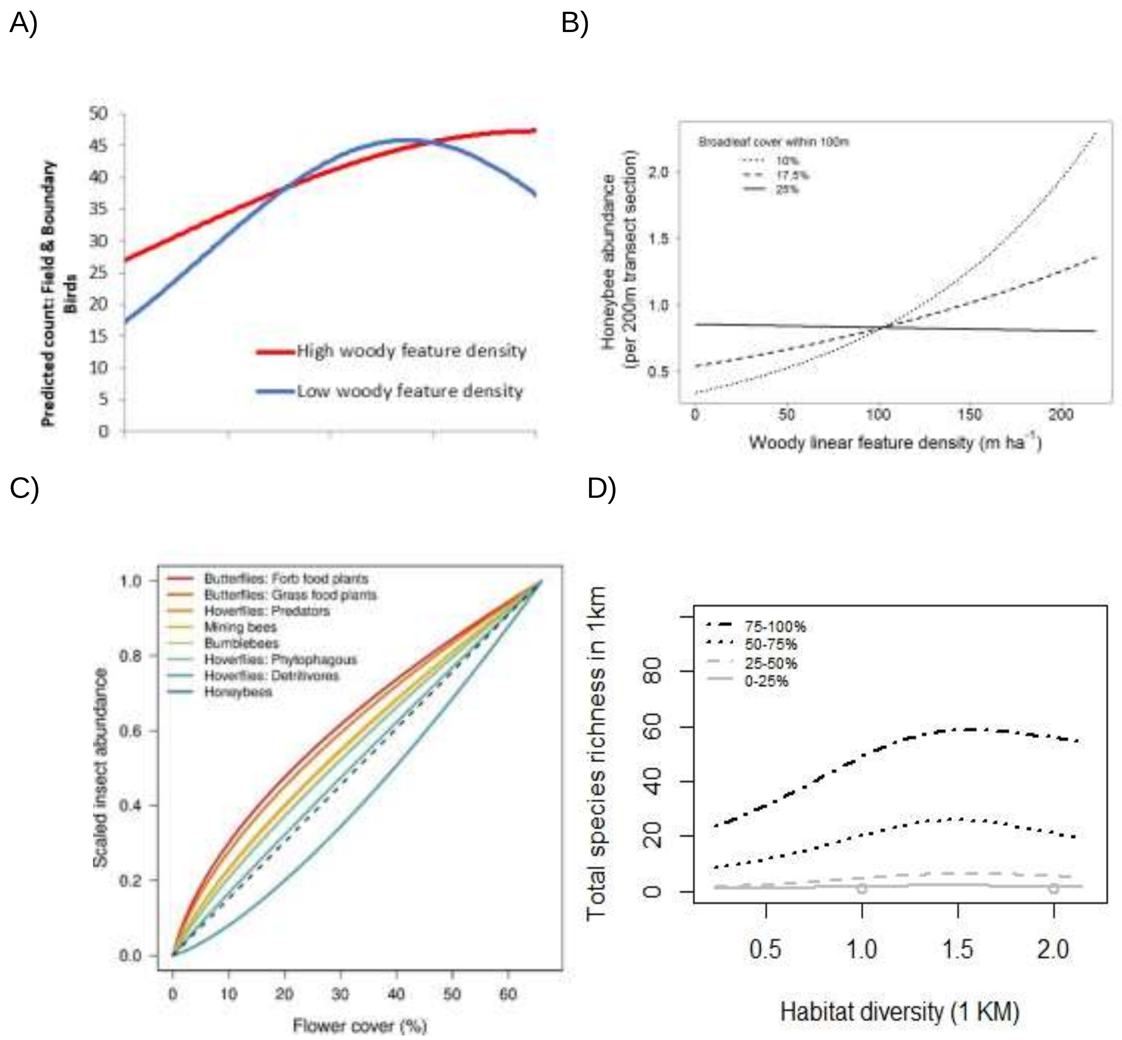


Figure 6-9. The relationship between; A) the density of Woody Linear Features and the total count of field and boundary specialist Bird species; B) the density of Woody Linear Features and the surrounding Broadleaf woodland cover with the presence of honeybee abundance; C) the percent cover of flower and abundance of seven wild Pollinator groups and the honey bees (Note honeybees are the only group which fall below the dashed 1:1 line i.e. for wild pollinators, there are diminishing returns as flower cover increases but increasing returns for honey bees i.e. honeybees are not a good proxy for wild pollinators); D) landscape-scale habitat diversity in a 1km square and generalist (labelled as 75-100%) versus specialist (labelled as 0-25%) plant species. Generalist species thrive where there are small patches of a wide variety of habitats, such as on Type II HNV farmland. The four lines represent four quarters of plant species after ranking them based on how generalist they are (75-100% = most generalist, 50-75% = upper middle, 25-50% = lower middle and 0-25% = least generalist). All Figures from (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022).

5 SOIL

Bentley, L.[1], Reinsch, S.[1], Feeney, F.[1], Williamson, J.[1], Jarvis, S.[1], Tandy, S., Lebron, I.[1], Brentegani, M.[1], Kimberley, A.[1], Maskell, L.[1], Emmett, B. A.[1] and Robinson, D.A.[1]

[1]UK Centre for Ecology

Wales covers a land area of 2,079,600ha and is geologically ancient, with a rich diversity of soils that drives differences in Vegetation cover and potentially complex responses to management. Wales has been sculpted in the recent past by the last ice age which scraped much of the surface bare of soil, meaning the soils of Wales tend to be young (<10,000 years) and often thin. As the ice retreated it left behind a variety of superficial deposits, such that soils have formed in either these unconsolidated deposits (35%) or the consolidated rocks laid bare (50%) (Tye, Williamson, Robinson, Cartwright, & Evans, 2021). The combination of relief, parent material and micro-climates has led to a rich diversity of soils with 91 soil associations found in Wales (Rudeforth, Hartnup, Lea, Thompson, & Wright, 1984). At the very highest level of grouping the dominant soil types are the podzolic soils (32.3%), often acidic and with peaty tops; and surface water gleys (24.6%) which are often waterlogged and brown soils (30.2%) which have no gleying. Peat soils (4%) occur in both the uplands and lowlands, they are an important store of carbon (Tye, Williamson, Robinson, Cartwright, & Evans, 2021). Moreover, Wales has a high proportion of organo-mineral soils (20.5%, double that of England), which intergrade between mineral soils and peats. These are particularly important in Wales as they represent 25.5% of the topsoil carbon stock but occupy landscape positions often vulnerable to agricultural and forestry activities, land use change and climate change (Bol, et al., 2011). The diversity of Welsh landscapes and parent material leads to a wide variety of niches and land uses, often within a local area. This diversity in turn affects hydrology which is intimately linked to soil formation, land use, and flood and drought risk. The wet climate and acidic nature of many soils constrains their use, whilst topography typically restricts the extent of Arable agriculture, resulting in grazing being the dominant farming activity as the conditions are best for grass growth.

5.1 Topsoil Sampling, Indicators and Thresholds

5.1.1 Topsoil Sampling

ERAMMP samples topsoil only from 0-15cm; this is considered to be the most dynamic component of the soil profile, responding to land use, climate and management change. ERAMMP samples the topsoil (0-15cm) only due to the operating budget the programme works within. ERAMMP sampling depth is consistent with other UK-based major monitoring programmes (with the exception of the National Soil Inventory, Scotland). However, the new England Ecosystem Survey which began in 2023, the equivalent of ERAMMP, is now sampling soils to greater depth (~0-45 cm) as well as describing soil profiles to 1.2m however the survey lacks the historical legacy of data (40 plus years) which ERAMMP can provide. Ideally, ERAMMP sampling would go to at least 30cm for Intergovernmental Panel on Climate Change (IPCC) reporting and rooting depth more generally as sampling to greater depths gives additional evidence to understand carbon changes, soil health more generally and determine soil types. However, evidence from 0-15 cm does reflect trends to depth in Arable and Grassland systems (68% of Wales) as it is where most changes due to management (tillage, fertiliser, pesticide) and climate happen. For example, the monitoring of topsoil picks up important trends in fertiliser usage, especially phosphorus and nitrogen, which is linked to eutrophication if not managed well and places more burden on our water industry to maintain water quality. Additional caution is however needed when interpretating topsoil trends for Woodlands where there are deep-rooting species, and in layered peaty topped soils. In order to better understand change in peaty topped soils, the ERAMMP survey now includes a measurement of the depth of the Organic horizon/Peat depth to aid interpretation.

The habitat continuum from Bogs to Woodlands provides an important context for interpreting changes in soil health trends across Wales. Moreover, it allows us to compare our results with those of our neighbouring countries when they collect data in a consistent way. This provides value for money in understanding soil health trends across Wales and land use, climate and management actions in the wider context.

Finally, additional care must be taken when interpreting measurements of topsoil carbon density (i.e. the amount of carbon stored per unit area to a specific depth rather than its concentration per gram of soil) as it is partially determined by bulk density (the mass of soil in a known volume), which changes with soil wetness and with compaction. Changes in bulk density can cause an apparent change in carbon density that does not reflect additional or indeed loss of carbon storage. The best evidence for an increase in topsoil carbon density occurs when an increase in both carbon concentration and carbon density have both occurred, with stable or decreasing bulk density.

5.1.2 Topsoil Indicators

The indicators selected are a small number known to relate to key soil functions and known threats. Many other indicators have been reported previously by CS including soil biodiversity, carbon and nitrogen turnover rates and contaminant levels but were not possible within the operating budget of ERAMMP. They are:

- Topsoil carbon concentration – this is strongly linked to soil organic matter (SOM) and important for carbon stock and sequestration (the rate carbon is stabilised and stored in soil) assessments and overall soil health. An increase in carbon concentration typically suggests an increase in soil health.
- Topsoil pH is a measure of soil acidity with lower numbers indicating more acid conditions. Soil acidity varies naturally between habitats, with some naturally more acidic (lower pH). Beyond this natural variation, decreasing pH is often linked to a decrease in soil health. In agricultural systems, specific ranges of pH may be associated with greater productivity.
- Soil nitrogen (N) concentration – this metric measures all forms of N in soil and thus is linked to but is not a direct measurement of N availability for plants. In improved soils, increases in N above the minimum required for production is typically considered to decrease soil health. In unimproved soils, where N levels are naturally low, increasing N is also considered a decrease in soil health as increases from atmospheric deposition or lateral flows from surrounding land benefit taller and more competitive plant species, reducing plant diversity.
- Olsen P indicates the abundance of the most plant-available phosphorus. This is only reported for improved Soils. It is not a suitable metric for unimproved and acid soils. Increases above the minimum required for production are typically considered a decrease in soil health due to potential eutrophication.
- Topsoil bulk density is a measure of soil mass per volume of soil. An increase is soil density suggest a decrease in soil health as it suggests compaction, although some fluctuation in soil density with soil wetting and drying cycles is natural.

- Soil degradation and erosion indicators in field and along Streamsides capture issues such as poaching and erosion.
- Soil Biodiversity using eDNA methods was carried out and reported by GMEP (Emmett & team, 2017); (George P. B., et al., 2019) but was not repeated in ERAMMP. Frozen samples were archived for potential future analysis.

5.1.3 Topsoil Health Indicator Thresholds/Trigger Points

The soil physical, chemical and biological environment determines levels of soil functioning within habitats. When maintaining optional functioning of soils in form of, for example, biomass production or habitat support, topsoil indicators are expected to fall into specific ranges across habitats. It is generally agreed that the greater topsoil carbon concentration is preferable, but also that different habitats have different capacities to store carbon. Low soil pH is known to affect production and should be above pH 6.5 in mineral Arable soil, and above pH 6 in mineral Improved Grassland soils. As many habitats in Wales are naturally acidic, with the notable exception of Calcareous Grassland, increasing soil pH through the use of lime is a standard agricultural practice to provide optimum production. This is particularly important when synthetic fertiliser is applied due to the acidifying nature of most manufactured fertilisers. A pH change of 0.5 pH units is biologically meaningful for ecological habitats and diversity (Merrington, et al., 2006), so there can be a trade-off between optimum acidity and nutrient levels for native plant species versus agricultural production. There is no agreed indicator for total soil nitrogen for England (Merrington, et al., 2006) or Wales. However, (Black H. , et al., 2008) suggest a range of 0.1g to 0.4g N 100g^{-1} mineral soil as suitable for food and fibre production.

Table 5-1. Acceptable ranges for Soil health indicators derived from trigger points in (Bhogal, Boucard, Chambers, Nicholson, & Parkinson, 2008) and (Merrington, et al., 2006), adapted from (Thomas, et al., 2023). Ranges for specific habitats are given for mineral soils, but alternate values for peaty Soils in specific habitats are provided in the primary source.

Broad Habitat	pH (production)	pH (habitat support)	Bulk density (production)	Olsen P (production)	Olsen P (habitat support)	Olsen P (leaching)
Arable and Horticultural	>6.5	x	<1.3g cm^{-3}	16 to 45mg/l	X	<60mg kg $^{-1}$
Improved Grassland	>6	5 to 7	<1.3g cm^{-3}	16 to 25mg/l	X	<60mg kg $^{-1}$
Neutral Grassland	x	5 to 7	x	X	<10mg/l	
Dwarf Shrub Heath	x	<4.5	x	X		
Acid Grassland	x	<5	x	X		
Peaty			<1.0g cm^{-3}			

5.1.4 National Trends

Overall, the soil health data from the NFS provides a picture of concern (if not decline) due to: the loss of carbon concentration in Arable Soils; increase in bulk density in 7 out of 10 habitats; two- to three-fold increase in number of Enclosed Farmland sites which have nutrient levels which risk leaching to water courses; the continued majority (>70%) of Improved Grassland Soils with soil acidity below production thresholds; re-emergence of acidification in three Mountain, Moor and Heath Soils; and a total of 4% of soils which are disturbed or eroded.

Positive Outcomes

- Topsoil carbon concentrations have remained stable in Welsh grasslands (Improved, Semi-Improved and Acid Grassland) for 50 years.
- Topsoil nitrogen levels have remained stable in Welsh grassland within the recommended range for mineral soils for food and fibre production (0.1g - 0.4g N 100g^{-1}).
- In Improved and Semi-Improved Grassland, topsoil pH has remained within the optimal functional range for habitat support in mesotropic grassland.
- Topsoil nitrogen levels have decreased in Arable and Horticultural land but remain within the recommended range for mineral Soils for food and fibre production. Topsoil carbon:nitrogen ratios have remained constant due to decrease in both carbon and nitrogen concentrations.
- Topsoil carbon and nitrogen concentrations have remained stable in upland habitats (Mountain, Moor and Heath).

Areas for Concern / Need for Further Action

- Topsoil carbon concentrations have significantly declined in Broadleaved, Mixed and Yew Woodland (-13%) and Arable and Horticultural land (-8%).
- Olsen P has significantly increased (+15%) in Improved Grassland, with the population mean nearing the upper limit of the suggested range for biomass production in Improved Grassland (24.7mg P kg^{-1}, compared to a range of 16-25mg P kg^{-1}).
- The percentage of sites with values above the critical threshold of 60mg Olsen P kg^{-1} above which risks leaching, has approximately tripled In Improved Grassland from 5.4% to 17.1% and doubled from 4% to 8% in Arable and Horticultural land.
- 72% of Improved Grassland has a pH below 6 in 2021-23, which has been identified as a trigger point for grassland productivity on mineral soils. This was 75% in 2013-16.
- Topsoil bulk density has significantly increased across Wales (+5%) and for a majority of habitats (7 out of 10 habitats with data). 18% of Arable and Horticultural Soils exceed the threshold of bulk density for well-functioning mineral soils in 2021-23 (>1.3g cm^{-3}). This change equates to a ~5% decrease in topsoil porosity with knock-on effects for infiltration and water storage. Whilst this is within the range of what might be expected due to drying and wetting soil cycles, increases in bulk density can also occur due to management (e.g. loss of carbon or compaction by stock and vehicles) dry weather causing shrinkage, or interactions between management and weather (e.g. increased compaction risk in wet winters). It should also be noted that sampling occurred across a 6-month period over 3 years which would normally be expected to even out temporary changes due to a single wet or dry season or year,
- There has been a widespread decrease in topsoil pH for habitats with low-intensity management (Dwarf Shrub Heath, Fen, Acid Grassland and Bog). This is reversing the signal of recovery from acid rain over the previous 30 years in the uplands and could benefit Soil carbon sequestration due to the slowing of decomposition rates but potentially reduce Biodiversity, increased rainfall and leaching. The underlying processes driving this new onset of acidification is not known but could include a combination of management and climate drivers.
- Topsoil carbon stocks have increased in many habitats across Wales due to changes in bulk density, not additional carbon storage (as shown by carbon concentrations that are stable or have decreased).

Erosion and Soil Damage

- Aerial imagery shows 4% of surveyed soil is disturbed or eroded in Wales.
- Soil compaction and poaching by livestock accounted for 76% of observed (2,580 features) Soil Erosion and Disturbance features across the surveyed area. Mass movements, e.g. scars, slips and scree accounted for 11%; peat erosion 9%; and mineral soil erosion 4%. Poaching was observed in approximately half of 26,100ha surveyed.
- The vast majority of soil disturbance occurred in Improved Grassland. However, the majority soil ‘mass movement’ (e.g. landslides and slips) occurred in Acid Grassland, followed by Improved Grassland. Peat erosion occurred in Acid Grassland and Bog.
- Erosion of Peat and Organic Soils in the uplands should be further investigated and mitigation strategies considered.

Table 5-2. Long-term and short-term trends in topsoil indicators for different Broad Habitats and Asset Classes. where ‘=’ no significant change, ‘+/-’ significant at p =< 0.05, and ‘++/--’ significant at p =< 0.01. Long-term trends for Wales were extracted from (Smart S. M., et al., 2009). No data are shown as grey boxes.

Asset Class	Broad Habitat	Indicator	Long-term analysis using CS data 1978/1990-2007	Mean 2013-16	Mean 2021-23	Short-term analysis using GMEP 2013-16 to 2021-23
Woodland	Broadleaved, Mixed and Yew Woodland	Carbon (g/kg, from Organic matter)	=	80.9	70.1	-
		pH	+	4.96	4.87	=
		N (g/100g dry Soil)*		0.49	0.46	=
		C density (tC/ha)	+	60.8	63.6	=
		Bulk density (g/cm^3)*		0.54	0.62	+
	Coniferous Woodland	Carbon (g/kg, from Organic matter)	-	146.9	134.6	=
		pH	=	4.21	4.25	=
		N (g/100g dry Soil)*		0.69	0.65	=
		C density (tC/ha)†	=	60.6	69.7	++
		Bulk density (g/cm^3)*†		0.34	0.45	++
GMEP Category: Habitat Land						
Mountain, Moor and Heath	Dwarf Shrub Heath	Carbon (g/kg, from Organic matter)	=	178.4	177.5	=
		pH	=	4.47	4.20	--
		N (g/100g dry Soil)*		1.01	1.01	=
		C density (tC/ha)	-	76.1	83.0	=
		Bulk density (g/cm^3)*		0.34	0.38	=

	Bog	Carbon (g/kg, from Organic matter)		343.0	364.2	=
		pH		4.27	4.03	--
		N (g/100g dry Soil)*		1.53	1.78	=
		C density (tC/ha)		66.3	73.2	=
		Bulk density (g/cm^3)*		0.15	0.15	=
	Bracken	Carbon (g/kg, from Organic matter)		71.4	64.7	=
		pH		4.74	4.74	=
		N (g/100g dry Soil)*		0.49	0.45	=
		C density (tC/ha)		56.9	58.9	=
		Bulk density (g/cm^3)*		0.55	0.63	++
	Montane	Carbon (g/kg, from Organic matter)				
		pH				
		N (g/100g dry Soil)				
		C density (tC/ha)				
		Bulk density (g/cm^3)				
	Fen, Marsh, Swamp	Carbon (g/kg, from Organic matter)		156.6	149.1	=
		pH		5.37	5.21	=
		N (g/100g dry Soil)*		0.98	1.03	=
		C density (tC/ha)†		55.9	65.6	++
		Bulk density (g/cm^3)*†		0.24	0.30	++
	Inland Rock	Carbon (g/kg, from Organic matter)				
		pH				
		N (g/100g dry Soil)*				
		C density (tC/ha)				
		Bulk density (g/cm^3)*				
Semi-Natural Grassland	**Calcareous Grassland**	Carbon (g/kg, from Organic matter)				
		pH				
		N (g/100g dry Soil)*				
		C density (tC/ha)				
		Bulk density (g/cm^3)*				
	Acid Grassland	Carbon (g/kg, from Organic matter)	=	135.4	129.3	=
		pH	=	4.79	4.56	--

		N (g/100g dry Soil)*		0.80	0.77	=
		C density (tC/ha)†	=	69.5	76.8	+
		Bulk density (g/cm³)*		0.40	0.45	=
Enclosed Farmland	**Semi-Improved Grassland**	Carbon (g/kg, from Organic matter)	=	59.8	57.6	=
		pH	+	5.61	5.51	=
		N (g/100g dry Soil)‡		0.46	0.46	=
		C density (tC/ha)†	=	64.7	70.6	++
		Bulk density (g/cm³)*†		0.72	0.81	++
GMEP Category: Improved Land						
Enclosed Farmland	**Improved Grassland**	Carbon (g/kg, from Organic matter)	=	54.9	54.7	=
		pH‡	+	5.75	5.78	=
		N (g/100g dry Soil)‡		0.46	0.46	=
		Phosphorus (Olsen P mg/kg)*‡		21.4	24.7	++
		C density (tC/ha)†	=	66.9	71.9	++
		Bulk density (g/cm³)*†		0.82	0.87	++
GMEP Category: Arable Land						
Enclosed Farmland	**Arable and Horticulture**	Carbon (g/kg, from Organic matter)	=	38.9	35.9	--
		pH‡	=	6.17	6.29	=
		N (g/100g dry Soil)*‡		0.33	0.30	--
		Phosphorus (Olsen P mg/kg)‡		23.9	28.2	=
		C density (tC/ha)	=	55.7	58.2	=
		Bulk density (g/cm³)*		0.99	1.09	++
All Wales						
All Wales	**All Habitats**	Carbon (g/kg, from Organic matter)	=	81.8	80.4	=
		pH	-	5.37	5.33	-
		N (g/100g dry Soil)		0.57	0.57	=
		C density (tC/ha)†	=	64.9	69.4	++
		Bulk density (g/cm³)*†		0.63	0.68	++

* An increase in this indicator is interpreted as a decline in condition for this habitat.

† As carbon concentrations have not increased, this is driven by the increase in bulk density and does not reflect an increase in soil carbon storage.

‡ Interpretations of change are dependent on land use and starting concentrations, relative to indicator thresholds impacting productivity and habitat condition. A judgement has been made as to whether any observed changes are likely to reflect an improvement or decline in soil condition, that may not hold true for all contributing sites.

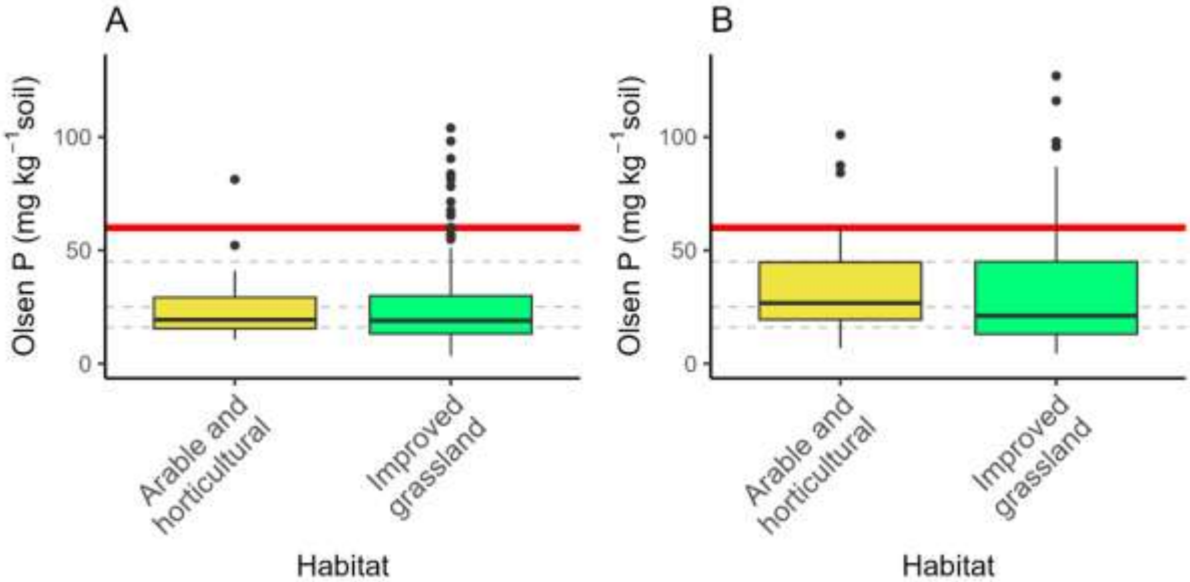


Figure 5-1. The difference in topsoil Olsen P concentration across Arable and Horticultural and Improved Grassland for: A) 2013-16, and B) 2021-23. The red line indicates the 60mg kg^{-1} threshold at which leaching occurs. The grey dashed lines indicate upper and lower thresholds for productivity in Arable and Horticultural systems (16-45g kg^{-1}) and Improved Grassland systems (16-25g kg^{-1}). The black horizontal lines in the boxes indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed.

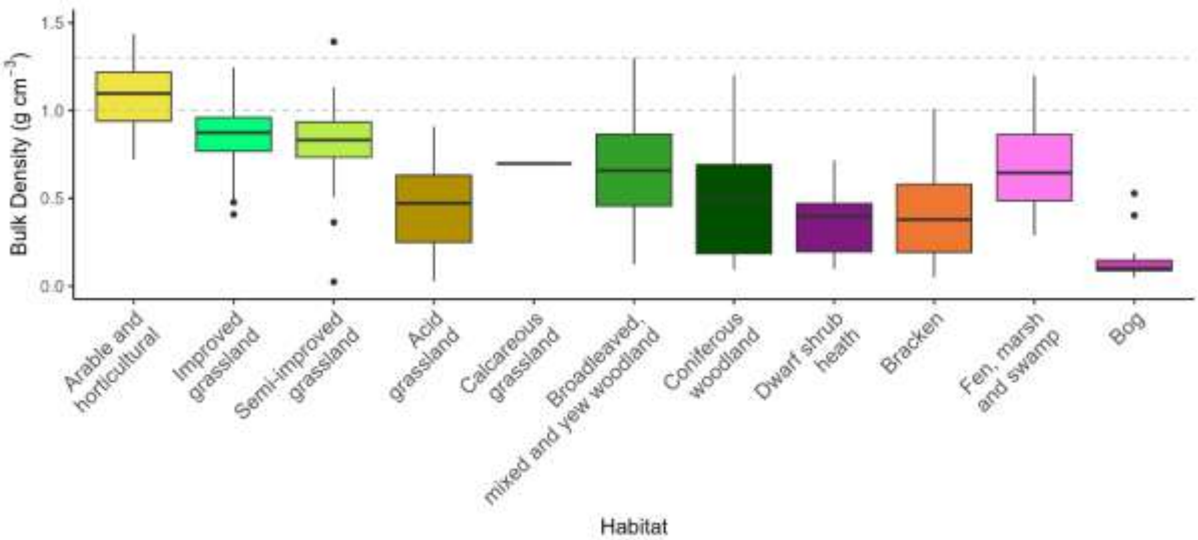


Figure 5-2. The difference in topsoil bulk density across different Broad Habitat classes between 2021-23. In mineral Soils, a bulk density below 1.3g cm^{-3} is good (top, grey dashed line) and in peaty Soils, bulk density below 1.0g cm^{-3} is good. The horizontal lines indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed. Corresponding plots for 2013-16 can be found in the ERAMMP Technical Annex-105TA1S7: Wales National Trends and Glastir Evaluation. Supplement- 7: Soil Health (Bentley, Reinsch, & Robinson, 2025).

5.1.5 Glastir Impact

Overall, Glastir management options had no detectable benefit for soil health with just four exceptions. Where Glastir has had a significant effect on soil health indicators we do not see this reflected in the National Trend, likely due to low rates of uptake and or extent of a particular habitat.

Positive Outcomes

- Glastir options for Habitat Management and Woodland Management (primarily reduced stocking density in both cases) have improved topsoil carbon concentration and bulk density in some habitats (Semi-Improved Grassland and Broadleaved, Mixed and Yew Woodland).
- Glastir options for Grazing Low/No Inputs management are associated with an increase in topsoil pH in Fen, Marsh, Swamp soils (a positive outcome). This is consistent with the expected effect of reduced nitrogen addition, but we do not see the expected reduction in topsoil nitrogen which may be slower for a signal to be detected. This change in topsoil pH is also consistent with the increased forb abundance and increase in positive indicator species reported in Fen Marsh, Swamp in response to this Glastir option bundle.
- Glastir Commons management in Bracken was associated with a significant increase in carbon concentration. The majority of Commons option uptake occurred before the baseline survey.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Glastir options for Habitat Management (primarily reduced stocking density) have led to a more rapid reduction in topsoil pH in Bog.
- Glastir options for Grazing Low/No Inputs management have had no effect on nutrient concentrations in grassland.
- Glastir options for Grazing Low/No Inputs management in Improved Grassland are associated with a decrease in topsoil carbon concentration from above, to in line with, the national average. The absence of associated responses in nutrient levels of the vegetation community suggests this may represent a delayed response to historic management changes rather than a direct result of reduced inputs on grazed land under Glastir. Further work may be warranted to reliably interpret this response.
- Retention of land from historic AES to Glastir has been low in some habitats (Broadleaved, Mixed and Yew Woodland, and Improved Grassland). Land coming out of historic AES is associated with the reversal of previous gains in topsoil carbon concentration.

Table 5-3. Effects of Glastir management bundles on topsoil indicators for different Broad Habitats and Asset Classes. Glastir management bundles were only tested when enough data points were present. If Glastir management bundle effects were tested, presence/absence in historic AES was tested as context variable, where '=' no significant effect of Glastir bundle or historic AES, '+/-' significant effect at p =< 0.05, and '++/--' significant effect at p =< 0.01. Grey boxes mark Glastir bundles which were not tested for effects due to low uptake.

Asset Class	Broad Habitat	Indicator	Glastir Arable Management bundle	Glastir Habitat Management bundle	Glastir Woodland Management bundle	Glastir Grazing Low/No Inputs management bundle	Glastir Organic bundle	Glastir Commons bundle	Context: presence in historic AES	All Glastir
Woodland	Broadleaved, Mixed and Yew Woodland	Carbon (g kg^{-1}, from Organic matter)			++				-	
		pH in water			=				=	
		N (g 100-1g dry Soil)*			=				=	
		Carbon density (t carbon ha-1)			=				=	
		Bulk density (g cm^{-3})*			=				+	
	Coniferous Woodland	Carbon (g kg^{-1}, from Organic matter)								
		pH in water								
		N (g 100-1g dry Soil)*								
		Carbon density (t carbon ha-1)								
		Bulk density (g cm^{-3})*								
Mountain, Moor and Heath	Dwarf Shrub Heath	Carbon (g kg^{-1}, from Organic matter)		=			=	=	=	
		pH in water		=			=	=	=	
		N (g 100-1g dry Soil)*		=			=	=	=	

		Carbon density (t carbon ha-1)		=			=	=	=	
		Bulk density (g cm^{-3})*		=			=	=	=	
	Bog	Carbon (g kg-1, from Organic matter)		=			=	=	=	
		pH in water		-			=	=	=	
		N (g 100-1g dry Soil)*		=			=	=	=	
		Carbon density (t carbon ha-1)		=			=	=	=	
		Bulk density (g cm^{-3})*		=			=	=	=	
	Bracken	Carbon (g kg^{-1}, from Organic matter)		=		=		++	=	
		pH in water		=		=		=	=	
		N (g 100-1g dry Soil)*		=		=		=	=	
		Carbon density (t carbon ha-1)		=		=		=	=	
		Bulk density (g cm^{-3})*		=		=		=	=	
	Fen, Marsh, Swamp	Carbon (g kg-1, from Organic matter)		=		=		=	=	
		pH in water		=		++		=	=	
		N (g 100-1g dry Soil)*		=		=		=	=	
		Carbon density (t carbon ha-1)		=		=		=	=	
		Bulk density (g cm^{-3})*		=		=		=	=	
Semi-Natural Grassland	Acid Grassland	Carbon (g kg^{-1}, from Organic matter)		=		=	=	=		
		pH in water		=		=	=	=	=	
		N (g 100-1g dry Soil)*		=		=	=	=	=	
		Carbon density (t		=		=	=	=	=	

		carbon ha-1)								
		Bulk density (g cm^{-3})*		=		=	=	=	=	
Enclosed Farmland	Arable and Horticulture	Carbon (g kg^{-1}, from Organic matter)								
		pH in water								
		N (g 100-1g dry Soil)*								
		Carbon density (t carbon ha-1)								
		Bulk density (g cm^{-3})*								
	Improved Grassland	Carbon (g kg^{-1}, from Organic matter)	=			--	=		-	
		pH in water	=			=	=		=	
		N (g 100-1g dry Soil)*	=			=	=		=	
		Phosphorus (Olsen P mg kg^{-1})*	=			=	=		=	
		Carbon density (t carbon ha-1)	=			=	=		-	
		Bulk density (g cm^{-3})*	=			=	=		=	
	Semi-Improved Grassland	Carbon (g kg^{-1}, from Organic matter)		+		=	=		=	
		pH in water		=		=	=		=	
		N (g 100-1g dry Soil)*		=		=	=		--	
		Carbon density (t carbon ha-1)		=		=	=		=	
		Bulk density (g cm^{-3})*		=		=	=		=	
All Wales	In Glastir Scheme Only relative	Carbon (g/kg, from Organic matter)								=
		pH								=

		N (g/100g dry Soil)*								=
		C density (tC/ha)								=
		Bulk density (g/cm^3)*								=

* An increase in this indicator is interpreted as a decline in condition for this habitat.

5.2 Peats

Peatlands in Wales cover 82,000ha based on the 2021 Welsh Peat Map. They perform an important role in below-ground carbon storage, water storage and provision of habitats of a wide range of specialist species. Peatlands in a near-natural condition are characterised by continuously high water levels, which enable net ecosystem carbon sequestration, prevents aerobic breakdown of carbon stored in peat, and supports native Biodiversity. However, peatlands in Wales have been subject to historical degradation through anthropogenic activity, including drainage, peat cutting, forestry, over-grazing and burning. This degradation has been linked with an increase in GHG emissions as drainage to allow for production of crops and/or pasture lowers the water table and allows the aerobic decomposition of previously waterlogged organic matter. Since approximately 2010, there has been an increasing focus on restoring these peatlands primarily using measures designed to increase water levels and remove invasive vegetation. Within the NFS, 5.5% of soils were sampled from peaty soils in 2021-23, with an average organic horizon over 40cm deep. (Note that the measurement was not undertaken during the 2013-16 survey.) This is comparable with the estimate of peats representing 4% of soils in Wales.

Peat health is best captured by water table depth, but this is not possible to capture using the NFS as it is so dynamic. Instead we report on the presence of important bog-building plant such as *Sphagnum*. Furthermore, contrary to other soils, an increase in carbon density in the top 15cm can suggest degradation of peatlands as when drained or drying the peat structure collapses, effectively increasing carbon density. A reduction in carbon concentration also suggests significant degradation as a decline indicated loss of surface peat (which is always ca. 50% carbon) down to underlying mineral layers. A loss of peat depth, which is also now measured, also provides information on this issue. Other priority chemical indicators in peat are acidity and nitrogen due to legacy from acidification from acidic deposition which reduced soil pH below that of some native plants and ongoing nitrogen deposition which can encourage colonisation of grass and other fast-growing plants which outcome the native Bog vegetation.

5.2.1 National Trends

The national picture of peatland health is also of concern due to loss of the bog-building species *Sphagnum* and increased acidity. Actions to restore 9,000ha have contributed to improvement in peatland health locally for 11% of peatlands, resulting in a reduction of 3% in GHG emissions. The disparity between area restored and GHG reductions is due to the targeting of restoration on peatlands with relatively low rates of GHG emissions.

Overall, the indicators selected for reporting here suggest a trend of decline for peatlands. However, GHG emissions are estimated to have been reduced (a positive outcome) due to restoration of 9,000ha of peatlands, which suggest local areas of improvement and / or lags in the response of indicators used in the NFS.

Positive Outcomes

- Topsoil carbon concentrations, nitrogen concentration, bulk density and carbon density in Bog have remained stable
- Overall an estimated total of 9,000ha of restoration actions have been carried out on peatland in Wales (most likely since 2010, from a range of funding sources).

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Peatland restoration and wider Glastir action on peats has not led to a detectable change in the National Trends of peat condition. Rather some signals of decline were detected with a decline in topsoil pH of Bog by 0.3 pH points to a current average of 4.0, in line with National Trends for GB.
- The topsoil pH of Bog Soils has significantly decreased from by 0.3 pH points to a current average of 4.0, similar to National Trends for GB.
- *Sphagnum* cover has significantly declined in both Bog (-29%) and Blanket Bog (-34%), representing a reversal of long-term trends of *Sphagnum* recovery.
- *Sphagnum* cover and topsoil pH are both sensitive to changes in management, rainfall and nitrogen deposition. Observed changes would be consistent with the anticipated effects of reduced rainfall and ongoing nitrogen deposition.

Table 5-4. Long-term and short-term trends in Peat condition indicators, where '=' no significant change, '+/-' significant at p =< 0.05, and '++/--' significant at p =< 0.01. No data are shown as grey boxes.

Asset Class	Broad Habitat	Indicator	Long-term analysis using CS data 1978/1990-2007	Mean 2013-16	Mean 2021-23	Short-term analysis using GMEP 2013-16 to 2021-23
Mountain, Moor and Heath	Bog	Carbon (g/kg, from Organic matter)		343.0	364.2	=
		pH		4.27	4.03	--
		N (g/100g dry Soil)*		1.53	1.78	=
		C density (tC/ha)		66.3	73.2	=
		Bulk density (g/cm^3)*		0.15	0.15	=
		Sphagnum cover	=	32.55	22.98	--
	Blanket Bog	*Sphagnum* (% cover)	=	32.81	21.71	--
	Peatland	Estimated total emissions (ktCO2e yr-1) †		**2010**	**2023**	**2010-23**
				506	491	-

* An increase in this indicator is interpreted as a decline in condition for this habitat.

† A decrease in this indicator is interpreted as an improvement in condition for this habitat.

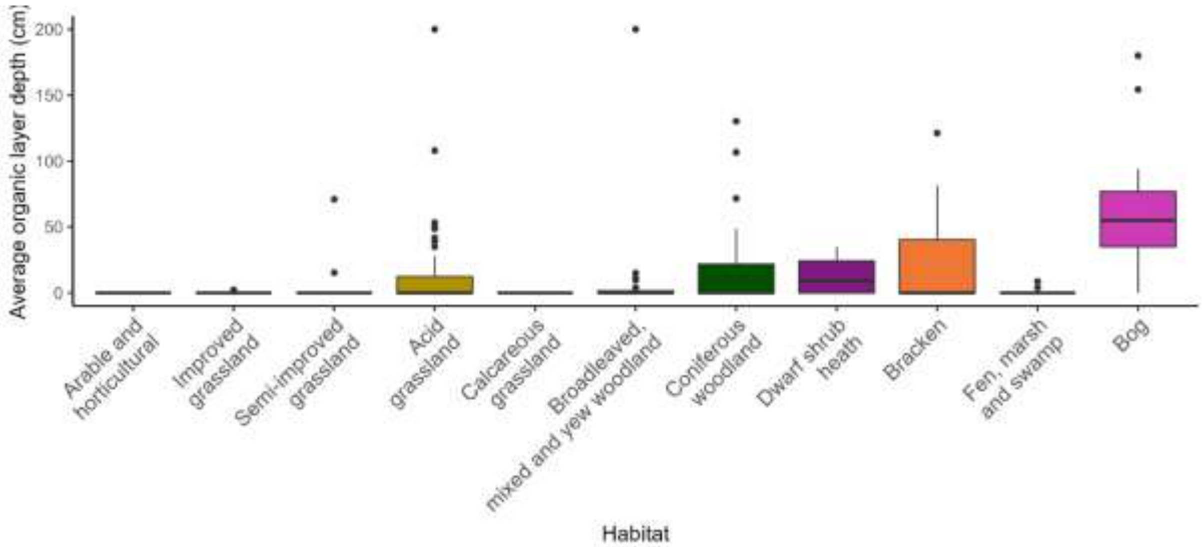


Figure 5-3. The difference in average organic layer depth across different Broad Habitat classes in 2021-23 (Note: data were not collected in 2013-16). A total of 5.5% of soil samples were from peaty soils with a peat layer of 40cm or more. The horizontal lines indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed.

The decrease in topsoil pH observed in Bog is consistent with changes observed in upland habitats more generally for Wales and changes for habitats with low-intensity management across GB from 2007 to 2019 (Seaton F. M., et al., 2023). Bog is a naturally acidic system, and low pH is conducive to greater carbon storage by reducing rates of carbon decomposition however where this acidity is enhanced to anthropogenic influence (i.e. acidic or nitrogen deposition or climate change) this cannot be seen as a positive outcome as the acidity may be detrimental to native vegetation and linked water bodies. As reductions in *Sphagnum* cover have been observed concurrently with a decrease in Bog pH this overall suggests a decline in the condition of Bogs, and is consistent with the anticipated impact of reduced rainfall on Bog systems as reduced rainfall was identified as a driver of reduced soil pH in GB (Seaton F. M., et al., 2023). Both *Sphagnum* cover and topsoil pH can respond to short-term variation in rainfall, in addition to longer-term climatic trends. Establishing a causal driver for these trends in Wales requires additional research.

5.2.2 Glastir Impact

For peatland, Glastir was responsible for 992ha of the 9,000ha of restoration which contributed 0.2% of GHG emission reductions from 1990 (but more likely from 2010) levels. Other Glastir management options covered 51,335ha (63% of Peat area). With the exception of the Commons management bundle on Blanket Bog, there was no detectable positive signal of Glastir management options on the condition of peatlands at the national scale with the exception of the modelled reduction in GHG emissions.

Positive Outcomes

- Glastir was responsible for 992ha of peatland rewetting-specific actions, representing ~10% of all rewetting on peatlands and 0.2% of GHG emission reduction since 1990 (but more likely since 2010).
- Wider Glastir actions on Peat covered 51,335ha (63% of peatland area), with nearly 40,000ha classified as Habitat Management (General). These actions were not

included in the contribution of Glastir actions to peatland rewetting or restoration for the purpose of GHG emissions calculations as there is not yet sufficient evidence to apply different emission factors following these actions, but they may have benefitted peatland condition more generally although currently the NFS cannot detect this improvement.

- Glastir Commons management led to a relative increase in *Sphagnum* cover in Blanket Bog.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Sites with uptake of Glastir options within the Habitat Management bundle on Bog (primarily consisting of reduced stocking density) showed a faster decrease in topsoil pH than those without Glastir option uptake.
- Glastir Habitat Management had no measurable impact on topsoil carbon and nitrogen concentrations, carbon density or bulk density.

Table 5-5. Analysis of Glastir management bundles for topsoil indicators for Bog and Blanket Bog, where '=' no significant change and '+/-' significant increase or decrease at p =< 0.05. No data are shown as grey boxes. Context effect was tested using information related to participation in historic AES.

Asset Class	Broad Habitat	Indicator	Arable Management	Habitat Management	Woodland Management	Grazing Low/No Inputs management	Organic	Commons	Context: Historic AES
Mountain, Moor and Heath	Bog	Carbon (g kg-1, from Organic matter)					=	=	
		pH in water		-			=	=	
		N (g 100-1g dry Soil)*					=	=	
		Carbon density (t carbon ha-1)					=	=	
		Bulk density (g cm-3)*		=			=	=	=
		Sphagnum cover		=		=		=	=
	Blanket Bog	*Sphagnum* cover		=		=		+	=

* An increase in this indicator is interpreted as a decline in condition for this habitat.

5.3 Soil Erosion and Disturbance

Soil Erosion and Disturbance (SED) represents major forms of land degradation worldwide. Soil compaction may arise from animals, termed poaching, or by repeated traffic by vehicles or machinery, particularly on wet Soils. This leads to structural degradation of the Soil, reduction of porosity and a heightened susceptibility to Soil Erosion. Additionally, compacted bare soil can be a potential source of N_2O emissions (Tye & Robinson, 2020). Erosion may strip agricultural areas of fertile topsoil, whilst surface runoff that is laden with eroded soils and excess nutrients contaminate receiving water bodies, posing risks to freshwater ecology and pushing up costs for water treatment. Three soil threats are interlinked: loss of SOM, compaction and erosion. Porosity in soils is linked to SOM (Robinson, et al., 2022; Thomas, et al., 2024), compaction reduces infiltration and enhances surface runoff, resulting in erosion of soil by water. Thus, Soil Erosion is often a manifestation of other soil health issues and is important for environmental policy, including in Wales where it is a compliance issue as outlined in Good Agriculture and Environmental Conditions 5 (Welsh Government, 2022).

National scale assessment can help address Soil Erosion by identifying locations, extent and links to land use practice. As part of ERAMMP, SED feature mapping has been undertaken in NFS squares across Wales. An Earth Observation (EO) based approach was carried out in 2020, using high-resolution (25cm) aerial images taken in May 2018 to map SED features across 261 out of 300 ERAMMP survey squares. This was followed up in 2021 in the NFS with ground-truthing of this EO assessment focussed on a 200m radius around botanical survey plots within each survey square and to identify other features that may not have been detected from aerial images. Full details of the EO and NFS datasets can be found in ERAMMP Report-70 (Tye, et al., Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-70: The use of remote sensing to assess soil erosion, poaching and disturbance features. Report to Welsh Government (Contract C210/2016/2017), 2023).

Separately, national-scale maps of Soil Erosion risk have been generated for GB using a version of the Revised Universal Soil Loss Equation from the InVEST toolkit (Integrated Valuation of Ecosystem Services and Trade-offs) as part of the UKRI-funded AgLand project[7] (Hooftman, et al., 2023). This Soil Erosion rate modelling reflects conditions for the period 2016-20, which closely aligns with both the ERAMMP EO and NFS assessments of SED. Furthermore, the modelling has been shown to possess good overall agreement with observed suspended sediment flux data from river catchments across the country; thus, it should present a robust picture of erosion risk across Wales.

This work provides an overview of the current state of SED in Wales. By complementing existing observational data (both the EO and NFS ERAMMP datasets) with modelling, we enhanced the extent of information on Soil Erosion that can be gleaned from SED features to answer four core questions:

i. What are the dominant types of SED within the NFS of Wales?
ii. What are the most important environmental controls on SED extent?
iii. How does SED occurrence vary by SED type and environmental control?
iv. Does SED feature extent correlate with modelled estimates of gross erosion rates by water?

As this is the first time the assessment has been carried out, no change or effect of Glastir management options are reported.

[7] https://gtr.ukri.org/projects?ref=NE%2FT000244%2F1

5.3.1 National Status

i. What are the dominant types of SED within Wales?

- Aerial imagery indicates that a mean of 4% of soil is disturbed or eroded in Wales (Tye, et al., Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-70: The use of remote sensing to assess soil erosion, poaching and disturbance features. Report to Welsh Government (Contract C210/2016/2017), 2023).
- Out of 2,580 individual SED features mapped under the EO survey, 76% were Soil Disturbance (e.g. poaching, compaction around feeders and gateways), 11% were Scar or Slip (e.g. landslides, scree and terracettes), 9% Peat and Organo-mineral Erosion (e.g. exposed peat and peat drainage ditch erosion), and 4% Mineral Soil Erosion (e.g. rills, gullies, riverbank and coastal erosion features) (Tye, et al., Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-70: The use of remote sensing to assess soil erosion, poaching and disturbance features. Report to Welsh Government (Contract C210/2016/2017), 2023).
- Soil disturbance occurred in 58% of EO and 43% of field surveyed squares, and dominated more sites than any other SED type.
- The dominant SED sub-categories were Poaching or Compaction, Gateway Disturbance and Soil Creep/Terracettes.
- Peat and Organo-mineral Erosion features cover the largest areas where present, and Soil Disturbance features covered the smallest areas. This indicates that although the number of sites that are dominated by Soil disturbance features is highest, other forms of SED (especially ‘Peat and organo-mineral erosion’ features) are substantially more extensive in size when they do occur.

ii. What are the most important environmental controls on SED extent?

- The vast majority of Soil Erosion and Disturbance has occurred in Improved Grassland. However, the majority of soil Mass Movement (e.g. Land slips, Scars and Scree) occurred in Acid Grassland, followed by Improved Grassland.
- Elevation, habitat type and mean annual rainfall were the strongest predictors of SED feature aerial coverages, with five distinct combinations of these factors controlling SED feature presence across Wales. These trends are elaborated further below under SED Risk Groups.

iii. How does SED occurrence vary by SED type and environmental control?

- On average, Peat and Organo-mineral Erosion features are several times larger than other SED feature types. Thus, these features show a disproportionate impact on the landscape compared to other forms of SED.
- Similarly, Wet Uplands on average show much larger extents of SED, mainly in the form of Peat and Organo-mineral Erosion and Scar or Slip, than areas represented by any other SED driver group. This suggests that whilst this group is one of the rarest environments (<1% of Wales), it may be contributing a disproportionately high amount of SED nationally.
- Analysing SED feature types by SED drivers reveals a split between predominantly agriculturally driven Soil Disturbance and wetter semi-natural

systems. Understanding the boundary between these two types of areas may help with more targeted monitoring and mitigation in the future.

iv. Does SED feature extent correlate with modelled estimates of gross erosion rates by water?

- For the most part, SED feature presence is not closely connected to rates of Soil loss and delivery to stream networks. This reflects that not all SED will contribute sediment to stream networks and that the amount of sediment contributed will depend on SED type and extent. Mapping of SED can therefore provide new information about risks to Soil health not captured in stream sediment models.
- Stronger associations between SED presence and sediment delivery to stream networks are present for Mineral Soil Erosion SED features for the EO dataset and Peat and organo-mineral Soil Erosion features for the NFS dataset.
- The dependence of these association on detection method (EO vs NFS) suggests that Mineral Soil Erosion features may be easier to identify from the air, whereas Peat and Organo-mineral Erosion features may be more accurately detected by a field survey.

5.3.2 Soil Erosion and Disturbance Risk Groups for Future Reporting

Risk groups are presented in order from those affecting a large national area at low frequency to those affecting small areas at high frequency. Upland and lowland habitats are defined by a threshold of 455m above sea level, as defined through model outputs.

Agriculturally Dominated

- Susceptible area is 1,585,500ha (74% Wales)
- SED is predicted to occur over 1.2% of susceptible area, on average
- Occurs in the lowland habitats (not Bog or Acid Grassland)
- Characterises 63% of field survey sites

Dry Lowland Bog and Acid Grassland

- Susceptible area is 278,900ha (13% Wales)
- SED is predicted to occur over 1.9% of susceptible area, on average
- Occurs in lowland Bog and Acid Grassland with rainfall <1,779mm yr^{-1}
- Characterises 13% of field survey sites

Wet Lowland Bog and Acid Grassland

- Susceptible area is 129,600ha (6% Wales)
- SED is predicted to occur over 6.1% of susceptible area, on average
- Occurs in lowland Bog and Acid Grassland with rainfall >1,779mm yr^{-1}
- Characterises 9% of field survey sites

Dry Uplands

- Susceptible area is 55,000ha (3% Wales)
- SED is predicted to occur over 10.1% of susceptible area, on average
- Occurs in upland habitats with rainfall <1,948mm yr^{-1}
- Characterises 6% of field survey sites

Wet Uplands

- Susceptible area is 83,600ha (4% Wales)
- SED is predicted to occur over 27.4% of susceptible area, on average
- Occurs in upland habitats with rainfall >1,948mm yr^{-1}
- Characterises 9% of field survey sites

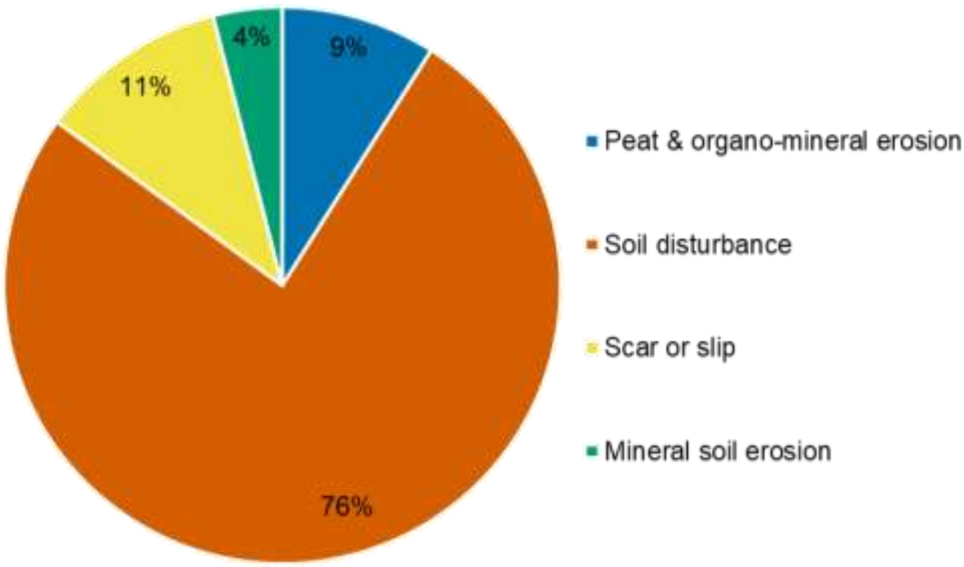


Figure 5-4. The proportion of individual SED features (n = 2,580) recorded in the EO survey under the four main SED features by category. Adapted from ERAMMP Report-70 (Tye, et al., Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-70: The use of remote sensing to assess soil erosion, poaching and disturbance features. Report to Welsh Government (Contract C210/2016/2017), 2023).

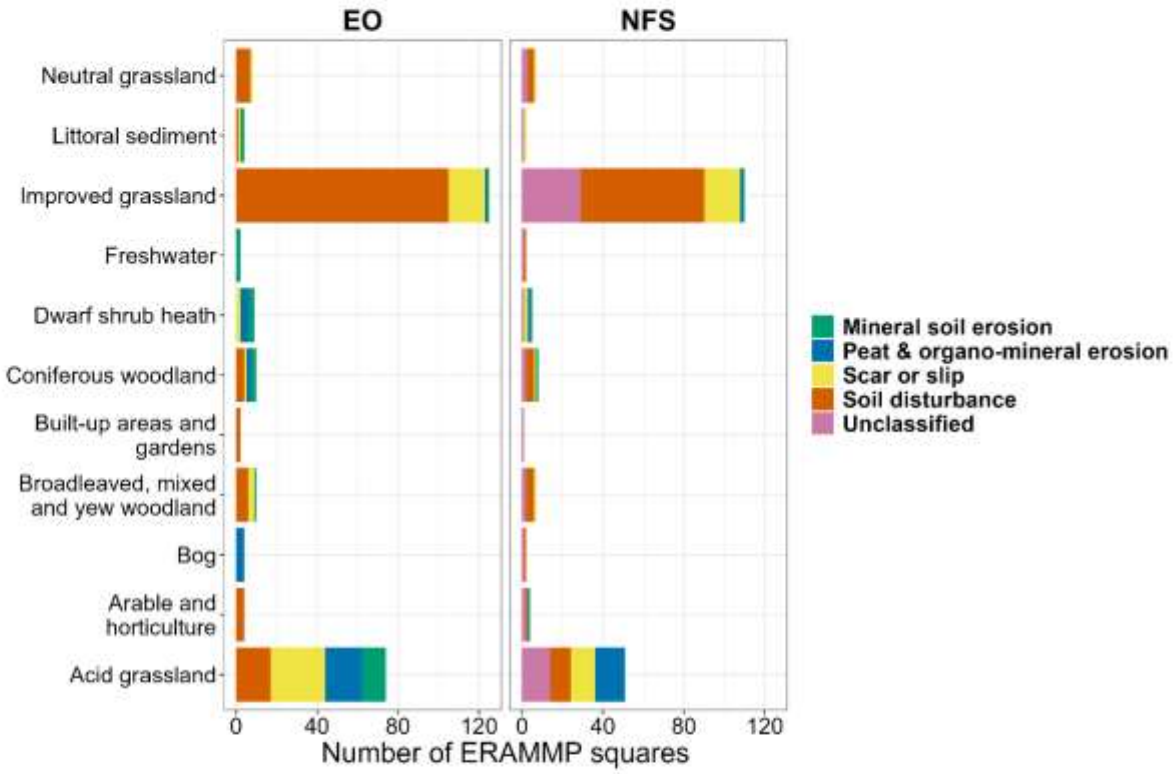


Figure 5-5. Frequencies of ERAMMP survey squares by most common Broad Habitat and most common SED feature category according to the EO and NFS surveys.

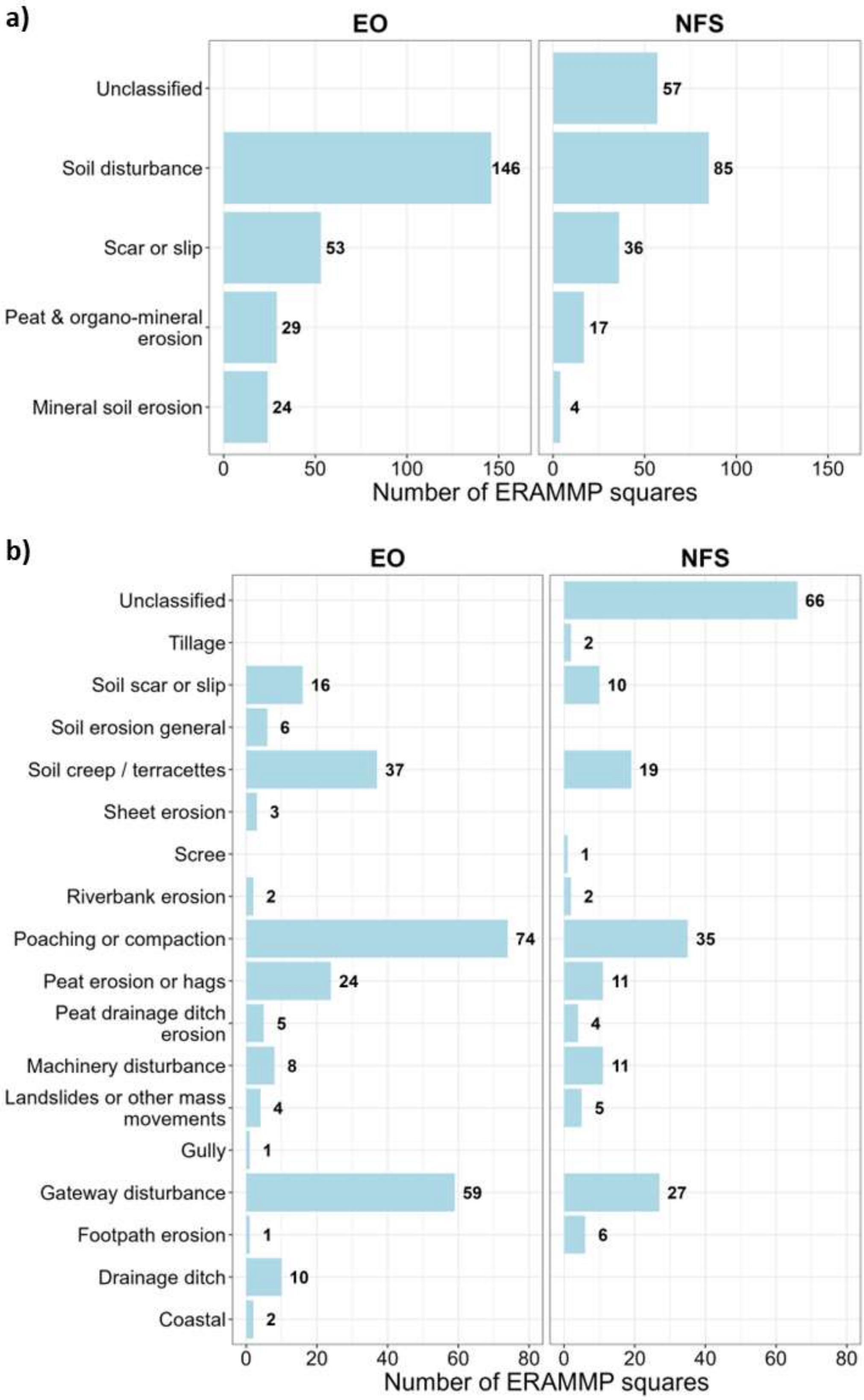


Figure 5-6. a) Total number of ERAMMP squares by most common aggregate SED feature category, and b) total number of ERAMMP squares by most common SED feature sub-group. Frequency tallies were computed for both the EO- and NFS-based SED feature assessments.

Table 5-6. Summary statistics of SED-affected area per square by major SED feature category.

SED feature category	Survey	Mean area (ha)	Minimum area (ha)	Maximum area (ha)
All	EO	4.2	0.0	97.0
Mineral Soil Erosion	EO	3.5	0.0	56.4
Peat & organo-mineral erosion	EO	12.3	0.0	97.0
Scar or slip	EO	2.4	0.0	23.2
Soil disturbance	EO	0.7	0.0	9.2
All	NFS	2.0	0.0	37.3
Mineral Soil Erosion	NFS	0.2	0.0	2.1
Peat & organo-mineral erosion	NFS	4.6	0.0	32.7
Scar or slip	NFS	1.1	0.0	16.0
Soil disturbance	NFS	0.4	0.0	8.0
Unclassified	NFS	1.0	0.0	8.0

Table 5-7. Summary statistics of SED-affected area per square by the five groups of environmental drivers of SED and for Wales overall.

SED driver group	Survey	Mean area (ha)	Minimum area (ha)	Maximum area (ha)
Overall	EO	4.2	0.0	97.0
Agriculturally dominated	EO	1.3	0.0	27.0
Dry lowland Bog and Acid Grassland	EO	2.0	0.0	12.0
Wet lowland Bog and Acid Grassland	EO	5.9	0.2	17.8
Dry uplands	EO	8.5	0.0	28.3
Wet uplands	EO	27.7	0.0	97.0
Overall	NFS	2.0	0.0	37.3
Agriculturally dominated	NFS	1.1	0.0	16.0
Dry lowland Bog and Acid Grassland	NFS	1.2	0.0	9.4
Wet lowland Bog and Acid Grassland	NFS	5.2	0.9	12.9
Dry uplands	NFS	0.6	0.0	2.7
Wet uplands	NFS	10.7	0.0	37.3

In summary, SED is a wide-ranging issue across Wales with a large diversity of different processes and forms occurring in the landscape. The statistical modelling presented here provides an important first step towards understanding the key controls on SED occurrence and extent across Wales. However, more information is required to understand the controls on specific forms of SED across the landscape, in particular, features that are heavily driven by land use such as compaction of bare soil and soil creep that has been exacerbated by livestock grazing in the form of terracettes. Moreover, developing the evidence chain for the link between SOM loss, compaction, change in infiltration and erosion could be one way to better understand and mitigate threats to soils and waterways.

We also need to better understand the full extent of the impacts of SED on the landscape. For example, we know that compacted bare soil can be a source of N_2O emissions, a highly potent GHG, yet the full extent of this issue is currently unknown. Correlation analysis between SED aerial extents and modelled Soil Erosion rates reveal that, in general, SED occurrence does not tend to translate into more soil washing directly into rivers as it may result in soil moved to other parts of the landscape. However, there is a need to explore the extent to which SED features, and direct delivery of soil into rivers, is a problem. The growing availability of high-resolution LiDAR data for Wales should offer an important opportunity to explore this link further. Enhancing our understanding of both environmental controls on specific SED features, how they interact, and the full magnitude of SED impacts on the land and freshwater environments are essential to design mitigation strategies.

6 FRESHWATER

Bentley, L.F.[1] & Doeser, A.[1], Feeney, C.[1], Kimberley, A.[1], Maskell, L.[1], Mondain-Monval, T.O.[1], Reinsch, S.[1] and Scarlett, P.[1]

[1]UK Centre for Ecology & Hydrology

6.1 Headwaters

6.1.1 Introduction

Headwater streams are defined as first- or second-order flowing water bodies within 2.5km of their sources. Headwater streams and their catchment cover a large area of the UK and constitute an estimated more than 70% of the total length of flowing waters (JNCC, 2011) . Routine national monitoring and surveillance of freshwaters often targets downstream larger water courses rather than Headwaters, since downstream locations integrate environmental quality signals from a larger extent of the catchment.

Headwater streams have a number of protection mechanisms and environmental quality targets relevant to them. Many will meet the UK Biodiversity Action Plan definition of a priority stream, although it is thought that very few are covered by a special protection such as Special Area of Conservation or Site of Special Scientific Interest. As well as policy drivers for protection, Headwaters comprise a unique set of physical and geographic conditions vital for sustaining freshwater ecosystems.

Headwater streams replenish the supply of clean water and organisms into downstream reaches. Typically, Headwaters are relatively isolated from environmental pressures common in lowland streams, as most point sources of pollution occur lower down in the catchment. This protected and isolated nature of Headwater streams offers refugia opportunities to freshwater taxa from pressures of invasive species, declining water quality or changing climate. Accordingly, any contamination or environmental stressors present in the Headwaters propagates into the downstream network. Due to their small size, Headwaters can be vulnerable to local impacts affecting the in-channel, riparian or catchment areas, such as habitat modification, abstraction or intensive land use.

The Headwater indices reported on here, demonstrate the ecological community's response to their environmental conditions which can be interpreted as a measure of ecological quality.

6.1.2 Headwater Indicators

- Macroinvertebrate Index of Stream Health is an indicator of stream condition that captures responses to many different pressures, where a higher score indicates better condition and a score of 1 means the site is near-pristine condition.
- The Macroinvertebrate Index of Stream Health is calculated using two metrics, both reported on below. Average score per taxon (ASPT) is the more robust by itself than the score based on number of sensitive taxa (NTAXA), but the overall condition assessment uses information in both scores.
- The Macroinvertebrate Sediment Index shows whether a stream contains more sediment than expected based on the presence of sediment-sensitive species. Sedimentation can act as stressor on stream communities and indicate wider disturbance where:
    - Index values of 1 indicate a naturally expected sediment level.

    - Index values < 1 indicate more sediment than naturally expected.
    - Index values > 1 indicate less sediment than naturally expected.
- Natural sediment levels vary between streams and a normal sediment load is delivered by natural fluvial processes. However, changes in the amount of sediment away from that baseline can be indication of changes in management or disturbance regimes.
- The species present were checked against a list of freshwater invasive species of concern to Wales (NBN Atlas, 2019) and those relevant to UK Biodiversity targets B6 (Harrower, Rorke, & Roy, 2021) .
- The metrics of invasive macroinvertebrate species presence and abundance calculated for Headwaters were:
    - Invasive species richness (%): the mean percentage of taxa in each sample that were invasive across samples.
    - Invaded streams (%): the percentage of streams that contained at least one invasive invertebrate taxa.
    - Mean invasive species abundance (% individuals): the mean percentage of individuals in each sample that were invasive, across samples.

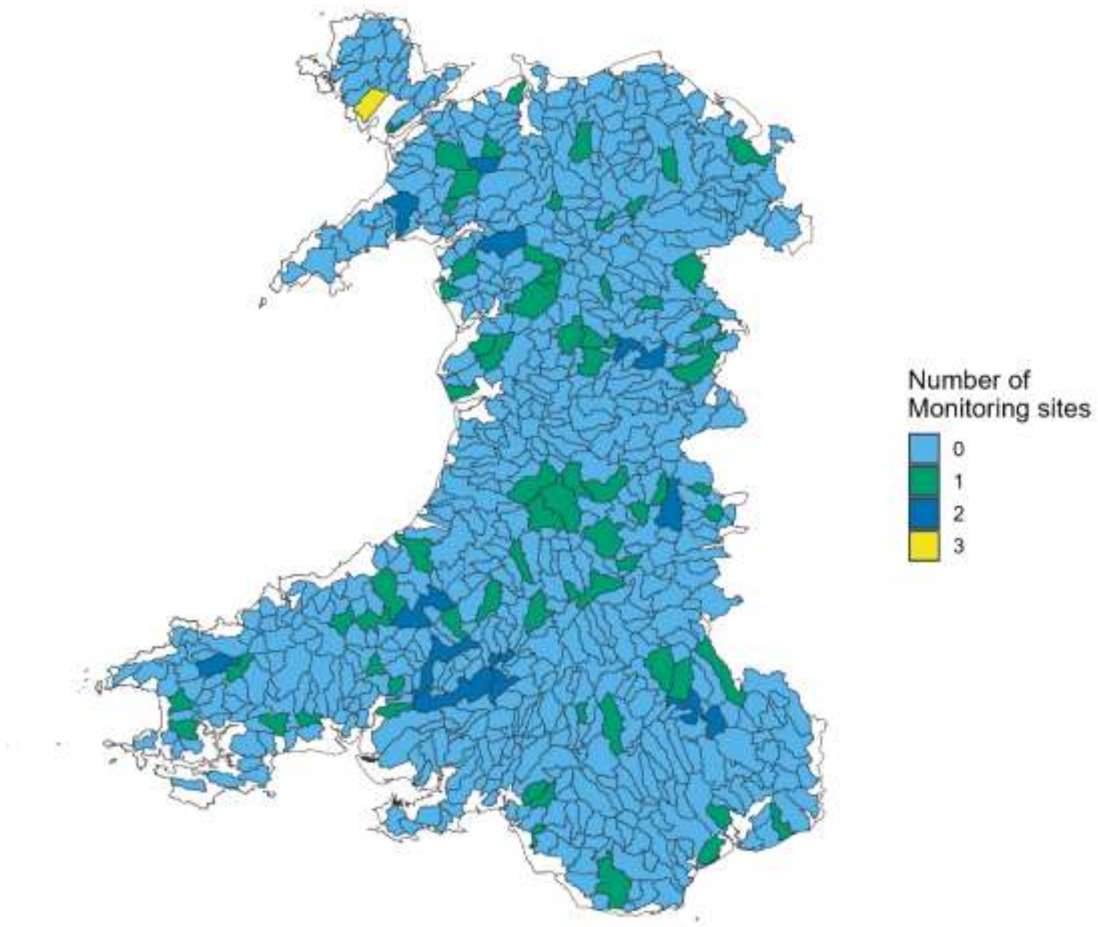


Figure 6-1. Distribution of NFS Headwater sampling sites (2021-23) within Water Framework Directive river catchments.

6.1.3 Headwater Habitat Context

- Three quarters of monitored upstream catchments are smaller than 150ha, up to a maximum of 760ha.
- The upstream catchments of the Headwater streams are predominantly Enclosed Farmland (49% of total upstream area), followed by Semi-Natural Grassland (29% of total upstream area).
- Individual catchments typically have high percentage cover of Enclosed Farmland (62%) and Semi-Natural Grassland (39%).
- Catchments typically have low percentage cover of Built-up and Urban areas (2%), Woodland (10%) and Mountain, Moor and Heath (6%).

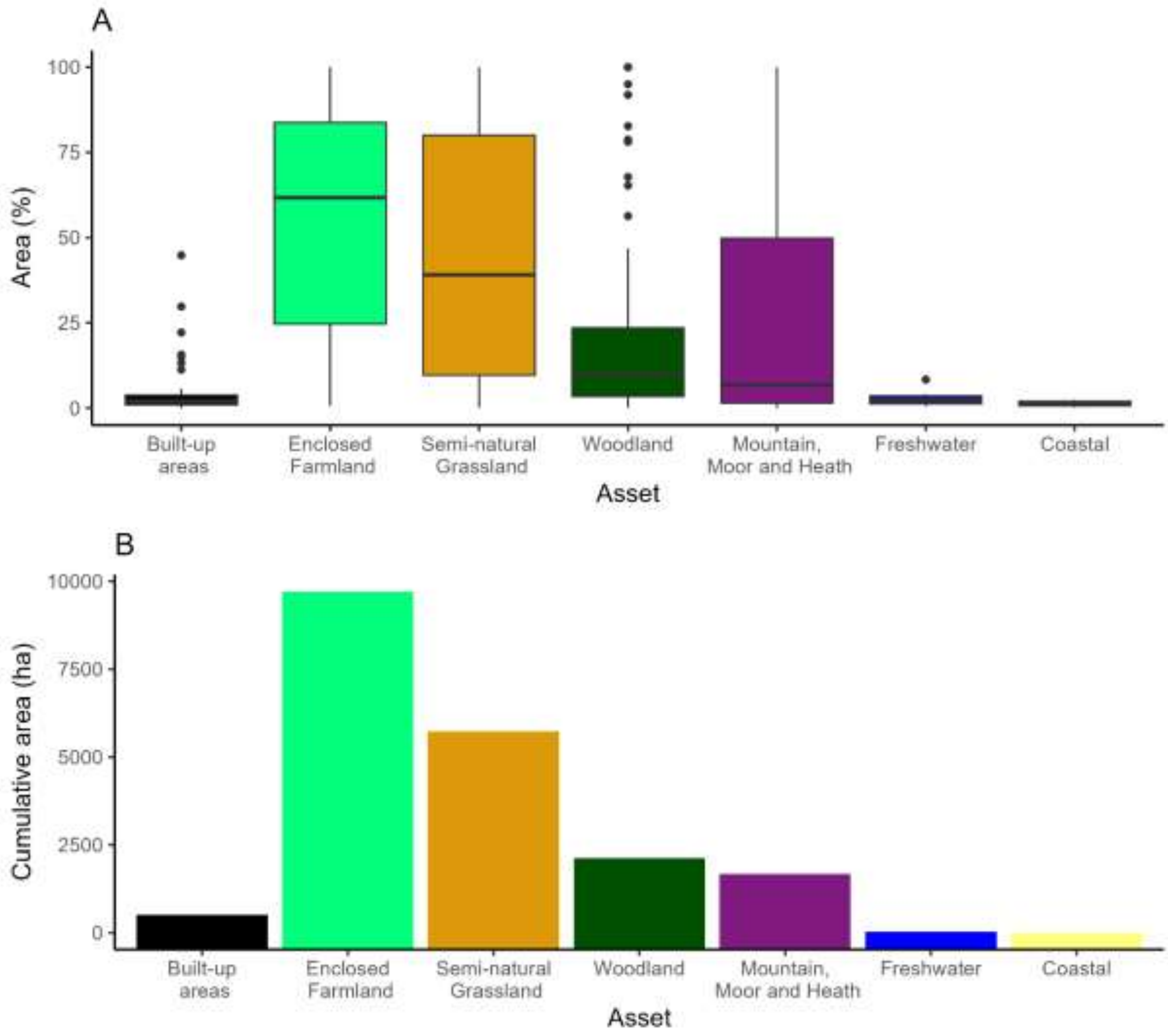


Figure 6-2. A) The distribution of detected Asset Class areas across Headwater monitoring sites established in 2013-16 in upstream catchments, shown as percentage of catchment area. The horizontal lines indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed. B) The cumulative area of all upstream catchments of all Headwater monitoring sites established in 2013-16 across different habitat Asset Classes.

6.1.4 Agri-Environment Scheme Presence

- 86% of re-surveyed catchments contain some Glastir option uptake.
- 100% of catchments contain some Tir Gofal or Tir Cynnal uptake.
- Mean Glastir option coverage within a catchment nearly doubled from 2013-16 (24.8%) to 2021-23 (42.4%).
- Mean Tir Gofal and Tir Cynnal coverage within a catchment was 58%.

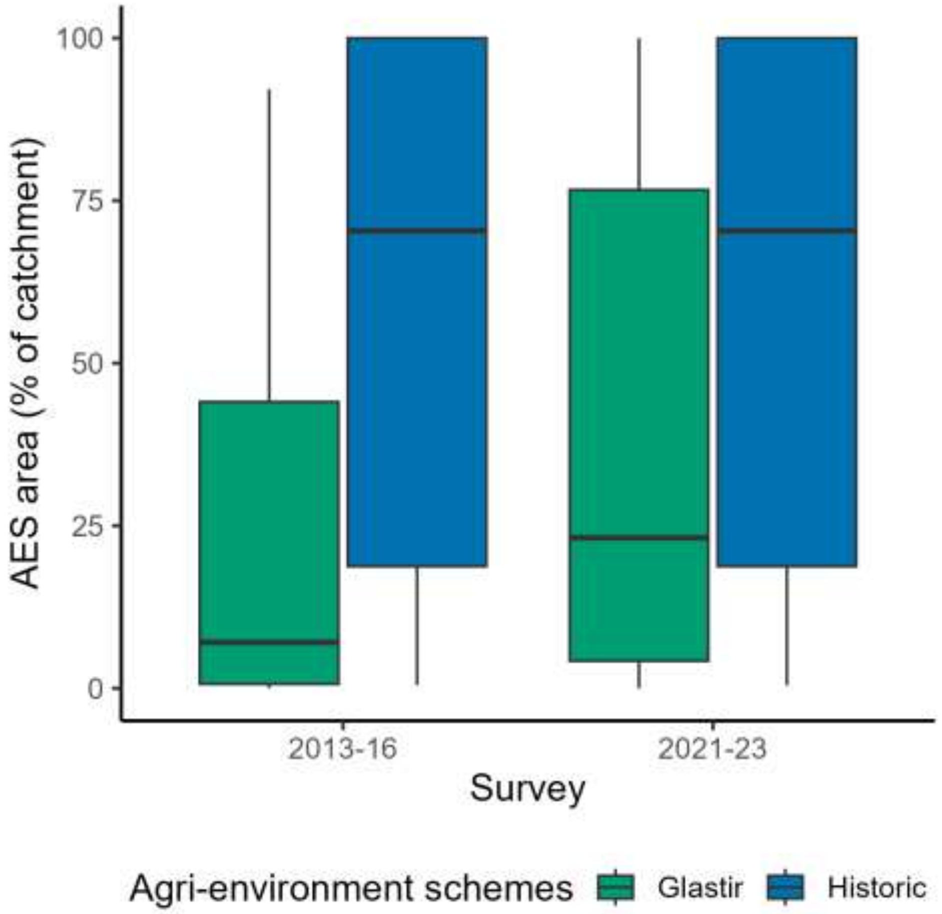


Figure 6-3. The area of Glastir options and historic AES (Tir Gofal and Tir Cynnal) across upstream catchments within the 2013-16 and 2021-23 Headwater surveys shown as a percentage of catchment area surveyed in both time periods. The horizontal lines indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed.

6.1.5 National Trends

Positive Outcomes

- The majority of Headwater streams (80%) remain in 'High' or 'Good' overall ecological condition, compared to 78.5% of those same streams in 2013-16.
- Macroinvertebrate indicators of overall stream health show Headwaters are in a stable condition across Wales and show little sign of Organic pollution and degradation overall.
- Macroinvertebrates in Mountain, Moor and Heath improved.

Areas for Concern / Need for Further Action

- Whilst the majority of streams are in a good overall ecological condition, an equal number of streams have improved a ‘quality category’ as have declined.
- The Macroinvertebrate Sediment Index shows that there has been a significant increase in the amount of sediment in Headwaters from 2013-16 to 2021-23.
- The largest decreases in the sediment index (increases in sediment) are positively associated with the area of Enclosed Farmland (-10%) and Mountain, Moor and Heath (-10%) within the upstream catchment.
- Headwater streams in Wales contain more sediment than expected for a Headwater in pristine condition (Macroinvertebrate Sediment Index < 1).
- Overall, there is a widespread (>50% of streams) and persistent pressure of invasive invertebrates in Headwater streams in Wales.
- Over half (59% increased to 66%) of Headwater streams have at least one invasive invertebrate species present, with some streams hosting three invasive taxa within a site.
- One additional invasive species was detected in Headwater streams in 2021-23, albeit in low abundances. All invasive species detected from 2013-16 remained present in 2021-23.
- The invasive species present with known impact ratings are considered to have low or moderate impact (WFD-UKTAG, 2015), however three of the species have an unknown impact. Those taxa with low and moderate impact when present, occur at high abundances.
- The number of dry streams encountered during the field survey has quadrupled from 2.6% in 2013-16 to 12.9% in 2021-23. This likely reflects the unusually hot summer in 2021 and to a lesser extent 2023. Whilst this may be an anomaly, it is likely the incidence of hot summers will increase with climate change and so we include these statistics as a new baseline for potential future reporting.

Table 6-1. Summary statistics for the National Trends for Headwaters by Asset Class, where '=' no significant change, '+/-' significant increase/decrease in the indicator (p<0.05), and '++/--' highly significant increase/decrease in the indicator (p<0.01). No data are shown as grey boxes. Analysis for each Asset Class used data weighted by the percentage area of each class present in the catchment.

Habitat	Asset Class	Index	Long-term analysis using CS data 1998-2007	Mean 2013-16	Mean 2021-23	Short-term analysis using GMEP 2013-16 to 2021-23
Headwaters	Woodland	Macroinvertebrate Index of Stream Health (O/E WHPT – ASPT)		0.95	0.96	=
		Macroinvertebrate Index of Stream Health (O/E WHPT – NTAXA)		1.12	1.20	=
		Macroinvertebrate Sediment Index (O/E PSI)†		0.76	0.76	=
	Mountain, Moor and Heath	Macroinvertebrate Index of Stream Health (O/E WHPT – ASPT)		0.97	1.00	=
		Macroinvertebrate Index of Stream Health (O/E WHPT – NTAXA)		0.91	1.22	+
		Macroinvertebrate Sediment Index (O/E PSI)†		1.01	0.91	=
	Semi-Improved Grassland and Fen	Macroinvertebrate Index of Stream Health (O/E WHPT – ASPT)		1.00	1.00	=
		Macroinvertebrate Index of Stream Health (O/E WHPT – NTAXA)		1.34	1.40	=
		Macroinvertebrate Sediment Index (O/E PSI)†		0.84	0.82	=
	Enclosed Farmland	Macroinvertebrate Index of Stream Health (O/E WHPT – ASPT)		0.98	0.97	=
		Macroinvertebrate Index of Stream Health (O/E WHPT – NTAXA)		1.43	1.44	=
		Macroinvertebrate Sediment Index (O/E PSI)†		0.82	0.74	=
	All Wales	Macroinvertebrate Index of Stream Health (O/E WHPT – ASPT)	=	0.98	0.98	=
		Macroinvertebrate Index of Stream Health (O/E WHPT – NTAXA)	=	1.34	1.39	=
		Macroinvertebrate Sediment Index (O/E PSI)†		0.81	0.77	-

† A ±0.2 deviation from 1 indicates a decline in condition (Extence, Chadd, England, Naura, & Pickwell, 2017).

Table 6-2. Incidence of dry Headwater streams, as a percentage of Headwater streams visited, across each survey period, for all sites and for sites specifically within the Nationally Representative Sites subset of squares.

Incidence of Headwater Streams	2013-16	2021-23
Dry streams (% All sites)	2.9 (5 out of 174)	9.9 (10 out of 101)
Dry streams (% Nationally Representative sites only)	2.6 (4 out of 150)	12.9 (8 out of 62)

Table 6-3. Presence and relative abundance of Headwaters in each category of stream condition based on the Macroinvertebrate Index of Stream Health for Nationally Representative sites, all where N is the number of streams. Separate counts are provided for all Nationally Representative sites surveyed in 2013-26 and the subset of those sites in the re-surveyed population, to facilitate comparison with results form 2021-23.

Class	2013-16 (N = 82)		2013-16 Re-surveyed (N = 57)		2021-23 (N = 57)	
	N	%	N	%	N	%
High	47	57.3	33	58.9	36	64.1
Good	18	22.0	11	19.6	9	16.1
Medium	17	20.7	12	21.4	9	16.1
Bad	0	0	0	0	2	3.6

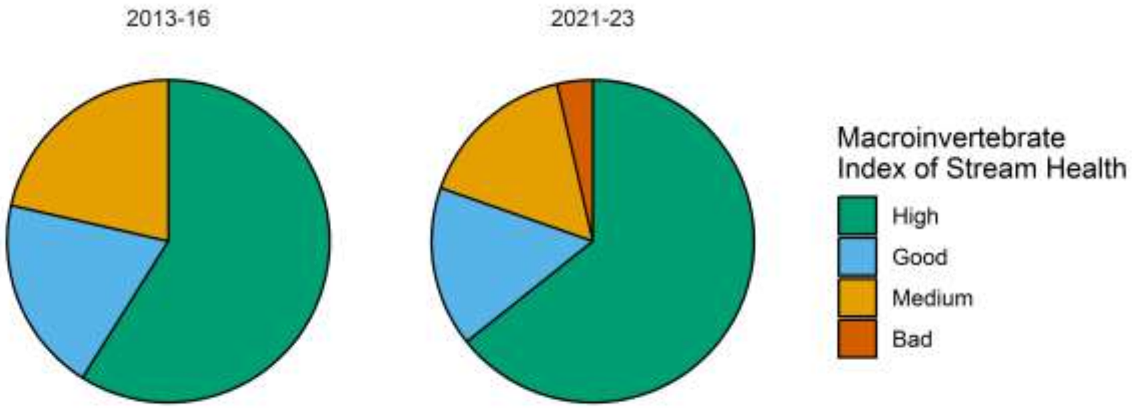


Figure 6-4. The proportion of Macroinvertebrate Index Stream Health indicators for re-surveyed sites within the Nationally Representative population by category.

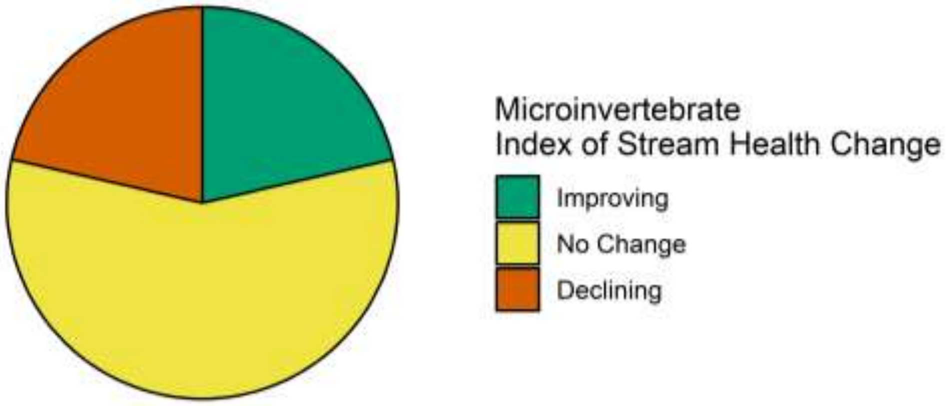


Figure 6-5. Proportion of change for the Macroinvertebrate Index Stream Health indicator between 2013-16 and 2021-23 within the Nationally Representative population by category.

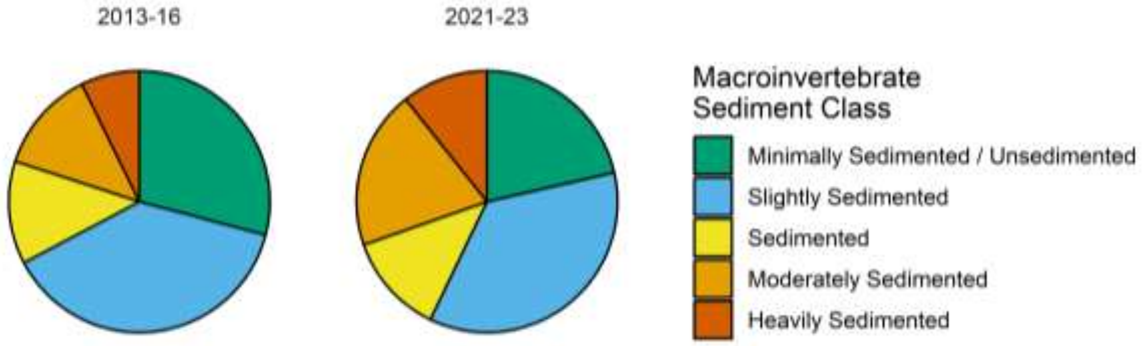


Figure 6-6. Proportion of Macroinvertebrate sediment categories for re-surveyed sites within the Nationally Representative population by category.

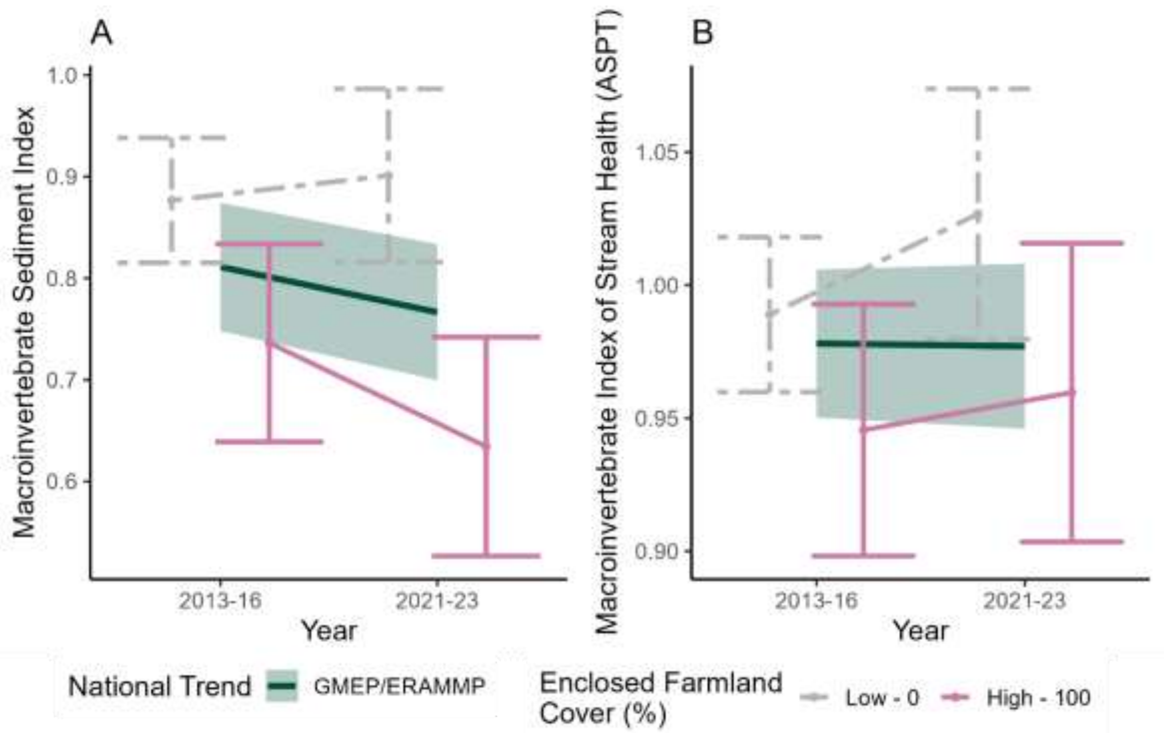


Figure 6-7. Trends in A) Macroinvertebrate Sediment Index, and B) Macroinvertebrate Index of Stream Health between 2013-16 and 2021-23 showing both National Trends and the effect of Enclosed Farmland cover.

Table 6-4. Relative abundance and presence of invasive macroinvertebrate species in Headwater streams across Nationally Representative surveyed Headwaters visited in both 2013-16 and 2021-23.

Abundance and presence of macroinvertebrate species	2013-16	2021-23
Invasive species richness (mean % of taxa)	1.5	1.9
Invaded streams (%)	58.9	66.1
Invasive abundance (mean % of individuals)	7.6	7.1

Table 6-5. Invasive invertebrate taxa present in streams across all sample sites and their WFD UKTAG impact rating.

Taxa	WFD UKTAG Impact
Crangonyx pseudogracilis/floridanus	Low
Girardia tigrina	Unknown
Physella acuta group	Unknown
Planaria torva	Unknown
Potamopyrgus antipodarum	Moderate

6.1.6 Glastir Impact

Positive Outcomes

- None reported

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Glastir options have had no significant effect on Headwater condition.
- The impact of options targeting stream management options specifically could not be assessed due to the low number of catchments with uptake focussed on this issue. However, expanding the re-surveyed population survey could allow us to revisit this question.
- Enclosed Farmland cover within a catchment was associated with a higher baseline amount of sediment (relative to expected values for a given catchment) and was associated with an increase in the rate of sediment loading over time. Enclosed Farmland cover was also associated with a lower average condition for both Macroinvertebrate Index of Stream Health and Macroinvertebrate Sediment Index.

Table 6-6. Summary statistics for the effects of Glastir options on Headwaters, where '=' no significant effect, '+/-' significant increase/decrease in the indicator relative to land without the options (p<0.05), and '++/--' highly significant increase/decrease in the indicator relative to land without the options (p<0.01).

Habitat	Indicator	All Glastir	Grazing Low/No Inputs	Habitat Management	Context Effect
Headwaters	Macroinvertebrate Index of Stream Health (O/E WHPT – ASPT)	=	=	=	No
	Macroinvertebrate Index of Stream Health (O/E WHPT – NTAXA)	=	=	=	No
	Macroinvertebrate Sediment Index (O/E PSI)‡	=	=	=	Yes

‡ A ±0.2 deviation from 1 indicates a decline in condition.

6.2 Streamsides

6.2.1 Introduction

In-channel structures, stream banks and riparian areas are vital features of streams, playing an integral role in ecological, hydrological and geomorphological processes.

The interface of stream flow with stream banks and beds dictates sediment mobilisation and movement, mediating stream power and creating varied and often dynamic habitats, for example, stable and eroding bank faces used by nesting birds and unconsolidated clean gravels used by spawning fish.

The physical structure of the riparian zone, along with the nature of the channel, controls lateral connectivity with the floodplain, determining to what extent high flows will overspill the bank and transport water and organic material to the floodplain.

Vegetation, both herbaceous and woody, plays a role in stream productivity and habitat complexity. Vegetation from stream banks is a direct source of organic material to the food chain, and indirectly via shading can limit the amount of in-channel growth of algae and higher plants. Plant detritus and roots can in themselves form structural habitat for invertebrates and fish. The shading function is also recognised in its cooling effect, mitigating against warming trends in high-stress peak temperatures.

Set within a managed and productive landscape, natural Headwater channels and riparian areas have been subject to management and stress. Water courses are manipulated via culverts or bank protection to direct flow and channel migration. Managed and productive land may be situated close to, or directly adjacent to, stream channels, impacting habitat and water quality via grazing, poaching and inputs of sediment and nutrients.

We report on trends in indicators of habitat modification, erosion and riparian vegetation. Erosion features, both in-channel and riparian, are reported on here as a new metric quantifying the type and extent of erosion features in Headwater streams.

6.2.2 Streamside Indicators

- Habitat Modification Score indicates the presence and extent of artificial modification to a stream and its banks, where a high score indicates more modification.
- Habitat Modification Score – Poaching is a sub-score of the overall index and is a sub-component likely to be more sensitive to AES management.
- Some erosion processes are indicative of natural stream function and habitat diversity (fluvial and biological processes). Others are indicative of artificial disturbance which can be ecologically harmful in excess (artificial processes and sources of runoff).
- Ellenberg (N) fertility is an indicator of soil nutrient availability, where high values indicate higher nutrient availability and potentially eutrophication.
- Ellenberg reaction is an indicator of soil pH, where lower values indicate more acidic soils.
- Ellenberg light is an indicator of light levels where lower scores indicate shading and successional advancement.
- Terrestrial plant species richness is reported for all species, nectar-producing species and AWI species. In all cases, higher scores indicate better condition for that metric. Scores are expected to vary with habitat type and condition of that habitat.
- CSM: Positive and CSM: Negative show the number of recorded terrestrial plant species that are associated with good or poor ecological condition, respectively.
- Cover-weighted mean canopy height measures the average height of vegetation in the plot.

6.2.3 Streamside Habitat Context

- Streamsides are predominantly in Semi-Natural Grassland (36% of total area) or Enclosed Farmland (35% of total area).
- Woodland cover was present in 52% of Streamsides, covering at least 15% of the area (within 100m of the bank) for 33% of streams.
- Presence of Mountain, Moor and Heath cover was comparatively rare (13% of streams) but relative cover is high when present (62%).

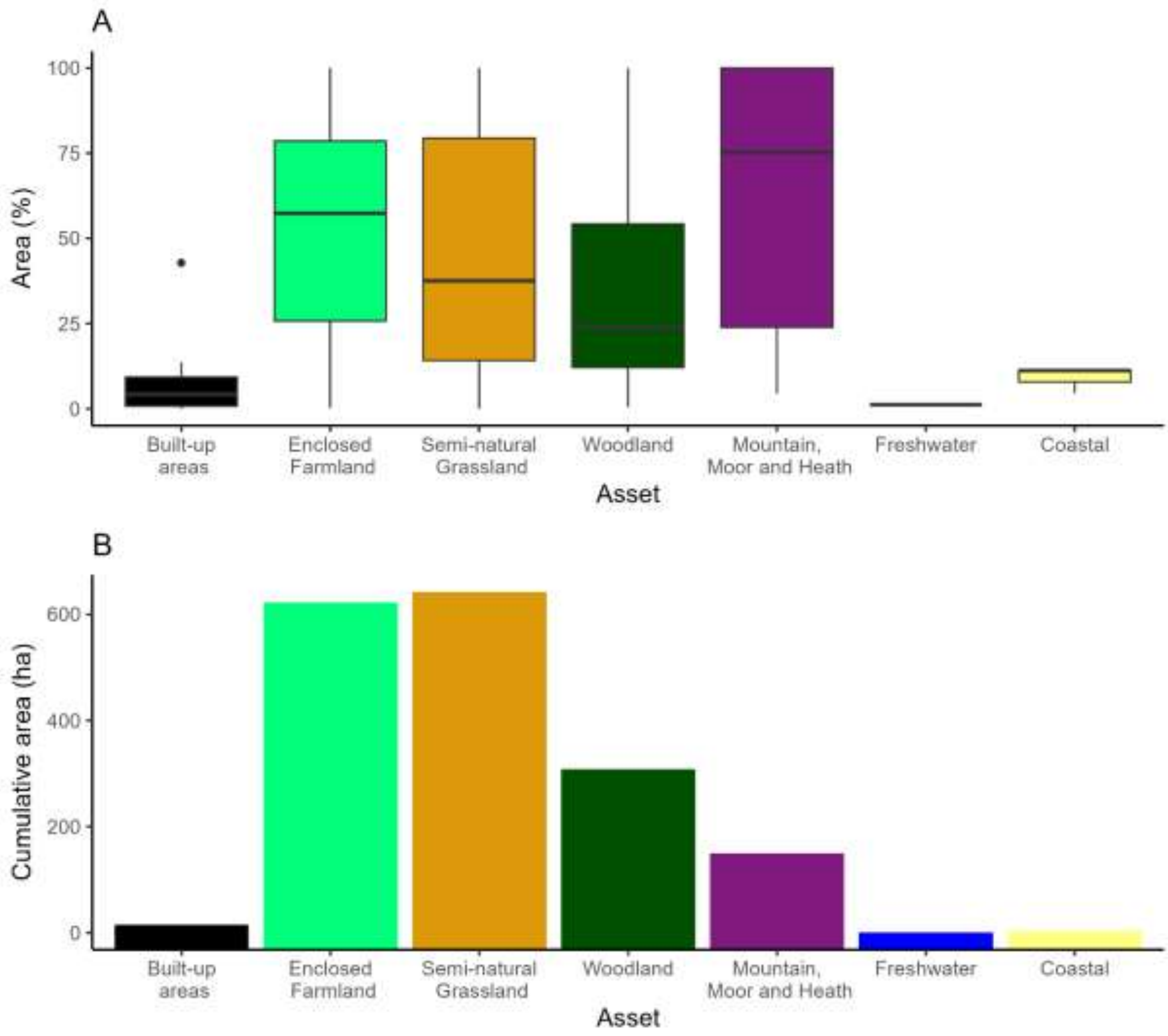


Figure 6-8. A) The distribution of detected Asset Class within a 100m radius of all Streamside monitoring transects established in 2013-16, as a percentage of total across different habitat Asset Classes. The horizontal lines indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed. B) Cumulative area of Asset Classes represented within a 100m radius of all stream bank monitoring transects established in 2013-16.

6.2.4 Agri-Environment Scheme Presence

- 64% of re-surveyed Streamsides had some Glastir option uptake.
- 59% of Streamsides had some Tir Gofal or Tir Cynnal uptake.
- 47% of Streamsides had both Glastir options and historic AES in place.

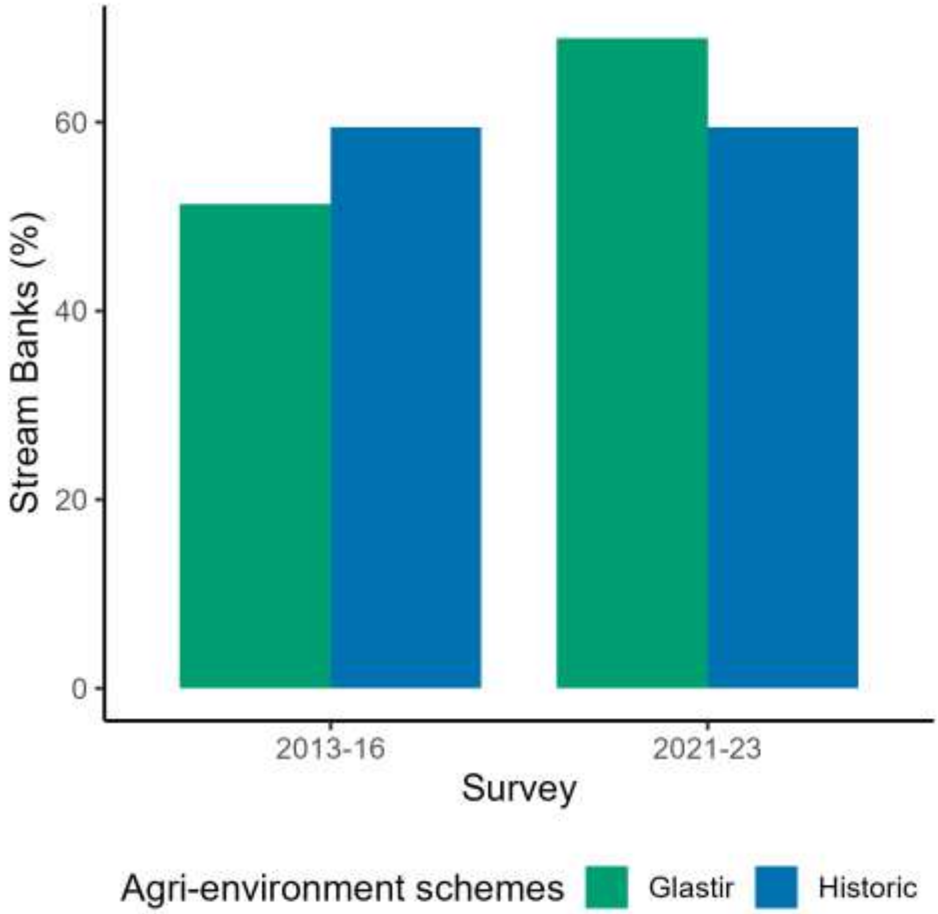


Figure 6-9. The presence of Glastir options and historic AES (Tir Gofal and Tir Cynnal) within 100m of Streamsides during the 2013-16 and 2021-23 surveys.

6.2.5 National Trend

Positive Outcomes

- Levels of habitat modification for Streamsides have remained stable. More Streamsides have improved the habitat modification score (20.6%) than have declined (11.1%).
- The number of significantly or severely modified streams has reduced from 42.9% to 30.2%.
- Headwater Streamsides display a wide range of natural erosional features indicating that hydromorphological processes are active in sediment delivery and transport, contributing to habitat diversity creation and natural disturbance regimes.
- Actual or potential sediment runoff was observed in a small proportion of streams (17%).
- Cover-weighted canopy height in Streamsides has increased suggesting taller vegetation cover and continued successional advancement.

Areas for Concern / Need for Further Action

- Poaching remains the most common form of Streamside bank modification and erosion, present in over 60% of sites and affecting 4.3% of surveyed Streamsides length.

- The number of Streamsides in pristine or predominantly unmodified condition has reduced from 46.0% to 41.3%.
- The majority of Streamsides have some form of artificial modification.
- There has been a decrease in overall terrestrial plant species richness, shading and the diversity of nectar-producing plants in Streamsides. This is commonly associated with an increase in vegetation height.

Table 6-7. Summary statistics for the National Trends for Streamsides, where '=' no significant change, '+/-' significant increase/decrease in the indicator (p<0.05), and '++/--' highly significant increase/decrease in the indicator (p<0.01). No data are shown as grey boxes.

Habitat	Index	Long-term trend using CS data 1990-2007	Mean 2013-16	Mean 2021-23	Short-term analysis using GMEP 2013-16 to 2021-23
Streamsides	Habitat Modification Score*		213.7	178.5	=
	Habitat Modification Score – Poaching*		14.6	12.9	=
	Ellenberg (N) Fertility*†	+	5.0	5.0	=
	Ellenberg Reaction†	+	5.4	5.4	=
	Ellenberg Light†	--	6.3	6.2	-
	Total Plant Richness†	--	20.5	19.4	--
	Nectar Species Richness†	-	10.2	9.2	--
	AWI Richness†	=	2.3	2.4	=
	CSM: Positive†	--	11.6	11.3	=
	CSM: Negative*†	-	10.9	10.4	=
	Cover-weighted Mean Canopy Height†	++	2.6	2.8	++

* This is a negative indicator, where a higher value is associated with a worse condition.

† Measured from specialised Vegetation plots within Streamsides. Asset Class, Glastir option and historic AES cover differs slightly to that described above.

Table 6-8. Presence and relative abundance of Streamsides in each category of Streamside condition based on the habitat modification score for Nationally Representative sites, all where N is the number of Streamsides. Separate counts are provided for all Nationally Representative sites surveyed in 2013-26 and the subset of those sites in the re-surveyed population, to facilitate comparison with results form 2021-23.

Class	2013-16 (N = 80)		2013-16 Re-surveyed (N = 63)		2021-23 (N = 63)	
	N	%	N	%	N	%
Pristine/semi-natural	17	21.3	12	19.0	13	20.6
Predominantly unmodified	22	27.5	17	27.0	13	20.6
Obviously modified	10	12.5	7	11.1	18	28.6
Significantly modified	19	23.8	17	27.0	10	15.9
Severely modified	12	15.0	10	15.9	9	14.3

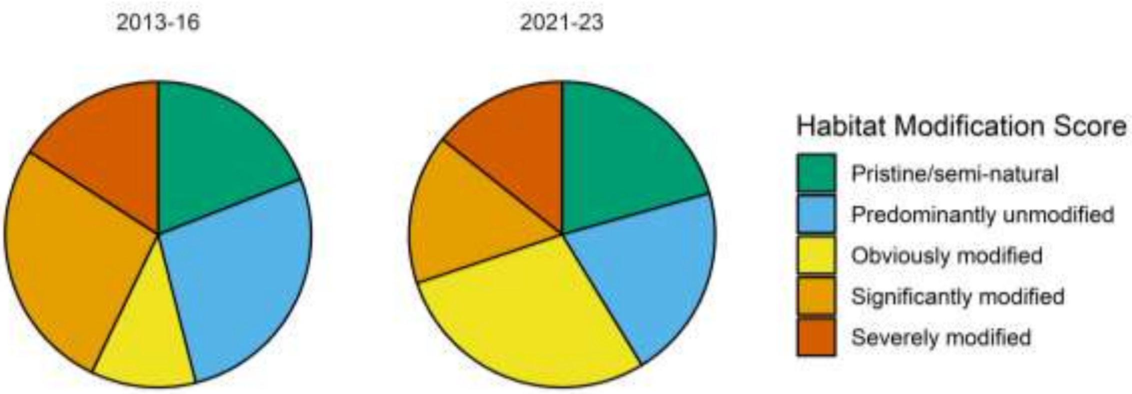


Figure 6-10. The proportion of Habitat Modification Score for Streamsides by category.

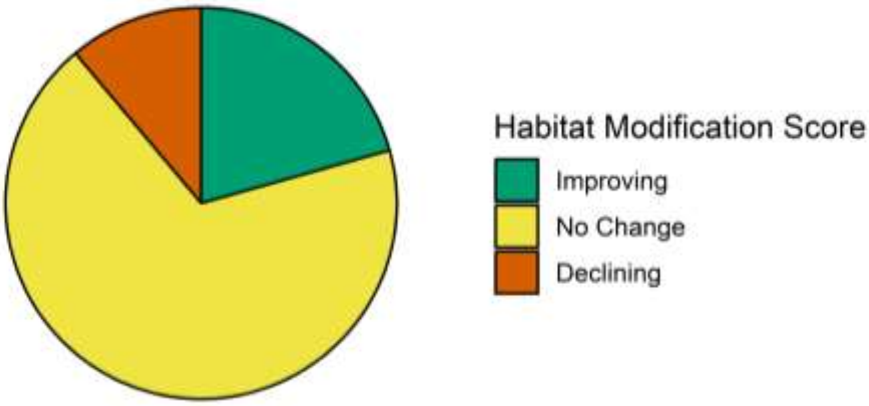


Figure 6-11. The proportion of change in Habitat Modification Score for Streamsides between 2013-16 and 2021-23 by category.

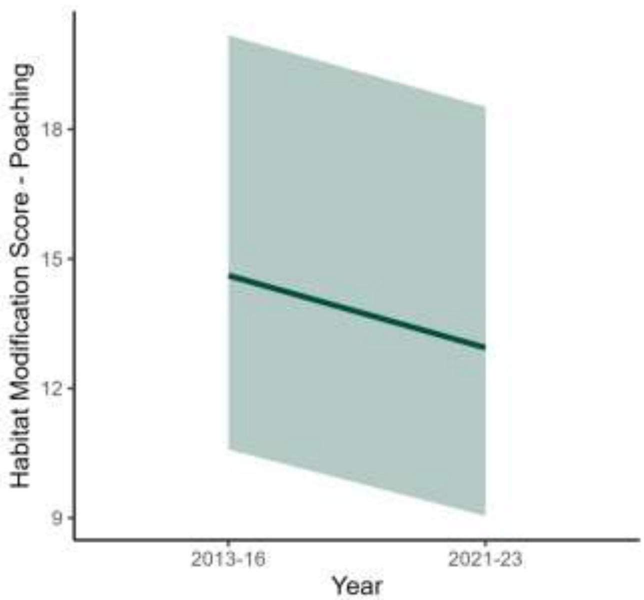


Figure 6-12. Trend in poaching for Streamsides within the Habitat Modification Score between 2013-16 and 2021-23 from Nationally Representative squares.

Table 6-9. Types of stream modification and presence in Headwater Streamsides 2013-16 and 2021-23 for Nationally Representative squares with repeat surveys.

Modification	2013-16		2021-23	
	Presence	Presence (%)	Presence	Presence (%)
Poaching	40	63.5	38	60.3
Culverts	30	47.6	29	46.0
Bank bed re-sectioning	15	23.8	15	23.8
Bank bed reinforcement	12	19.0	7	11.1
Bridges	8	12.7	7	11.1
Fords	7	11.1	9	14.3
Weirs, dams and sluices	7	11.1	5	7.9
Outfalls and deflectors	5	7.9	2	3.2
Berms and embankments	4	6.3	2	3.2

Table 6-10. Types and mean extent per site of erosion features on Headwater Streamsides surveyed in Nationally Representative squares.

Process type	Process	Presence	Presence (%)	Affected bank length (%)	Features per site	Maximum recorded features per site
Artificial	Poaching	42	64.6	4.9	3.7	17
	Access	10	15.4	0.8	1.1	2
	Ford	1	1.5	0.8	1.0	1
	Footpaths	0	0.0	0.0	0.0	0
Fluvial	Below structure	43	66.2	4.0	2.8	18
	Full bank scour	26	40.0	3.3	2.1	9
	Stable cliff	25	38.5	7.5	1.8	5
	Bed scour	19	29.2	0.4	1.2	2
Biological	Tree fall	4	6.2	0.5	1.0	1
	Burrowing	3	4.6	0.1	1.0	1
Other	Tributary	43	66.2	0.3	1.6	6
	Potential non-field runoff	8	12.3	2.5	1.0	1
	Potential field runoff	5	7.7	4.3	3.6	9

6.2.6 Glastir Impact

Positive Outcomes

- Glastir options for Wildlife Corridor management targeting Streamside Corridors were associated with a reduction in the number of plant species indicative of poor ecological quality, suggesting a net improvement in ecological quality.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Sites associated with Glastir options or historic AES had a higher level of Streamside habitat modification than sites without each respective scheme.
- We can detect no effect of Glastir on the rate of change of poaching incidence and extent. However, due to the relatively low uptake of some options within the re-surveyed population, expanding the number of re-surveyed sites may allow us to revisit this.

Table 6-11. The effect of Glastir option management bundles on Headwater Streamside indicators for all Wales, where '=' no significant effect, '+/-' significant increase/decrease in the indicator relative to land without the options (p<0.05), and '++/--' highly significant increase/decrease in the indicator relative to land without the options (p<0.01).

Habitat	Indicator	All Glastir	Grazing Low/No Inputs	Habitat Management	Wildlife Corridors (Streams)	Woodland Management	Context Effect
Streamsides	Habitat Modification Score – Poaching	=	=	=	=	=	Yes
	Ellenberg (N) Fertility	=	=	=	=	=	No
	Ellenberg Reaction	=	=	=	=	=	No
	Ellenberg Light	=	=	=	=	=	No
	Total Plant Richness	=	=	=	=	=	No
	Nectar Species Richness	=	=	=	=	=	No
	AWI Richness	=	=	=	=	=	No
	CSM: Positive	=	=	=	=	=	No
	CSM: Negative*	=	=	=	-	=	No
	Cover-weighted Mean Canopy Height	=	=	=	=	=	No

* This is a negative indicator, where a higher value is associated with a worse condition.

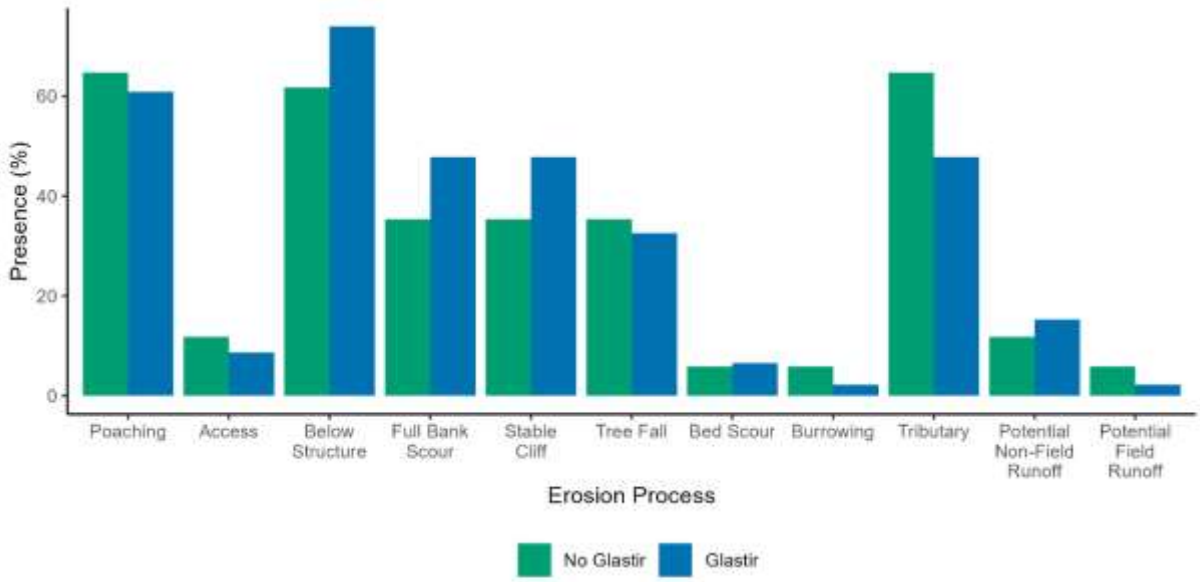


Figure 6-13. Presence of erosion features in Streamsides surveyed in 2021-23, for stream banks with and without Glastir option uptake, as a percentage of all Streamsides with or without Glastir option uptake.

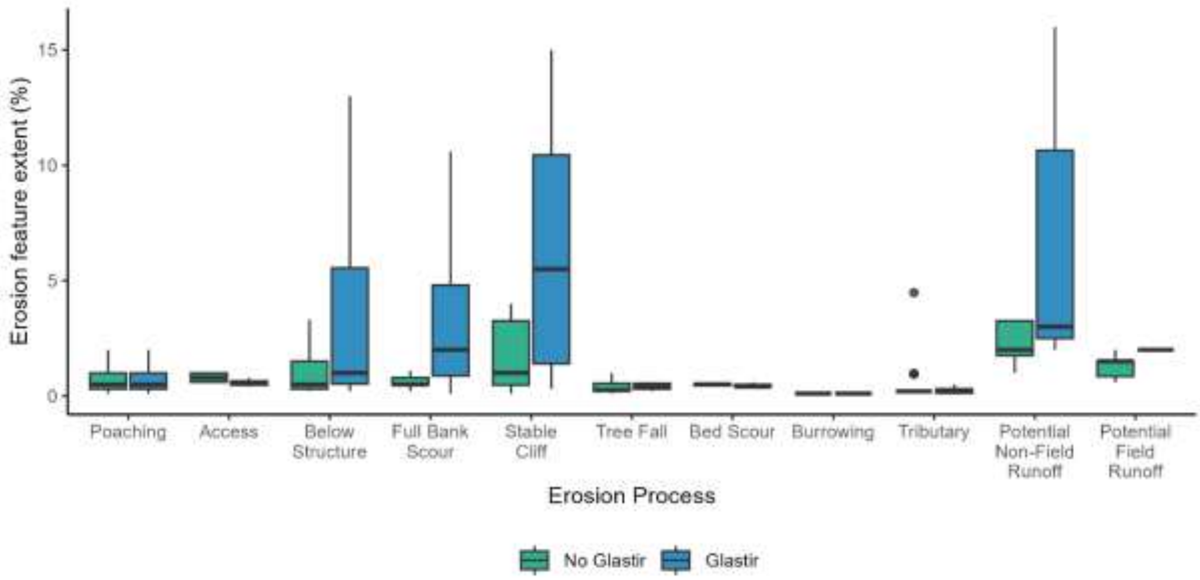


Figure 6-14. The extent of erosion features in Streamsides with and without Glastir option uptake surveyed in 2021-23, as a percentage of surveyed Streamside length. The horizontal lines indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed.

6.3 Ponds

6.3.1 Introduction

Ponds are incredibly diverse habitats for their size, often containing collectively within a certain area a greater diversity of taxa compared to other waterbody types (Williams, et al., 2004) As such, Ponds form an important part of the hydroscape, contributing significantly to habitat diversity, forming a mosaic of niches and resources valuable to a range of organisms.

In agricultural settings, Ponds are recognised as an important source of insect biomass to support farmland Bird populations (Lewis-Phillips, et al., 2020).

Given their relative hydrological isolation in the landscape from overland sources of water pollution, Ponds often have good water quality relative to other water bodies. In addition to contributing to landscape Biodiversity, Ponds have a role to play in water resource management. By collecting and processing small amounts of run off from within their relatively small catchments, Ponds contribute not only to water quality but also by slowing the flow, reducing flood peaks (Miller, Vesuviano, Wallbank, Fletcher, & Jones, 2023).

Historically Ponds have been overlooked in terms of protection in legislation due to their small size (<2ha) (Biggs & Williams, 2024) excluding them from the protection of the EU Water Framework Directive. Ponds are at risk of loss from the landscape through land drainage, land development and also natural succession. The number of Ponds in the UK has drastically reduced, estimated to have halved from over 1 million in 1880 to 478,000 in 2007 (Biggs & Williams, 2024), leading to fragmentation and a loss of landscape connectivity, particularly impacting amphibians.

Ponds within an agricultural landscape received sediments, nutrients and pesticides from their catchments often resulting in reduced biodiverse as sensitive taxa are eliminated. More recently the colonisation by invasive non-native species is recognised as an emerging threat to Pond Biodiversity (Hill, et al., 2021).

We report on trends in Pond drying, the presence of invasive species and overall Pond quality.

6.3.2 Pond Indicators

- Pond Biotic Quality is an overall indicator of Pond condition, where a high score indicates higher biotic quality. Pond Biotic Quality is calculated by comparing survey Ponds to an undegraded reference condition for that Pond type (Freshwater Habitats Trust, 2019).
- Macrophyte richness indicates the diversity of submerged and marginal plant species, relative to that expected under undegraded conditions. Higher values (closer to 1) indicate better condition.
- Uncommon macrophyte index is the number of local, nationally rare or rare species.
- Macrophyte-derived nutrient condition indicates the nutrient status of the Pond, where:
    - Scores of 1 is considered preferable in the overall quality assessment.
    - Scores > 1 indicate a more nutrient-rich (more eutrophic) Pond than expected.
    - Scores < 1 indicate a more nutrient-poor (more dystrophic) Pond than expected.
- Macroinvertebrate-derived water quality is sensitive to a range of pressures, including water nutrient status. High values indicate higher water quality.
- *Odonata* and *Megaloptera* richness is the diversity of dragonfly and alderfly families.
- *Coleoptera* richness is the diversity of beetle families present and is an indicator of water quality and habitat diversity.
- Invasive plant presence.
- Invasive macroinvertebrate presence and abundance.

6.3.3 Pond Habitat Context

- Asset Classes surrounding Ponds are predominantly Enclosed Farmland (46% of total area), followed by Semi-Natural Grassland (28% of total area) or Woodland (17% of total area).
- Woodland cover was present for 42% of Ponds, covering at least 15% of the area (within 100m) for 26% of Ponds.
- Presence of Mountain, Moor and Heath cover was comparatively rare (11% of streams) but relative cover is high when present (68%).

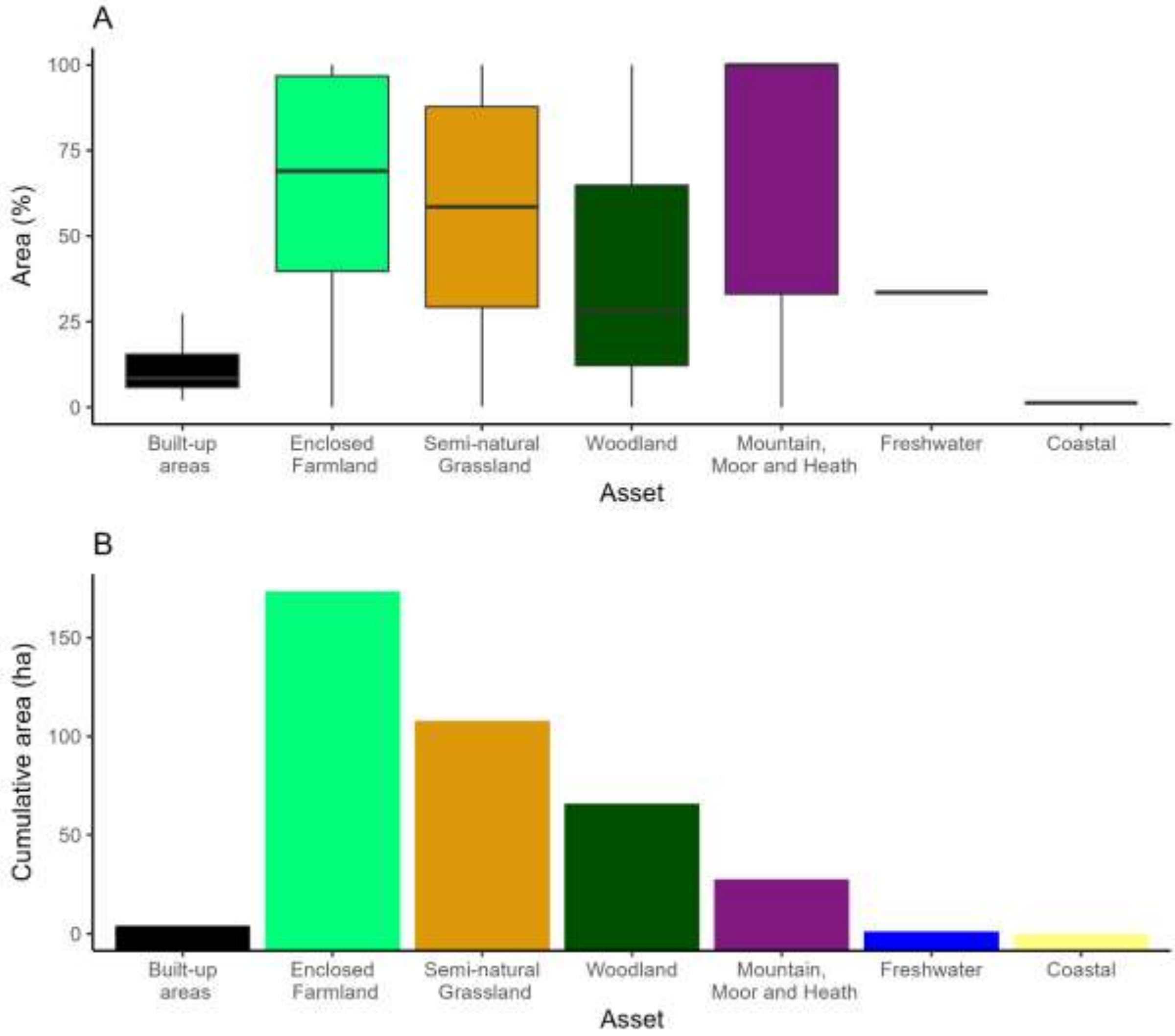


Figure 6-15. A) The distribution of detected Asset Class within a 100m radius of all Pond monitoring sites established in 2013-16, as a percentage of the area across different habitat Asset Classes. The horizontal lines indicate the midpoint, the boxes indicate where the mid 50% of all values sit and the vertical lines represent the full range of values observed. B) Cumulative area of Asset Classes represented within a 100m range of all Pond monitoring sites established in 2013-16.

6.3.4 Agri-Environment Scheme Presence

- 40% of re-surveyed Ponds had some Glastir option uptake within a 100m radius.
- 53% of Ponds had some Tir Gofal or Tir Cynnal Option uptake within the 100m buffer.
- 27% of Ponds had both Glastir options and historic AES options in place within the 100m buffer.

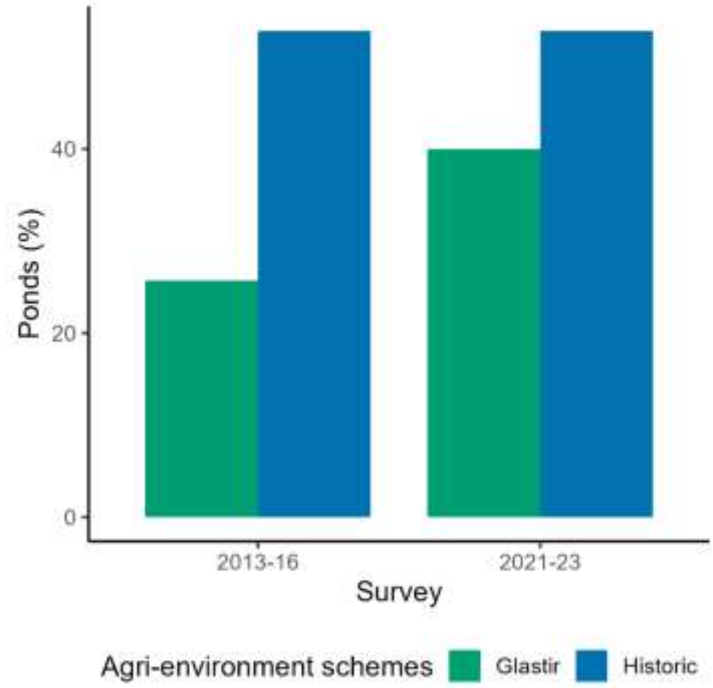


Figure 6-16. Glastir option and historic AES (Tir Gofal and Tir Cynnal) presence within 100m of Ponds during the 2013-16 and 2021-23 surveys, for Ponds surveyed in both time periods.

6.3.5 National Trend

Positive Outcomes

- Overall Pond biotic integrity has remained stable from 2013-16 to 2021-23 with 53.7% now in good or moderate biotic condition (63.4% previously).
- Plant community richness in Welsh Ponds has significantly increased. Uncommon plant species community condition has also improved, but not significantly.
- The average nutrient content of Ponds in Wales shows a non-significant downward trend to near-mesotrophic states in 2021-23, indicated by the macrophyte-derived nutrient condition indicator, which is associated with overall higher Pond quality.

Areas for Concern / Need for Further Action

- Whilst statistically stable, Pond quality shows a non-significant downwards trend that is largest in Ponds within Semi-Improved Grassland and Fen.
- The percentage of Ponds in a poor or very poor condition has increased from 36.6% to 46.3%.
- More have declined in quality than improved. Improved Ponds had a lower initial quality score and declined Ponds had higher initial quality scores, although the differences were not significant.
- All indicators of macroinvertebrate community condition show a downward trend.

- The richness of water beetle families declined significantly from 2013-16 to 2021-23.
- Water beetle richness declined significantly for all Welsh Ponds, and for Ponds in a predominantly Enclosed Farmland or Semi-Natural Grassland and Fen matrix. The lack of a significant decline in Woodland Ponds could be due to lower statistical power or differential conditions across habitats.
- Invasive plant species have become more common in Ponds. The percentage of Ponds with invasive plant species present has increased from 8.6% of Ponds to 18.6%, and now represent 1.2% of taxa, up from 0.6% in 2013-16.
- Many of the invasive plant species present are considered to be of high impact. The high-impact species *Crassula helmsii* was detected in Pond plant communities for the first time in 2021-23 in the ERAMMP survey but a small number of records for Wales previously.
- Invasive invertebrates in Ponds are more widespread than invasive plants, present in 57% of sites.
- The invasive invertebrates *Proasellus coxalis* (one site) and *Girardia tigrina* (two sites) were detected for the first time in the ERAMMP survey 2021-23 but reported before for Wales.
- *Proasellus coxalis* was added in 2023 to the list of B6 invasive species. Known to be present in Norway, Germany, France (CABI, 2022) and Belgium (Wouters & Vercauteren, 2009), there are currently no UK records of this species on the Biological Records NBN Atlas.
- The percentage of dry Ponds at the time of visit has increased seven-fold from 1.6% to 11.2%. This likely reflects the unusually hot summer in 2021 and to a lesser extent 2023. Whilst this may be an anomaly, it is likely the incidence of hot summers will increase with climate change and so we include these statistics as a new baseline for potential future reporting.

Table 6-12. Summary statistics for the National Trends for Ponds by Asset Class, where '=' no significant change, '+/-' significant increase/decrease in the indicator (p<0.05), and '++/--' highly significant increase/decrease in the indicator (p<0.01). Analysis for each Asset Class used data weighted by the percentage area of each class present in the 100m buffer surrounding each Pond.

Habitat	Asset Class	Indicator	2013-16	2021-23	GMEP/ERAMMP trend 2016-22
Ponds	Woodland	Pond Biotic Quality	56.78	44.83	=
		Macrophyte richness	0.52	0.43	=
		Uncommon macrophyte index	0.32	0.09	=
		Macrophyte-derived nutrient condition†	1.04	0.82	=
		Macroinvertebrate-derived water quality	0.85	0.78	=
		Odonata and *Megaloptera* richness	0.58	0.26	=
		Coleoptera richness	0.90	0.60	=
	Semi-Natural Grassland and Fen	Pond Biotic Quality	55.47	52.21	=
		Macrophyte richness	0.63	0.70	=
		Uncommon macrophyte index	0.27	0.41	=
		Macrophyte-derived nutrient condition†	1.08	1.01	=

		Macroinvertebrate-derived water quality	0.90	0.84	=
		Odonata and *Megaloptera* richness	0.76	0.70	=
		Coleoptera richness	0.95	0.72	-
	Enclosed Farmland	Pond Biotic Quality	51.37	49.37	=
		Macrophyte richness	0.52	0.60	=
		Uncommon macrophyte index	0.27	0.28	=
		Macrophyte-derived nutrient condition†	1.31	1.12	=
		Macroinvertebrate-derived water quality	0.82	0.84	=
		Odonata and *Megaloptera* richness	0.54	0.41	=
		Coleoptera richness	0.93	0.68	--
	All Wales	Pond Biotic Quality	53.57	52.45	=
		Macrophyte richness	0.55	0.62	+
		Uncommon macrophyte index	0.28	0.33	=
		Macrophyte-derived nutrient condition†	1.19	1.07	=
		Macroinvertebrate-derived water quality	0.85	0.83	=
		Odonata and *Megaloptera* richness	0.61	0.53	=
		Coleoptera richness	0.93	0.71	--

† An increase above 1 indicates more eutrophic conditions than expected and below 1 indicates dystrophic conditions, both considered a decrease in Pond quality.

Table 6-13. Presence and relative abundance of Ponds in each category of Pond condition based on the Pond Biotic Quality Indicator for Nationally Representative sites, all where N is the number of Ponds. Separate counts are provided for all Nationally Representative sites surveyed in 2013-16 and the subset of those sites in the re-surveyed population, to facilitate comparison with results form 2021-23.

Pond condition category (PSYM Class)	2013-16 (N = 59)		2013-16 Re-surveyed (N = 41)		2021-23 (N = 41)	
	N	%	N	%	N	%
Good	7	11.9	5	12.2	4	9.8
Moderate	32	54.2	21	51.2	18	43.9
Poor	16	27.1	12	29.3	16	39.0
Very Poor	4	6.8	3	7.3	3	7.3

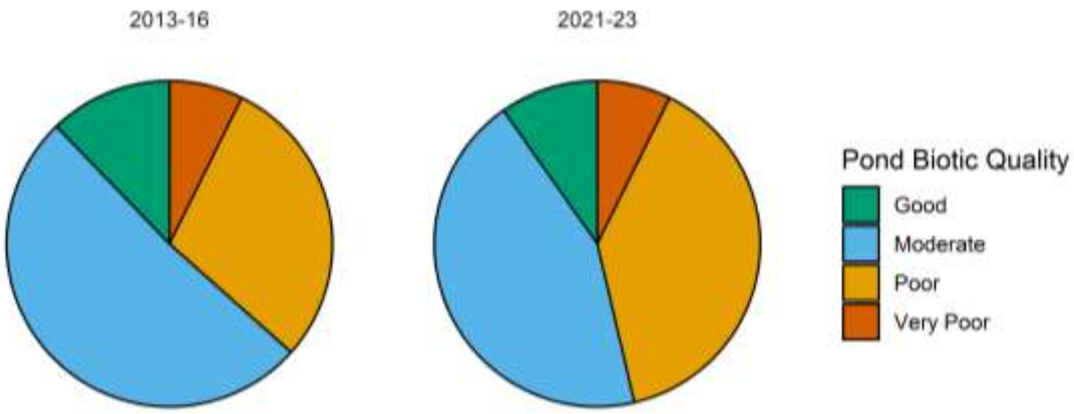


Figure 6-17. The proportion of Pond Biotic Quality for 2013-16 and 2021-23 by Pond condition category.

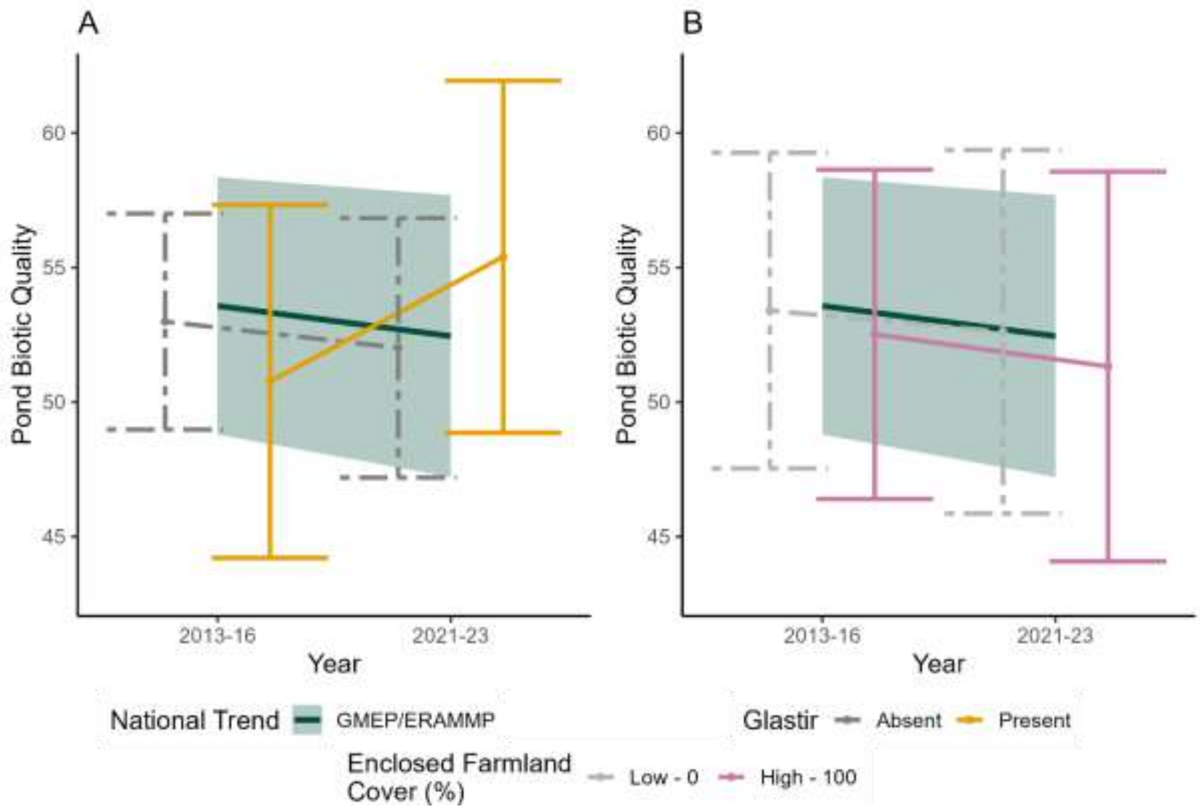


Figure 6-18. Trend in Pond Biotic Quality between 2013-16 and 2021-23 for all Wales showing both National Trends and effect of: A) all Glastir options, and B) Enclosed Farmland cover.

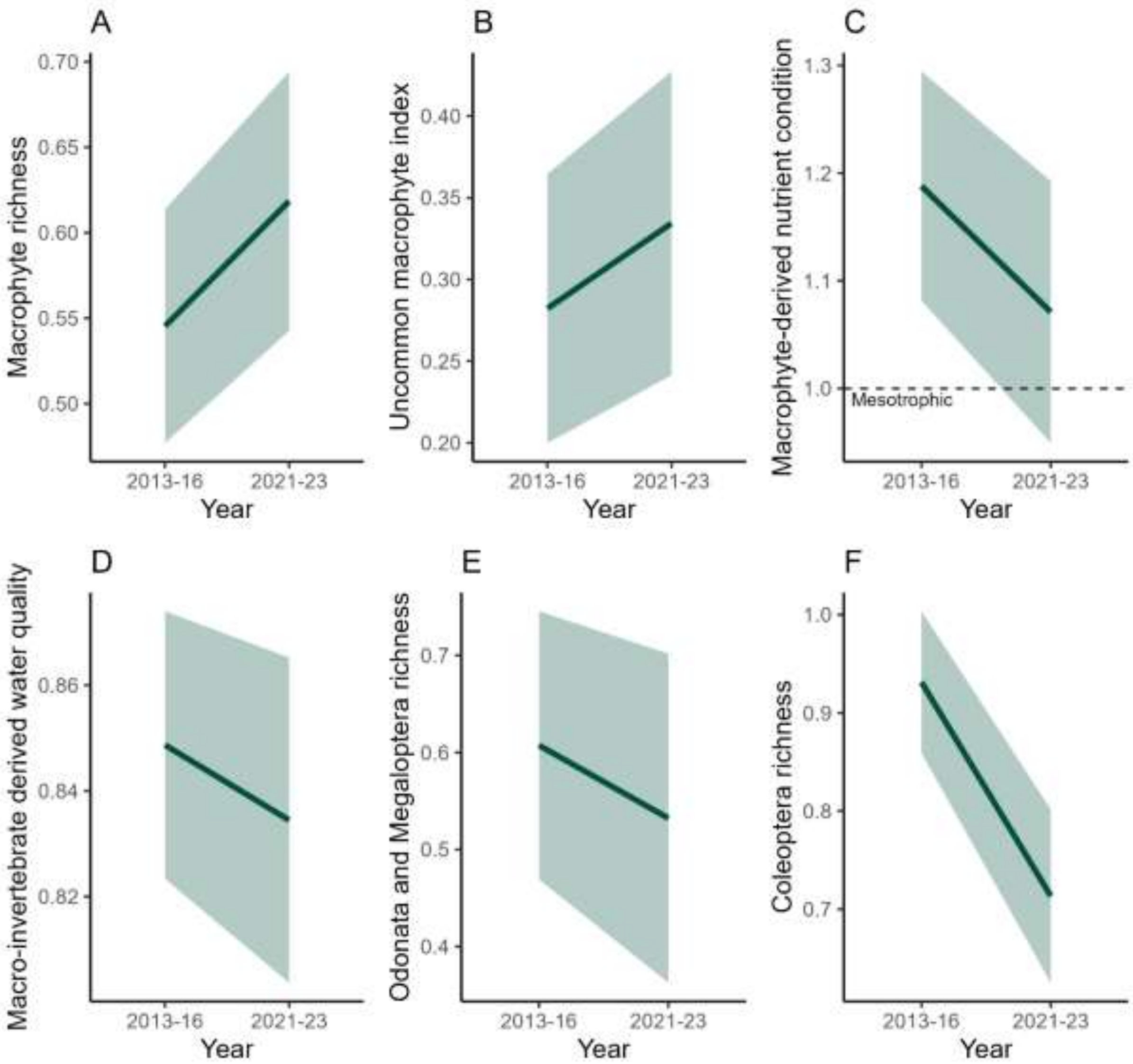


Figure 6-19. Trend in Pond: A) Macrophyte richness, B) uncommon Macrophyte index, C) Macrophyte-derived nutrient condition, D) macroinvertebrate-derived water quality, E) Odonata and Megaloptera richness, and F) Coleoptera richness between 2013-16 and 2021-23 from Nationally Representative squares.

Table 6-14. Invasive taxa found present in the Pond population across all sites and the species WFD UKTAG impact rating.

Group	Taxa	WFD UKTAG Impact
Invasive Plants	*Azolla filiculoides*	High
	Crassula helmsii	High
	Elodea canadensis	Moderate
	Elodea nuttallii	High
	Impatiens glandulifera	High
	Lagarosiphon major	High
	Lemna minuta	Moderate
Invasive Macroinvertebrates	*Crangonyx pseudogracilis/floridanus*	Low
	Girardia tigrina	Unknown
	Physella acuta group	Unknown
	Planaria torva	Unknown
	Potamopyrgus antipodarum	Moderate
	Proasellus coxalis	Not on list

Table 6-15. Presence and abundance of invasive plant and invertebrate taxa across Ponds in Wales, considering all Nationally Representative re-surveyed sites.

Issue	2013-16	2021-23
Ponds with invasive plants (%)	9.3	23.3
Mean invasive plant taxa (% of taxa per Pond)	0.7	1.6
Maximum invasive plant prevalence (% taxa)	11.0	12.0
Ponds with invasive invertebrates (%)	57.1	57.1
Mean invasive macroinvertebrate taxa (% of taxa per Pond)	2.0	2.3
Maximum invasive invertebrate taxa (% taxa)	9.0	9.0
Mean invasive invertebrate abundance (% individuals)	10.5	8.5

Table 6-16. Incidence of dry Ponds, as a percentage of Ponds visited across each survey period for all Wales sites and Nationally Representative sites.

Incidence of Dry Ponds	2013-16	2021-23
Dry Ponds – All sites (%)	4.3% (4 out of 115)	14.1% (10 out of 71)
Dry Ponds – Nationally Representative sites (%)	1.6% (1 out of 62)	11.4% (5 out of 44)

6.3.6 Glastir Impact

Positive Outcomes

- None reported

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Glastir options have had no significant impact on Pond condition.
- There was insufficient Glastir option uptake in Woodland surrounding Ponds to analyse the effects of Glastir options for that Asset Class.
- Increasing the number of re-surveyed Ponds would allow us to re-evaluate these questions with greater analytical power.

Table 6-17. Summary statistics for Pond indicators for all Wales and by Asset Class. Where '=' no significant change and no data are shown as grey boxes.

Habitat	Asset Class	Indicator	All Glastir	Habitat Management	Grazing Low/No Inputs	Context Effect
Ponds	Semi-Natural Grassland	Pond Biotic Quality	=	=	=	No
		Macrophyte richness		=	=	No
		Uncommon macrophyte index		=	=	No
		Macrophyte-derived nutrient condition		=	=	No
		Macroinvertebrate-derived water quality		=	=	No
		Odonata and *Megaloptera* richness		=	=	No
		Coleoptera richness		=	=	No
	Enclosed Farmland	Pond Biotic Quality	=	=	=	No
		Macrophyte richness		=	=	No
		Uncommon macrophyte index		=	=	No
		Macrophyte-derived nutrient condition		=	=	No
		Macroinvertebrate-derived water quality		=	=	No
		Odonata and *Megaloptera* richness		=	=	No
		Coleoptera richness		=	=	No
	All Wales	Pond Biotic Quality	=	=	=	No
		Macrophyte richness	=	=	=	No
		Uncommon macrophyte index	=	=	=	No
		Macrophyte-derived nutrient condition	=	=	=	Yes
		Macroinvertebrate-derived water quality	=	=	=	Yes
		Odonata and *Megaloptera* richness	=	=	=	No
		Coleoptera richness	=	=	=	Yes

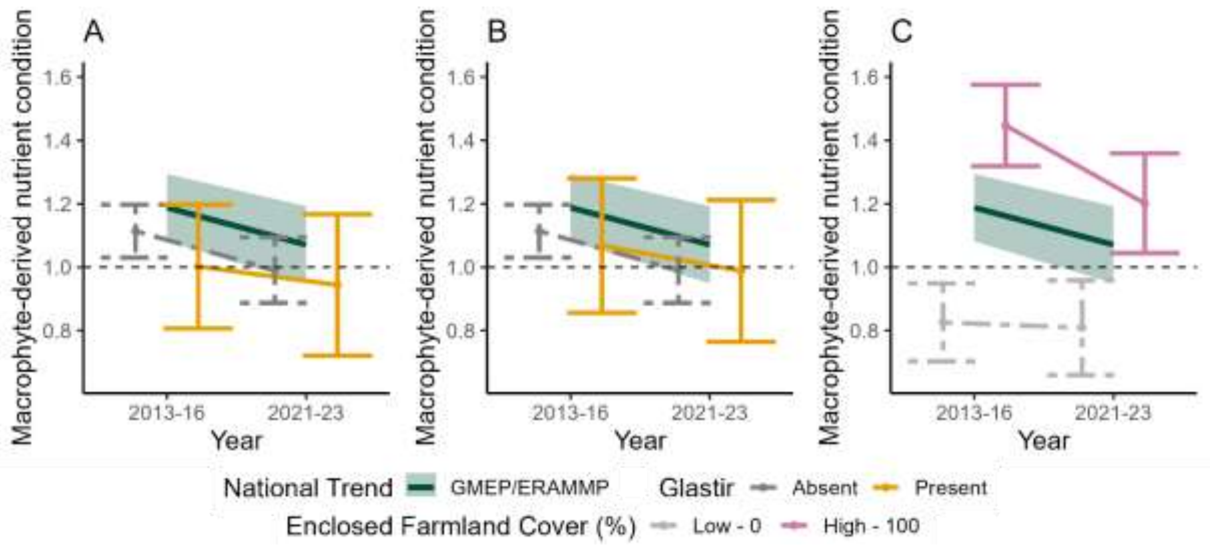


Figure 6-20. National Trend in Macrophyte-derived nutrient condition and impacts for Glastir by management bundle for: A) Habitat Management, B) Grazing Low/No Inputs, and C) Enclosed Farmland control factor. Dotted line shows mesotrophic nutrient status. High values indicate more eutrophic systems, whereas low values indicate more dystrophic systems.

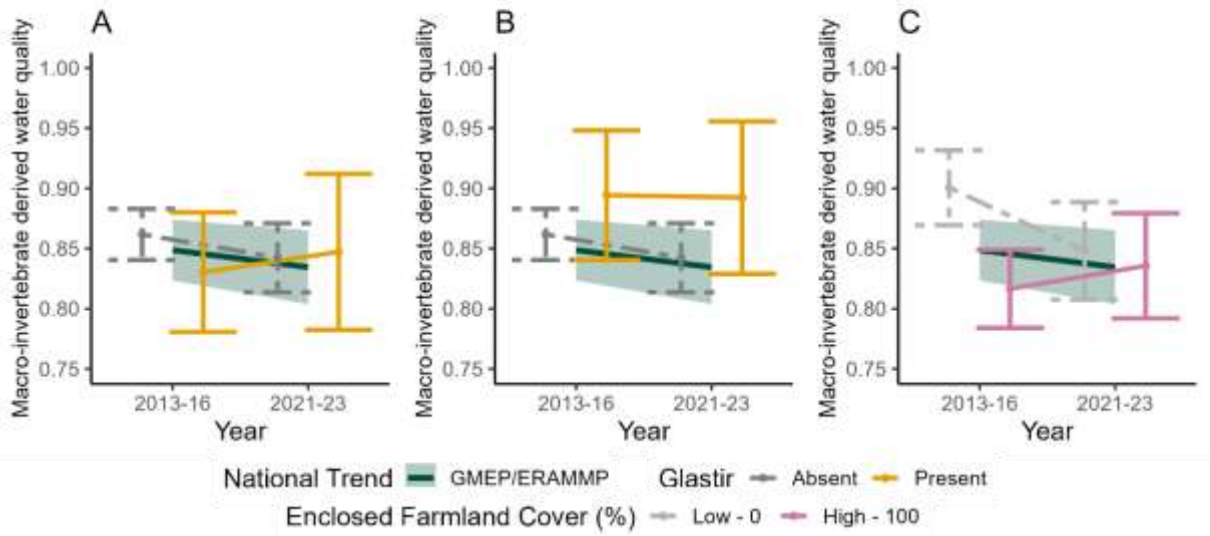


Figure 6-21. National Trends in macroinvertebrate-derived water quality indicator and impacts for Glastir by bundle for: A) Habitat Management, B) Grazing Low/No Inputs, and C) Enclosed Farmland control factor. Dotted line shows mesotrophic nutrient status. High values indicate more eutrophic systems, whereas low values indicate more dystrophic systems.

7 HISTORIC LANDSCAPES AND ACCESS

Reinsch, S.[1], Monkman, G.[1], and Jarvis, S.[1]

[1]UK Centre for Ecology & Hydrology

7.1 Introduction

The status and change of three elements of Wales's cultural assets have been captured by ERAMMP. The results also enable reporting the outcomes for the following Glastir Objectives:

- Managing landscapes and historic environments
- Improving public access to the countryside

In this chapter, two elements captured by the NFS are reported namely the status and change in the condition of Historic Environment Assets (HEAs) and PROWs. Changes in the status and condition of Landscapes and characteristics linked to resilience (including Landscapes associated with High Nature Value Farmland) are reported in the following chapter as a combination of NFS, FPS and EO was used to capture the relevant evidence which was not suited to the NFS-only approach.

7.2 Historic Environment Assets

Two classes of Historic Environment Assets (HEAs) were surveyed:

- Scheduled Ancient Monuments are nationally important with statutory protection under the Ancient Monuments and Archaeological Areas Act.
- Historic Environment Features are regionally important but without statutory protection.

An agreed maximum of seven features per square were surveyed and in squares where more than seven occurred, CADW and the Welsh Archaeological Trusts (WATS) advised as to which seven to survey.

Field survey staff received training from specialists at CADW or the WATS annually throughout the two projects, GMEP (2013-16) and ERAMMP (2021-23). The training included HEA condition assessment which was assessed in six categories and the assessment of threats to the HEAs which were assessed in four categories and extent and severity scores were assigned. Broad Habitat was not recorded for HEA assessment.

Between 2013 and 2016, out of 461 HEAs identified for survey within the 300 squares, 220 HEAs were surveyed. In 2021-23, a total of 252 HEAs were located in surveyed squares, with 147 being surveyed. A total of 86 HEAs were direct re-surveys. Note that a smaller number of HEAs fall into the Nationally Representative squares population. The survey methodology and the data analysis can be found in the ERAMMP Technical Annex-105TA1S11: Wales National Trends and Glastir Evaluation. Supplement-11: Historic Environment Assets (Reinsch, Jarvis, & Monkman, 2025).

7.2.1 National Trends

Within the Nationally Representative squares, a total of 91 HEAs were surveyed in 2013-16 (42% of all HEAs in squares) compared to 71 HEAs in 2021-23 (45%). In 2013-16, most HEAs were not surveyed due to missing information or HEAs not found. In 2021-23, most of the none-surveyed HEAs were in areas with refused access. A total of 42 HEAs were re-surveyed in Nationally Representative squares between 2013-16 and 2021-23 (46% of surveyed HEAs in 2013-16).

Positive Outcomes

- HEA condition has not significantly changed over time. 59% of all surveyed HEAs were in excellent or sound condition in 2013-16, compared to 54% in 2021-23. 52% of re-surveyed HEAs were in excellent or sound condition in both time periods.
- Between 2013-16 and 2021-23, the number of threats to re-surveyed HEAs has decreased by 32%.
- A total of 18% of HEAs in 2013-16 and 15% in 2021-23 showed no threats. For re-surveyed HEAs, 17% had no threats associated with them.

Areas for Concern / Need for Further Action

- Although there has been no overall change in the national picture of HEA condition, there are examples of both improved and decreased condition, creating the stable picture.
- Vegetation threats and other threats significantly degraded HEA condition, with agricultural operations potentially having the same effect.

Table 7-1. Long-term and short-term trends in Historic Environment Asset condition, where '=' no significant change and '+/-' significant at p =< 0.05. No data are shown as grey boxes.

Asset Class	Indicator	Long-term analysis using CS data 1978/ 1990-2007	Mean Trend 2013-16	Mean Trend 2021-23	Short-term analysis using 2013-16 to 2021-23
Historic Environment Assets	HEAs in excellent or sound condition (%)		59	54	=

Table 7-2. National Trend threat counts and percentage per threat category for all and re-surveyed HEAs in 2013-16 and 2021-23. Impact on HEA condition shows if the threat category had an impact on HEA condition, where '-' significantly negative effect on condition (worse condition), '=' no change; Agri = threats caused by agricultural operations, Other = other threats, Stock = stock threats and Veg = Vegetation threats. No data are shown as grey boxes.

Threat Category	All HEAs			Re-surveyed HEAs (n=42)		
	2013-16	2021-23	Threat impacts on HEA condition	2013-16	2021-23	Threat impacts on HEA condition
Agri	50 (18%)	28 (17%)	-	20 (18%)	12 (16%)	=
Other	29 (10%)	37 (22%)	-	16 (14%)	14 (18%)	-
Stock	83 (30%)	40 (24%)	=	29 (25%)	14 (18%)	=
Veg	118 (42%)	63 (38%)	-	49 (43%)	37 (48%)	-
Total (n)	**280**	**168**		**114**	**77**	**- (-32%)**

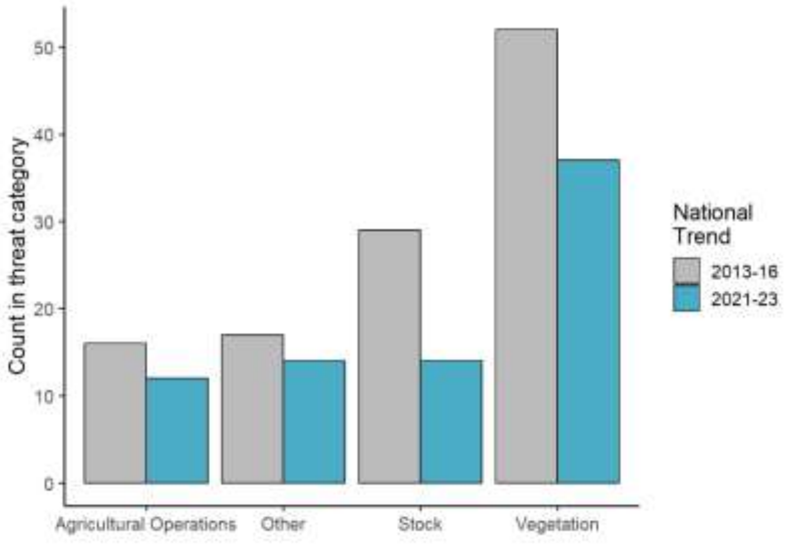


Figure 7-1. National Trend in threat counts per threat category from 2013-16 and 2021-23 for re-surveyed HEAs. Overall threat count has decreased by 32% between 2013-16 and 2021-23.

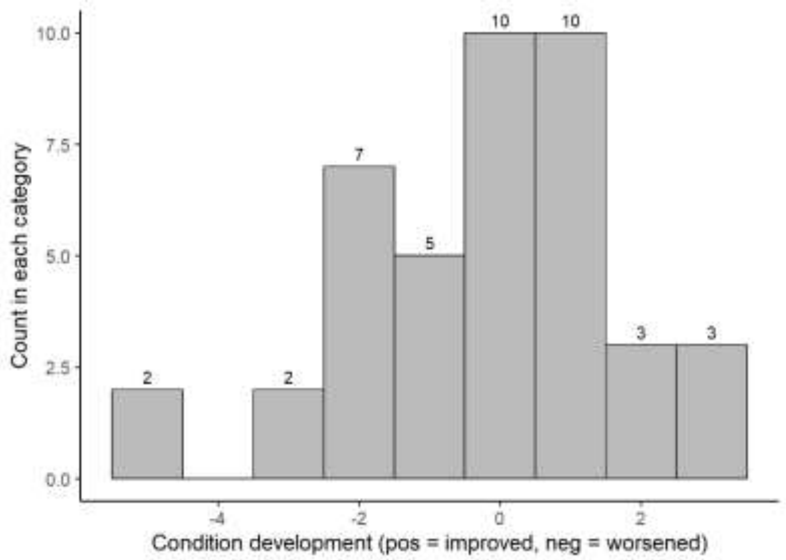


Figure 7-2. Change in the condition of HEAs from 2013-16 to 2021-23. Numbers above bars represent counts within each bar.

7.2.2 Glastir Impact

A total of six Glastir options were specific to HEAs with only one option 106 (historic parks and gardens) taken up. As part of the NFS, no historic parks and gardens are assessed. As a consequence, we evaluated the potential co-benefit of average Glastir extent within each survey square on the condition of HEAs and on threats to HEAs. Associated effects of Glastir management on HEA condition and threats could result from, for example, changed grazing regimes or reduced fertiliser inputs or Commons management.

Survey permission to land (with HEAs) was lower when average Glastir extent in the square was low in 2021-23.

Positive Outcomes

- None were detected (but note no actions targeted to HEAs were taken up and present in the NFS)

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- In 2021-23, neither good nor bad HEA condition could be associated with average Glastir extents, suggesting that the legacy effect as reported by of better HEA condition in land entering the scheme (Emmett & team, 2017) was not maintained by the Glastir AES.
- Higher average Glastir extents in squares were associated with higher numbers of threats through agricultural operations and other threats. The statistical analysis underpinning this result can be found in the ERAMMP Technical Annex-105TA1S11: Wales National Trends and Glastir Evaluation. Supplement-11: Historic Environment Assets (Reinsch, Jarvis, & Monkman, 2025).
- Higher average Glastir extents over time increased Vegetation threats, with Vegetation being the biggest threat to HEAs.
- Severe degradation of HEA condition was limited to squares low in average Glastir extent, but relatively low average Glastir extent was also associated with the biggest condition improvements.

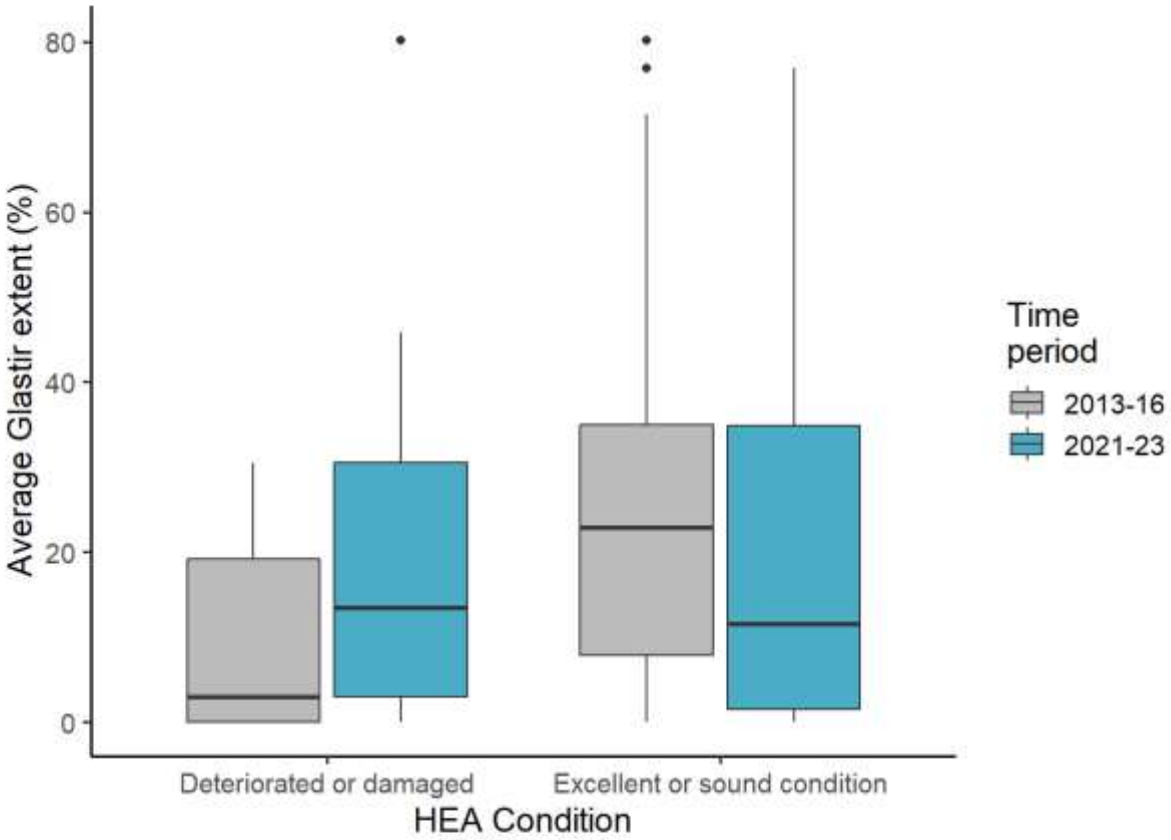


Figure 7-3. Percentage of HEA condition categories for re-surveyed HEAs against average Glastir extent in survey squares in 2013-16 and 2021-23. Higher average Glastir extent in survey squares was positively associated with HEAs of excellent or sound condition (legacy effect) but average Glastir extent over time is associated with worse HEA condition.

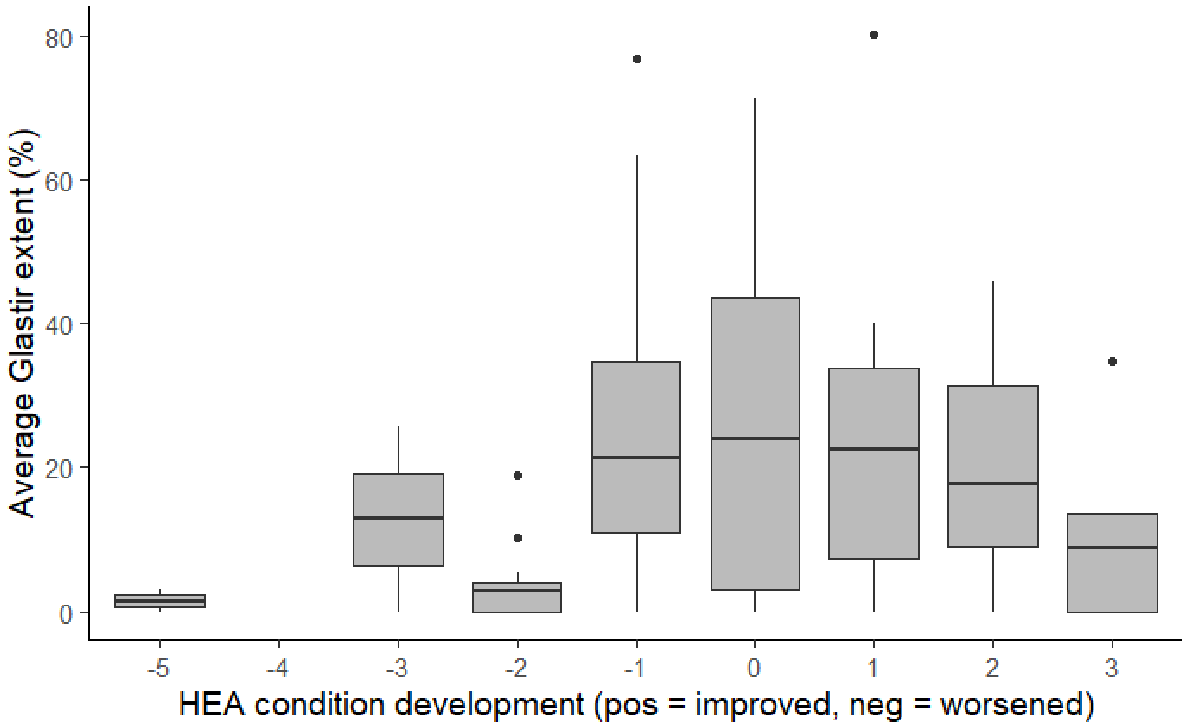


Figure 7-4. Percentage of condition development between 2013-16 and 2021-23 for re-surveyed HEAs as a function of average Glastir extent in survey squares. Average Glastir extent did not explain HEA condition development.

Limitations of Future Data Analysis

The following would ideally be explored but data limitations mean they will not be possible:

- Co-benefit of average Glastir extent on HEA type (e.g. quarry, houses, forts) due to the limited size of the dataset.
- Co-benefit of average Glastir bundles on HEA condition due to the small size of the dataset and categorical data.
- Effects of Broad Habitat on HEA condition because of the highly variable sizes of HEAs (e.g. standing stone vs Pond vs fort).

7.3 Public Rights of Way

In the UK, Public Rights of Way (PROW) are typically classed into four categories (UK Government, 1981). The public footpath and bridleway categories were surveyed for GMEP and ERAMMP.

Table 7-3. The four categories of PROW typically used in Wales.

Category	Description
Public Footpaths	Conclusive right of passage to walkers
Bridleways	Conclusive right of passage for walkers, horse riders and pedal cyclists
Roads Used as a Public Footpath (RUPP)	Right of passage primarily for the benefit of walkers and horse riders, with possible access for motorised vehicles and pedal cyclists
Byway Open to All Traffic (BOAT)	A right of passage to all classes of user

The detailed survey methodology is given in the ERAMMP Birds Field-Survey Handbook (Siriwardena & Bowgen, 2023) and further general methods in ERAMMP Technical Annex-105TA1S12: Wales National Trends and Glastir Evaluation. Supplement-12: Public Rights of Way (Monkman, 2025).

Briefly, surveyors observed accessible PROW to their reasonable limits of vision within the survey square. The path extents were recorded on GIS software. PROW extents were then assigned a two-letter code evaluating pedestrian accessibility and signage presence at code positions 1 and 2 respectively. Water damaged PROW were recorded as WD. As an example, an Open and Signed PROW would be recorded as 'OS'. The total surveyable PROW extents within a square were derived from historical PROW data provided by WG.

Table 7-4. PROW assessment codes, where a PROW is assigned a letter from Access Code and Sign Code or, exclusively, WD to indicate water damage.

Access Code	Sign Code
O – Open (Easily Traversable)	**S** – Signed
P – Poor (Passible Obstacles)	**N** – Not Signed
B – Blocked	
WD – Water Damaged (Not used with Access or Sign Codes)	

During 2013-16, 171 squares had PROW assessments with 95 squares surveyed during 2021-23. Surveyed lengths were 452km and 262km in 2013-16 and 2021-23 respectively. Unfortunately, the path categories were not available for the 2013-16 assessments. However, for 2021-23, public Footpaths were the dominant PROW category, matching the pattern for Wales.

Table 7-5. Extent of PROW by their categorisation, giving PROW length (km), PROW section counts (n) and the percentage length. '2021-23 Surveyed', PROW surveyed during 2021-23; '2021-23 In-square', total PROW length in the survey square during 2021-23 some of which could not be surveyed, typically because of restrictions on land access; 'All Wales', PROW data for the whole of Wales. Measurements could not be estimated from the 2013-16 data. 'BOAT', Byway Open to All Traffic; 'RUPP', Road Used as a Public Path. Grey cells represent no available data.

Category	2013-16	2021-23 Surveyed	2021-23 In-Square	All Wales
BOAT		1.7km [1.2%, n=5]	6.7km [1.6%, n=26]	434km [1.3%, n=971]
Bridleway		23.5km [17.3%, n=56]	69.6km [16.6%, n=208]	4,814km [14.8%, n=9,417]
Footpath		82.9km [61.1%, n=284]	278km [66.2%, n=965]	24,676km [75.9%, n=61,517]
RUPP		15.2km [11.2%, n=27]	26.9km [6.4%, n=91]	1,488km [4.6%, n=3,473]
Unspecified/Other		12.5km [9.2%, n=42]	38.5km [9.2%, n=137]	1,104km [3.4%, n=3,076]
Totals		**135.8km**	**419.7km**	**32,516km**

7.3.1 National Trends

WG's historical PROW data had 35,516km of PROW. Of the 1.3% present in NFS squares, we had permission to survey 135.8km (0.45%).

Positive Outcomes

- All four national positive indicators for PROW (Open, Blocked, Signed, Not Blocked and Signed) were stable. 50% of PROW were Not Blocked and Signed as reported in 2013-16.

Areas for Concern / Need for Further Action

- 50% of PROW were Blocked and/or not Signed.

National Trend data analysed PROW assessments from Nationally Representative squares only. It was not possible to compare survey results for the same PROW between 2013-16 and 2021-23 due to limitations with the 2013-16 survey data. Figure 7-5 gives the breakdown of access classes across 2013-16 and 2021-23.

Table 7-6. Change in National Trend of PROW. Repeated National Trend squares only. Values in columns 2013-16 and 2021-23 are calculated by summation across all squares and are not sample means. Where '=' no significant change and grey cells represent no available data. Note that indicator 'not blocked and signed' is derived from the sum of lengths of PROW assessed as open-signed and poor-signed.

	Indicator	Long-term analysis using data 1994-2007	2013-16	2021-23	Short term analysis 2021-23 and 2016-22
PROW	Proportion by length Open		73%	82%	=
	Proportion by length Blocked		17%	13%	=
	Proportion by length Signed		53%	51%	=
	Proportion by length Not Blocked and Signed		52%	50%	=

The proportion by length of PROW which were Not Blocked and Signed is important because local authorities have legal requirements to ensure PROW remain unblocked and display signage where appropriate. This responsibility is shared with land custodians. Across Nationally Representative squares, not blocked and signed (open-signed + poor-signed) PROW proportions fell by 2.5% from 2013-16 to 2021-23. Figures for the remaining indicators are given in the same table. None of these changes were statistically significant. Water damage was exceptionally rare, with only two instances recorded across both surveys on different squares. The total water damaged PROW length for both squares was 386m.

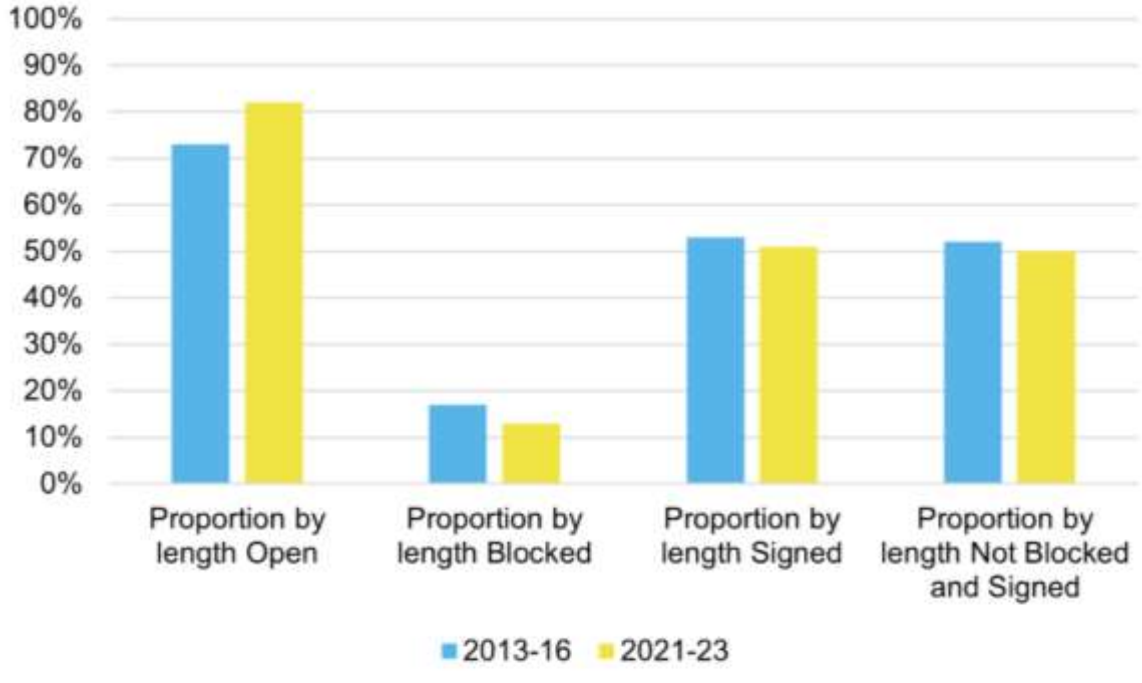


Figure 7-5. Percentage of length with 95% bootstrapped confidence intervals, across PROW access classes for Nationally Representative squares. Includes squares with and without revisits. Values are sample means.

7.3.2 Glastir Impact

Positive Outcomes

- None reported

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- Uptake of Glastir options specific to PROW improvements was very small.
- No impact of Glastir was detected.

Glastir impact data used all Glastir Targeted squares which were surveyed for PROW (GMEP, n=111; ERAMMP, n=17). This was necessary as no Targeted squares were re-surveyed for PROW in 2021-23. Glastir has 30 options associated with enhancing path access and signage (ERAMMP Technical Annex-105TA1S12: Wales National Trends and Glastir Evaluation. Supplement-12: Public Rights of Way (Monkman, 2025)). Unfortunately, option uptake was minimal across all 300 squares (n=7). This low uptake necessitated using a maximal option uptake area per square in Glastir effect modelling.

Considering the modelled data, open PROW length proportion increased by 5%. The remaining three indicators all decreased from 2013-16 to 2021-23 (Blocked 6%; Signed 5%, Not Blocked and Signed 5%). None of these trends were significant, with large differences in Glastir-modelled effects for both high and low Glastir areas in square. The modelled values are subject to a very high level of statistical uncertainty because of the low numbers of 2021-23 Targeted squares available.

Table 7-7. PROW indicator values as measured between the GMEP survey (2013-16) and the ERAMMP survey (2021-23). Values were calculated across all Glastir Targeted surveyed squares. Note that these indicators are means and take no account of the Glastir areas. Glastir area had no significant effect on any indicator, with $p \geq 0.24$ for all indicators. (See Figure 7-6 for the modelled area effects).

	Indicator	2013-16	2021-23
PROW	Proportion by length Open	76%	81%
	Proportion by length Blocked	18%	11%
	Proportion by length Signed	54%	50%
	Proportion by length Not Blocked and Signed	53%	48%

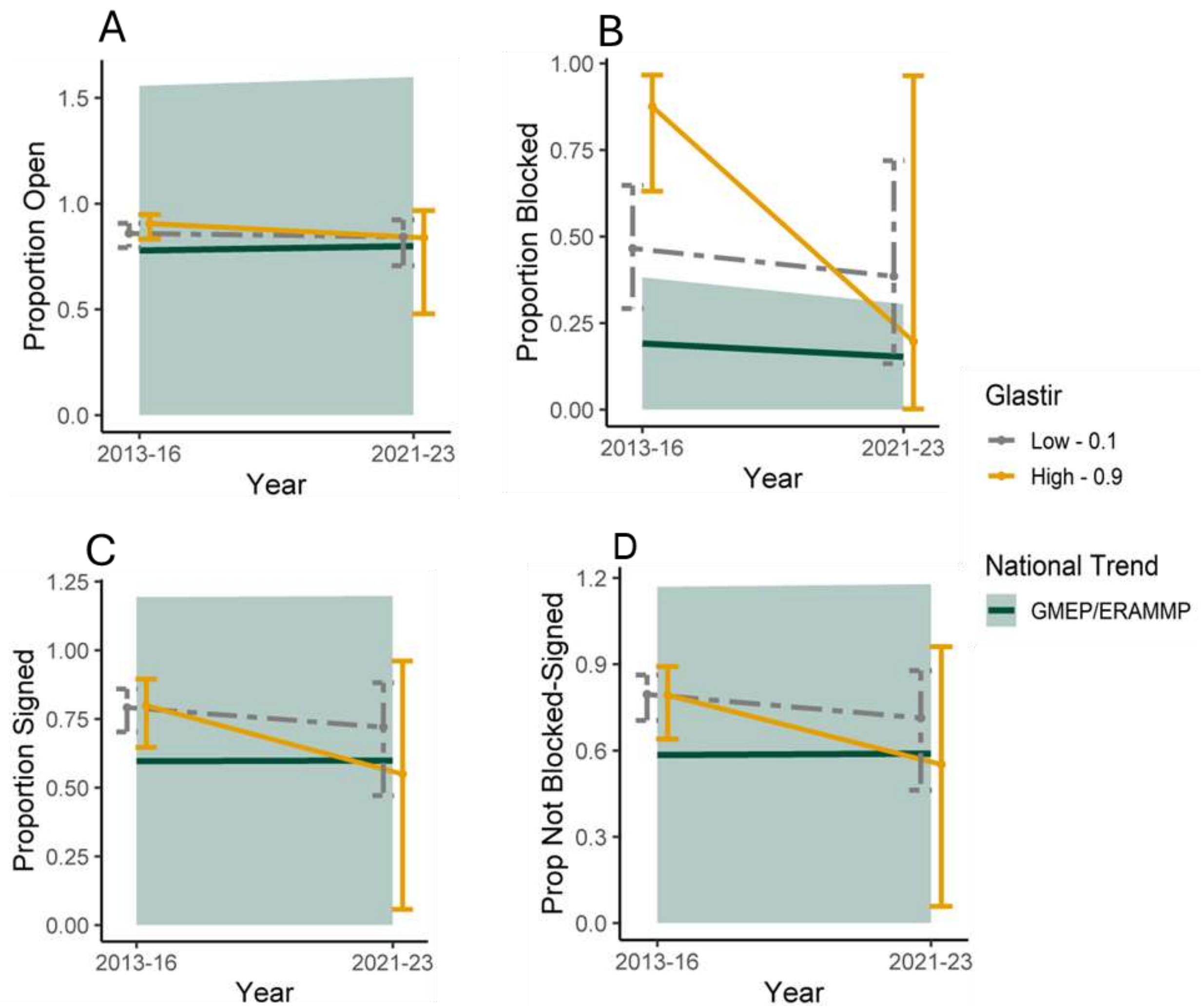


Figure 7-6. National Trend and Glastir effect on proportion of PROW lengths within squares for: a) proportion open, b) proportion blocked, c) proportion signed, and d) not blocked and signed. (Note that the trend line gives fitted model estimates with samples being each square, hence values differ from those in

Table 7-6 and Table 7-7 with values calculated across sample squares.)

Despite the options available under Glastir which reward actions to enhance path access and signage, these are fine grained and there is a legislative requirement for landowners to maintain access and signage for PROW (UK Government, 2000; UK Government, 1981), hence these result are unsurprising.

A refined grading of access and signage would be recommended to assess scheme impact because open, poor, and closed are likely to crude to detect improvements arising directly through targeted scheme interventions. However, given the low uptake, any additional survey effort is likely unjustified.

7.4 Future Opportunities and Next Steps

CADW visits or inspects HEAs on a 10-year cycle. The HEAs database built by CADW could be analysed to get a broader impression on conditions and threats, and provide more accurate spatial data on the location of all HEAs that was unavailable to UKCEH. The large number of HEAs in the database would allow for exploring, for example, habitat effects or social impacts (touristic areas vs rural).

Combining 2021-23 data with citizen science collected by the Ramblers for PROW could provide a greater power of detection going forward. Additionally, a follow-up analysis on Glastir effects would be beneficial with the increase in statistical power that will be gained with the additional ERAMMP Targeted squares to be surveyed in 2025.

PROW access gradings may be receptive to assessment by drone where there is low density or no tree coverage. A third assessment method would also provide opportunities to cross-validate citizen science observations against the infield survey ground-truth observations. In turn, this would improve the viability of establishing nationwide estimates of PROW access quality.

The PROW analysis, in its current form, depends on spatial information of all PROW nationally. This current analysis used historical data during preparatory steps. Access to a contemporary and comprehensive PROW spatial register across Wales would improve analysis power.

8 Landscape Quality, Resilience and High Nature Value Farmland

Maskell, L.[1], Emmett, B.A.[1], Hunt, M.[1], Mondain-Monval, T.O.[1], O'Neil, A.W.[1] and Rowland, C.S.[1]

[1]UK Centre for Ecology & Hydrology

Three elements are reported here using data from the NFS, satellite data and the FPS to provide a more broad assessment of the structure, condition and resilience of the Welsh landscape as a whole. The three elements are:

I. Landscape quality. This is captured using a suite of indicators which relate to landscape condition to report habitat diversity, extent of Semi-Natural Habitat and connectivity of key habitats. Both National Trends and the impacts of Glastir management options are reported. Landscape quality was also reported in GMEP using a newly developed Landscape VQI which was a citizen-tested approach and exploited the rich NFS database including many landscape photographs (Emmett & team, 2017); (Swetnam, Harrison-Curran, & Smith, 2016). However, this analysis was not repeated in ERAMMP as it was considered it would be relatively slow to respond to change and therefore could be moved into next cycle of NFS re-survey. It should also be noted that, both in GMEP and ERAMMP, 16 landscape photographs are taken looking within and out from each square which provide a unique nationally representative, time-stamped and geo-located record of landscape status and change across Wales available for future analysis.

II. Resilience. Various landscape elements are thought to contribute to the concept of a Resilient Wales which is one of the seven WFG Goals. "Resilience is defined as a nation which maintains and enhances a bio-diverse natural environment with healthy functioning ecosystems that support social, economic and ecological resilience and the capacity to adapt to change (for example, climate change)". [8]The Environment Act (Wales) 2016, specifically requires public authorities to maintain and enhance Biodiversity and in so doing promote the resilience of ecosystems through early thinking for all policies, plans, programmes and projects. In SoNaRR 2020[9], ecosystem resilience was defined as 'An environment that can respond to pressures by resisting, recovering or adapting to change; and is able to continue to provide natural resources and benefits to people'. Properties which are thought to confer resilience to ecosystems include: Diversity, Extent, Condition, Connectivity and Adaptability. In 2016, GMEP amalgamated a range of landscape and farm management indicators captured from the NFS, satellite information and the FPS to assess whether land which had come into the Glastir scheme had more or less characteristics which are thought to confer resilience than land outside of the scheme.

---

[8] https://www.gov.wales/sites/default/files/pdf-versions/2024/9/4/1727339452/wellbeing-wales-2024.pdf

[9] https://naturalresources.wales/evidence-and-data/research-and-reports/state-of-natural-resources-report-sonarr-for-wales-2020/?lang=en

III. High Nature Value (HNV) Farmland. An approach to integrate many aspects of landscape quality to capture agriculture land spatially across Wales which is of higher value for species and habitats. As many elements of nature need different landscapes to thrive, there are three types of HNV Farmland which cover (Type 1) capturing areas of high Semi-Natural Habitat; (Type 2) representing farmland with a mosaic of habitats and/or land uses; and (Type 3) targeting land suitable for specialised species. In 2016, the GMEP developed an approach to identify these HNV areas Type 1 and 2 which directly used the intensive information available from both satellites and the NFS for Wales. This resulted in the identification of 15% of HNV Type 1 and 15% of HNV Type 2 with 2% overlap, so 28% of Wales was identified as HNV Type 1 and 2 (Emmett & team, 2017); (Maskell, et al., 2023). Maintaining the condition and resilience of this HNV land could be seen as a priority due to its importance for a wide range of biodiversity.

Here we update the data relating to these three elements.

8.1 Landscape Quality

Landscape quality was calculated previously (Emmett & team, 2017) using a suite of indicators which included:

- Wetland connectivity
- Grassland connectivity
- Heathland connectivity
- Broadleaved Woodland connectivity
- Percentage of Semi-Natural Habitat
- Rare and occasional Soils
- Density of Hedgerows
- Percentage of improved land
- Habitat diversity

Many of these metrics were calculated in GMEP using the NRW Phase 1 habitat data, however, this has not been updated so UKCEH Land Cover Map (LCM) 2010 and 2021 were used here instead (Levy, et al., 2024)(Martson, Rowland, O'Neil, & Morton, 2022).

Connectivity between habitats was determined by calculating the Euclidean Nearest Neighbour distance between habitat patches of the same type, (i.e. Woodland, Wetland, Grassland, Heathland) and averaging over the 1km square. This value has then been scaled to between 0 and 1 and inversed so that higher values indicate greater connectivity. There were instances where we could not calculate connectivity because either there was none of the habitat in the square (given a zero) or because there was one large patch. In that case, if the area was >50ha it was scored as 0.5.

Habitat diversity was calculated using the Shannon-Wiener diversity metric, which is a unitless metric where higher values indicate greater diversity. It is likely that diversity would be lower from the LCM as it is not possible to detect some of the smaller habitats, e.g. fens, flushes.

Trends have been calculated using integrated models as for the other chapters. Tables shows the direction of results; where a result is identified as positive or negative this is statistically significant.

8.1.1 National Trends

There is a mixed picture from the individual indicators suggesting no major change in landscape quality according to this set of indicators.

Positive Outcomes

- The amount of Semi-Natural Habitat has remained stable. An increase of 1.2% is within detection limits.
- Grassland connectivity has increased.
- Broadleaved Woodland, Wetland and Heathland connectivity has remained stable.

Areas for Concern / Need for Further Action

- Habitat diversity has decreased between 2010 and 2021

Table 8-1. Change in landscape metrics between 2010 and 2021 using UKCEH LCM for all of Wales. Connectivity was calculated as the average distance between habitat patches of the same type - these values were then scaled to between 0 and 1 and inversed so a higher value indicates greater habitat connectivity. The Shannon-Wiener diversity index is unitless index, where higher values indicate greater diversity.

Landscape Topic	Indicator	2010	2021	Change (+/- or =)
Land Cover Map – calculated as a mean per each 1km square for all Wales				
Semi-Natural Habitat Area	Semi-Natural Habitat (%)*	41.4	42.6	=
Habitat Diversity	Shannon-Wiener diversity	0.82	0.74	--
Connectivity	Broadleaved Woodland	0.9	0.9	=
	Grassland	0.85	0.88	++
	Heathland	0.97	0.97	=
	Wetland	0.98	0.98	=

* Semi-Natural Habitat refers to all land that is not Arable, Coniferous Woodland, Improved Grassland, Urban or Suburban.

8.1.2 Glastir Impact

There is no evidence of any impact of Glastir management options on landscape metrics.

Positive Outcomes

- None reported

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- No improvement in landscape metrics was identified due to Glastir management options.

Table 8-2. Impacts of Glastir management options on landscape metrics. These have been calculated using integrated models with the presence/absence of Glastir (selected bundles have been amalgamated) in a 1km square. The metrics shown are the mean per 1km. Connectivity was calculated as the average Euclidean Nearest Neighbour distance between habitat patches of the same type - these values were then scaled to between 0 and 1 and inversed so a higher value indicates greater habitat connectivity. The Shannon-Wiener diversity index is unitless index, where higher values indicate greater diversity.

Resilience features	Metric	Source of data and method	Glastir				Trend with Glastir (+/- or =)
			In scheme 2022		Not in scheme 2022		
			2010	2021	2010	2021	
Semi-Natural Habitat Area	Semi-Natural Habitat (%)*	UKCEH LCM	43.44	45.12	33.96	34.29	=
Connectivity	Broadleaved Woodland	UKCEH LCM	0.90	0.90	0.91	0.91	=
	Grassland		0.84	0.86	0.88	0.91	=
	Heathland		0.97	0.97	0.98	0.98	=
	Wetland		0.98	0.98	0.98	0.99	=
Habitat Diversity	Habitat Diversity (Shannon-Wiener)	UKCEH LCM	0.83	0.75	0.82	0.75	=

* Semi-Natural Habitat refers to all land that is not Arable, Coniferous Woodland, Improved Grassland, Urban or Suburban.

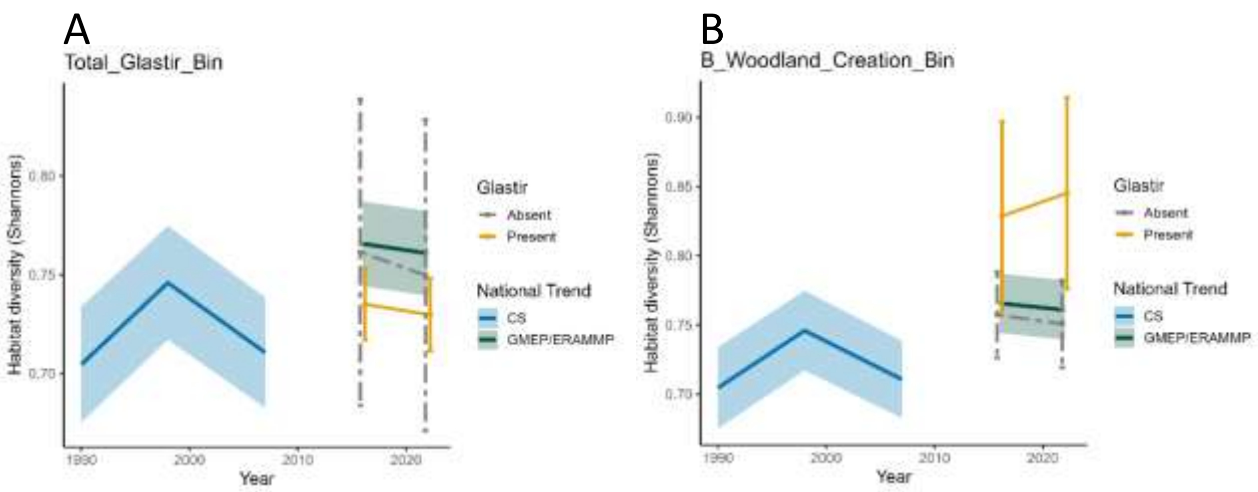


Figure 8-1. Trends in habitat diversity with: A) total presence of Glastir bundles in a 1km square, and B) presence/absence of the Woodland Creation bundle.

8.2 Change in Resilience Due to Glastir Management Options for All Wales

In 2017, GMEP amalgamated a range of landscape and farm management indicators captured from the NFS, satellite information and the FPS to explore if land which had entered the Glastir scheme (but not yet subject to Glastir management options) had more characteristics which were thought to confer resilience, compared to land outside of the scheme. This was found to be the case for most indicators.

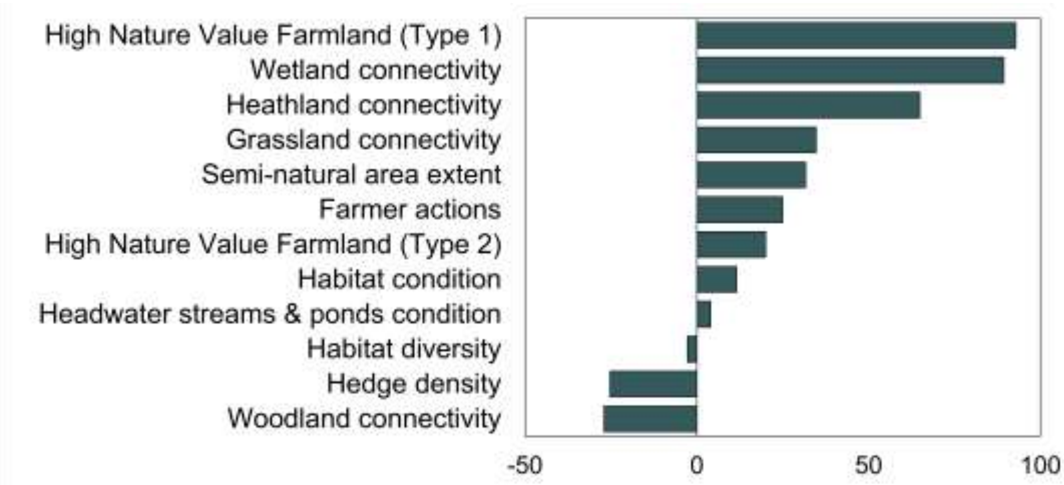


Figure 10-3. The GMEP 2017 comparison of land in Glastir compared to the national mean for metrics of resilience. Bars to the right of the central '0' line indicate a more positive value for that characteristic.

The newly captured data from the NFS and FPS indicate some improvement in resilience to land with Glastir management options relative to land outside of scheme, but most data suggest no change.

Positive Outcomes

- An increase in Hedgerow length of land in scheme.
- An increase in the number of farm managers undertaking diversification and efficiency actions in scheme.

Outcomes Not as Intended, Trade-Offs and Contextual Dependencies

- No increase in Semi-Natural Habitat area
- No change in habitat diversity. However, note that habitat diversity has significantly decreased in the National Trends so this is no change of this decline.
- No change in connectivity for Woodland, Grassland, Heathland or Wetland.
- No change in status of Headwater Streams and Ponds

Table 8-3. Trends in metrics between 2010-16 to 2021-23 which may promote resilience of land in scheme with Glastir management options compared to land not in scheme. UKCEH LCM data are from 2010 and 2021. NFS field data are from 2013-16 to 2021-23. Connectivity was calculated as the average Euclidean Nearest Neighbour distance between habitat patches of the same type - these values were then scaled to between 0 and 1 and inversed so a higher value indicates greater habitat connectivity. The Shannon-Wiener diversity index is unitless index, where higher values indicate greater diversity.

Resilience features	Metric	Source of data	Trend with Glastir management options
Extent	Semi-Natural Habitat (%)*	UKCEH LCM	=
Diversity	Habitat diversity (Shannon-Wiener)	UKCEH LCM	=
Connectivity	Broadleaved Woodland	UKCEH LCM	=
	Grassland		=
	Heathland		=
	Wetland		=
	Hedgerow length	NFS	+
Condition	CSM plant species across all habitats	NFS	=
	Headwater streams and Ponds condition	NFS	=
Farm diversification and efficiency	Number of farms undertaking actions	FPS	+

* Semi-Natural Habitat refers to all land that is not Arable, Coniferous Woodland, Improved Grassland, Urban or Suburban.

8.3 Change in Resilience of High Nature Value Farmland

HNV Farmland has been defined as ‘Areas in Europe where agriculture is a major (usually the dominant) land use and where that agriculture supports or is associated with either a high species and habitat diversity or the presence of species of European concern or both’. The use of HNV as an impact indicator for Glastir and the RDP was a regulatory requirement. As part of the GMEP contract, the team were asked to develop an approach which could exploit national level data in partnership with some key stakeholders. Repeated rounds of analysis and consultation with stakeholders resulted in final agreement on the methodological approach to defining the extent and condition of HNV in Wales and this can be seen in (Maskell, et al., 2023).

In summary, there are three types of HNV Farmland:

- Type 1: Farmland with a high proportion of semi-natural Vegetation.
- Type 2: Farmland with a mosaic of habitats and/or land uses.
- Type 3: Farmland supporting rare species or a high proportion of European or world populations.

Statistical approaches were taken to test the fundamental hypothesis that amount of semi-natural habitat (HNV Type 1) and habitat diversity and complexity (HNV Type 2) could explain gradients in a range of different elements of Biodiversity across Wales. We used data from GMEP baseline measurements covering mapped habitats (Broad Habitats and Section 8 Priority Habitats of the Environment (Wales) Act 2016: Hedgerows, trees, streams), plants (including CSM indicators of habitat condition, Woodland and Wetland plants), and Bird and Pollinator numbers and diversity (bees, butterflies, rare invertebrates) counted within the squares. Based on the analysis of the GMEP 1km squares, we scaled up to a national map of all 1km squares in Wales. This was accomplished using statistically significant variables which represented the two axes of habitat complexity and land use intensity but where the datasets representing each axis were available for all 1km squares as opposed to just GMEP NFS squares. The variables finally selected were:

- Wetland connectivity
- Grassland connectivity
- Heathland connectivity
- Broadleaved Woodland connectivity
- Rare and occasional Soils
- Percentage of semi-natural habitats
- Density of Hedgerows
- Percentage of improved land
- Habitat diversity

Data came from the LCM, the Soil Survey of England and Wales (NATMAP) and the NRW Phase 1 survey, i.e. all nationally available data sources. Applying the outcome of the analysis to the whole of Wales gave an estimate of approximately 15% of land as HNV Type 1 and 15% as HNV Type 2 with an overlap of 2%, hence 28% of Wales in total was HNV Type 1 or 2 Farmland. Note that the cut-off point separating HNV from non-HNV is essentially arbitrary since the underlying ecological gradients that have been used to define HNV are continuous in nature. Whilst we have estimated the extent of HNV Type 1 and 2 at the national scale, the approach ought to be able to accommodate regional variation.

Here we have not updated the extent of HNV, however, we have overlain the previous classification with some indicators of resilience for land defined as HNV Type 1 and 2 and added in an additional indicator of condition of presence of positive plant CSM species.

8.3.1 National Trends

The data suggests mixed results with no strong evidence for differences in change in indicators of resilience for HNV land relative to those reported in the National Trends for all of Wales.

Positive Outcomes

- No change in Semi-Natural Habitat area in HNV Type 1 or 2
- An increase in Grassland and Heathland connectivity in land classified as HNV Type 2.
- An increase in positive indicator plant species on HNV Type 1 land.

Areas for Concern / Need for Further Action

- A decrease in Wetland connectivity HNV Type 1 – this is land where Semi-Natural Habitat dominates, and it would be expected that Wetland connectivity would be an important component of overall area.
- Habitat diversity has declined in both HNV Type 1 and HNV Type 2 land as observed in the National Trends for all Wales.

Table 8-4. Differences in metrics which may promote resilience of land classified as HNV Type 1 and HNV Type 2 in 2010-16 and 2021-23. These have been calculated using integrated models with the presence/absence of HNV Type 1 and HNV Type 2 (selected bundles have been amalgamated) in a 1km square. The metrics shown are the mean per 1km square. UKCEH LCM data are from 2010 and 2021. Field data are from 2013-16 to 2021-23. Connectivity was calculated as the average Euclidean Nearest Neighbour distance between habitat patches of the same type - these values were then scaled to between 0 and 1 and inversed so a higher value indicates greater habitat connectivity. The Shannon-Wiener diversity index is unitless index, where higher values indicate greater diversity.

Resilience features	Metric	Source of data and method	HNV Type 1			HNV Type 2		
			2010	2021	Trend	2010	2021	Trend
Area	Semi-Natural Habitat (%)*	UKCEH LCM	89.24	90.38	=	23.5	25.1	=
Diversity	Habitat Diversity (Shannon-Wiener)	UKCEH LCM	0.45	0.42	-	0.93	0.86	-
Connectivity	Broadleaved Woodland	UKCEH LCM	0.98	0.98	=	0.89	0.89	=
	Grassland		0.69	0.69	=	0.91	0.95	+
	Heathland		0.92	0.92	=	0.98	0.99	+
	Wetland		0.98	0.97	-	0.99	0.99	=
	Metric	**Source of data and method**	**2013-16**	**2021-23**	**Trend**	**2013-16**	**2021-23**	**Trend**
	Hedgerow Density	Mean per square from NFS	121.4	117.7	-	127.6	126.8	=
Condition	CSM species across all habitats	Number of indicators species from NFS	9.64	10.15	+	6.45	6.47	=

* Semi-Natural Habitat refers to all land that is not Arable, Coniferous Woodland, Improved Grassland, Urban or Suburban.

9 Climate Change and the Potential Contribution of Glastir to GHG Emission Reductions

Emmett, B.A.[1], Bentley, L.F.[1], Maskell, L.[1], Reinsch, S.[1], Rowland, C.S.[1], Williamson, J.L.[1]

[1]UK Centre for Ecology & Hydrology

9.1 Introduction

Four elements relating to climate change are reported here: (i) interpretation of trends reported in the Wales national greenhouse gas (GHG) emission inventories, (ii) the potential contribution of Glastir to GHG emission reductions, (iii) evidence of climate change adaptation by farm managers, and (iv) early signs of possible climate change signals in the wider countryside from the NFS.

9.2 Trends in Agriculture, and Land Use, Land Use Change and Forestry GHG Inventories

Within agriculture and land use, progress has slowed towards meeting the Net Zero target.

Key Messages

- From 2010 to 2021 there has been an increase in emissions from agriculture reported in the Agriculture GHG Inventory for Wales of 0.33Mt CO_2eq/yr to 5.7Mt CO_2eq/yr in 2021 and a reduction in the sink within the LULUCF sector of 0.02Mt CO_2eq/yr to -0.7Mt CO_2eq/yr s.[10]
- There remains a significant gap between the two inventories of 5Mt CO_2eq/yr which needs to be closed if the agriculture and land use sector is to achieve Net Zero as a whole.

[10] https://naei.beis.gov.uk/reports/reports

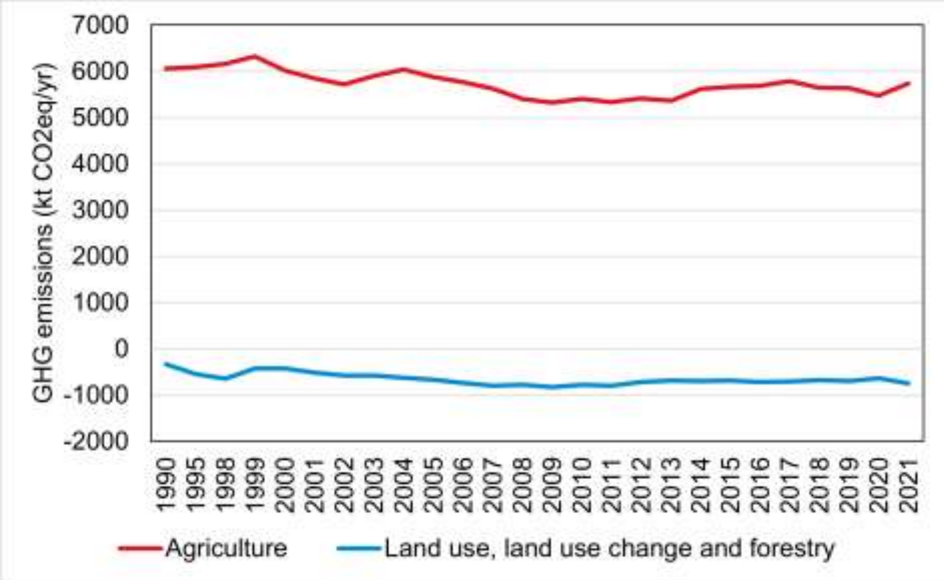


Figure 9-1. Trends in GHG emissions from Agriculture and the LULUCF as captured in the 2021 GHG Inventory for Wales.

Forest planting and peatland restoration were the main likely potential contributors to increasing the LULUCF sink in 2020 (Thomson, Evans, Buys, & Cliverd, 2020)..

9.3 The Potential Contribution of Glastir Management Options to GHG Emission Reductions

The main likely contributors to GHG emission reduction due to Glastir management options are: Woodland and Hedgerow Creation; reductions in ruminant animal numbers, reduction in the use of manufactured fertiliser Use and increased soil carbon sequestration.

Key Messages

- Woodland Creation of 3,780ha of new Woodland since 2010 and 2,200km of new and restored Hedgerows was supported by Glastir. This is an uplift of the national population (<1%) and it will contribute to an increase in the carbon sink in time. More new Woodland was created outside of the scheme (+6%) than in scheme.
- There was a 4% reduction in breeding ewe numbers on entry to the Glastir scheme and 8-9% reduction in use of manufactured fertiliser but no difference in animal numbers or fertiliser use by the end of the scheme. Contribution to GHG emission reductions on land in scheme due to change in animal numbers or fertiliser use is unlikely.
- No consistent evidence of topsoil carbon sequestration due to Glastir management options was reported. Furthermore, increased compaction of soil in 7 out of 10 habitats increases the risk of nitrous oxide emissions which is a potent GHG.

In summary, there is limited evidence that Glastir has contributed to GHG emission reductions to any significant extent between 2010 and 2023.

9.3.1 Animal Numbers and Fertiliser Use

Within the agriculture sector, numbers of ruminant animals and fertiliser use are important contributors to the Agriculture GHG Inventory. There has been no consistent National Trend in the number of sheep and lamp or cattle and calves from 2010 to 2023 reported by the WG

Survey of Agriculture and Horticulture: June 2023. With respect to Glastir, the ADAS 2nd FPS (Anthony, Stopps, & Whitworth, 2016) found a reduction of 4% of breeding ewes on entry to the scheme, but no difference in animal number between those in scheme or out of scheme in the 3rd FPS (Anthony & Whitworth, 2024).

There has been a general decline in the use of fertiliser of 25% in England and Wales since 2010, but again the FPS found no difference between those in scheme or out of scheme (British Survey of Fertiliser Practice 2023 (DEFRA, 2024)).

Overall, this evidence would suggest that Glastir has had a limited effect through these two elements on the Agriculture GHG Inventory.

9.3.2 Woodland and Hedgerow Creation

For the period 2010 to 2021, existing Woodland was the largest sink (68% in the LULUCF inventory for this period, i.e. if emissions sources are excluded). 16Mt CO_2eq over the 11-year period (1.4Mt CO_2eq/yr in 2021). This compares to a sink of just 0.1Mt CO_2eq over the 11-year period for land converted to Woodland (0.01Mt CO_2eq/yr in 2021) and 1.5Mt CO_2eq over the 11-year period for land converted from Woodland to another land use (0.13Mt CO_2eq/yr in 2021). New Woodland accounted for 5%. Satellite data used by UKCEH LCM indicated there has been an increase of 23,600ha / 7% of Woodland cover since 2010, with Woodland now covering 358,400ha/16.9% of Wales.

According to RPW data provided by WG, Glastir has funded the creation of 3,780ha of new Woodland since 2010, of which 5ha was for agroforestry, and 2,200km of new and restored Hedgerows. Additionally small increases are expected from orchard planting and Streamside woody management. These changes are unlikely to be detected by satellites and will not significantly contribute to Wales's carbon sink and climate change mitigation efforts until the trees enter the rapid growing phase and potential losses due to establishment practices have ended.

The numbers from the LULUCF inventory are calculated using the Forest Research Carbine model and are not easily translated across from Woodland area as the GHG sink size of Woodland depends on many variables including age and species, establishment methods and final assumptions as to the lifetime of wood products.

In time, however, an increase in Woodland and Hedgerow area should overall contribute to a net increase in the GHG sink.

9.3.3 Soil Carbon Sequestration and Nitrous Oxide Emissions from Soil

With respect to topsoil carbon change, the evidence presented suggests there is no detectable change in the topsoil carbon stock (the combination of soil carbon concentration and bulk density) in the National Trends. Many results are complicated by a general increase in soil bulk density (i.e. compaction) which is used to calculate carbon stock numbers. This does not reflect increases in soil carbon stocks which are only present where there are increases in soil carbon concentration and there is no compaction. This suggests that whilst some increase and losses may be occurring, they are within our ability to detect change. As this is only topsoil, it is possible that changes are happening in deeper layers, but in general (with the exception of Woodland soils where the effect of deeper rooting tree species will be the dominant effect) topsoils are more sensitive to change and provide a good overall indicator of change. It is estimated that new Woodland and Hedgerows can contribute between 0.04 to 0.28 tCO_2/ha/yr in soil to 1m depth (i.e. excluding tree biomass) when grassland is converted to Woodland, which represents the majority of carbon sink in Wales according to the LULUCF 2021 inventory (Emmett, Evans, Matthews, Smith, & Thomson, 2023).

The general trend towards more compacted soils across Wales will increase the risk of nitrous oxide emissions which is produced by soil microbes particularly where there are anaerobic microsites in soil (which increase in compacted soil) and elevated levels of nitrogen. The risk of increased emissions particularly from Improved Grassland where nitrogen levels are maintained for production and an increase in compaction of 6% is reported is therefore of particular concern.

With respect to Glastir impacts, evidence from the NFS indicated no consistent effect on carbon sequestration in topsoil with some positive and some negative trends observed, but the majority of analyses indicated no detectable change.

Overall, it is estimated soil carbon sequestration could contribute 5-10% of that needed to mitigate current UK agricultural emissions per year (Emmett, Evans, Matthews, Smith, & Thomson, 2023) due to a lack of actions which result in major transformative change combined with issues of uptake, permanence and saturation.

9.4 The Contribution of Peatlands and Peatland Restoration to GHG Emissions, and the Role of Glastir

9.4.1 Introduction

Peatlands in Wales have been subject to historical degradation through anthropogenic activity including drainage, Peat cutting, forestry, over-grazing and burning. Since approximately 2010 there has been an increased focus on restoration of these peatlands, primarily via measures designed to increase water levels and remove invasive Vegetation. In 2020, to provide a mechanism for upscaling peatland restoration across Wales, the National Peatland Action Programme (NPAP) was commissioned, with the aim of delivering the peatland component of Net Zero by 2050 (P. Jones, NRW pers. comm).

Peatlands in a near-natural condition are characterised by continuously high water levels, which enable a negative net ecosystem carbon balance (i.e. more carbon dioxide is taken up via photosynthesis than is released via respiration or carbon lost as dissolved organic carbon or methane (CH_4), which is released following incomplete anaerobic breakdown of organic matter). When peatlands are drained the water table drops, which allows the aerobic decomposition of previously waterlogged organic matter. This releases carbon dioxide to the atmosphere and once the mean annual water table drops below approximately 15-20cm below the surface the carbon balance switches from a sink to a source (Evans, et al., 2021).

The contribution of peatlands to Net Zero is, however, complicated by the emission of methane from peatlands as they become increasingly waterlogged, and potentially inundated in areas following restoration. As methane has a global warming potential of 28 times that of carbon dioxide on a 100-year timeframe (IPCC, 2013), increased methane emissions resulting from higher water tables can switch sites from a sink to a source when reporting emissions as tonnes of carbon dioxide equivalents (Evans, et al., 2021).

Key Messages

National Trends

- Peatlands in Wales cover nearly 82,000ha based on the 2021 Peatlands of Wales map[11], which represents 4% of landcover in Wales.
- By area, modified Bog covers the highest percentage of Welsh peatlands (33%), closely followed by near-natural Bog and Fen (28%).
- An estimated total of 9,000ha of restoration actions have been carried out (most likely since 2010). However, only ~5,000ha of this restored area (6% of peatlands) overlapped with the Peatlands of Wales map, meaning 45% of restoration actions by area cannot be accounted for using methods described here.
- Between 1990 and 2023, the area of rewetted peatlands (Bog and Fen) increased from 0 to 3,400ha (4% of all peatlands). The remaining restoration area covers those that have undergone vegetation management but not rewetting.
- GHG emission rates from peatlands decreased to 491,000 t CO_2-e yr-1 by 2023, a decrease of 15,000 t CO_2-e yr-1; a reduction of 3% from 1990 values. Most of this reduction will have been achieved since 2010 due to peatland restoration activities.
- The mismatch between the percent area restored (6%) and GHG reductions (3%) is due to restoration being targeted on peatlands with low rates of GHG emission i.e. Bogs.

Glastir outcomes

- Glastir was responsible for 992ha of peatland rewetting-specific actions but only 507ha overlapped with the Peatlands of Wales map, representing ~11% of all rewetting on peatlands.
- Overall, GHG emissions from peatlands in Wales in 1990 were 506,000 t CO_2-e yr-1, i.e. 10% of the combined Agricultural and LULUCF inventory. The greatest emissions were from extensive grassland on peatlands in both 1990 and 2023 (decreased from 220,000 t CO_2-e yr-1 to 212,000 t CO_2-e yr-1), followed by Woodland (decreased from 155,000 t CO_2-e yr-1 to 151,000 t CO_2-e yr-1).
- Glastir-funded rewetting is potentially directly responsible for 1,100 t CO_2-e yr-1, assuming all restoration activity converted modified Bog to rewetted Bog (a reduction in emissions of 2.19 t CO_2-e ha-1 yr-1). This is ~7% of the total reduction in GHG emissions from Welsh peatland restoration from all known funding sources.
- Wider Glastir actions on Peat covered 51,335ha, with nearly 40,000ha classified as Habitat Management (General). These actions were not included in the contribution of Glastir actions to peatland rewetting or restoration for the purpose of GHG emissions calculations as there is not yet sufficient evidence to apply different emission factors following these actions, but they will have contributed potentially to overall peatland condition at a local scale. Nationally no positive detectable trends on peatland condition were observed.

It should be noted that these GHG emission figures do not match those provided in the LULUCF inventory for 2021 which indicates peatlands were a net source of GHG emissions in Wales at 285,612 t CO_2-e yr-1. This is due to use of more spatially explicit data sources available for Wales which cannot be used for the UK inventory as they are not currently available for the whole of the UK.

[11] https://datamap.gov.wales/maps/peatlands-of-wales-maps/

9.4.2 Baseline Peatland Data Sources

Table 9-1. Peatland data sources used.

Data	Source	Information
Peatlands_of_Wales_scg8	Welsh data portal	Peatlands of Wales Map procured in 2020.
Peatlands of Wales emissions	Welsh data portal	Not used. Based on old emission factors and unsure as to how land was categorised per area.
Wg_unified_peat_2019	Welsh data portal	Updated version of Unified Peat Map developed in GMEP to include restoration up until 2017 and newly surveyed lowland peats.
NPAP funded restoration activity	NRW (split by restoration type)	Six shapefiles, erosion control, grazing management, hydrology management, tree management and Vegetation management. Also total area.
Glastir peatland rewetting area	WG	Area of land with specific rewetting options under the Glastir action.
SNPA restoration activity	SNPA	Overlaps with NPAP data but not all SNPA restoration work was NPAP funded.
Blocked ditches as of 2017	NRW	Ditches blocked by any restoration funding source up until early 2017.
GA poly and GA point	NRW	Rewetting work funded under GA up until 2018. Used to check against Glastir rewetting.
All LIFE raised Bog restoration data	NRW	Restoration activity funded under EULIFE programme for Welsh Raised Bogs Life project.
NNR polygon area for Fenns and Whixall	NE	NE did not have all restoration data immediately accessible but communicated that restoration had covered the whole NNR area under multiple funding sources.

Table 9-2. Funding sources, area restored which do or do not overlap with the new Peatlands of Wales Map (which may miss small areas of peat).

Funding stream	Area Restored (ha)	Area overlapping peat map (ha)
Glastir – rewetting	992	507
NPAP – Vegetation management	4,951	1,955
NPAP – rewetting	393	229
LIFE Raised Bogs	482	437
SMS Peatlands	139	116
Fenns and Whixall	583	519
Other (pre-2016)	1,582	1,305
Total	**9,122**	**5,068**

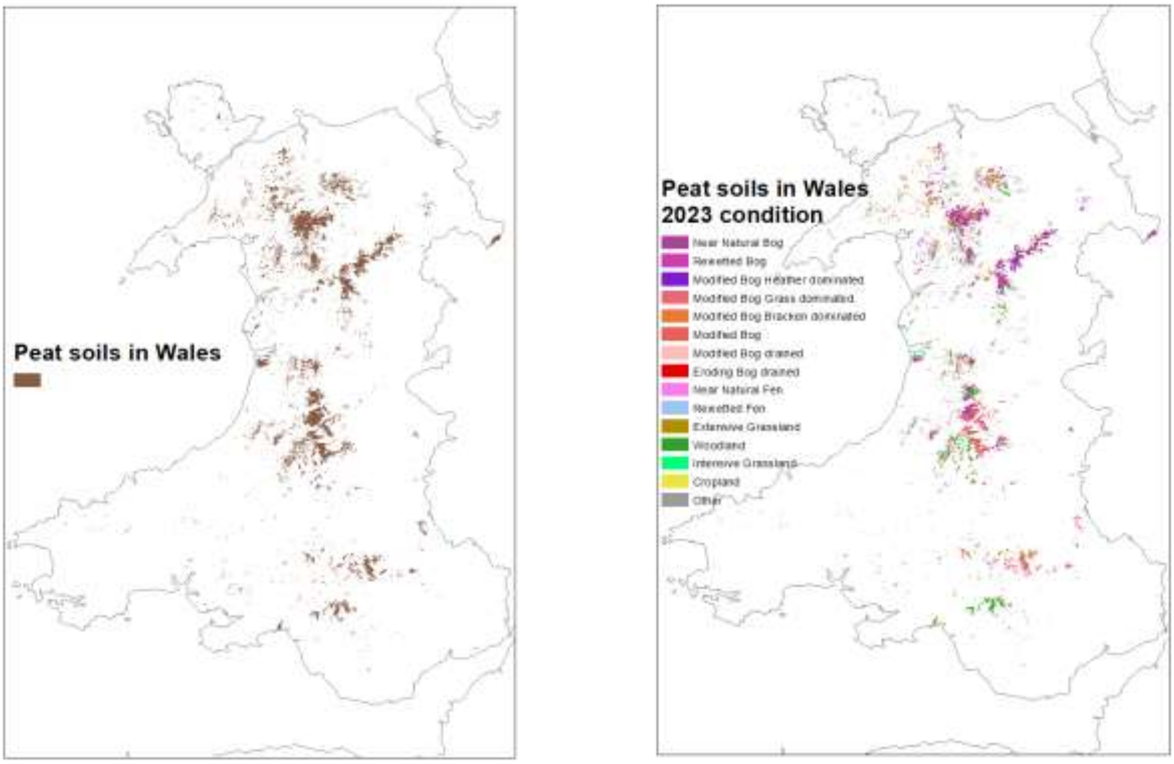


Figure 9-2. Peat Soils in Wales and their condition in 2023 based on Phase 1 habitat survey data and available peatland restoration data.

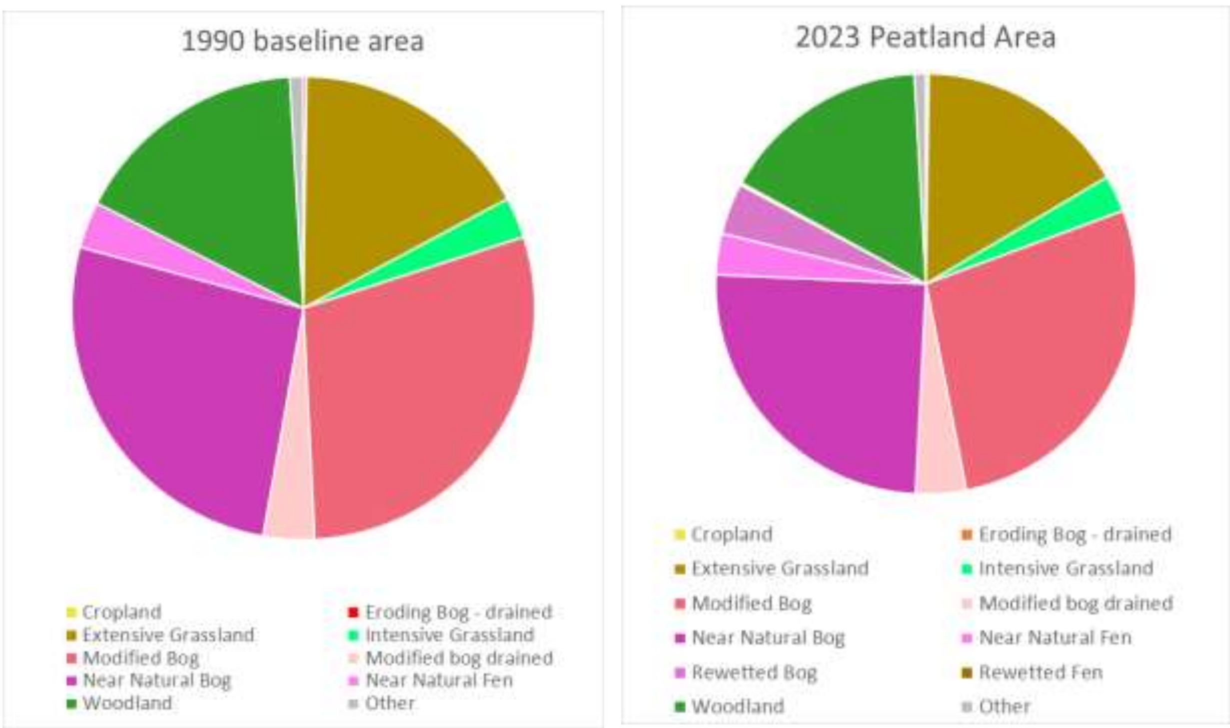


Figure 9-3. The proportion of peatlands in different habitat and modification states in 1990 and 2023 across Wales.

Table 9-3. Peatland types by area for 1990 and 2023 based on Phase 1 habitat survey data and available peatland restoration data.

Land use	1990 Area (ha)	2023 Area (ha)
Cropland	33	31
Eroding Bog – drained	168	155
Extensive Grassland	13,845	13,320
Intensive Grassland	2,330	2,306
Modified Bog	23,853	22,534
Modified Bog – drained	2,928	3,167
Near-Natural Bog	21,617	20,354
Near-Natural Fen	2,637	2,590
Rewetted Bog	0	3,226
Rewetted Fen	0	131
Woodland	13,554	13,203
Other	766	713
Total	**81,730**	**81,730**

9.4.3 A Comparison of the Method Used to Calculate GHG Emissions for the LULUCF Inventory and ERAMMP

The UK Greenhouse Gas Inventory provides annual spatially resolved emissions estimates at a 1km grid resolution for each sector (Tsagatakis, et al., 2023). GHG emissions from peatlands are reported within the section covering agriculture, land use and forestry, and a methodology applicable across all areas of the UK is used to ensure the consistency of approach. Estimates of land use change over time are tracked using a Bayesian data assimilation approach, whilst specific changes in land use as a result of peatland restoration are assumed to occur in proportion to the extensive grassland and modified peatland areas on Peat (Brown, et al., 2023).

At a Wales-wide scale, spatially explicit maps of peatland restoration resulting from rewetting, vegetation management and grazing management on peatlands are now available from NRW as part of the NPAP. This allows us to map the location of restoration against baseline (1990) land use data from the Phase 1 habitat survey of Wales, thus providing far more detailed and spatially resolved estimates of the impact of peatland restoration across Wales.

Specific methodological differences between the approach outlined here for reporting the impacts of restoration on GHG emissions from Welsh peatlands and the UK GHG Inventory are listed below.

Table 9-4. Comparison of GHG mapping approaches for peatlands between the UK GHG Inventory and ERAMMP reporting.

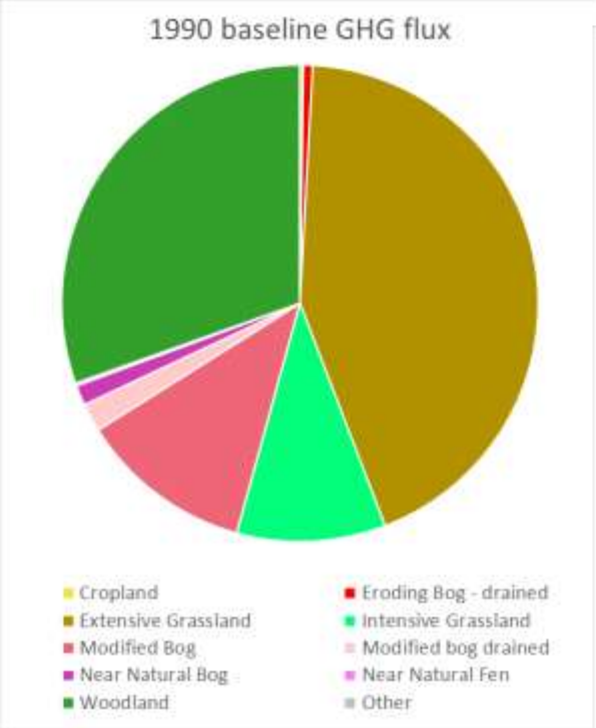
	LULUCF	ERAMMP	Comments
Peat map source	GMEP	Peatlands of Wales Map	Overall reduction of peats = 10,000ha WG map is at a 50*50m resolution and excludes some smaller Peat areas.
Emission Factors (EF)	Carbine used for forest on peats	2017 GMEP report	All other EF apart from forest land are the same.
Drainage assumptions	Assume fixed %	Use of mapped drainage from a range of data sources	Mapped drainage does not provide 100% coverage of Wales.
Restoration extent and land use	Assumes 427ha yr^{-1} proportionally split across habitat present in 1990	Use of a range of data sources from actual restoration projects	LULUCF assumed most restoration is on extensive grassland. ERAMMP identified most is on modified Bog.
GHG emissions 2021	285,612 t CO_2-e ha^{-1} yr^{-1}	490,986 t CO_2-e ha^{-1} yr^{-1}	Driven by higher emissions from forest and continued presence of extensive grassland in ERAMMP database.

Overall, ERAMMP has used best data sources to provide the most up-to-date information to WG with respect to restoration extent and land use, and GHG emissions. The use of the gridded Welsh Peat Map limited the mapping of small Peat fragments and provided much of the spatial disconnect between the ERAMMP reporting and the UK GHG Inventory reporting. A decision needs to be made as to how WG wish to align peatland reporting against the UK GHG Inventory.

9.4.4 Emission Factor Approach

At present, carbon dioxide and methane fluxes from peatlands are determined using a Tier 2 (UK-specific) emission factor methodology following the guidance issued in the IPCC Wetlands Supplement (IPCC, 2014). Peatland areas are assigned a condition category depending on land cover and management, and emissions are calculated as emission per unit area * area.

To capture National Trends in peatland restoration, the potential impacts for GHG emissions and the contribution from Glastir, spatial data covering peatland area and peatland restoration was compiled up until February 2023 from available data. There may be additional peatland restoration in Wales that was not covered by this dataset, for example additional restoration on the Vyrnwy Estate.



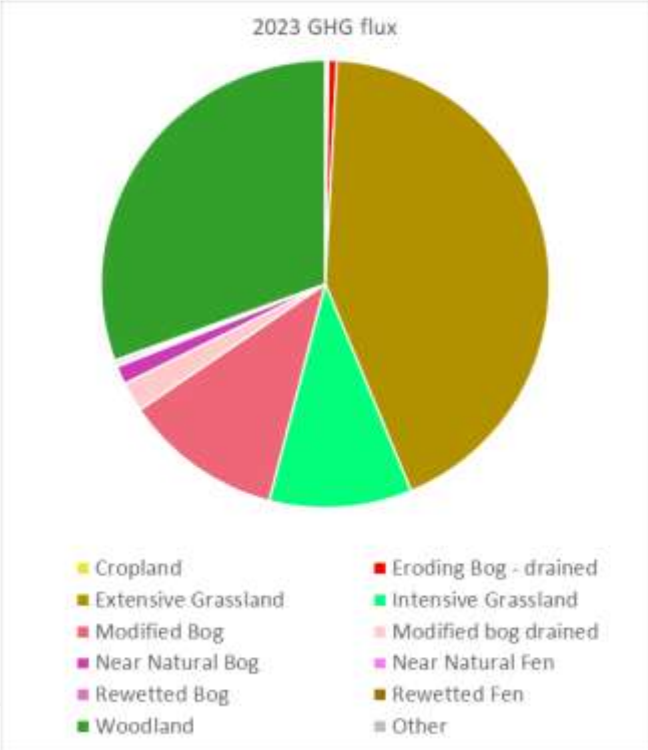


Figure 9-4. The GHG emissions from peatland in 2010 and 2023 following a range of restoration actions – primarily rewetting.

Table 9-5. Modelled GHG emissions using Tier 2 methodology and UK-specific emissions factors for 2010 and 2023, taking into account peatland restoration activities which have been identified.

Land use	1990 GHG emissions ($t\ CO_2$-e yr^{-1})	2023 GHG emissions ($t\ CO_2$-e yr^{-1})
Cropland	1,208	1,163
Eroding Bog – drained	3,160	2,921
Extensive Grassland	219,858	211,525
Intensive Grassland	51,260	50,739
Modified Bog	59,879	56,566
Modified Bog – drained	9,720	10,515
Near-Natural Bog	6,917	6,513
Near-Natural Fen	-949	-932
Rewetted Bog	0	1,032
Rewetted Fen	0	433
Woodland	154,516	150,511
Other	0	0
Total	**505,570**	**490,986**

Aligning area and GHG emissions for 2023 illustrates the importance of understanding the restoration areas and the need for better targeting of the high emitting peatlands, i.e. extensive grassland and Woodland on peats.

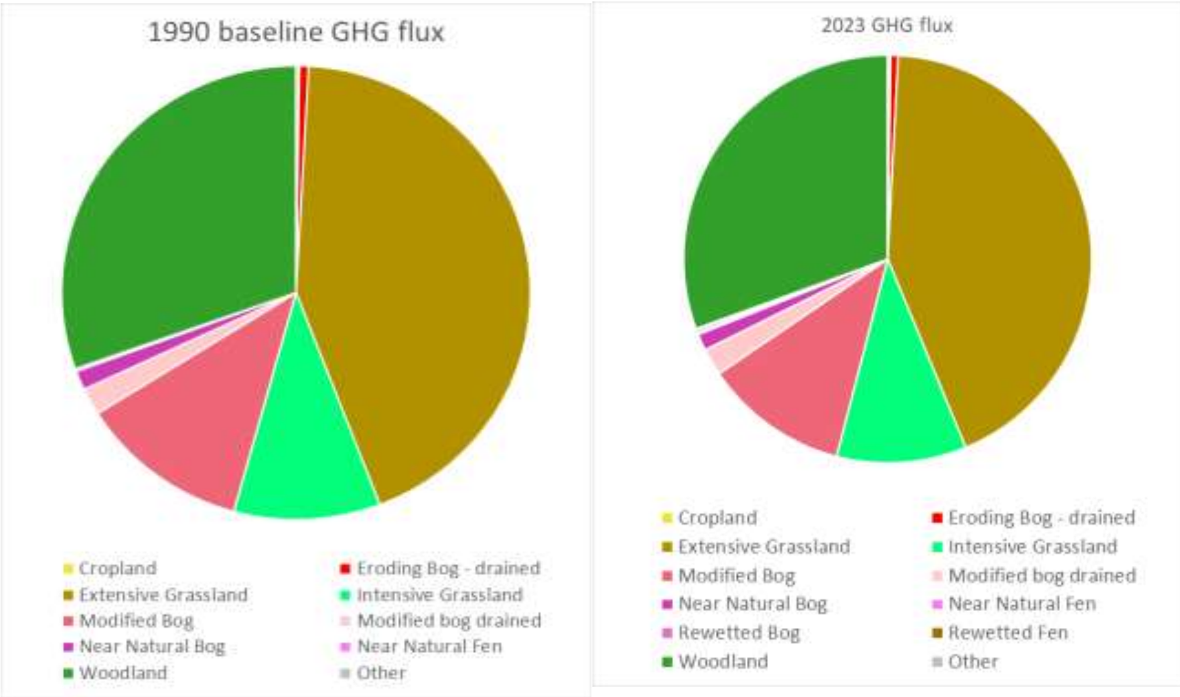


Figure 9-5. Peatland area by condition and GHG emissions for 2023. Note the much larger emissions relative to area for extensive grassland and Woodland.

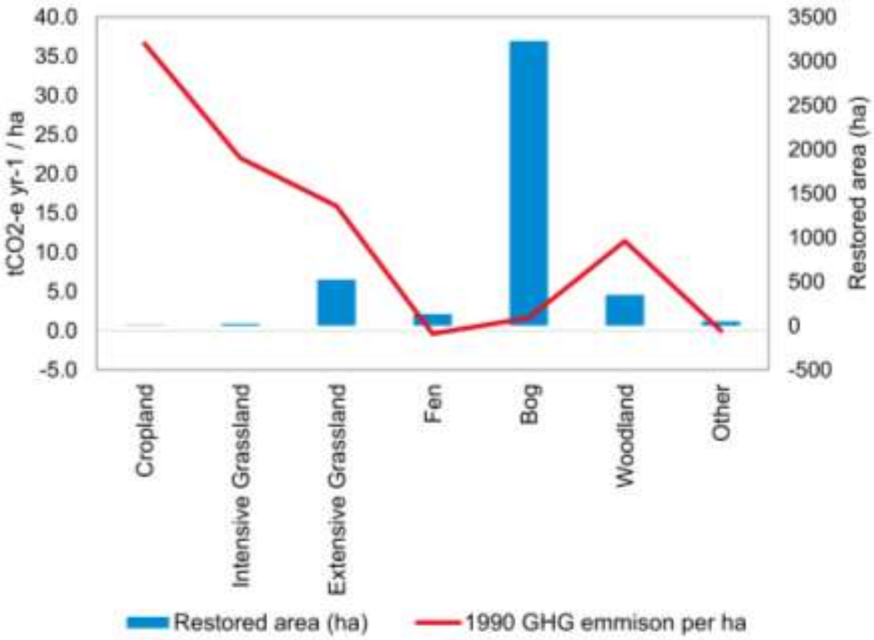


Figure 9-6 Emission rates by area from different types of peatland and peatland restoration areas in 2023. Note little restoration area has occurred on high emitting peatland types such as Cropland, Intensive and Extensive Grassland and Woodland. Most restoration has been on Bog which has low rates of GHG emissions resulting in lower net emission reductions than the restoration area would suggest.

9.5 Climate Change Adaptation on Farms

Key Messages

- According to the ADAS 3rd FPS, between 9% and 40% of farms had taken actions to mitigate specific climate change threats in the past three years, with the average number of actions being 1 out of a possible 6. The dairy sector was most active in this space. Glastir contributed an additional 0.3 actions.

Climate change projections for Wales of increasing summer temperatures and winter rainfall present a business risk to farms vulnerable to events that are at present relatively infrequent. Between 9% and 40% of all farms had taken action to mitigate specific climate change threats in the past three years. The majority of actions were focussed on the management of heat stress. Overall, 40% of Dairy farms and 24% of Cattle & Sheep farms reported having taken action on heat stress. The results are similar to the 2nd FPS but with increased action to mitigate the threat of drought. The average number of actions per farm in the 3rd FPS was 1.1 out of 6 possible actions. A high percentage of respondents took no action to adapt to climate change threats (49%) whilst others took multiple actions. The total number of actions carried out on the Dairy farm type (1.5) was significantly higher than on the Cattle & Sheep farm type (1.0). Participation in the GE and/or GA element of Glastir contributed a significant additional 0.3 total actions per farm, and 68% of respondents who had taken one or more actions acknowledged some form of support by the scheme.

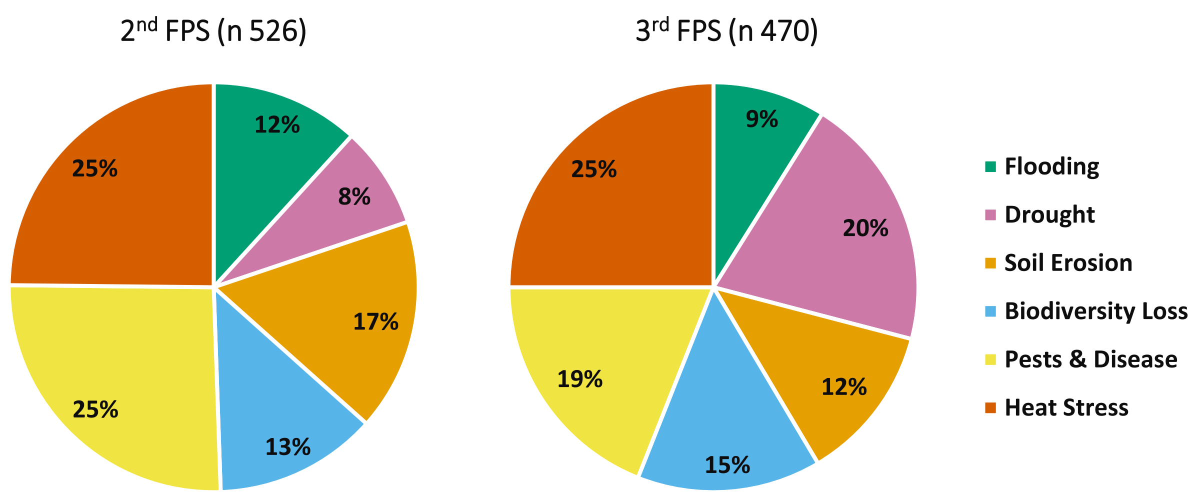


Figure 9-7. Share of the total number of actions taken by survey respondents for adaptation to climate change threats in the past three years, in the 2nd (respondents = 526) and 3rd (respondents = 470) FPS. Excludes Organic farms and those in the Glastir Commons scheme.

9.6 Early Signs of Climate Change Impacts from the National Field Survey

Analysis of the NFS data provides some early indicators of potential climate change impacts either directly or through interactions with management practices. This issue deserves more investigation but some initial findings which may be linked to climate change include:

- A decrease in the bog-building, moisture-loving plant *Sphagnum*. A possible driver is drier summers.
- A four-fold increase in the numbers of dry Headwater streams in the ERAMMP re-survey and a seven-fold increase in dry Ponds.
- Increased topsoil compaction in many habitats since 2013, which could be driven by both wetter winters and drier summers potentially compounded by animal and machinery management practices which may not have been modified to account for changes in soil moisture conditions. The only exceptions are Acid Grassland, Dwarf Shrub Heath and Bog which are the more peaty Soils suggesting a possible soil texture link which needs further exploration. For arable and improved grassland, compacted soils will increase the risk of nitrous oxide production due to the creation of more anaerobic microsites in the soil together with presence of enhanced nitrogen levels both of which favour the denitrification process which create nitrous oxide.
- A generally observed acidification of soil, reversing the benefits observed from declining in sulphur deposition since the 1980s. This may be driven by a decrease in summer rainfall and drier summer conditions (Seaton F. , et al., 2023).

There are many opportunities to further explore the data to identify, for example, shifts in native species distribution on land and in Freshwaters; the link to status and change of invasives and non-native species; and links to Soil health including erosion and Soil damage.

9.7 Further work

Further work going forward could include exploring:

- Shifts in Freshwater biota populations and distributions; plant abundance and distributions; Pollinator and Bird populations and distributions linking this to their known climatic ranges. This should include non-native and invasive species.
- Peatland condition and presence, and cover of moisture-loving plants and possible links to declining summer rainfall and knock-on consequences for GHG emissions.
- Potential impacts of climate change for the survival of newly planted Woodland and Hedgerow success rates, and links to species selection.
- The interactive effects between climate wet and dry cycles, soil type and management practices with respect to the observed loss of soil carbon in Arable Habitats.
- The causes of the observed increase in Soil compaction and why these are limited to certain habitat types and soil types and their potential knock-on consequences for nitrous oxide production.
- Future trends of the new Soil Erosion and Degradation indicators as extreme rainfall events condition, and their interactive effect with soil type, slope and management practices.
- Extending soil monitoring to lower depths (30cm as a minimum; ideally deeper) to help resolve the issue of both changes in soil carbon stock and bulk density changes.

10 Future Opportunities and Next Steps

Emmett, B.A.[1], Anthony, S.[2], Arnett, J.[1], Bentley, L.F.[1], Bell, C.[1], Blaker, J.[1], Botham, M.[1], Bowgen, K.M.[3], Brentegani, M.[1], Campbell, H.[1], Chetiu, N.F.[1], Crossley, P.[1], Deacon, A.[1], Dhiedt, E.[1], Doeser, A.[1], Dos Santos Pereira, G.[1], Ebuele, V.[1], Feeney, C.[1], Fitos, E.[1], Garbutt, R.A.[1], Hunt, M.[1], Jarvis, S.G.[1], Keenan, P.[1], Kimberley, A.[1], Lord, W.[1], Macgregor, C.J.[3], Maskell, L.[1], Monkman, G.[1], Mondain-Monval, T.O.[1], Norton, L.[1], O'Neil, A.[1], Radbourne, A.[1], Reinsch, S.[1], Richardson-Jones, V.[1], Robinson, D.A.[1], Robinson, I.[1], Rowland, C.S.[1], Salisbury, E.[1], Scarlett, P.[1], Siriwardena, G.M.[3], Smart, S.M.[1], Tandy, S.[1], Thacker, S.[1], Wallace, H.[4], Waters, E.[1], Whitworth, E.[2], Williams, B.[1], Williams, G.[1], Williamson, J.L.[1] and Wood, C.[1]

[1]UK Centre for Ecology & Hydrology, [2]RSK ADAS Limited, [3]British Trust for Ornithology and [4]Ecological Surveys

10.1 Introduction

There are many opportunities to exploit the rich evidence base provided by GMEP and ERAMMP to increase the value of the evidence base to support policy development, better understand drivers of change, and improve our overall scientific understanding of what works, where and why to support the development of future AES schemes including the SFS. Some of these opportunities are outlined below.

10.2 Completion of Outstanding Data Analysis, Integration with Other Data Sources and Modelling

There is a wealth of data which remain to be analysed and interpreted. This includes:

- Exploitation of the RPW, NFS, FPS and EO data within a wide range of models to explore the consequences for impacts which it is not possible to measure directly in the field. These include: (i) GHG production from the soil driven by increased compaction and elevated soil nitrogen status, (ii) total carbon stock, stores and flows linked to increased woodland extent and hedgerow length, height and width, (iii) the impact of Glastir on water quality and exports to coastal area beyond the headwaters and ponds reported here and (iv) the economic valuation of all the changes reported in the National Trends and Glastir Outcomes sections of this report using an integrated modelling approach such as ERAMMP Integrated Modelling Platform (IMP).
- The impact of past legacy schemes on present-day outcomes and trends observed. A start has been made on this but time limitations prevented full analysis.
- The role of landscape context (e.g. land use intensity, HNV presence) influencing the outcomes observed. Whilst some work has explored this issue here and in ERAMMP Report-43 (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022), much more needs to be done to enable better targeting of actions going forward as it is clear it has a major influence on outcomes observed. A repeat or extension of the (Alison J. , Maskell, Siriwardena, Smart, & Emmett, 2022) report to include ERAMMP as well as GMEP data would be valuable.

- More detailed analysis of specific options and how they 'stack' on individual land parcels, as many have been applied together on a single area of land and their interaction has not been explored.
- Further analyses disaggregating bundled options and targeting the individual species that are most likely to show responses. These can consider both temporal change, as used for indicators to date, and spatial patterns, i.e. habitat selection, and could be conducted for both Birds and Pollinators.
- Analysis of options to create habitats (i.e. Habitat Reversion and Woodland Creation) are difficult to measure using the indicators chosen which prioritise change in habitat condition. More bespoke analyses are required. For example, in newly created Woodland it takes time for canopy closure, so indicators of shade and Woodland species indicators will not be detected for some time but it is still important to understand the trajectories.
- More analysis of spatial data from mapping of Woodland and woody features would enable the context dependencies of change in different woody features (Woodland, Hedgerows, Individual and Veteran trees) on Woodland outcomes.
- Within the ERAMMP consortium we have potential access to other sources of data, (e.g. Ramblers' citizen science database on path condition; the DEFRA/WG Pollinator Monitoring Scheme; Ordnance Survey aerial photography) in addition to WG/NRW LiDAR data, and water quality in the large rivers and coastal areas. Integrated analysis of this data with GMEP and ERAMMP data would provide additional information on Glastir outcomes.
- Analyses formally combining GMEP/ERAMMP data with those from national schemes, particularly for Birds and Pollinators, may deliver greater power to detect species-level change and effects of Glastir.

10.3 Development of National Benchmarks by Habitat, Soil Type and Climate Regime for Biodiversity and Other Natural Resources.

Benchmarks are useful in providing targets for nature-recovery landscape projects to directly connect them to national representative monitoring programmes delivered by programmes such as GMEP and ERAMMP. Currently, these landscape projects have little way of knowing what realistic targets they should be aiming for with respect to Soil Health, Vegetation condition or Pollinator numbers. In brief, national monitoring such as GMEP and ERAMMP can help projects establish their relative starting position according to the known distribution of national populations for a specific indicator, e.g. Soil Organic Matter. A realistic target can then be agreed on which is within known levels already captured from the national population, e.g. to attain the levels observed for the top 10% of a specific land use, soil type and climate combination. These would provide minimum targets of that already present in the 'best of' comparable land use types with similar soils and climate, and it would be hoped in time that the envelope of what constitutes say, the top 10%, would expand as an overall improvement in environment condition was achieved for the national population as a whole.

This approach has already been demonstrated for GB using UKCEH's Countryside Survey data for four soil health indicators (SOM; Soil pH, Soil bulk density and earthworm numbers) for over 139 specific habitat, soil type, and climate combinations. This large number of benchmarks recognises how our expectations need to change depending on land use, soil type and climate conditions to provide realistic targets for land managers suitable for their particular situation. (See the Soil Fundamental Tool.[12]).

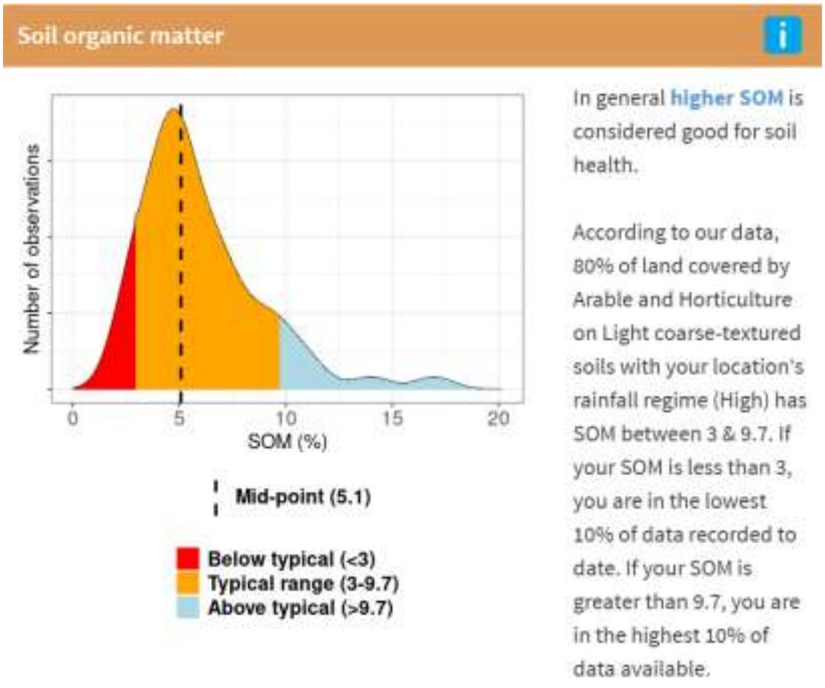


Figure 12-1 An example of output from the UKCEH Soil funDamentals benchmarking tool. This example illustrates the distribution of SOM content recorded by Countryside Survey from across the GB for just one particular soil, land use and climate combination. In the example shown this is for Arable and Horticulture on light-coarse textured soil with high rainfall (1000mm for this combination). SOM content in the red zone indicates low levels of SOM relative to other similar situations whilst SOM content in the blue zone identifies the highest currently observed and could therefore be considered a target for a land manager to aim for. (See the Soil Fundamental Tool.[13]).

Similar work has also been done in England for Vegetation indicators by UKCEH using a combination of literature review, discussions with habitat specialists and analysis of data from multiple surveys to create benchmarks in indicators for every habitat.

Note also that the Bird data collected for GMEP/ERAMMP could support benchmarking at a finer spatial and habitat resolution than would be possible using national BBS data, and that the co-location of sampling of a wide range of environmental targets in ERAMMP would allow this process to consider ecosystems more comprehensively than is possible elsewhere.

This type of work could be developed specifically for Wales and for a wider set of Biodiversity, Soil and Freshwater resources using the uniquely rich resource now captured by GMEP and ERAMMP. One note of caution is that measurement approaches would have to match those in the national programmes to allow comparison of data.

[12] https://www.ceh.ac.uk/news-and-media/news/new-web-tool-measuring-health-soils
[13] https://www.ceh.ac.uk/news-and-media/news/new-web-tool-measuring-health-soils

10.4 Data Analysis to Establish Drivers of Change

Statistical analysis to quantify the main drivers of the changes that we have reported. This should include more detailed analysis of the combined interactive effects of management, climate change and air pollution on National Trends, and how inherent properties at a local or regional scale (e.g. soil type, climate) influence and interact with these drivers.

10.5 Completion of the National Field Survey Re-Survey

The remaining 53 NFS 1km squares will be re-surveyed in 2025 to capitalise on the investment already made by WG in capturing a robust baseline for Wales prior to the start of Glastir and track trends going forward. WG were unique in this commitment to monitoring 10 years ago and completion of the re-survey may provide additional power to detect change for some elements where no change is reported here. This will be particularly important for the Freshwater habitats which were under-represented in our current re-survey population reported here.

The ERAMMP re-survey of Glastir Targeted squares has highlighted the importance of access permissions: clearly, repeat surveys are stronger where area surveyed is consistent over time (i.e. there is no change in access to land by land managers). Further, whilst nominally a survey of 1km squares, the actual coverage unit was the local area in each square for which access permissions could be secured. The same area coverage needed to be secured in ERAMMP as was in GMEP for the evidence value of comparisons to be maximised, and the same will be true of any future, repeat surveys. One way to facilitate this would be to permit non-invasive recording (i.e. that which involves only records by sight, on foot) from rights of way, which was not permitted by WG in the NFS.

The original GMEP model was of four years of ‘baseline’ recording, followed by a second four years, repeating the surveys, to detect change. However, this design had to be changed for reasons of funding and constraints due to COVID-19 in ERAMMP. This had significant impacts on all concerned, timing of publication of this report and particularly for our teams of surveyors who had no job security as a consequence and have no commitment from WG and UKCEH from 2025 onwards. Clearly, all monitoring work has to be exposed to continual review and the ERAMMP approaches will need to integrate with the monitoring requirements of SLM and 30 by 30 Biodiversity targets. However, a long-term view is essential if monitoring is to effective and efficient as for all statistics used by governments.

10.6 Increased Use of Remote Sensing and Integration with Field Data

All remotely sensed data (which includes aerial photography, satellite data and LiDAR) requires ground-truthing, and an ongoing programme of work should ensure there is better connectivity between field and satellite observations. Neither is the ‘truth’ but rather are reliant on their integration to provide the most robust evidence.

The investment by WG in LW should ensure land use/habitat change is routinely and efficiently reported for Wales. The commitment by UKCEH to the annual release of their UKCEH LCM at the GB scale will also enable an ongoing comparison with trends observed in England and Scotland as we have reported here.

Currently, remotely sensed land cover mapping does not capture small biotopes and heterogeneous mosaics (e.g. fens/flushes) and linear habitats (e.g. Hedgerows) very well.

The development of high-resolution land cover/habitat maps (< 3m compared to current 10m approach) is underway by several organisation including UKCEH, which should help more spatial explicit policy outcome reporting for some indicators. A lot of progress has been made using LiDAR for Hedgerow extent (Broughton, et al., 2024) where coverage is available. However, it is not yet possible to monitor all elements of Hedgerow condition remotely and field survey is required for ground-truthing.

It is also very important to ensure that it is possible to detect change. Continuing work is required to link data collected from new methods with historical data and to ensure that change detection from established remotely sensed products is robust. In addition to the potential to represent heterogeneous landscapes better through 3m resolution data, there are also opportunities to go beyond land cover and to use other remotely sensed products to detect changes in condition (e.g. spectral variation in the Normal Difference Vegetation Index (NDVI) has been used to reflect heterogeneity) and RADAR interferometry has been used to determine condition change in Blanket Bogs (e.g. small changes in surface height have been found to correlate with changes in Bog condition). Remotely sensed data enables multiple aspects of condition to be assessed and could involve new metrics and interpretation not available to field survey. However, the major opportunity is the combination of field and remote sensed data to develop a whole new set of metrics linking above and below ground at the landscape scale (e.g. for Net Zero reports of carbon sequestration in biomass and soils) and to provide this information directly to land managers to help inform their business decisions. This could include for example, spatially explicit risk areas of enhanced erosion and nutrient loss to water bodies (as done in England by the Environment Agency and in Northern Ireland) as well as spatial carbon stock maps.

10.7 Support of the Sustainable Farming Scheme and Sustainable Land Management

There are many findings here which could help inform the future development of the SFS and, more generally, targets and monitoring approaches for SLM.

More specifically, the Glastir management option analyses provide robust evidence of the effectiveness of many practices when rolled out in national schemes which are often supported with little evidence of their outcomes away from site-specific experimental conditions which often are not achieved once rolled out in national programmes.

It is recommended that the new ERAMMP spatial database which contains Glastir, Tir Gofal, LCM and many other data sources is maintained and added to, for example as the SFS and SLM is rolled out, thereby streamlining and ensuring consistency of future analysis. ESA data and detailed management data for Tir Cynnal were not made available but could be added to provide a more complete analysis of past AES and land management schemes if they become available in a useable digital format.

Finally, to provide early sight of ongoing trends, a move to an annual rolling programme, which would be completed over a 5-year cycle, is recommended together with a review of priority metrics and indicators with our ERAMMP Stakeholder Group. This would require some investment in automating analysis and reporting.

An additional value would be avoiding the uncertainty of employment of our highly qualified and dedicated field survey teams who currently have no security from year to year as to whether there will be NFS work for the survey season (Apr to Sep) and without which none of this report would be possible.

11 ACKNOWLEDGEMENTS

The project team want to add special thanks to the following for their contribution to the delivery of the National Field Survey:

Ardeshir, D., Beath, A., Betts, N., Biddle, A., Boffey, C., Clews-Roberts, B., Cope, S., Davies, S., Dawson, R., Douglas, N., Duckham, M., Duffell, J., Duffell, M., Ellson, M., Foster-Brown, C., Fothergill, C., Friend, R., Haigh, M., Handley, J., Handley, T., Higgins, A., Horninge, L., Hughes, T., Hunter, E., Jenks, P., Jones, E., Knight, T., Lowe, A., Lucas, A., Owen, R., Parry, C., Roberts, M., Savage, C., Sayer, H., Scott, H., Shepherd, S., Smith, A., Squires, R., Thomas, T., Vallis-Wilks, E., Vallis-Wilks, M., Vaughan, D., Ward, T., Winder, J., Winder, J.

To Spencer, J. (CADW) for his continued engagement, training and support to survey staff and the project team.

To the 1,355 farmers who allowed us to survey their land, and the farmer unions for their advice and support.

To Tye, A. (British Geological Survey) for mapping the Soil Erosion and disturbance features in ERAMMP survey squares from aerial images captured ca. 2018 (Tye & Robinson, 2020). He is also credited for helping to co-design the field survey to ground-truth and record additional features to the ones identified from the aerial images (Robinson, et al., 2021).

To the Welsh Government ERAMMP management team: Skates, J., Massey, O., Jones, D., Gillett, F., Harris, L.

12 REFERENCES

Alison, J., Botham, M., Maskell, L. C., Garbutt, A., Seaton, F. M., Skates, J., . . . Emmett, B. A. (2021). Woodland, cropland and hedgerows promote pollinator abundance in intensive grassland landscapes, with saturating benefits of flower cover. *Journal of Applied Ecology, 59*(1), 342-354. doi:https://doi.org/10.1111/1365-2664.14058

Alison, J., Bowgen, K., Siriwardena, G. M., Williams, B., Reinsch, S., Garbutt, R. A., & Emmett, B. A. (2021). *ERAMMP Report-58: ERAMMP Square Selection Protocol 2021/2022.*

Alison, J., Maskell, L. C., Siriwardena, G. M., Smart, S. M., & Emmett, B. A. (2022). *ERAMMP Report-43:Analysis of National Monitoring Data to Inform Future Land Management.*

Anthony, S., & Whitworth, E. (2023). *Third Wales Farm Practices Survey. First Design Report: Design and Delivery of Survey. Report to Welsh Government and the Centre for Ecology and Hydrology. ADAS.*

Anthony, S., & Whitworth, E. (2024). *Third Wales Farm Practices Survey Second Main Report – Statistical Analysis and Results. Report to the Welsh Government.*

Anthony, S., Jones, I., Naden, P., Newell-Price, P., Jones, D., Taylor, R., . . . Edwards-Jones, G. (2012). *Contribution of the Welsh agri-environment schemes to the maintenance and improvement of soil and water quality, and to the mitigation of climate change. Welsh Government, Agri-Environment Monitoring and Technical Services Contract Lot 3: Soil, Water and .*

Anthony, S., Lee, D., Emmett, B., Cosby, J., Henrys, P., Thomas, A., . . . Hodge, I. (2016). *Landscape typology – A framework for prioritisation of sustainable intensification strategies.* Defra, Sustainable Intensification Research Platform, 232 pp.

Anthony, S., Stopps, J., & Whitworth, E. (2016). *Second Wales Farm Practices Survey: Second Interim Report – Statistical Analyses and Main Results. Report to the Welsh Government and the Centre for Ecology and Hydrology, ADAS, .*

Anthony, S., Stopps, J., & Whitworth, E. (2017). *Wales Farm Practices Survey. Legacy and Synthesis. Annex 4. In: Emmett B.E. and the GMEP team (2017) Glastir Monitoring & Evaluation Programme. Final Report to Welsh Government (Contract reference: C147/2010/11). NERC/CEH Projects NEC04780/NEC05371.*

Arnott, D., Chadwick, D., Harris, I., Koj, A., & Jones, L. D. (2019). What can management option uptake tell us about ecosystem services.

Beauchamp, K., Jenkins, T. A., Alison, J., Bathgate, S., Bell, C., Braban, C., . . . Emmett, B. A. (2020). *ERAMMP Report-32: National Forest in Wales - Evidence Review Report.*

Bentley, L., Reinsch, S., & Robinson, D. (2025). *ERAMMP Technical Annex-105TA1S7: Wales National Trends and Glastir Evaluation. Supplement- 7: Soil Health. Report to Welsh Government (Contract C210/2016/2017)(UKCEH 06297).*

Bhogal, A., Boucard, T., Chambers, B., Nicholson, F., & Parkinson, R. (2008). *Road testing of 'trigger values' for assessing site specific soil quality. Phase 2-other soil quality indicators. Science Rep. SC050054SR2.*

Biggs, J., & Williams, P. (2024). *Ponds, Pools and Puddles. William Collins.*

Black, H., Bellamy, P., Creamer, R., Elston, D., Emmett, B., Frogbrook, Z., . . . Booth, P. (2008). *Design and operation of a UK Soil monitoring network (CEH Project Number: C03357, Science report SC060073, Product Code: SCHO0908BOMX-E-P).* Bristol: Environment Agency.

Blackstock, T., Howe, E., Stevens, J., Burrows, C., & Jones, P. (2010). *Habitats of Wales - a comprehensive field survey, 1979-1997.* Cardiff: University of Wales Press.

Bol, R., Blackwell, M., Emmett, B., Reynolds, B., Hall, J., Bhogal, A., & Ritz, K. (2011). *Assessment of the response of organo-mineral soils to change in management practices. In: Sub-Project ii of Defra Project SP1106: Soil carbon: studies to explore greenhouse gas emissions and mitigation.*

Broughton, R. K., Burkmar, R., McCracken, M., Norton, L. R., Pallett, D. W., Patton, J., . . . Pywell, R. F. (2024). UKCEH Land Cover Plus: Hedgerows 2016-2021 (England). *NERC EDS Environmental Information Data Centre*. Retrieved from https://doi.org/10.5285/d90a3733-2949-4dfa-8ac2-a88aef8699be

Brown, P., Cardenas, L., Del Vento, S., Karagianni, E., MacCarthy, J., Mullen, P., . . . Willis, D. (2023). *UK Greenhouse Gas Inventory, 1990 to 2021: Annual Report for Submission under the Framework Convention on Climate Change.* BEIS.

Burns, F., August, T., Eaton, M., Noble, D., Powney, G., Isaac, N., & Hayhow, D. (2023). *UK Biodiversity Indicators.* Retrieved from https://data.jncc.gov.uk/data/1f47d611-dbfc-421a-bc26-b019433306d1/ukbi2023-techbg-c4a.pdf

CABI. (2022). *CABI Compendium, CABI International, Proasellus coxalis.* doi:doi:10.1079/cabicompendium.116545

Carey, P., Wallis, S., Chamberlain, P., Cooper, A., Emmett, B., Maskell, L., . . . Ullyett, J. (2008). *Countryside Survey: UK Results from 2007.* NERC/Centre for Ecology & Hydrology, 105pp. (CEH Project Number: C03259).

Carrasco, L., O'Neil, A. W., Morton, R. D., & Rowland, C. S. (2019). Evaluating Combinations of Temporally Aggregated Sentinel-1, Sentinel-2 and Landsat 8 for Land Cover Mapping with Google Earth Engine. *Remote Sensing, 11*, 288. doi:https://doi.org/10.3390/rs11030288

Deacon, A., Fitos, E., Prosser, M., & Wallace, H. (2025). *ERAMMP Technical Annex-105TA1S4: Wales National Trends and Glastir Evaluation. Supplement-4: Vegetation Quality Assurance. Report to Welsh Government (Contract C210/2016/2017)(UKCEH 06297).*

DEFRA. (2022). *Fertiliser use on farm crops for the crop year 2021.* Retrieved from https://assets.publishing.service.gov.uk/media/62e11e8d8fa8f5649797ae08/fertiliseruse-annualreport2021-28jul22.pdf

DEFRA. (2024). Dataset for The British Survey of Fertiliser Practice 2023, Great Britain. Retrieved from https://www.gov.uk/government/statistical-data-sets/british-survey-of-fertiliser-practice-dataset

Dutton, A., Jassi, J., Jones, L., Emmett, B. A., & Bentley, L. (2023). *ERAMMP Report-28B: Welsh Mountain, Moor and Heath (MMH) Condition Account .*

Ellenberg, H., Weber, H. E., Dull, R., Wirth, V., Werner, W., & Paulissen, D. (1991). *Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica.*

Emmett, B. A., & team, t. G. (2014). *Glastir Monitoring & Evaluation Programme. First Year Annual Report to Welsh Government (Contract reference: C147/2010/11). NERC/Centre for Ecology & Hydrology (CEH Project: NEC04780).*

Emmett, B. A., & team, t. G. (2017). *Glastir Monitoring & Evaluation Programme. Final Report to Welsh Government.*

Emmett, B., & the ERAMMP Team. (2025). *ERAMMP Report-105: Wales National Trends and Glastir Evaluation. Report to Welsh Government (C208/2021/2022) (UKCEH 08435).*

Emmett, B., Bentley, L., Bowgen, K., Doeser, A., Jarvis, S., Kimberley, A., Smart, S. (2025). *ERAMMP Technical Annex-105TA1S2: Wales National Trends and Glastir Evaluation. Supplement-2: Broad Habitat Results. Report to Welsh Government (C208/2021/2022) (UKCEH 08435).*

Emmett, B., Evans, C., Matthews, R., Smith, P., & Thomson, A. (2023). *The opportunities and limitations of carbon capture in soil and peatlands.*

Emmett, B., Reynolds, B., Chamberlain, P., Rowe, E., Spurgeon, D., Brittain, S., . . . Woods, C. (2010). *Countryside Survey: Soils Report from 2007. NERC/Centre for Ecology and Hydrology, 192pp. (CS Technical Report No. 9/07, CEH Project Number: C03259).*

Evans, C. D., Peacock, M., Baird, A. J., Artz, R., Burden, A., Callaghan, C., . . . Morrison, R. (2021). Overriding water tbale control on managed peatland greenhouse gas emissions. *Nature*, 458-552.

Extence, C. A., Chadd, R. P., England, J., Naura, M., & Pickwell, A. G. (2017). *Application of the Proportion of Sediment-sensitive Invertebrates (PSI) biomonitoring index. River Research and Applications, 33(10), 1596–1605.* doi:https://doi.org/10.1002/RRA.3227

Forest Research. (2023). Retrieved from https://www.forestresearch.gov.uk/publications/forestry-facts-figures-2023/

Forestry Comission. (2020). *NFI woodland ecological condition in Wales: classification results.* Retrieved from https://cdn.forestresearch.gov.uk/2022/02/fr_nfi_condition_scoring_results_wales_cxzeel5.pdf#:~:text=This%20report%20contains%20the%20classification%20results%20for%20Wales,woodland%20type%20%28native%2C%20non-native%20and%20%E2%80%98near-native%20and%20f

Freshwater Habitats Trust. (2019). *A guide to monitoring the ecological quality of ponds and canals using PSYM.*

Fuller, R. J., Smith, K. W., Grice, P. V., Currie, F. A., & Quine, C. P. (2007). *Habitat change and woodland birds in Britain: implications for management and future research.*

George, P. B., Lallias, D., Creer, S., Seaton, F., Kenny, J. G., Eccles, R. M., . . . Jones, D. L. (2019). *Divergent national-scale trends of microbial and animal biodiversity revealed across diverse temperate soil ecosystems. Nature Communications 10.*

Gill, R. M., & Fuller, R. J. (2007). *The effects of deer browsing on woodland structure and songbirds in lowland Britain. .*

Harrower, C. A., Rorke, S. L., & Roy, H. E. (2021). *UK biodiversity indicators. Technical background document (p. 12).* Retrieved from https://data.jncc.gov.uk/data/647caed5-93d0-4dc0-92bf-13d231a37dda/ukbi2021-techbg-b6-a.pdf

Heywood, J., Massimino, D., Balmer, D., Kelly, L., Marion, S., Noble, D., . . . Gillings, S. (2024). *The Breeding Bird Survey 2023. BTO Research Report 765.* British Trust for Ornithology, the Joint Nature Conservation Committee and the Royal Society for the Protection of Birds.

Hill, M. J., Greaves, H. M., Sayer, C. D., Hassall, C., Elanie Milin, M., Milner, V. S., . . . Jeffries, M. J. (2021). *Pond ecology and conservation: research priorities and knowledge gaps. Ecosphere, 12(12), e03853.* doi:https://doi.org/10.1002/ECS2.3853

Hill, M. O., Preston, C. D., & Roy, D. B. (2004). *PLANTATT - attributes of British and Irish plants: status, size, life history, geography and habitats. Abbotts Ripton, Centre for Ecology & Hydrology. .*

Hill, M. O., Roy, D. B., Mountford, J. O., & Bunce, R. G. (2000). *Extending Ellenberg's indicator values to a new area: an algorithmic approach.* J. Appl. Ecol.

Hodgson, J., Tallowin, J., Dennis, R., Thompson, K., Poschlod, P., Dhanoa, M., . . . Hynd, A. (2014). *Changing leaf nitrogen and canopy height quantify processes leading to plant and butterfly diversity loss in agricultural landscapes. Funct Ecol, 28: 1284-1291. https://doi.org/10.1111/1365-2435.12253.*

Hooftman, D., Bullock, J., Evans, P., Redhead, J., Ridding, L., Varma, V., & Pywell, R. (2023). A model of sediment retention by vegetation for Great Britain: New methodologies & validation. *bioRxiv*, preprint.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

IPCC. (2014). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.* Switzerland: IPCC.

Jackson, D. (2000). *Guidance on the interpretation of the Biodiversity Broad Habitat Classification (terrestrial and freshwater types): Definitions and the relationship with other classifications,. JNCC Report No. 307, JNCC.*

Jarvis, S. G., Redhead, J. W., Henrys, P. A., Risser, H. A., Da Silvia Osorio, B. M., & Pywell, R. F. (2020). *CEH Land Cover plus: Pesticides 2012-2017 (England, Scotland and Wales).* doi:https://doi.org/10.5285/99a2d3a8-1c7d-421e-ac9f-87a2c37bda62

Jarvis, S., Bentley, L., Reinsch, S., Feeney, C., Bowgen, K., Macgregor, C., . . . Monkman, G. (2025). *ERAMMP Technical Annex-105TA1S1: Wales National Trends and Glastir Evaluation. Supplement-1: Data Analysis Methods. Report to Welsh Government (Contract C210/2016/2017)(UKCEH 06297).*

JNCC. (2011). *UK Biodiversity Action Plan Priority Habitat Descriptions Rivers.* Retrieved from https://data.jncc.gov.uk/data/01d6ab5b-6805-4c4c-8d84-16bfebe95d31/UKBAP-BAPHabitats-45-Rivers-2011.pdf

Kirby, K. (2005). *Long-term ecological changes in British broadleaved woodland 1971-2002.* Peterborough, UK.: English Nature, Research Report. 653, part 1. Retrieved from http://publications.naturalengland.org.uk/publication/94019?category=550043

Levy, P., Rowland, C., Buys, G., Clark, L., Correia, V., Ditchburn, B., Evangelides, C., Higgins, A., Marston, C., Morton, D., Olave, R., O'Neil, A., Raine, B., Tomlinson, S., Walker, A., Watterson, J., Whitton, E., Williamson, J., and Thomson, A., (2024). *Improving land use change tracking in the UK Greenhouse Gas Inventory: final outputs report.* NAEI, online at: https://naei.energysecurity.gov.uk/reports/improving-land-use-change-tracking-uk-greenhouse-gas-inventory-final-outputs-report

Lewis-Phillips, J., Brooks, S. J., Sayer, C. D., Patmore, I. R., Hilton, G. M., Harrison, A., . . . Axmacher, J. C. (2020). *). Ponds as insect chimneys: Restoring overgrown farmland ponds benefits birds through elevated productivity of emerging aquatic insects. Biological Conservation, 241, 108253.* doi:https://doi.org/10.1016/J.BIOCON.2019.108253

MacDonald, M., Angell, R., Dines, T., Dodd, S., Haysom, K., Hobson, R., . . . Wilberforce, E. (2019). *Have Welsh agri-environment schemes delivered for focal species? Results from a comprehensive monitoring programme.*

Marston, C., Morton, R., O'Neil, A., & Rowland, C. (2024). *Land Cover Map 2022 (10m classified pixels, GB).* doi:https://doi.org/10.5285/1e09f53f-55de-4960-b2a1-da2a42029e7e

Martson, C., Rowland, C., O'Neil, A., & Morton, R. (2022). Land Cover Map 2021 (1km summary rasters, GB and N. Ireland).

Maskell, L., Alison, J., Forbes, N., Jarvis, S., Robinson, D., Siriwarenda, G., . . . Smart, S. (2023). *Inconsistent relationships between area, heteogeneity and plant species richness in temperate farmed landscapes.*

Merrington, G., Fishwick, S., Barraclough, D., Morris, J., Preedy, N., Boucard, T., . . . Fang, C. (2006). *The development and use of soil quality indicators for assessing the role of soil in environmental interactions. Report to UK SIC, SC030265.* Environment Agency.

Miller, J. D., Vesuviano, G., Wallbank, J. R., Fletcher, D. H., & Jones, L. (2023). *Hydrological assessment of urban Nature-Based Solutions for urban planning using Ecosystem Service toolkit applications. Landscape and Urban Planning, 234, 104737.* doi:https://doi.org/10.1016/J.LANDURBPLAN.2023.104737

Monkman, G. (2025). *ERAMMP Technical Annex-105TA1S12: Wales National Trends and Glastir Evaluation. Supplement-12: Public Rights of Way. Report to Welsh Government (Contract C210/2016/2017)(UKCEH 06297).*

Morton, R., Marston, C., O'Neil, A., & Rowland, C. (2024). *Land Cover Map 2023 (10m classified pixels, GB).* doi:https://doi.org/10.5285/7727ce7d-531e-4d77-b756-5cc59ff016bd

Natural Capital and Ecosystem Assessment Programme. (2022). Retrieved from www.GOV.uk: https://www.gov.uk/government/publications/natural-capital-and-ecosystem-assessment-programme/natural-capital-and-ecosystem-assessment-programme

Natural Resources Wales. (2020). *State of Natural Resources Report (SoNaRR).*

NBN Atlas. (2019). *NNS of interest to Wales list. INNS Portal. National Biodiversity Network Atlas Wales.* Retrieved from NBN Atlas: https://docs.nbnatlas.org/invasive-non-nativespecies-portal/overview_inns-portal-species-lists/

Noble, D., & Barnes, A. (2023). *Development of an Upland Bird Indicator BTO Research Report 757.*

Rayment, M., Deane, R., Pieterse, M., & Parker, S. (2012). *Dynamic Deadweight in Environmental Stewardship. Defra project DO0120, Final Report. Land Use Consultants, 73 pp.*

Reinsch, S., Jarvis, S., & Monkman, G. (2025). *ERAMMP Technical Annex-105TA1S11: Wales National Trends and Glastir Evaluation. Supplement-11: Historic Environment Assets. Report to Welsh Government (Contract C210/2016/2017)(UKCEH 06297).*

Robinson, D. A., Thomas, A., Reinsch, S., Lebron, I., Feeney, C. J., Maskell, L. C., . . . Cosby, B. J. (2022). Analytical modelling of soil porosity and bulk density across the soil organic matter and land-use continuum. *Scientific Reports, 12*(1), 7085. doi:10.1038/s41598-022-11099-7

Robinson, D., Tye, A., Feeney, C., Fitos, E., Garbutt, R., Scarlett, P., & Wood, C. (2021). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Document-71: Field-Survey Handbook (Procedures) - Soil Erosion and Damage Recording 2021. .* For Welsh Government (Contract C210/2016/2017)(UK Centre for Ecology & Hydrology Projects 06297 & 06810).

Rowe, E., Sawicka, K., Hina, N., Carnell, E., Martín, Hernandez, C., . . . Jones, L. (2023). *Air Pollution Trends Report 2023: Critical load and critical level exceedances in the UK. Report to Defra under Contract AQ0849, UKCEH project 07617.* Retrieved from https://uk-air.defra.gov.uk/library/reports?report_id=1130

Rowland, C. S., Marston, C. G., Morton, R. D., & O'Neil, A. W. (2020). *Land Cover Change 1990-2015 (25m raster, GB).* doi:https://doi.org/10.5285/07b6e5e9-b766-48e5-a28c-5b3e35abecc0

Rudeforth, C. C., Hartnup, R., Lea, J. W., Thompson, T. R., & Wright, P. S. (1984). Soils and their use in Wales. *Soil Survey of England and Wales Bulletin No. 11*.

Seaton, F. M., Robinson, D. A., Monteith, D., Lebron, I., Buerker, P., Somlinson, S., & Emmett, B. A. (2023). Fifty years of reduction in sulphur deposition drives recovery in soil pH and plant communities. *Journal of Ecology, 111*(2), 464-478.

Siriwardena, G. M., & Bowgen, K. M. (2023). *ERAMMP Document-88: Field-Survey Handbook (Procedures) - Birds. Report to Welsh Government (Contract C210/2016/2017)(UKCEH 06297/06810).* UKCEH.

Siriwardena, G., & Bowgen, K. (2025). *ERAMMP Technical Annex-105TA1S6: Wales National Trends and Glastir Evaluation. Supplement-6: Birds. Report to Welsh Government (Contract C210/2016/2017)(UKCEH 06297).*

Siriwardena, G., Henderson, I., Noble, D., & Fuller, R. (2019). *How can assemblage structure indices improve monitoring of change in bird communities using ongoing survey data? Ecological Indicators 104: 669–685.*

Smart, S. M., Allen, D., Murphy, J., Carey, P. D., Emmett, B. A., Reynolds, B., . . . Wood, C. (2009). *Countryside Survey: Wales results from 2007.* NERC/Centre for Ecology & Hydrology, 88pp. (CEH Project Number: C03259).

Snaddon J L, T. E. (2007). A child's eye view of the insect world: perceptions of insect diversity. *Environmental Conservation, 34*(1), 33-35. doi:https://doi.org/10.1017/S0376892907003669

Swetnam, R., Harrison-Curran, S., & Smith, G. (2016). *Quantifying visual landscape quality in rural Wales: A GIS-enabled method for extensive monitoring of a valued cultural ecosystem service, Ecosystem Services.* doi:http://dx.doi.org/10.1016/j.ecoser.2016.11.004.

Thomas, A., Bentley, L., Feeney, C., Lofts, S., Robb, C., Rowe, E., . . . Emmett, B. (2023). Land degradation neutrality: Testing the indicator in a temperate agricultural landscape. *Journal of Environmental Management, 346*, 118884.

Thomas, A., Seaton, F., Dhiedt, E., Cosby, B. J., Feeney, C., Lebron, I., . . . Robinson, D. A. (2024). Topsoil porosity prediction across habitats at large scales using environmental variables. *Science of the Total Environment, 922*, 171158. doi:10.1016/j.scitotenv.2024.171158

Thomson, A., Evans, C., Buys, G., & Cliverd, H. (2020). *Updated quantification of the impact of future land use scenarios to 2050 and beyond. Final Report. Report for Climate Change Commission. 07610/Final report for CCC .*

Tsagatakis, I., Richardson, J., Evangelides, C., Pizzolato, M., Ben, R., Hows, S.-M., . . . Otto, A. (2023). *UK Spatial Emissions Methodology: A report of the National Atmospheric Emission Inventory 2021.* BEIS.

Tye, A., & Robinson, D. (2020). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-45: Soil Degradation: Erosion & Compaction Phase-1. Report to the Welsh Government (Contract C210/2016/2017)(UK Centre for Ecology & Hydrology Projects 06297 & 06810).*

Tye, A., Moir, A., Reinsch, S., Cartwright, C., Feeney, C., & Robinson, D. (2023). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-70: The use of remote sensing to assess soil erosion, poaching and disturbance features. Report to Welsh Government (Contract C210/2016/2017).*

Tye, A., Williamson, J., Robinson, D. A., Cartwright, C., & Evans, D. (2021). *Soil Formation Rates Scoping Study. 2020-21 Soil Policy Evidence Programme. Report code: SPEP2020-21/09.* Welsh Government. Retrieved from https://www.gov.wales/sites/default/files/publications/2022-01/soil-formation-rates-scoping-study.pdf

UK Government. (1981). *Wildlife and Countryside Act 1981.* UK Government. Retrieved 06 01, 2024, from https://www.legislation.gov.uk/ukpga/1981/69/contents

UK Government. (2000). *Countryside and Rights of Way Act 2000*. Retrieved from https://www.legislation.gov.uk/ukpga/2000/37/contents

UK Government. (n.d.). Environment (Wales) Act (2016) Section 7. Retrieved from https://www.legislation.gov.uk/anaw/2016/3/notes/contents

Wales Audit Office. (2014). *Auditor General for Wales.* Retrieved from https://www.audit.wales/sites/default/files/Glastir_English_2014_10.pdf

Welsh Government. (2021). *Net Zero Wales Carbon Budget 2 (2021-25).* Retrieved from https://www.gov.wales/sites/default/files/publications/2021-10/net-zero-wales-carbon-budget-2-2021-25.pdf

Welsh Government. (2022). *Common Agricultural Policy Cross Compliance 2022. Verifiable standards for classifying breaches of Good Agricultural and Environmental Conditions (GAEC) and Statutorry Management Requirements (SMR) 2022.* Retrieved from https://www.gov.wales/sites/default/files/publications/2021-12/cross-compliance-verifiable-standards-2022.pdf

Welsh Government. (2023). *Written Parlimentary Question and Answer*. Retrieved from https://record.assembly.wales/WrittenQuestion/88064

WFD-UKTAG. (2015). *Classification of aquatic alien species according to their level of impact.*

Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P., & Sear, D. (2004). *Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biological Conservation, 115(2), 329–341.* doi:https://doi.org/10.1016/S0006-3207(03)00153-8

Wouters, K., & Vercauteren, T. (2009). *Proasellus coxalis sensu auct. (Crustacea, Isopoda) in a lowland brook in Heist-op-den-Berg: first record in Belgi-um.*

This page is intentionally blank

ERAMMP Programme Office
UKCEH Bangor
Environment Centre Wales
Deiniol Road
Bangor, Gwynedd
LL57 2UW
+ 44 (0)1248 374500
erammp@ceh.ac.uk

www.erammp.cymru

www.erammp.wales