GLASTIR MONITORING & EVALUATION PROGRAMME

FINAL REPORT

Prepared by CEH on behalf of the Glastir Monitoring & Evaluation Programme Team

July 2017

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Contents

1. Introduction to the GMEP Programme 4
2. GMEP activities 7
   2.1 Field survey 8
   2.2 Exploitation of new technologies 9
   2.3 Scenario Modelling 9
   2.4 Social research and surveys 9
3. The Glastir scheme 10
   3.1 Glastir design 10
   3.2 Uptake of Glastir 11
   3.3 Glastir related changes in management practices reported by farmers 13
   3.4 GMEP coverage of the scheme and designated land 14
4. GMEP results by Glastir Outcome 16
   4.1 Diversification and Efficiency 17
   4.2 Profitability and wider sustainability 18
   4.3 Climate Change adaptation 19
   4.4 Woodland 20
   4.5 Biodiversity 28
   4.6 Freshwater 46
   4.7 Climate Change Mitigation 57
   4.8 Soil 65
5. How does land in the Glastir scheme differ to the national average overall? 76
6. Can GMEP results be used to explore resilience? 77
7. Legacy of past agri-environment schemes 79
8. Ecosystem functions, services and opportunity mapping 80
   8.1 Comparison of Ecosystem Service models 81
   8.2 Opportunities to improve agriculture and the management of designated land 81
   8.3.Opportunities for woodland expansion and creation whilst protecting and enhancing other services 82
   8.4 Areas to target for protection of carbon stocks and maximise carbon sequestration 83
   8.5 Areas to target for flood mitigation 85
   8.6 Land with multiple opportunities for service improvement and the relationship to land which has come into Glastir 87
9. International activities and other outputs 90
10. Next steps 91
11. Conclusions: 'GMEP at a Glance' 93
12. Acknowledgements 94
13. References 95

1. Introduction to the GMEP Programme

The Glastir Monitoring and Evaluation Programme (GMEP) provides a comprehensive programme to establish a baseline against which future assessments of Glastir can be made. GMEP also contributes national trend data which supports a range of national and international biodiversity and environmental targets. GMEP fulfils a commitment by the Welsh Government to establish a monitoring programme concurrently with the launch of the Glastir scheme. The use of models and farmer surveys provides early indicators of the likely direction, magnitude and timing of future outcomes. The programme ensures compliance with the rigorous requirements of the European Commission's Common Monitoring and Evaluation Framework (CMEF) through the Rural Development Plan (RDP) for Wales. This report represents the final results of the GMEP programme which ran from 2012 to 2016.

Agri-environment schemes in Wales are funded under Axis 2 of the RDP (Improving the Environment and the Countryside), and provide funding for farmers to manage their land in a way that benefits biodiversity and landscape features, and improves the quality of water and soil. The Glastir agri-environment scheme was introduced in 2009 following a review of the RDP (Welsh Government, 2008) and became the single operational agri-environment scheme in Wales from 2013. The scheme objectives reflect the government's environmental objectives and a reframing of support to farmers as payments for ecosystem goods and services. The six intended outcomes from the Glastir scheme are:

- *Combating climate change*
- *Improving water quality and managing water resources*
- *Improving soil quality and management*
- *Maintaining and enhancing biodiversity*
- *Managing landscapes and historic environment and improving public access to the countryside*
- *Woodland creation and management*

There are currently 4,600 participants in the Entry level scheme, including 1,400 in the Advanced level and 500 in the Decoupled Advanced, managing 37% of the total utilised agricultural area in Wales. As a comparison, at their peak, there were 7,600 participants in Tir Cynnal and Tir Gofal, managing 52% of the total utilised agricultural area in Wales.

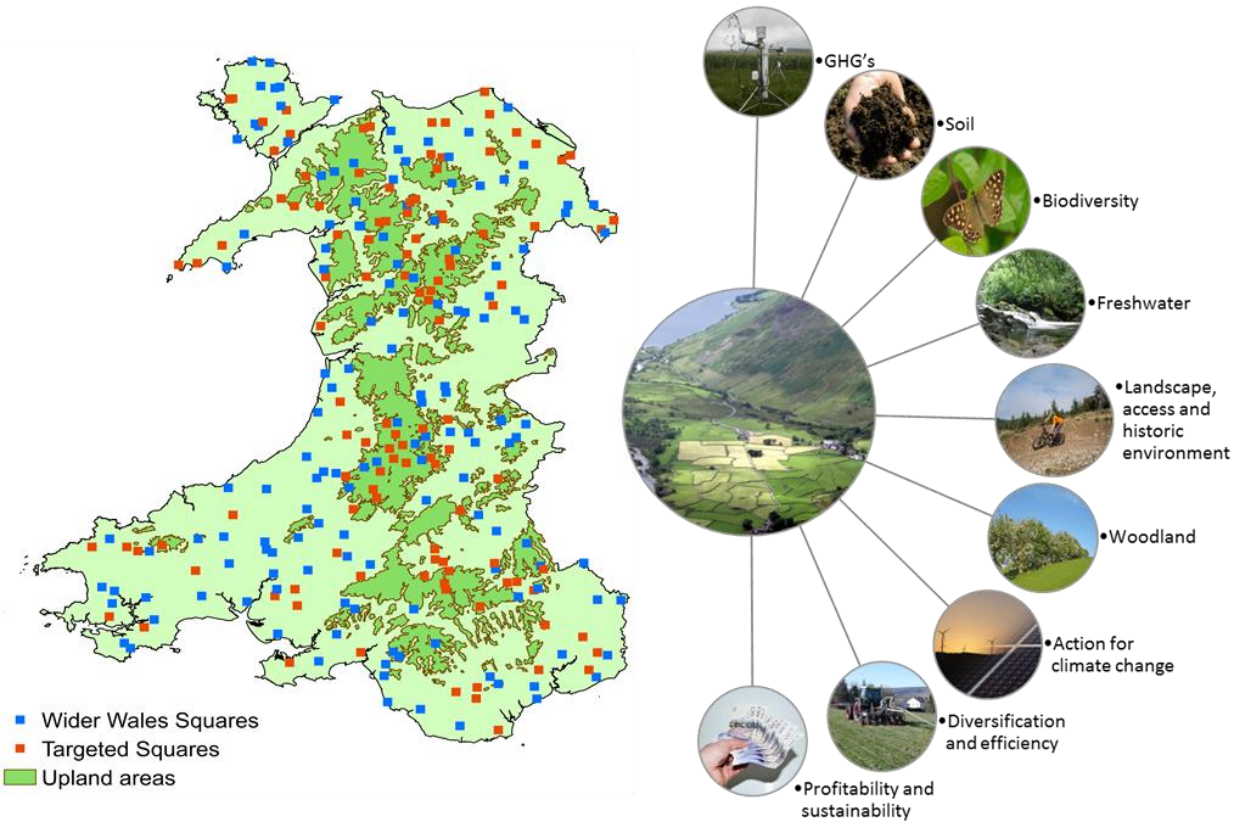
The Auditor General for Wales in 2014 requested two additional strategic objectives for Glastir. These are to use the agri-environmental investment in a way that encourages positive environmental outcomes, but also contributes towards:

- farm and business profitability and the wider sustainability of the rural economy farm and business profitability and the wider sustainability of the rural economy;
- an increase in the level of investment into measures for climate change adaptation, with the aim of building greater resilience into both farm and forest businesses and the wider Welsh economy and environment to ongoing climate change

To respond to these new objectives, three additional outcomes for reporting were agreed for GMEP (FIGURE-GMEP-OVIEW-A-1):

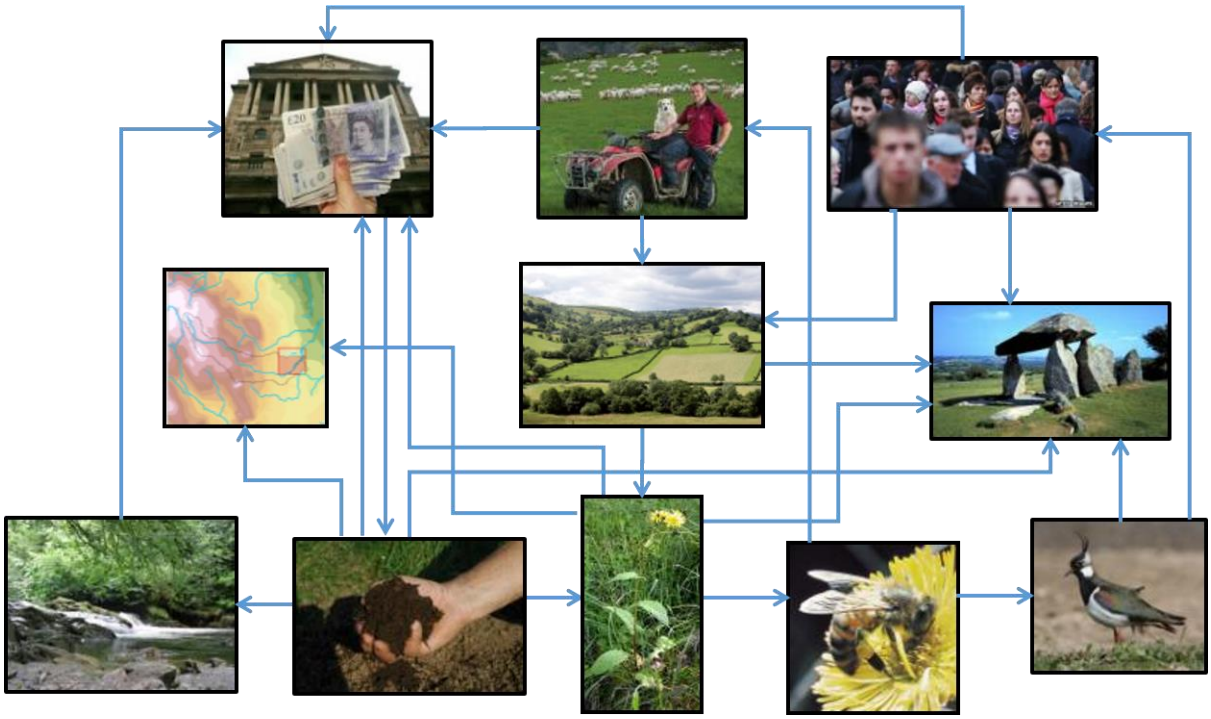
- Improving numbers of farms undertaking action concerning climate change
- Improving diversification and efficiency of farms
- Improving profitability and wider sustainability

FIGURE-GMEP-OVIEW-A-1: Location of GMEP survey squares and Glastir Outcomes



The design of GMEP provides a fundamental, robust and objective data source which can underpin a wide range of scheme and policy questions whilst being flexible to changing policy priorities. GMEP also takes an integrated approach which recognises the feedbacks and interaction between people, our natural resources and the services and the benefits they provide (FIGURE-GMEP-OVIEW-B-1).

FIGURE-GMEP-OVIEW-B-1: The complexity of just some of the interactions between people, services and benefits which are supported by our natural resources.



Glastir impacts will be superimposed on top of a wide range of local and global drivers such as climate change, air pollution and change in land management practices in response to a range of technological, social and economic drivers and constraints. The challenge of future assessment work to establish the impacts of Glastir will be to isolate the changes which can be directly attributable to the Glastir scheme (FIGURE-GMEP-OVIEW-C-1).

Much of our data is co-located is a systematic survey which recognises the interaction and feedback between our natural resources and the benefits they deliver. GMEP focuses on gathering fundamental evidence which can be combined into a range of different indicators as priorities change. Field measurements capture diversity and condition (and in some cases stock) of habitats, vegetation, soil, water, historic features, pollinators, birds, footpaths and landscape visual quality. This integrated approach is a key requirement of the Environment (Wales) Act 2016. The potential to develop multiple indicators of condition for each ecosystem property and their spatial

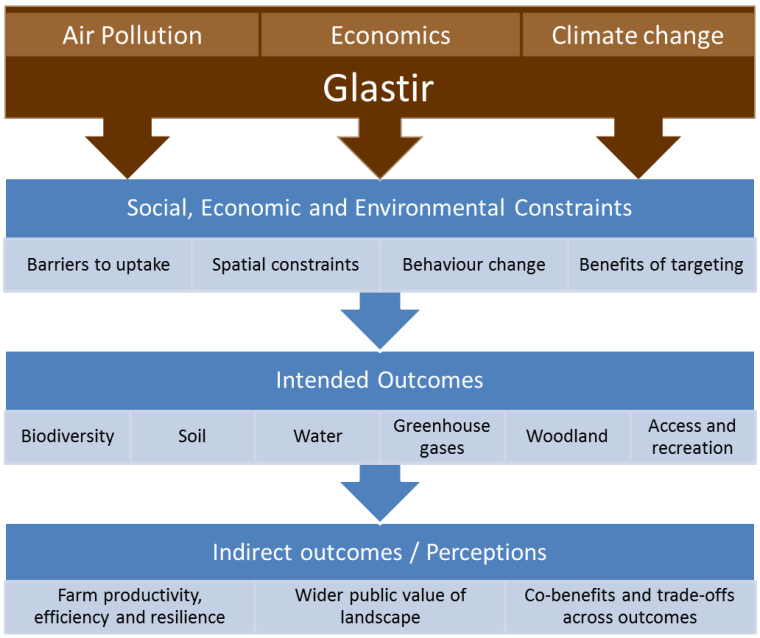


FIGURE-GMEP-OVIEW-C-1: Illustration of range of drivers superimposed on Glastir interventions, some constraints which may limit Glastir uptake, direct and indirect outcomes to services

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 and the impacts of Glastir and identify the lag times e.g. from change in soil condition to a change in vegetation composition. This approach also provides an opportunity to identify the indirect impacts of Glastir interventions beyond their primary intended target whether they are beneficial or a trade-off between one outcome and another.

The GMEP team which has delivered this comprehensive programme comprises a mix of organisations with different specialisations covering the different schemes activities, objectives and outcomes. This multi-organisation approach is an example of the partnership approach encouraged by the Environment (Wales) Act 2016. The programme is led by the Natural Environment Research Councils' Centre for Ecology & Hydrology (CEH), an independent public research body. The programme consortium has been changed over the lifetime of the programme according to shifting priorities from the Welsh Government (WG) and has included work by the following organisations: ADAS, APEM, Bangor University, BiodiverseIT, Biomathematics and Statistics Scotland, Bowburn Consultancy, British Geological Survey, British Trust for Ornithology, Butterfly Conservation, Ecological Surveys Bangor, ECORYS, Edwards Ecological Services Ltd, Freshwaters Habitats Trust, Staffordshire University, University of Aberdeen, University of Southampton, University of St Andrews, University College London and Victoria University of Wellington, New Zealand.

Over the whole programme, work focussed on biodiversity (including woodland habitats) accounts for 47% of the total GMEP budget, 36% is allocated across soils, waters, climate change mitigation, landscape and historic features, trade-offs and co-benefits, and the remaining 17% allocated to underpinning activities such as informatics, the GMEP data portal and project management.

In summary, GMEP contributes towards the empirical evidence base for the current state and integrity / condition of Wales's natural assets (termed natural capital) and provides the baseline for future assessments of the Glastir scheme outcomes. Other sources of information include State of Natural Resources Report (2016)[1] and glastir evaluations such as the Glastir Woodland Element Up-take Survey (2015)[2].

2. GMEP activities

GMEP activities have included a combination of field survey, data integration, development of new indicators, scenario modelling and social surveys[3]. A subset of the large number of GMEP results has been agreed with the Welsh Government and the GMEP Advisory Group as high level indicators and these are highlighted in this report. Many more results and a description of all methods are available in the Final Report Annexes which are available on the GMEP portal (https://gmep.wales/). In brief GMEP activities included:

[1] www.naturalresources.wales/sonarr

[2] http://gov.wales/funding/eu-funds/previous/project-evaluations/glastir-woodland/?lang=en

[3] Emmett, B. A. (2013) An integrated ecological, social and physical approach to monitoring environmental change and land management effects: the Wales Axis II Monitoring and Evaluation Programme'. Aspects of Applied Biology, 118: 31-39.

2.1 Field survey

Structured unbiased reporting of ongoing national trends of widespread habitat, soil and landscape types across the rural and peri-urban landscape. This 'Wider Wales' survey of 150 1km were sampled over a 4 year period between 2012 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 represents 0.7% of Wales land area and the number of squares needed was calculated using power analyses of past Countryside Survey data to ensure national trends of change would be detected for some common metrics (Annex 1). The land surveyed captured a higher proportion of designated land types (2%) reflecting both the efficiency of the stratified sampling approach and the targeting of Glastir payments for many biodiversity outcomes. With respect to the field survey, whenever possible the programme has used methods employed in past national surveys such as Countryside Survey (http://www.countrysidesurvey.org.uk/) which enables longer term trends to be reported and thus the impacts of Glastir to be put into historical context of changes resulting from other drivers. Confidentiality of the square locations is maintained to reassure land owners additional action by statutory authorities cannot be triggered and to prevent land owner fatigue by un-authorised follow-up studies.

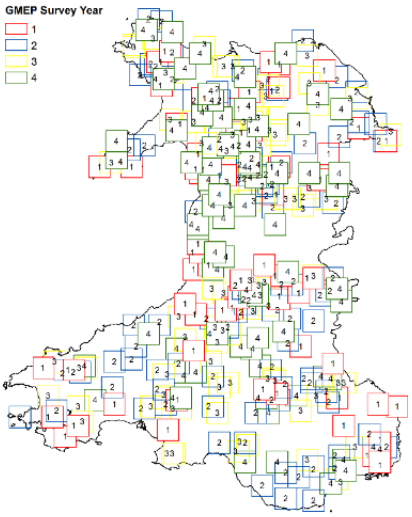


FIGURE-GMEP-OVIEW-D-1: Distribution *of GMEP 1km survey squares but enlarged and relocated within a 10km grid to protect locations. Squares include Years 1-4 Wider Wales Survey and Targeted Survey*

- A baseline survey for assessing future Glastir impacts. This involved a structured sampling of 150 1km squares in land targeted for Glastir payments (the Targeted Survey). Prior to square selection, land was weighted according to the eligibility of land for payments in Years 1 and 2 as no uptake data was available, and land which had come into the scheme when uptake data became available in Years 3 and 4 to ensure an adequate sampling of land in scheme (49% of land surveyed) compared to out of scheme (51% of land surveyed). The Targeted Survey employed identical methods for field survey as for the Wider Wales survey to allow the Wider Wales survey to act as the control (i.e. counterfactual) population.
- Assessment of the type and condition of land in scheme compared to the national average.
- Assessment of the long term legacy effects of past agri environment schemes (Tir Cynnal and Tir Gofal).
- Quantification of metrics associated with resilience (area, condition, diversity and connectivity)

Analysis and comparison of GMEP national trend data with data from other national schemes and the development of new indicators and products.

- New analysis of data from other long term national monitoring schemes (Natural Resources Wales small rivers data; BTO/RSPB/RSPB Breeding Bird Scheme; unstructured, citizen science data analysed by the Biological Records Centre (http://www.brc.ac.uk/).

- Comparison of GMEP results with data from other national schemes (e.g. CADW historic monument condition assessment; the Welsh Government footpath condition data) to provide historical context or to augment information from other schemes (e.g. National Forest Inventory data).
- Development of new metrics (e.g. an objective and repeatable public perception Landscape Visual Quality Indicator; a new Priority Bird Indicator; a new approach to assess habitat suitability for a range of Priority species; a new unified peat map; a proposed new approach to report on High Nature Value Farmland – a requirement of EU reporting)

2.2 Exploitation of new technologies

- Exploitation of satellite and aerial photography to assess land condition and function e.g. (i) objective and repeatable metrics which reflect overall peatland condition and their consequences for greenhouse gas emission source combining soil mapping data, land-cover data and the use of aerial photographs to map drainage ditches; (ii) a net primary production map for Wales through testing and calibration of satellite imagery with field survey; and (iii) a new fine resolution Woody Cover Product which captures small-scale woody features such as hedgerows and small patches of trees using a combination of airborne radar data, optical imagery from satellites and data from the National Forest Inventory.

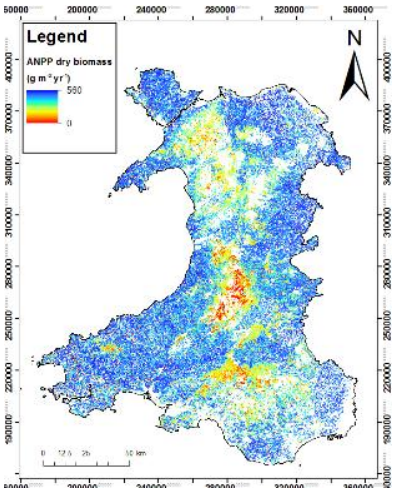


FIGURE-GMEP-OVIEW-E-1: Annual net primary productivity map for Wales produced using Landsat 5 TM imagery from 2011

- Molecular genomic approaches to assess soil biodiversity and presence of pathogens building on the eDNA work pioneered by Countryside survey in 2007 which led to the first national GB map for soil bacteria diversity[4]. GMEP is the first ever repeat of a soil biodiversity survey at a national scale. The role of soil biodiversity for soil function and resilience is a very active research area in the soils community.

2.3 Scenario Modelling

- Scenario modelling to project likely impact of Glastir interventions on water quality, greenhouse gas emissions, habitat suitability for indicator plant species, land accessible to broadleaved focal species, land mitigated for flood, carbon sequestration and whole farm carbon footprints.
- Scenario modelling for climate change impact on soil and biomass based greenhouse gas emissions (excludes agricultural activity / ruminant animals).
- Opportunity modelling to identify land where there are significant opportunities to create woodland and optimise multiple ecosystem services to help inform future schemes.

2.4 Social research and surveys

- A structured survey of 600 farms in Year 4 to:
    - Establish farm level changes in management that are reported by farmers as a direct response to Glastir management options.

[4] P:\Wales agri-environment monitoring\Team Publications and presentations\2017\Final report\Outcome summary 2017\2nd stage draft\outcome images

    - Account for background level of change on non-scheme farms in response to other drivers of change, including farm economics and set within the context of national long-term trends in nutrient inputs and livestock numbers
    - Provide evidence of investment by farms into measures for climate change adaptation and the enhancement of business profitability and the wider sustainability of the rural economy.
- A series of 4 focus groups, with 22 individual and 9 interviews with Local Authority Officers to understand barriers to the uptake of Glastir woodland options
- Interviews with 16 farms to quantify using farm data whole farm carbon footprints and the impact of the Glastir Efficiency Grant scheme using a semi-structured approach.

3. The Glastir scheme

3.1 Glastir design

The operation of the Glastir scheme retains the basic model of the preceding Tir Gofal scheme [5] and operates as system of points and payments for adoption of management options. Glastir is composed of an Entry (GE) level element that is accessible to all farmers in Wales, an upper level Advanced (GA) element which spatially targets issues of concern in pre-defined priority areas (addressing soil carbon management, water quality, water quantity, biodiversity, the historic environment, and improved access), a Commons element (GC), the Efficiency (GF) capital grant element, an Organic farming (GO) element, and a stand-alone Woodland (Creation and Management) (GW) element[6]. Farms participating in Glastir are required to adhere to a Whole Farm Code that concerns record keeping and habitat protection, and prohibits some practices such as application of livestock manures when soils are waterlogged. When introduced, participants were required to join the Entry level scheme before progressing to the Advanced scheme. This is no longer necessary and participants can join the Advanced scheme directly. (See Annex 2 for a fuller description of this section).

Prior to Glastir, between 1999 and 2009, support for agri-environmental action under Axis 2 was provided by four schemes: Tir Cynnal (TC), Tir Gofal (TG), Tir Mynydd (TM) and the Organic Farming and Maintenance Schemes (OFS). The TC scheme was an entry-level scheme that ran between 2005 and 2013 with first payments made in 2006. Participants were required to prevent erosion of biodiversity through protecting wildlife habitats (and have a minimum 5% of the farm area in a wildlife habitat), and expected to complete a Farm Resource Management Plan specifying the actions that need to be taken to remove the risks to the environment from their current farm practices, including the use of potential pollutants such as fertiliser, manures and chemicals. The TG scheme was launched in the year 2000 and the last agreements concluded in 2015. It had stricter requirements than the TC scheme and imposed an obligatory suite of measures going beyond mandatory requirements (GAEC) for good environmental practice, and obligatory conservation and sustainable management of priority habitats. It provided for optional payments for capital works and management for the restoration and preservation of habitats and landscape features. The OFS was

[5] Auditor General for Wales (2014) Glastir. Welsh Audit Office, 63 pp.

[6] Rose, H. (2011) An introduction to Glastir and other United Kingdom agri-environment schemes. National Assembly for Wales, Paper No. 11/012, 22 pp.

introduced in 1999 and provided area payments for organically certified fields to farmers to help them convert from conventional to organic farm management, and to sustain the change. The TM scheme supported livestock production in the less productive farming areas by a direct forage area payment. At their peak, there were 7,600 participants in Tir Cynnal and Tir Gofal, managing 52% of the total utilised agricultural area in Wales.

There are currently 4,600 participants in the Glastir Entry level scheme, including 1,400 in the Advanced level and 500 in the Decoupled Advanced, managing 37% of the total utilised agricultural area in Wales. At their peak, there were 7,600 participants in the past agri-environment schemes Tir Cynnal and Tir Gofal, managing 52% of the total utilised agricultural area in Wales.

Environmental payments, generally between £1,000 and £10,000 per farm annually[7] contribute to total farm income. Environmental payments to farms in Wales average between <1 and 10% of total farm output, and are highest for hill cattle and sheep farms, in comparison to the Single Payment Scheme that accounted for between 6 and 23% of total farm output. Overall, the total direct payments made to farms through Glastir were £37 million in 2015 (and provisional sum of £40 million in 2016), compared to a total of £208 million (£221 million in 2016) under the Single Payment Scheme[8].

The agricultural sector accounts for 4.1% of all employment in Wales. Total labour engaged on farms in Wales was 58,300 in 2015, showing little change from 57,100 in 2005[9]. The majority of workers are family (77%) with only small numbers of full-time non-family (6%), part-time non-family (8%) and seasonal or casual workers (9%)[10]. Total income from farming in Wales is £201 million in 2014/15. Annual average farm business income varied from £22,500 and £25,500 for grazing livestock (Less Favoured Area and Lowland, respectively) to £42,000 for dairy farms, but an estimated 19% of farms in Wales had a net farm business income less than zero.

3.2 Uptake of Glastir

Uptake of Glastir has been highly variable across Wales (FIGURE-GMEP-OVIEW-F-1). Powys, Gwynedd and Ceredigion has the greatest area in scheme whilst in terms of proportion of land Gwynedd, Conwy and Powys have the highest percentage of land in the scheme.

[7] Wales Farm Income Booklet. 2014/15 Results The Farm Business Survey in Wales. Aberystwyth University.
[8] Defra Agriculture in the United Kingdom, 2015, 2016.
[9] Welsh Government (2016) Farming facts and figures, Wales 2016. 6 pp.
[10] Wales Rural Observatory (2010) Survey of farming households in Wales. Aberystwyth University and Cardiff University, 122 pp.

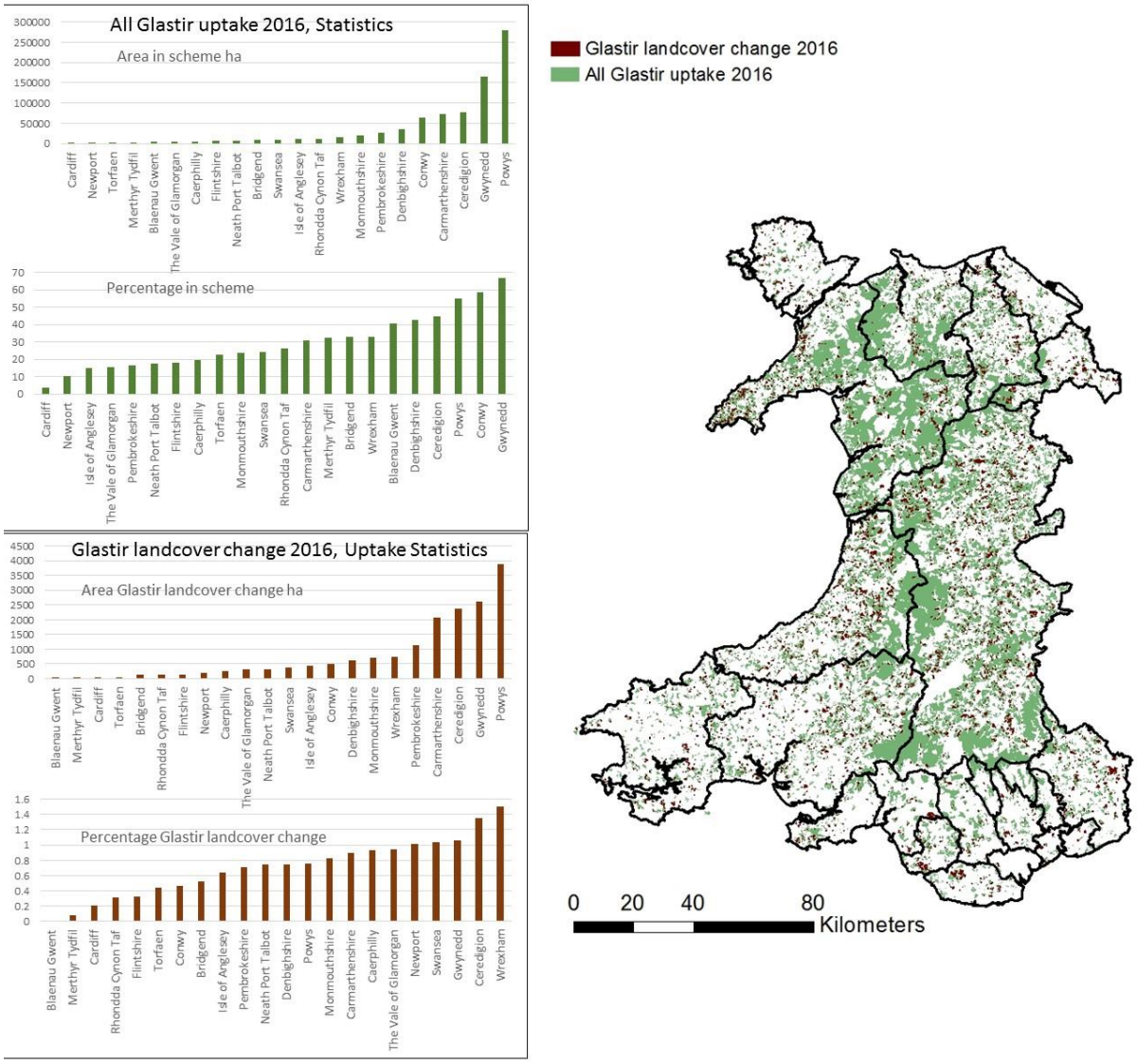


FIGURE-GMEP-OVIEW-F-1 Distribution of total Glastir uptake by county and that involving landcover change only

The spatial link between the levels of uptake achieved were compared to spatial prioritisation of payments available for each parcel of land by Welsh Government based on a points system in 2015. This provides an insight as to whether targeting of money (through the points system) influenced uptake which presumably was the intention of the targeting and point approach. (FIGURE-GMEP-OVIEW-G-1).

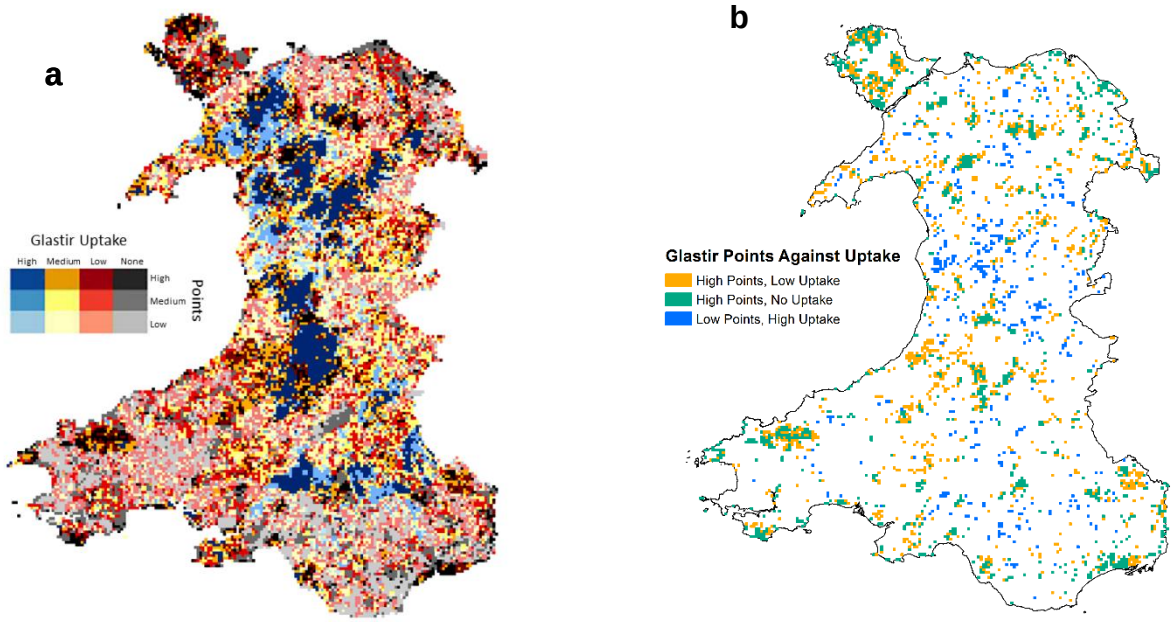


FIGURE-GMEP-OVIEW-G-1: a *Comparison of uptake by farmers compared to total points available across all outcomes;* **b** *Simplified figure highlighting the extremes of Figure a. Data used includes land in scheme by end 2015.*

A clear relationship can be seen with only 308km^2 or 1.5% of Wales where there was high uptake in areas with low points. However, there was 3041km2 (ca. 15% of Wales) with high points where there was little or no uptake. This was related to poor uptake of the Woodland Creation scheme (18km^2 / 578 grants) – the reasons for which were explored by GMEP (Annex 3 and 6) and in the Woodland Element Survey[11]

3.3 Glastir related changes in management practices reported by farmers

A Farmer Practice Survey in 2016 was used to quantify actual changes in livestock numbers and fertiliser use undertaken by farmers participating in the Glastir scheme, and compared the uptake of farm management plans and diffuse pollution control actions with non-scheme farms. The survey is stratified by enterprise type (dairy, beef and sheep) and level of scheme participation. A full description of the methods and results are in Annexes 2-5. It is compatible with a survey of the preceding Tir Cynnal and Tir Gofal agri-environment schemes [12] and designed to assess the level of additionality achieved by Glastir and the persistence of any changes in management delivered by Tir

[11] http://gov.wales/funding/eu-funds/previous/project-evaluations/glastir-woodland/?lang=en.

[12] Anthony, S., Jones, I., Naden, P., Newell-Price, P, Jones, D., Taylor, R., Gooday, R., Hughes, G., Zhang, Y., Fawcett, L., Simpson, D., Turner, A., Fawcett, C., Turner, D., Murphy, J., Arnold, A., Blackburn, J., Duerdoth, C., Hawczak, A., Pretty, J., Scarlett, P., Laize, C., Douthwright, T., Lathwood, T., Jones, M., Peers, D., Kingston, H., Chauhan, M., Williams, D., Rollett, A., Roberts, J., Old, G., Roberts, C., Newman, J., Ingram, W., Harman, M., Wetherall, J. and 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, AgriEnvironment Monitoring and Technical Services Contract Lot 3: Soil, Water and Climate Change (Ecosystems), No. 183/2007/08, Final Report, 477 pp + Appendices.

Cynnal and Tir Gofal. The surveyed changes in management and scheme records of options taken up were used as input to the ADAS FarmScoper computer model of pollutant emissions from agricultural land to calculate the national scheme effect (Annex 5 and Section 4.6 and 4.7).

The results indicate farms participating in Glastir reported a net 9% reduction in manufactured nitrogen and phosphate fertiliser use on grassland fields on scheme entry, and a net 6% reduction in breeding ewe numbers for farms in the Advanced level only. There were non-statistical significant in the numbers of beef sucklers, beef finishers or dairy cows (with the changes for finishers and dairy animals being small increases in stock numbers).

These reductions are significantly different relative to out of scheme farms with the exception of nitrogen fertiliser reductions. Fewer than 5% of Glastir participants recorded an increase in the use of nitrogen fertiliser as a result of their present Glastir agreement, with the majority (35%) recording a decrease. The 9% reduction in nitrogen fertiliser use on grassland fields was equal to the net reduction occurring on surveyed non-scheme farms that provided a measure of background rate of change due to other causes. According to the questionnaire design, the change due to scheme agreement and background rate of change ought to be independent and additional. However, a high percentage of Glastir farms cited fertiliser cost (50%) and change in stock numbers (37%) as a factors also influencing their decision to change fertiliser rates. These were also important influences of change on the non-scheme farms. Therefore the effect of Glastir scheme participation cannot be considered as totally independent and in addition to the changes recorded on non-scheme farms. However, we are confident that a reduction due to Glastir did occur as the recorded net reduction is also in agreement with prevailing fertiliser application rates and the area of permanent grassland on which scheme options taken up by farmers explicitly restricted nitrogen fertiliser use.

In scheme farms also had the following improvements relative to non-scheme farms:

- 10% increase in the likelihood of calibrating fertiliser spreaders (from 62% to 72%)
- 10% increase in the likelihood of carrying out soil nutrient testing (from 51% to 61%).
- 6.8% more farms covering manure heaps and 8% increase in calibration of manure spreaders and more likely to increase the size of slurry store
- 18% more likely to have completed nutrient (from 41% to 59), manure (64% to 76%) or soil protection reviews (52 to 58%) than non-scheme farms.
- 29% more likely to have fenced off streams
- 26% more likely to have established vegetation and uncultivated buffer strips
- 15% more likely to have left stubble in fields to provide over-winter cover (from 44% to 59%).

3.4 GMEP coverage of the scheme and designated land

Coverage of land in and out of scheme was 49% and 51% respectively indicating a good balance and adequate counterfactual for future analyses. Landowners granted access to 75% (scheme and none scheme holdings) of the total land area within the 300 1km squares. A major problem gaining access to land is the lack of information on the owners of 25% of land in Wales as the GMEP team were not allowed to cold call to establish ownership. It should be noted this constraint on the GMEP team and all other public surveys contrasts with the increasing use of citizen science for government statistics

which does allow for cold-calling (e.g. the new England and Wales pollinator survey) even though the disturbance to the landowners is presumably the same.

There is a good match of Glastir options within GMEP survey squares and options taken up across all of Wales (Annex 7). Knowledge of where options have been taken up were used to inform square selection in Years 3 and 4 rather than using the proxy of available points which had to be used in Years 1 and 2. This increased capture of Glastir Advanced options in Years 3 and 4. Faster access to uptake data would benefit survey design if a similar approach is taken in the future.

An assessment in 2015 identified that Entry Level element was present in 63% of GMEP survey squares, with the other elements lower at between 2 and 53% squares. Surveyed options counts ranged from 4 to 135, with the highest number from the Advanced element, and the lowest the Woodland Creation element. Biodiversity accounted for the largest amount of surveyed uptake at 78% of GMEP survey squares, with the other non-Woodlands Outcomes between 72 – 77% squares, and Woodlands the lowest with only 37% of squares. Biodiversity was also the largest overlay for options counts, at 89, with the remaining Outcomes ranging from 36 to 77 options (Figure XX). Note that the intended Glastir Outcome was based on expert judgement by the GMEP team as this data was not available from Welsh Government.

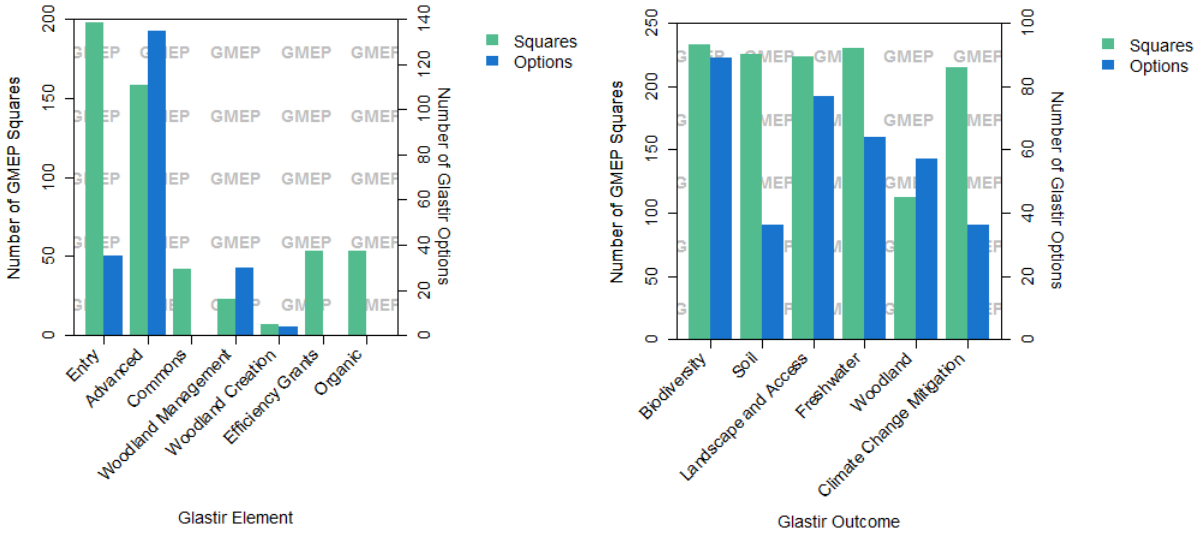


FIGURE-GMEP-OVIEW-H-1: Coverage of a) Glastir options and b) Glastir Outcome by the full baseline GMEP field survey 2013-2016.

Within these squares, the following were surveyed for a wide range of natural resource and landscape properties including birds and pollinators, soils and headwater streams, historic features and footpath condition, hedgerows and woodlands. Examples of the scale of the survey include:

- 7489 botanical plots surveyed.
- 5226 soil samples taken from 1388 plots coincident with permanent botanical survey.
- 9096 point features identified and assessed.1
- 1050 surveys of birds (April – July).
- 596 surveys walking 2384 km of transects to count butterfly species, bee and hoverfly groups plus timed searches within 178,800m^2
- 2979 km of linear features (hedgerows, stream banks etc.).

- 167 streams and 119 ponds assessed. First survey of its kind to simultaneously monitor freshwater invertebrates, diatoms (streams only), physical habitat, water chemistry, in both ponds and streams.
- 204 historic features assessed for their condition.
- 8738 landscape photos taken to provide a baseline for future assessment of change in our landscape 'Visual Quality Indicator'

A full description of methods are available in Annex 1.

The survey covered a higher proportion of designated land relative to national average with reflecting the benefits of the stratification approach taken and the priority given to biodiversity in Glastir.

TABLE-GMEP-OVIEW-A-1: Coverage of designated land by GMEP

Designated land type	Area (ha)	%
SSSI	4656	2.12
National Nature Reserves	479	2.2
National Parks	8362	2.07
Natura 2000	3693	2.52
Special Protection Areas (SPAs)	2526	3.07
Special Areas of Conservation (SAC's	2989	2.36

Future work could provide an assessment of the general condition of designated lands benchmarked against national trends average e.g. is change in soil condition above or below that of the national average? Are there more or less Common Standard Monitoring species indicative of good condition relative to the national average? This could provide evidence of a co-benefit of designation beyond that of the condition of features for which the land was designated which would require a specific assessment.

4. GMEP results by Glastir Outcome

A subset of indicators was agreed with the GMEP Steering Group to provide a high level overview of the six intended Outcomes of the Glastir scheme. For each Outcome, these indicators are reported as either 'positive outcomes' or 'areas of concern or a need for further action' for:

- Glastir Impacts
- National Trends

Short *Headline Results* are also included for related questions that were addressed with GMEP data relating to the:

- Assessment of land in Glastir relative to national averages or land out of scheme
- Legacy effects of past agri-environment schemes
- Attribution of land as 'High Nature Value' farmland
- Characterisation of land with respect to properties which can increase resilience
- New products and maps

Finally, the report ends with a high level summary of GMEP results.

4.1 Diversification and Efficiency

Outcome: Improving diversification and efficiency of farms

The extent to which farm managers had taken action to improve aspects of the farm business was quantified by survey of 600 farms across Wales, representative of the dairy, beef and sheep enterprises. For each aspect of resource efficiency and diversification the number of farm managers claiming to have taken any action in the past 3 years were recorded. Members of Glastir were also asked whether the scheme had supported action. Full methods and results are available in Annexes 2 - 4. A survey of 15 farms in the Glastir Efficiency Grant scheme was carried out to quantify changes in production efficiency. A full report is available in Annex 8.

Glastir Impacts

Positive Outcomes

- 4% increase in number of farms reporting they were undertaking actions to improve diversification and efficiency of their farms compared to non-scheme farms (from 16% to 20%). This included the following specific increases:
    - +11% to improve nutrient efficiency
    - +17% to increase business diversification (Glastir Advanced only)
    - +8% to combat soil erosion
    - +13% to prevent biodiversity loss
- 9.5% and 18% decrease in the average carbon footprints expressed per kg of lamb live weight and milk on surveyed farms in receipt of Glastir Efficiency Grants, indicating improved production efficiency. These results include embedded emissions resulting from the production and transport footprints of materials bought and used by the farm (such as animal feeds, fertilisers and plastic sheeting in the Bangor Carbon Footprinting Tool). These embedded emissions are not included in current national inventories but are important to consider if emissions are not to be exported, thus complying with the WFG goal of a Globally Responsible Wales.

FIGURE GMEP-OVIEW-I-1 Share of actions taken by farm managers for business improvement, by aspect of resource efficiency and diversification, all surveyed farms (n 508).

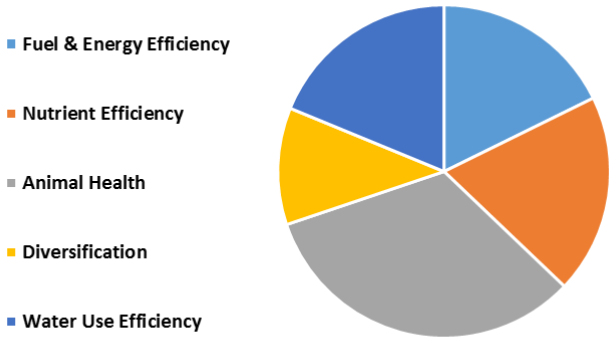


TABLE-GMEP-OVIEW-B-1: Percentage (%) of farms taking action for business improvement, by farm type and aspect of resource efficiency and diversification (n 508) Glastir

Farm Type	Aspect of Business Improvement				
	Fuel & Energy Efficiency	Nutrient Efficiency	Animal Health	Diversification	Water Use Efficiency
Dairy	59	62	79	23	51
Beef & Sheep	28	32	62	23	26

National trends

Positive outcomes

- Improvement in Welsh farm practices between 2009 and 2016. This is particularly the case for manure management on cattle & sheep farms. These actions concerned activities relating to the improvement of farm business through more efficient use of resources and control of diffuse water pollution that were relatively simple to implement and involved a low capital cost, such as soil nutrient testing and calibration of the fertiliser spreader. These management actions have been encouraged through government and agricultural sector advice and guidance, most notably the Code of Good Agricultural Practice, Cross Compliance, Tried and Tested and Farming Connect. Increase in specific soil management actions was particularly observed for dairy farms on grassland fields.

4.2 Profitability and wider sustainability

Outcome: Improving profitability and wider resilience

The extent to which farm managers had considered Glastir had improved farm viability, changed their management practices and improved wider sustainability was quantified by survey of 600 farms across Wales, representative of the dairy, beef and sheep enterprises. Full methods and results are available in Annex 2, 3 and 4.

Glastir impact

Positive Outcomes

- 77% of respondents stated farm viability had increased as a consequence of receiving the Glastir Efficiency Grant, with 21% reporting no change.
- More than 90% of respondents agreed that the Glastir Efficiency Grants had encouraged them to undertake new capital investments whilst 83% agreed that access to the grant increased their scale of planned investment.

Areas of concern / need for further action

- 34% of participants in the Glastir Entry and Advanced schemes agreed that participation in an agri-environment scheme had ‘changed my management of the farm’ compared to 61% of participants in the Tir Cynnal or Tir Gofal schemes. The response by the Glastir

participants was unaffected by any history of participation in the previous schemes. It should be noted this may reflect the intention of providing legacy and continuity between schemes.

- There was no reliable evidence of a change in the overall number of persons employed on farm, although farm diversification was most frequently associated with an increase.

4.3 Climate Change adaptation

Outcome: Improving numbers of farms undertaking action concerning climate change

The extent to which farm managers had taken action to adapt to climate change threats was also quantified to identify if the knowledge, financial and organisational support provided through participation in Glastir may help advance adaptation with the aim of building greater resilience into both farm and forest businesses and the wider Welsh economy and environment to ongoing climate change. Full methods and results are available in Annex 2, 3 and 4.

Glastir impact

Positive Impacts

- 17% increase in number of farms in scheme compared to non-scheme farms reporting they were undertaking actions concerning climate change including actions concerning flood, drought, soil erosion, biodiversity, pests and disease and heat stress (from 37% to 54%).
- 15% increase in investment by farms in scheme in on-farm renewable energy production (from 21% to 36%) although it is suspected that this is an attribute of the participants rather than an effect of scheme. Current capacity is sufficient to off-set an estimated 1% of net greenhouse gas emissions from agriculture.
- A majority (70%) of farms participating in Glastir and who had taken action on climate adaptation also explicitly acknowledged the support provided by the scheme. This included provision of relevant information (72%) and receipt of grants for capital investment (53%).

FIGURE GMEP-OVIEW-J-1: Share of actions taken by farm managers for adaptation to climate change threats, all surveyed farms (n 508).

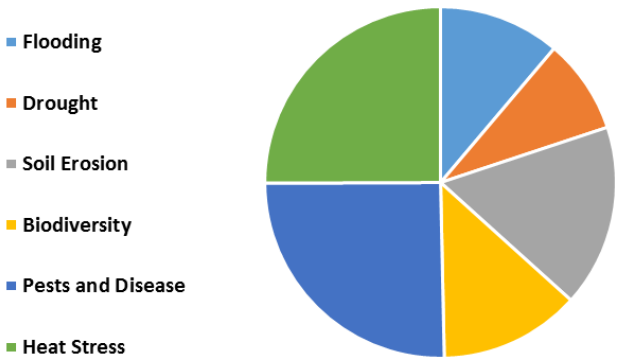


TABLE-GMEP-OVIEW-C-1: Percentage (%) of farms taking action for adaptation to climate change threats, by farm type and threat (n 508)

Farm Type	Climate Change Threat					
	Flooding	Drought	Soil Erosion	Biodiversity	Pests and Disease	Heat Stress
Dairy	9	9	22	13	27	36
Beef & Sheep	9	7	13	11	20	18

4.4 Woodland

Outcome: Woodland creation and management

The Welsh Government is committed to planting an additional 100,000 ha of woodland by 2020 to provide ecosystem services, especially relating to wildlife habitat and carbon sequestration[13]. As farmland covers approximately 71% of land in Wales, much of this new woodland will need to be planted on current farmland[14]. Farms presently manage approximately one quarter, or 75,700ha, of the current woodland area[15]. Supportive measures to encourage farm woodland restoration and planting have been in place since the 1950's [16] through various schemes and grants, with Better Woodlands for Wales being the most popular until it ended in 2011. The uptake of these schemes by farmers was increasing between 2000 and 2013.

Only around 5% of woodlands in Wales have been designated for their international and national importance to nature conservation and of this only 26% is classed as in a favourable condition. However, woodlands can be used for a wide range of services with some bringing financial gains. At present only 3% of farm woodlands are used commercially, with the majority of farm woodlands not appearing to generate any kind of income[17].Therefore, there is also a desire to increase the proportion of farmers harvesting firewood and timber from their woodland or generating income from woodlands in other ways in order to contribute to the resilience of the agricultural sector.

Here we present a selection of indicators as a high level summary of ongoing change in this important ecosystem. As the field survey methodology used in GMEP is identical to that used in Countryside Survey these datasets can be combined to look for long-term national trends. Future surveys can use the baseline data to assess the impacts of Glastir payments. For reporting purposes GMEP focuses on small woodlands and metrics of condition relating to natural resources rather than yield. The national estimate for all woodlands is different to Forestry Commission data due to smaller samples size but also due to the capture of small woodland parcels by GMEP (< 0.5ha) which are not currently included in Forestry Commission data. These small woodlands are more likely to be targeted for Glastir payments.

[13] National Assembly for Wales, (2013) Forestry in Wales: Quick Guide. Research Service, National Assembly for Wales, Cardiff. 5 pp.
[14] Institute of Welsh Affairs, (2016) Agriculture and Food. Institute of Welsh Affairs. 56 James Street, Cardiff Bay, Cardiff. CF10 5EZ. www.iwa.wales/click/wp-content/uploads/16_Factfile_Agriculture&food.pdf, Aaccessed 27/10/2016.
[15] Grove, R., (2015). Woodlands for Wales Indicators 2014-2015. Welsh Government, Cathays Park, Cardiff, 64 pp.
[16] Forestry Commission, (2015) History of the Forestry Commission. www.forestry.gov.uk/forestry/cmon-4uum6r, Updated 08/05/2015.
[17] Marsh, R., (2013) Woodland management in Wales: Recent research and implications for policy. Rob Marsh Woodland Services and Wales Forest Business Partnership. 31 pp.

Countryside Survey / GMEP categorises an area to be woodland if it is more than 20m x 20m in area and 25% of the vegetation is above 1 m high – so recently felled areas will not be included. Various other methodological differences exist therefore it is recommended both datasets are considered together to get a complete picture as they are very complimentary. Other sources of data include:

- Biodiversity modelling work using the CEH Multimove model (Annex 9);
- Ecosystem service modelling and woodland opportunity mapping using the UVW/CEH LUCI model (Annex 10)
- Our Farmer Practice Survey (Annex 2-5)
- A semi-structured social survey of woodland managers and land owners (Annex 6);
- BTO/RSPB/JNCC Breeding Bird Survey (BBS) data

A woodland opportunity map has also been developed (see Section 8; Annex 10) which avoids conflicts with a wide range of other benefits / priorities including agricultural production, red squirrel habitat, historic features, designated land etc. and optimises for benefits for carbon and runoff / flood mitigation. This map could help future targeting of incentive schemes for woodland expansion and creation.

Impacts of Glastir

Positive Outcomes

- 11% (Entry) or 20% (Advanced) increase in the number of farms restoring or creating woodland in the past three years compared to non-scheme farms.
- Woodlands were more likely to be managed for 'wildlife habitat' rather than 'shelter for livestock' if farms were in the Advanced level of Glastir.

Area for Concern / need for further action

- Modelling work using the Multimove model indicates likely lag time of 10-23 years for soil and canopy height conditions to be suitable for 4 indicator and 1 rare woodland tree and ground flora plant species tested in response to 2 woodland Glastir prescriptions (AWE 9b; Create streamside corridor on improved land with tree planting; and AWE 24; Allow woodland edge to develop out into adjoining fields). This indicates there is a need for consistency in management if improvements in biodiversity are to be realised. (FIGURE-GMEP-W-OUTCOME-B-1; Annex 9).
- Modelling work using the LUCI model projected a 2.8% increase in area accessible to broadleaved woodland species in response to prescriptions included in Glastir contracts by the end of 2016. Area is limited by the low uptake of woodland options. (Annex 10).
- The LUCI model also estimated an additional 2.5 t yr^{-1} (0.1% increase) extra sequestration of carbon was calculated to be delivered at the cost of reduced agricultural intensity on 4,451 ha. This area was downgraded from high and very high production to moderate production or less. Limited reduction in actual production may be expected, since it is likely that less productive land was chosen for reductions in intensity of farming (Annex 10).
- Both the Farmer Practice Survey (Annexes 2-5)) and a series of focus groups and structured interviews (Annex 6) identified a series of barriers to uptake of Glastir Woodland Creation and Management Scheme. Recommendations to remove these specific scheme barriers were:
    - Application process should be simplified as operation prescriptions are a barrier

    - Scheme needs to be more flexible to account for external influences
    - Auditing process is complex. Penalties need to be clearer, auditing process less threatening
    - Payment rates are obscure. There is confusion about what is covered, rates for contractual labour
- Project Glastir impact on greenhouse gas emissions and long term trends are presented in Climate Change Section.

Baseline assessment of woodland coming into scheme compared to all of Wales

- No difference in the condition of woodlands coming into the scheme compared to national average.
- Lower connectivity of broadleaved woodland which is 73% of that found in Wales as a whole. (TABLE-GMEP-NRM-OUTCOME-A-1 in Section 6; Annex 11)
- Proportion of land in scheme which is woodland is lower than for all of Wales. Area of broadleaved woodland in scheme is 4% and for conifer 2% compared to national coverage of 6% and 7% respectively based on CEH's Landcover map 2007.

National trends

Positive Outcomes

Overall a picture of stability has emerged for our woodlands. This does not appear to reflect the ambitious targets for expansion of woodlands set by the Welsh Government nor the multiple benefits woodlands can bring for biodiversity, carbon sequestration and water regulation.

- An improvement in ancient woodland indicator plant species in large broadleaved woodlands which have increased in the last 10 years. These plants may have benefitted from shadier up until 2007 after which no change has been observed. This is not seen in small woodlands.
- Stability in all other condition metrics including connectivity, patch size and light/shade index over the last 10 years
- An increase in BTO/RSPB/JNCC Breeding Bird Survey (BBS) woodland bird indicator over the last 8 years.
- The Farmer Practice Survey identified woodland was most frequently managed all or part of their woodland for "wildlife habitat" (62%), "livestock shelter" (52%) and "fuel or firewood" (44%). The survey rankings match those reported by Cao and Elliott (2015[18]). However, Cao and Elliott (2015) make a potentially important distinction between provision of "fuel or firewood for personal use" (44%) and "to provide wood fuel for sale" (18%). Similarly, they make a distinction between "provision of a place for personal recreation and relaxation" (47%) and "to provide public access and recreation" (23%). It is clearly important to

[18] Cao, Y. and Elliott, J., (2015) Glastir woodlands and element uptake survey – Final report. Welsh Government. 110 pp.

recognise the separate private and public services resulting from woodland management. (See Annex 2-5).

Areas for concern/ need for further action

- No change in the area of small woodlands (< 0.5ha). The small amount of area planted within the scheme (3,923 ha) is within the variability of the GMEP sample. These small woodlands are the woodlands most likely to be affected by Glastir. This and the small increase reported by the National Forestry Inventory in forest area as a whole does not appear to reflect the ambitious targets for expansion of woodlands set by the Welsh Government nor exploit the multiple benefits woodlands can bring for biodiversity, carbon sequestration and water regulation.

FIGURE GMEP-W-OUTCOME-A-3: Trends in Woodland Creation and Management. Figures show:

a. Total area of Woodland in Wales;
b. Coniferous Woodland in Wales over time;
c. Total area of Broadleaved Woodland in Wales over time;
d. The area of small woodlands in Wales over time, created by national estimates from field survey (CS and GMEP)
e. Ground Vegetation Light Score as a proxy for canopy density;
f. Mean number of Ancient Woodland Indicator species;
g. A Habitat Connectivity index for Broadleaved Woodland over time (uses simple metric of straight line distance) for GMEP squares (additional data is available for all Wales in the Resilience Section of the report);
h. BTO / JNCC / RSPB Breeding Bird Survey Woodland Bird Indicator

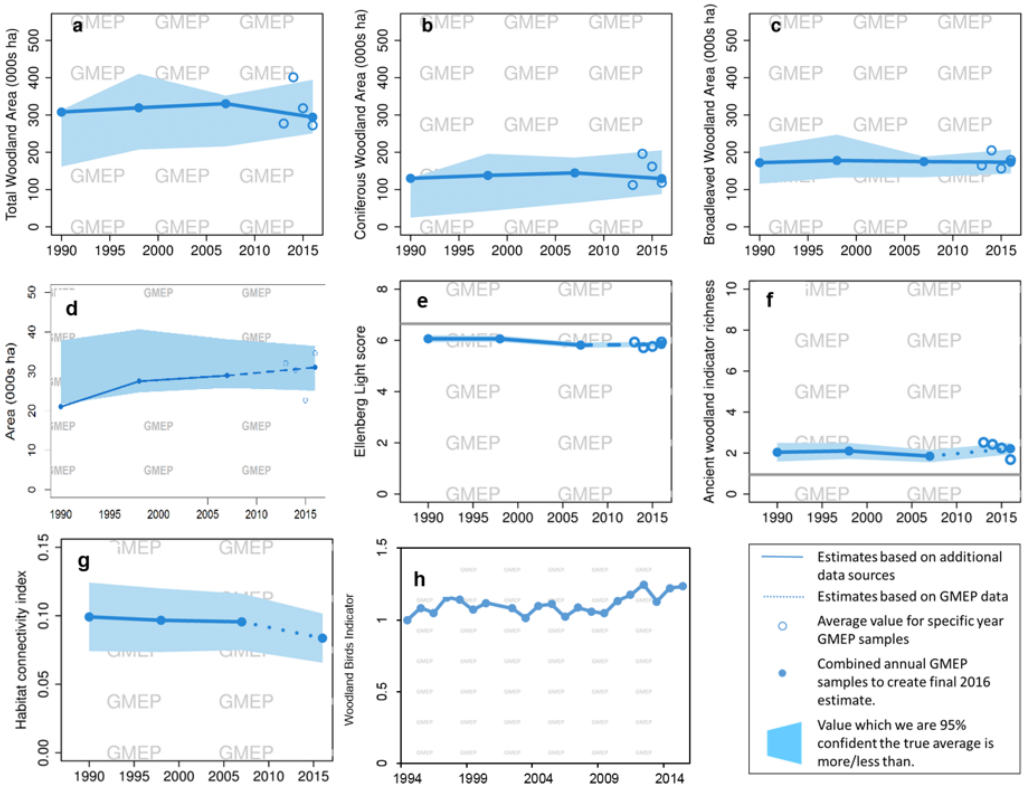


FIGURE GMEP-W-OUTCOME-B-1 Multimove model results for Woodland expansion (AWE 24) and Streamside buffer strips (AWE 9B) for 2 example target plant species. Scenarios cover 23 years of natural succession from baseline habitat of a) improved grassland or b) arable due to Glastir prescriptions relative to target habitat of broadleaved woodland. Model results are available for 5 species: blackberry (*Rubus fruticosus*), common ash (*Fraxinus excelsior),* common hazel *(Corylus avellana) and bluebell (Hyacinthoides non-scripta)* and Betony *(Stachys oficinalis).* See Annex 9 for full results and model description.

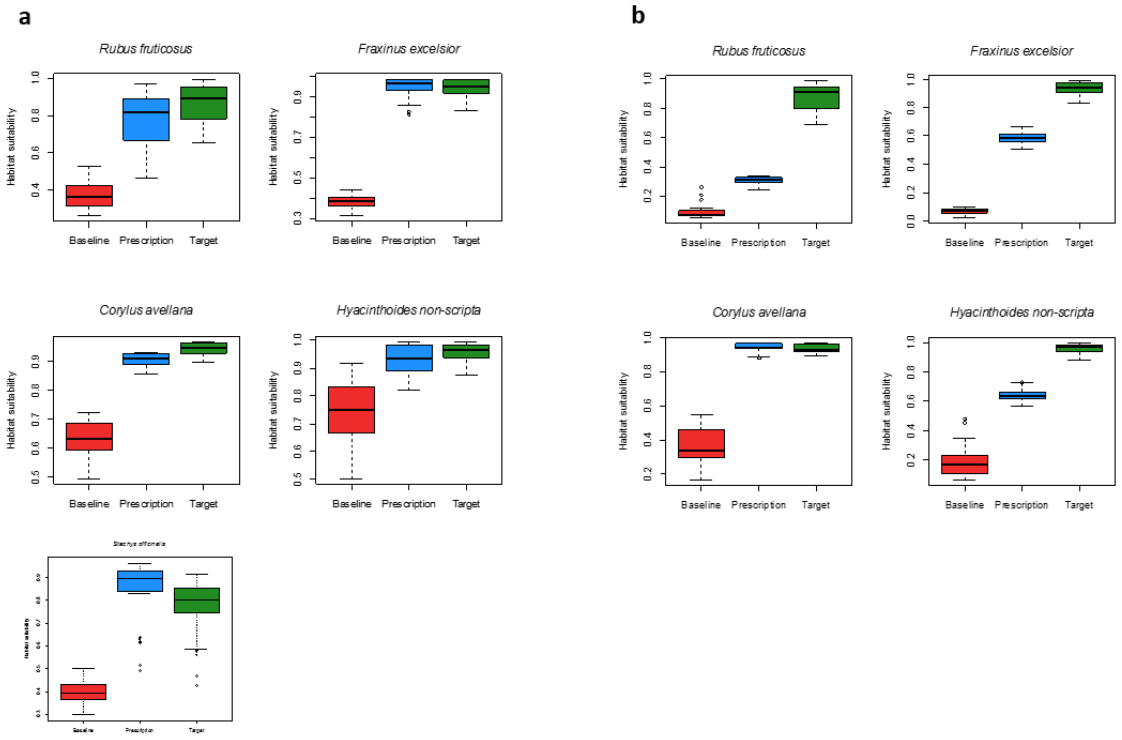


TABLE-GMEP-W-OUTCOME-A-3: Trends in Woodland Indicators. Data from Countryside Survey (CS), GMEP, Forestry Commission (FC) and BTO/JNCC/RSPB Breeding Bird Survey (BBS).

Significant differences over data series and latest period are indicated by: + significant increase; - significant decrease; = no change; n/a not available. Significant differences between land in scheme compared to all Wales is also shown.

Habitat	Indicator		CS	CS	CS	GMEP	National trends		Land in scheme relative to national mean
			1990	1998	2007	2013-16	Overall	Last period	
Woodland	Total Woodland Area ('000 has)[1]		307	319	330	294	=	=	=
		FC 1980		FC 1995-1999		FC 2014/15			
Woodland	Total Woodland area ('000 has)[2]	241		287		306 (150 conifer, 156 Broadleaved)	increase	increase	
			1990	1998	2007	2013-16	Overall	Last period	
Woodland	All broadleaved woodland Area ('000s ha)		172	178	175	173	=	=	=
Woodland	All coniferous woodland ('000s ha)		130	138	145	130	=	=	=
Woodland	Large Broadleaved Woodland Ancient Woodland indicator plant species[3]		2.0	2.0	1.8	2.4	=	+	=
Woodland	Large Broadleaved Woodland ground vegetation light score[4]		6.1	6.1	5.8	5.8	-	=	=
Woodland	Small Woodland Area ('000 has)[6]		21.0	27.5	28.9	31.,0	=	=	=
Woodland	Small Broadleaved Woodland Ancient Woodland indicator plant species[1,3]		1.5	1.8	1.2	1.6	=	=	=
Woodland	Small Broadleaved Woodland ground vegetation light score[4]		6.3	6.2	6.0	6.2	=	=	=

Woodland	Connectivity[5]		0.10	0.10	0.10	0.08	=	=	=
Woodland	Patch size		6095	5213	5840	6357	=	=	n/a

		BBS								
		1994 – 1999	**2000-2004**	**2005-2009**	**2010-2012**	**2013**	**2014**	**2015**	**2016**	**Trend**
Woodland	Woodland Bird Indicator (averaged)	1.084	1.078	1.065	1.185	1.128	1.222	1.235	Available 2018	Recent increase
						GMEP				
						2013	**2014**	**2015**	**2016**	
Woodland	Birds[7]					0.899	1.089	1.057	0.955	Baseline
	Pollinators[8]					Ongoing analysis				n/a

[1]National extent of woodland estimated from the sampled survey data using a statistical approach based on the sampling design within landclasses (created using variables such as geology, soils and climate).

[2] Data taken from NFI , http://www.forestry.gov.uk/pdf/ForestryStatistics2014.pdf/$FILE/ForestryStatistics2015.pdf.

[3] Number of Ancient Woodland Indicators per 4m^2 random plots located in all areas mapped as broadleaved woodland Broad and Priority (sec 8) Habitats. The indicator is under development and will change. At present it is based on an indicator species list largely defined for England and we hope to replace these counts with a Wales-only indicator in the near future.

[4]Mean Ellenberg light score per 2x2m plot that indicates light preference of ground vegetation is used as a proxy for canopy density. Higher numbers indicate more light.

[5]Uses simple metric of straight line distance between woodlands within the GMEP 1km squares.

[6] Includes only broadleaved woodland < 0.5ha not captured by the National Forestry Inventory.. National extent of woodland estimated from the sampled survey data using a statistical approach based on random stratified within ITE landclasses (created using variables such as geology, soils and climate).

[7] Average, standardized count data for 31 species recorded in all four years of GMEP. Further woodland species were recorded in one, two or three years and could therefore provide additional information from future, repeat surveys. Significance was assessed from the average linear trend across the four years for the same species set.

[8] Pollinator abundance is summarised at the 1km square level and so cannot be meaningfully separated into fractions associated with land in or out of Glastir. Future analysis will explore whether counts recorded at particular transect locations can be associated with the management status of adjacent habitat.

4.5 Biodiversity

Outcome: Maintaining and enhancing biodiversity

High level Indicators have been selected which cover different elements of biodiversity both for the countryside as a whole and for Priority Species and Habitats. Note that soil and water diversity have not been included here as they are included as indicators for Soil and Freshwater Outcomes. It is important the wider countryside is assessed as well as our biodiversity 'hotspots' to ensure conditions are not so hostile as to prevent the movement of species e.g. due to climate change. Greater diversity is also thought to support greater resilience of ecosystem processes which we rely on for some benefits the wider countryside delivers including those in farmland although the evidence is not strong or absent for some ecosystem services[19] .

The GMEP Biodiversity results have been used for a range of assessments over and above that of baseline measurements to assess future Glastir impacts and long term national trends. These include:

Species Accounts: The GMEP biodiversity data are relevant to the evidence base required to track progress towards reversing the decline of Wales' native biodiversity and meeting our obligations under the Convention for Biological Diversity 2020. For example they have been used to test an approach for creating National Species Accounts[20].

Area: With respect to extent, GMEP can provide an estimate in specific Broad Habitats and overall change in area of semi-natural habitat. This provides an independent estimate of change in semi-natural land which is one proposed indicator for tracking progress towards the goals of the Well-Being of Future Generations (Wales) Act 2015 with respect to the 'Area of Healthy Ecosystems in Wales'. Use of remote sensing which currently provides only 8-10 years snapshots of change in landcover is likely to be able to provide more spatial coverage and new rolling programmes are being planned which could deliver a more frequent data source. However ongoing problems with accuracy will remain and some element of ground-truthing to adjust estimates for difficult habitats such as grassland is always likely to be needed.

Priority species and habitats: Due to the rare nature of some Priority Species and Habitats, and the many 1000s of parcels of land involved, a subset of 12 Priority Habitats have been selected for reporting using the survey data together with a subset of Priority birds and butterflies. For all other Priority species, GMEP is developing metrics quantifying improvement in habitat specifically required for each species. Results for five species and one group are presented to illustrate this process; lapwing, curlew, dormouse, rare arable plants, lesser horseshoe bat and the marsh fritillary butterfly. This approach reflects the rationale behind Glastir farmer payments for creating or improving the condition of habitat within areas with known populations of the Priority species. In the future, a repeat field survey could report on the success of those payments by detecting whether changes in habitat area and condition resulting from the impact of options has actually occurred in areas targeted for the priority species. Combining this type of analysis with any changes in actual abundance of the priority species from a range of monitoring and recording schemes could provide added confidence Glastir has supported improvement in both habitat and the species population. Detection level and attribution is often

[19] Biodiversity loss and its impact on humanity. Cardinale, Bradley J.; Duffy, J. Emmett; Gonzalez, Andrew; Hooper, David U.; Perrings, Charles; Venail, Patrick; Narwani, Anita; MacE, Georgina M.; Tilman, David; Wardle, David A.; Kinzig, Ann P.; Daily, Gretchen C.; Loreau, Michel; Grace, James B.; Larigauderie, Anne; Srivastava, Diane S.; Naeem, Shahid. (2012) Nature, Vol. 486, No. 7401, 07.06.2012, p. 59-67.

[20] UNEP-WCMC (2016) Exploring approaches for constructing Species Accounts in the context of the SEEA-EEA.

challenging due to the multiple drivers which can affect populations and this combined approach could help to provide a more explicit link. Further information can be found in Annex 12.

High Nature Value (HNV) Farmland: This 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'*[21]. The use of High Nature Value Farmland (HNV) as an impact indicator for Glastir and the RDP is 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 have resulted in final agreement on the methodological approach to defining the extent and condition of HNV in Wales. A full report is available in Annex 11. In summary, there are 3 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 (Type 1 HNV) and habitat diversity and complexity (Type 2 HNV) could explain gradients in a range of different elements of biodiversity across Wales. We used data from GMEP baseline measurements covering mapped habitats (broad and section 8 priority habitats, hedgerows, trees, streams), plants (including Common Standards Monitoring 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 from step 2, 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 field survey squares: The variables are:

- Wetland connectivity
- Grassland connectivity
- Heathland connectivity
- Broadleaved woodland connectivity
- % of semi-natural Habitats
- Rare and occasional soils
- Density of hedgerows
- % of Improved land
- Habitat diversity

Data comes from the Land Cover Map, the soil survey of England and Wales (NATMAP) and the NRW Phase 1 survey i.e. all nationally available data sources. Connectivity between habitats was

maskell[21] Andersen E., Baldock D., Bennet H., Beaufoy G., Bignal E., Brower F., Elbersen B., Eiden G., Godeschalk F., Jones G., McCracken D.I., Nieuwenhuizen W., van Eupen M., Hennekes S., Zervas G. (2003). Developing a high nature value indicator. Report for the European Environment Agency, Copenhagen.

determined by calculating the distance between habitat patches of the same type i.e. woodland, wetland, grassland, heathland and averaging over the 1km square. Applying the outcome of the analysis to the whole of Wales gives an estimate of approximately 15% of land as Type 1 HNV and 15% as Type 2 with an overlap of 2%, hence 28% of Wales in total is Type 1 or 2 HNV farmland (FIGURE-GMEP-BD-OUTCOME-G-1,a and b). 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. To this end a prototype HNV exploration tool was produced. This is a web-based application that would allow users to explore the impacts of adjusting cut-off values for variables that define HNV on the extent and location of HNV in their region of interest. Type 3 HNV which captures land important for rare species. Further work is needed to incorporate up-to-date species distributional data at optimal resolution. Since the focus is on rare species, datasets from the Wales Local Environmental Record Centres should be fully exploited to increase the accuracy and realism of a map of Type 3 HNV (FIGURE-GMEP-BD-OUTCOME-G-1,c).

To see the use of HNV metrics in the assessment of resilience of land which has come into the Glastir scheme compared to the national average see TABLE-GMEP-NRM-OUTCOME-A-1, Section 6.

Resilience: GMEP covers different elements of biodiversity which could contribute to resilience of our natural resources and the benefits they deliver i.e. diversity, extent, connectivity and condition of habitats and species. We have brought together these indicators in Section 6 to visualise differences of land in scheme compared to all Wales to ask the question: Are properties associated with resilience greater for land in the Glastir scheme compared to national average? Future assessments could use the same approach to compare rates of change in and out of scheme. However, additional work is also needed to understand how the benefits of some of these landscape properties could reduce resilience and increase risks e.g. for water and contaminant runoff, spread of disease and pests. Even for biodiversity, some of these landscape properties do not sit well with some priorities for biodiversity such as the High Nature Value Type 2 farmland which is associated with a mosaic of land uses. By definition this type of land will be fragmented with relatively low areas for each habitat. Finally, resilience may not be something we want for land in poor condition as it will be hard to change.

Headline results

The high level Outcome Indicators for Biodiversity are:

1. Species richness for plants, pollinators and birds in the wider countryside
2. Habitat condition as indicated by Common Standard Monitoring plant indicators,
3. Habitat condition as indicated by habitat diversity and patch size
4. High Nature Value Farmland (Types 1-3)
5. Total diversity of all bird species
6. Farmland bird indicators for different habitats
7. Abundance of priority bird species (% populations increasing or stable)
8. Pollinator count
9. Metrics indicating habitat conditions required by 5 Priority Species and one species group

10. The condition of 12 Priority Habitats (5 available at present. The full set requires additional analysis jointly with NRW).

As the sampling and analytical methodology used for plant biodiversity assessment in GMEP is identical to that used in Countryside Survey these datasets can be combined to look for long-term national trends. Data is also provided from the BTO/RSPB/JNCC Breeding Bird Survey and UK Butterfly Monitoring Scheme to give an indication of other high quality long term trends.

The overall picture of biodiversity in Wales is complex and variable. Specialist species continue to be under threat even though some improvements are occurring, e.g. 35% of priority bird species continue to decline whilst 65% are stable or improving. Specialist habitat as dwarf shrub heath also appear to be declining in area whilst others such as blanket bog are improving. Land which has come into the scheme appears to be dominated by large areas of well-connected semi-natural land rather than mosaics of different habitat types and large variability in condition resulting in no overall difference in condition.

Glastir Impact

Positive Outcomes

- Multimove modelling projects that habitat suitability will improve for the majority of target plant species they are intended to benefit in scheme. Individual Glastir prescriptions resulted in the expected changes in habitat suitability for 75% of the 21 plant species modelled, resulting from de-intensification of vegetation management and changes in soil properties (Annex 9).
- Farms in scheme are 13% more likely to have taken action to combat biodiversity loss (from 6% to 19%) (Annex 4).

Areas for concern / further action needed

- Modelling using the Multimove relating to bracken control in acid grassland suggests a long lag period of 10-23 years for habitat to become suitable for 21 common and rare species associated with target habitats. This highlights the importance of consistency (and patience) for the benefits of changes in management practices to be realised (FIGURE-GMEP-BD-OUTCOME-D1; Annex 9)

Baseline assessment of land in scheme relative to national average

- 54% of land in scheme is semi-natural habitat compared to the national average of 41%. Values were similar whether calculated from the GMEP field survey squares or from landcover data for all of Wales indicating the effective sampling strategy used by GMEP.
- 27% of land in scheme is High Nature Value Type 1 farmland which is characterised by having a high proportion of semi-natural land. This compares to 14% Type 1 HNV for all of Wales.
- There was little difference in Type 2 HNV which is characterised by having mosaics of habitats, with 18% in scheme compare to 15% in the national average. Habitat diversity was also similar in scheme and for all of Wales.
- Wetlands, grassland and heathland are all more connected in scheme compared to national average (189%, 135% and 154% respectively) whilst broadleaved woodland is less connected and there is lower hedge density in scheme compared to all of Wales (73% and 74% respectively) (TABLE-GMEP-NRM-OUTCOME-A-1, Section 6; Annex 11).

- Overall there is no statistical difference in the plant species which indicate condition on land which has come into the scheme relative to land out of scheme (TABLE-GMEP-BD-OUTCOME-A-3). The high variability of land in scheme indicated capture of a greater diversity of land type and condition relative to past schemes. It is important that this baseline has been established as it will provide far greater power to detect change going forward in future surveys. Change can be calculated both as change from specific starting conditions rather than a rather variable mean and change relative to that seen in both the national average and land out of scheme.
- No differences were identified for the condition of priority habitats using Common Standard Monitoring plant species in scheme compared to outside.
- Habitat suitability for five priority species and one species group (Marsh fritillary, Lapwing, Curlew, Dormouse, Lesser Horseshoe Bat and rare arable plants) in and out of scheme option was tested. No difference in 50 out of 60 tests was found for land in relevant scheme options versus that outside (TABLE-GMEP-BD-OUTCOME-C-3).

Preliminary analysis of impact of past agri-environment schemes

- New analysis of data from BTO/JNCC/RSPB Breeding Bird Survey in Wales following the approach published for England data[22],[23] has identified a series of Tir Gofal options for which positive associations were much more common than negative ones. This was particularly strong for woodland and hedgerow management, followed by arable seed provision and scrub management. (Annex 13)
- An initial exploration of the legacy effect of 9 Tir Gofal options on plant species composition used a suite of 45 indicators. The analysis was limited to where Tir gofal options coincided with Yr 1 and 2 GMEP survey squares. The results indicated:
    - Some evidence that upland heathland which had been in Tir Gofal (Option 5) continues to have a more appropriate mix of grass and forb species. The monitoring programme for Tir Gofal [24]also concluded that heathland sites were generally being well protected by Tir Gofal, with 45% of sites improving in ecological condition. The report also concluded that changes in condition in heathland were likely to occur in the long term as most changes were observed in only the second of two resurveys, eight years after the start of Tir Gofal. This supports the Multimove modelling projections that vegetation response to management change can take 10-23 years and consistency is required in management schemes if the intended outcome is to be realised.

[22] Morris, A.J., MacDonald, M.A., Smart, J., Haysom, K.A., Rasey, A., Williams, C., Hobson, R., Dines, T., Parry, R.J. & Wilberforce, E.M. 2010. The role of desk review in assessing the potential for biodiversity delivery by the Tir Gofal agri-environment scheme in Wales. *Aspects of Applied Biology*, 100, 89-99.

[23] MacDonald, M.A., Morris, A.J., Dodd, S., Johnstone, I., Beresford, A., Angell, R., Haysom, K., Langton, S., Tordoff, G.M., Brereton,T., Hobson, R., Shellswell, C., Hutchinson, N., Dines, T., Wilberforce, E.M., Parry, R. & Matthews, V. 2012. Welsh Assembly Government Contract 183/2007/08 to undertake Agri-environment Monitoring and Services: Lot 2 – Species Monitoring Final report: October 2012.

[24] Medcalf K., Whittick E., Turton, N., Cross, D. 2012. Wales Agri-Environment Monitoring Lot 1: Habitats. Final Report. Welsh Government.

- For ungrazed broadleaved woodland (option 1A), species richness was higher in plots that had entered Tir Gofal before 2006 compare to that after 2006. There was no evidence for a legacy effect for 7 other Tir Gofal options explored however, the analysis only included Year 1 and 2 data and this initial analysis demonstrates the potential value of this approach (Annex 13).

Long term national trends

Positive outcomes

- Recent positive trends over the last 10 years in the presence of plant species which are indicative of good condition for habitat and improved land. No change in condition of woodlands and arable habitats.
- Improvement in the Priority Habitat Blanket Bog (FIGURE-GMEP-BD-OUTCOME-C-1) and Purple moor Grass and Rush Pasture as indicated by presence of plant species which indicate good condition. These habitats have been targeted for improvement for many years and many actions have been undertaken to support their recovery. The relative importance of restoration practices, an improving pollution climate and/or rainfall changes need to be explored.
- Initial analysis suggests a recent increase in the area of blanket bog and montane habitats.
- A decline in woody species richness in the priority habitat of hedgerows and amount of new planting but increased evidence of hedgerows being managed
- For freshwater Priority Habitats – see Freshwater Section 4.6.
- A new metric for priority bird species calculated from the BTO/JNCC/RSPB Breeding Bird Survey indicates 65% have stable or increasing populations. There is no consistent trend in this indicator over the last 20 years.
- BTO/JNCC/RSPB Breeding Bird Survey data indicate an average decline (15 years) in lowland farmland species that may have turned upward since 2012, a decline in upland species from 2008 that turned around after 2011. Stable overall bird diversity over the last 15 years
- A composite indicator of Butterfly Monitoring Scheme data indicates a historic decline in specialist butterfly species but no further decline over the last 10 years. Stable trends for more generalist butterfly species.
- Analysis of opportunistic recording data by many different organisations for 18 poorly studies groups covering 1,990 native species over the period 1970-2009 identified 10 taxonomic groups with negative net change trends, with the remaining 8 taxonomic groups showing a positive net change trend for the period 1990-2000 (Annex 14).
- A decline in habitat diversity and an increase in mean patch size for habitat and woodland over the last 20 years which suggests reduced fragmentation.
- Two new proposed High Nature Value Farmland Indices have been developed in collaboration with a range of stakeholders. High Nature Value farmland Type 1 farmland which is characterised by having a high proportion of semi-natural land represents 14% of Wales. Type 2 HNV which is characterised by having mosaics of habitats represents 15% of Wales. (TABLE-GMEP-NRM-OUTCOME-A-1; Annex 11).

Areas for concern / further action needed

- A recent decline in the area of dwarf shrub heath.

- BTO/JNCC/RSPB Breeding Bird Survey data indicate an average decline (15 years) in lowland bird populations which may have turned upwards since 2012.
- New analysis of BTO/JNCC/RSPB Breeding Bird Survey data for GMEP to create a priority bird index suggests 35% of priority bird species remain at risk with declining populations.
- New analysis of trends in under-studied species by the Biological Records Centre identified 10 taxonomic groups with negative net change trends, with the remaining 8 taxonomic groups showing a positive net change trend for the period 1990-2000 (FIGURE-GMEP-BD-OUTCOME-F-1). The data was captured by opportunistic biological recording by 16 societies and recording schemes[1].

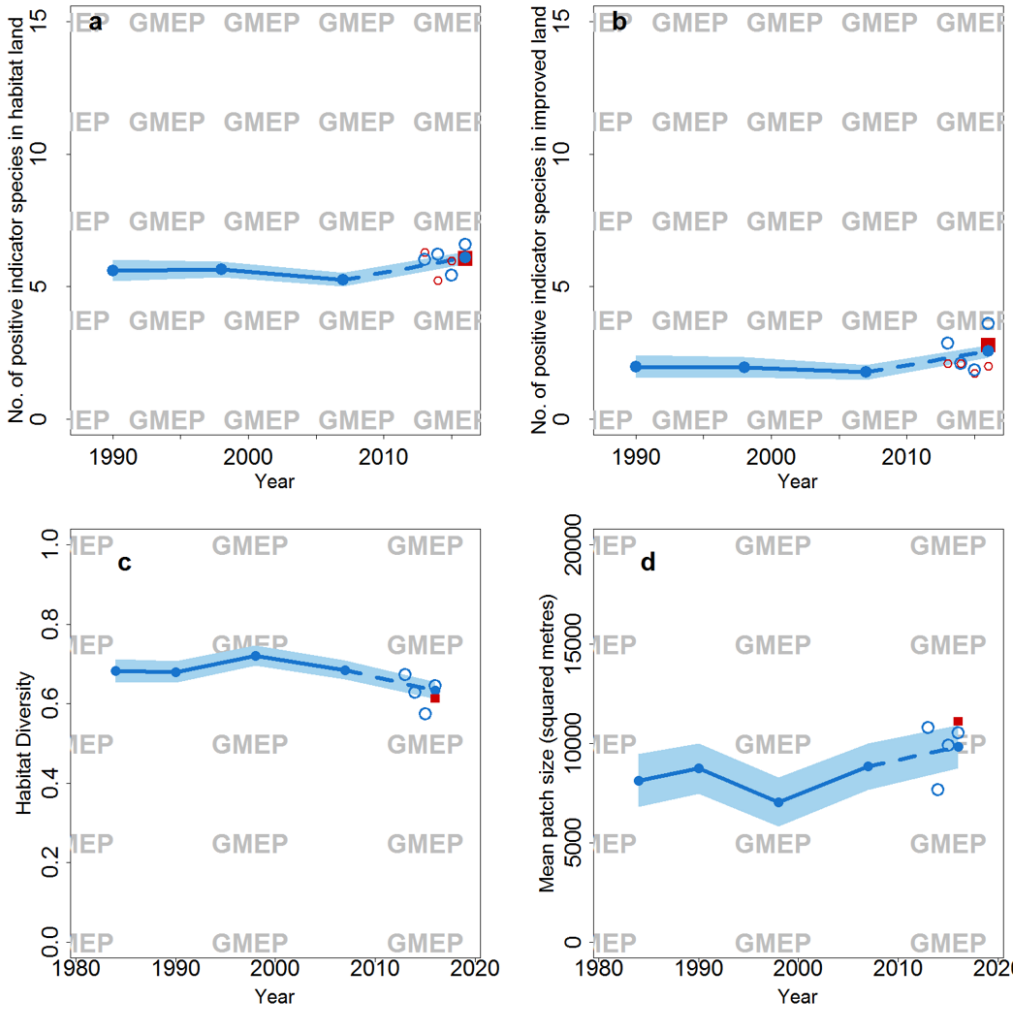
FIGURE-GMEP-BD-OUTCOME-A-3: Trends in Habitat Condition including:

a. High-quality habitat plant indicator species (positive Common Standard Monitoring (CSM) Species) for Habitat Land[1]. (Indicator species were drawn from a compilation carried out by Botanical Society of Britain and Ireland in 2013 based on published CSM guidance notes);

b. High-quality habitat plant indicator species (CSM positive) for Improved Land[2]

c. Trends in habitat diversity (Shannon diversity index- standardised to create value between 0 and 1);

d. Trends in mean habitat patch size for habitat land and broadleaved woodland.



1 Habitat Land follows the description in Glastir guidance and is defined as all vegetation with less than 25% total cover of White Clover and Rye Grass species. It also excludes woodlands, arable, linear features and urban habitats and therefore focusses on semi-natural habitats.
2 Improved Land is defined as all Improved Grassland and if Neutral Grassland then with greater or equal to 25% total cover of White Clover and Rye Grass species.

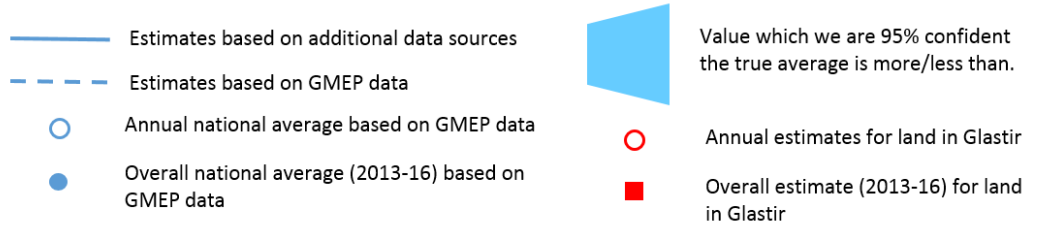


FIGURE-GMEP-BD-OUTCOME-B-3: Trends in Biodiversity including:

a. The total number of plant species observed in 4 m^2 plots located in Habitat Land.

b. The total number of plant species observed in 4m2 plots located within Improved Land.

c. BTO/JNCC/RSPB Breeding Bird Survey data

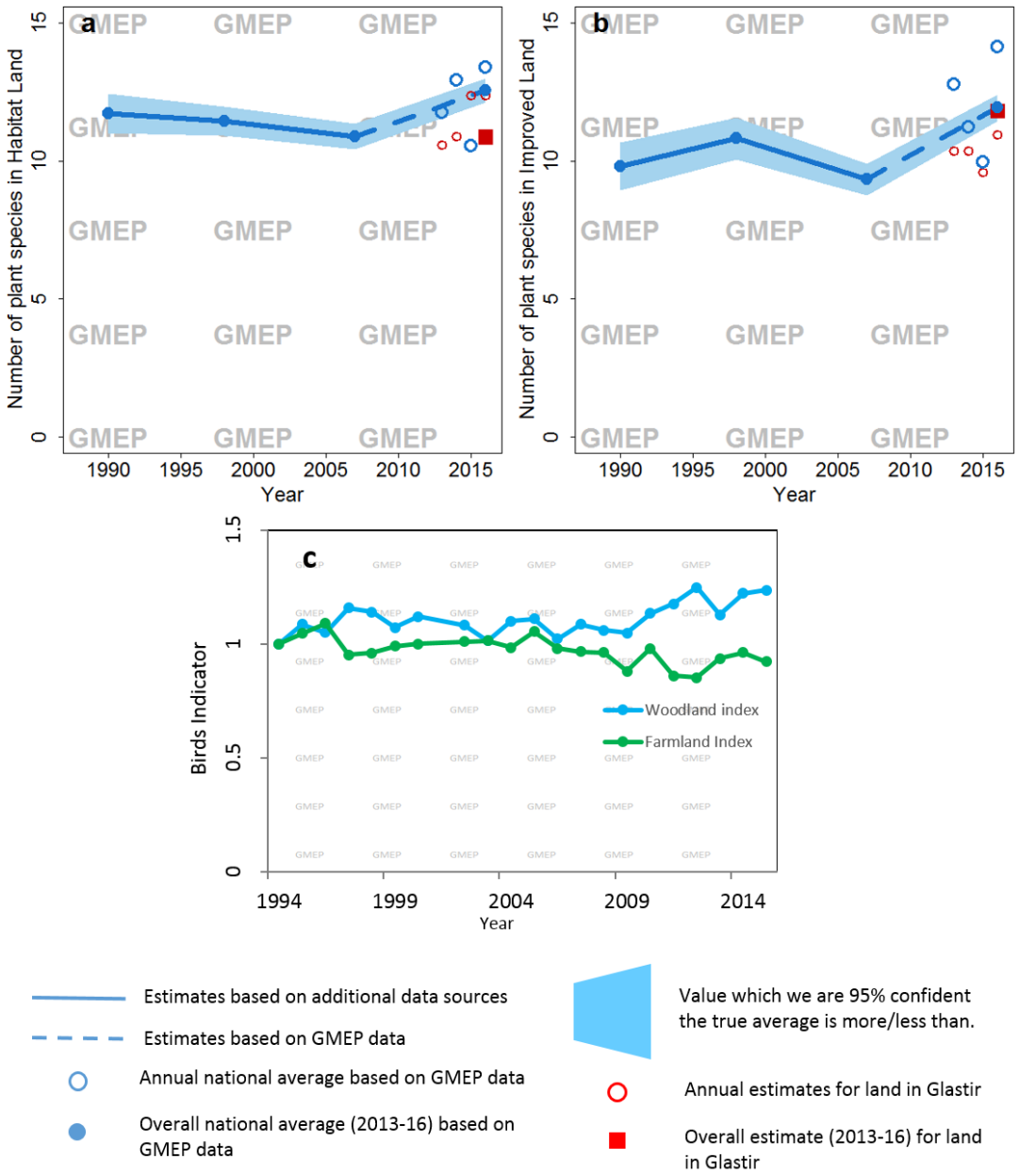


FIGURE-GMEP-BD-OUTCOME-C1: Trends in condition of the Priority Habitat Blanked Bog for a set of indicators:

a. Common Standard Monitoring Species

b. Species richness, *Sphagnum* cover, *Eriophorum vaginatum* cover, Dwarf Shrub Heath and vegetation moisture index for 2mX2m plots

c. Trends in blanket bog condition as indicated by topsoil carbon concentration

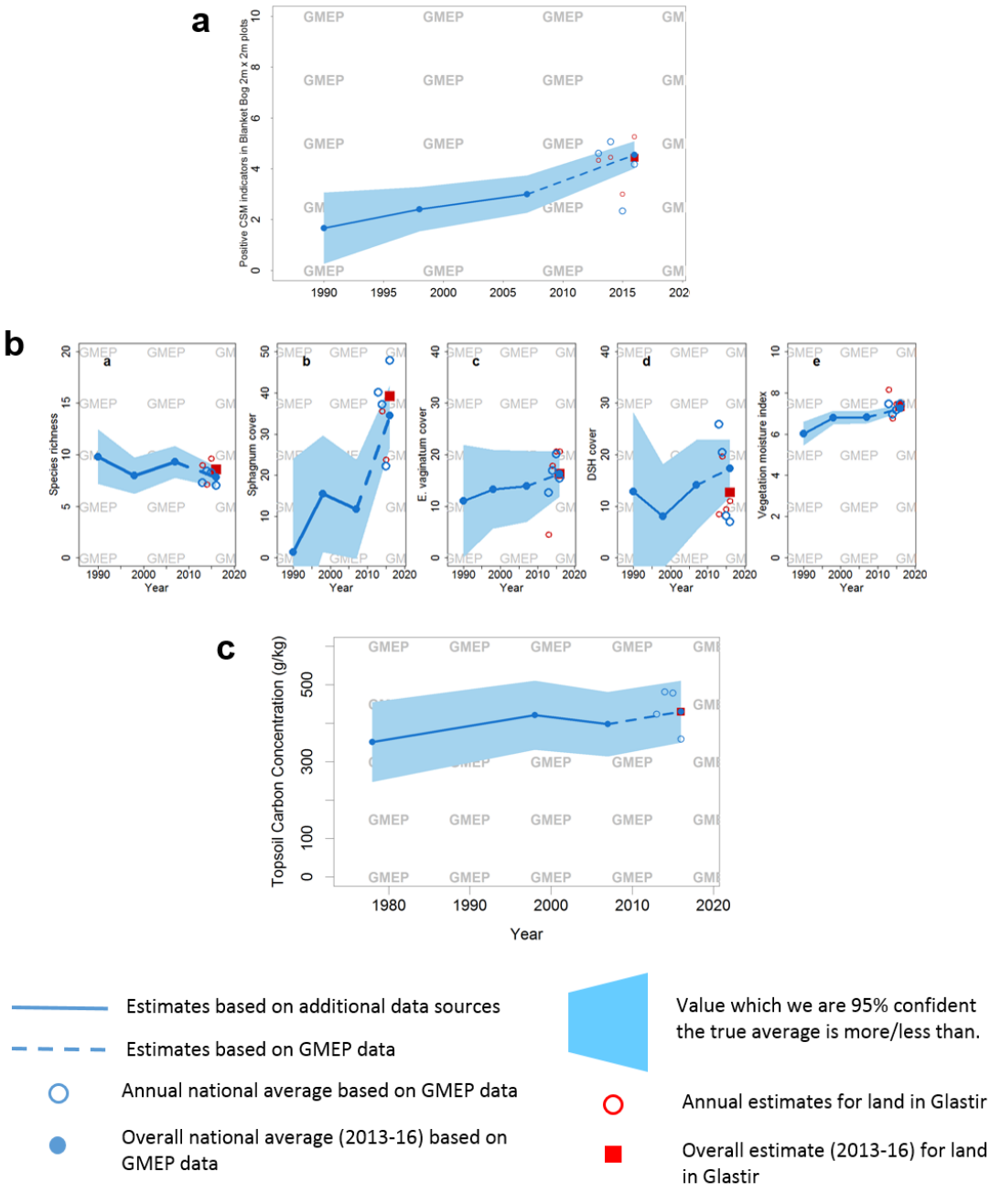


FIGURE GMEP-BD-OUTCOME-D1: An example of Mulitmove projections of change in habitat suitability. Here projections of the likely success of bracken control on acid grassland (AWE 44/Common land) for common bent grass (*Agrostis capillaris*); sweet vernal grass (*Anthoxanthus odoratum*); bilberry (*Vaccinium myrtilus*) and dog violet (*Viola riviniana*) in the Conwy catchment over a 10-23 year period.

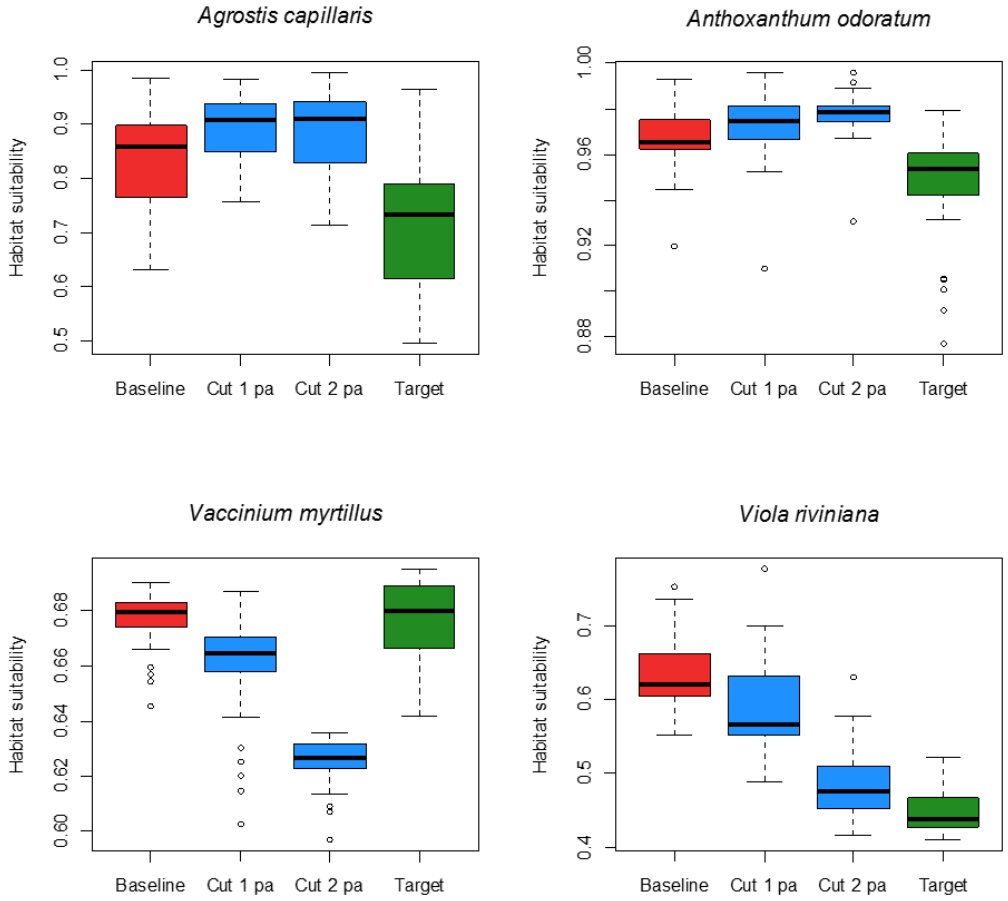


FIGURE GMEP-BD-OUTCOME-E1: Percentage of bird species tested with positive, negative and non-significant associations with Tir Gofal option groups targeting specific habitats or resources. Numbers in parentheses show how many species were tested for each option type.

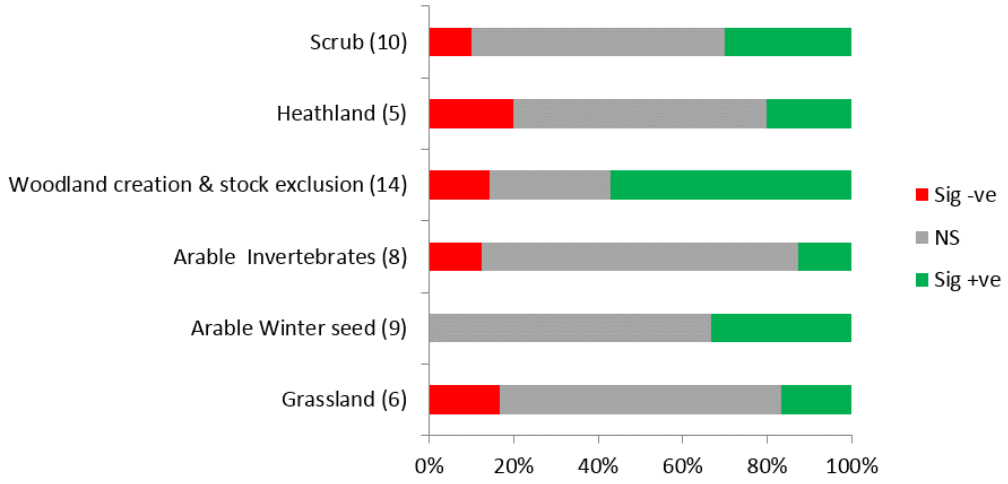


FIGURE-GMEP-BD-OUTCOME-F-1: A bar plot showing the proportion of species that fall within each trend category based on the change in the probability of observation between 1990 and 2000. The number of species for which trends were estimated is listed in brackets alongside the name of the taxonomic group. Net change was negative for 10 groups (red > green) whilst a positive net change was observed for 8 groups (green > red).

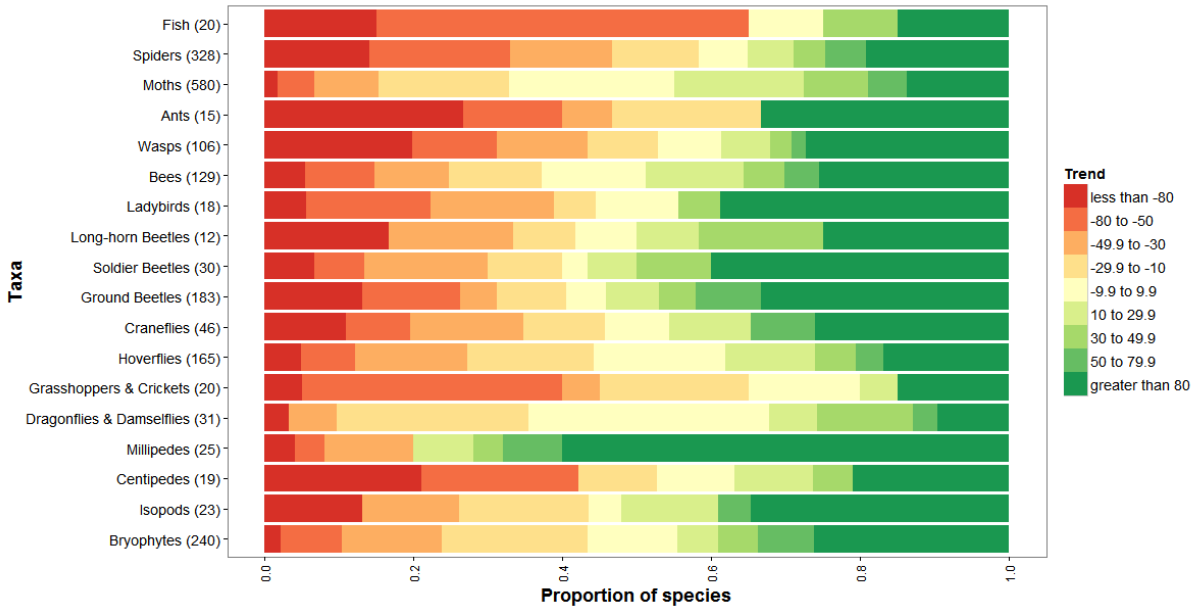
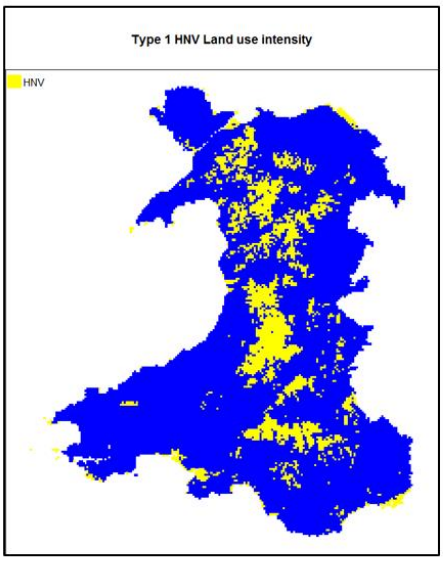


FIGURE GMEP-BD-OUTCOME-G1: Draft maps of High Nature Value farmland in Wales
a.) Type 1; a high proportion of semi-natural land, low land-use intensity
b.) Type 2; complex habitat structures, high habitat diversity, woodland connectivity, hedgerows.
c) Draft maps of Type 3 High Nature Value farmland in Wales created using the Glastir advance target layers of species/habitats and their scores within the Glastir advanced scheme i) species, ii) habitats

a



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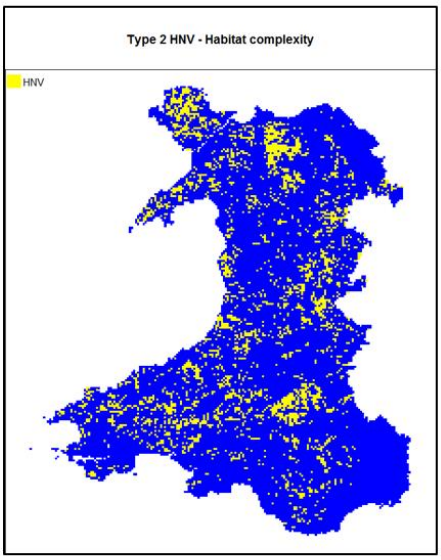

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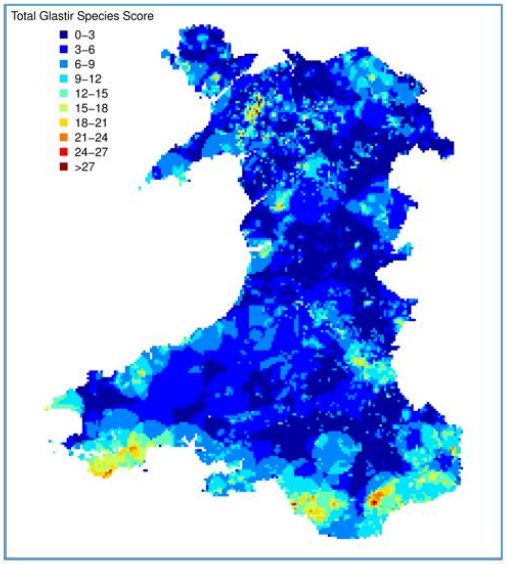

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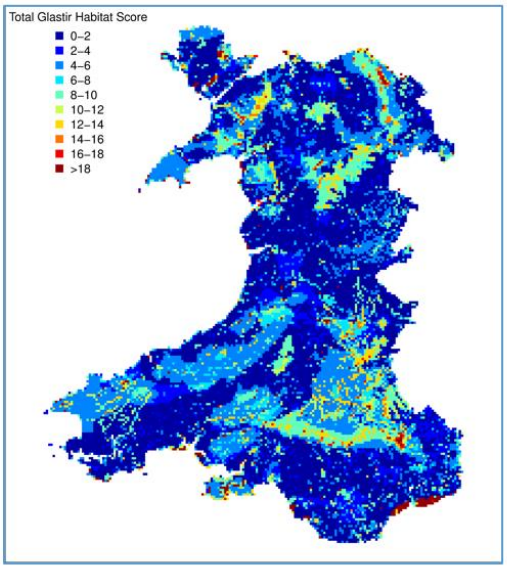


TABLE-GMEP-BD-OUTCOME-A-3: Trends for Habitat diversity and condition, and species richness. Habitat condition is calculated from presence of high quality plant indicators. Plant species richness are split by Whole Farm Code habitats for high level reporting.

Significant differences over data series and latest period are indicated by: + significant increase; - significant decrease; = no change; n/a not available. Significant differences between land in scheme compared to all Wales is also shown.

Indicator	Sub-category	CS				GMEP	Significant differences		In scheme compared to national average
		1984	1990	1998	2007	2013-16	Overall	Latest	
Farmland	High Nature Value Type 1 and 2 (%)	N/A				28	N/A		+
Habitat diversity (no. of habitats)	All[8]	0.68	0.68	0.72	0.69	0.63	-	-	=
Mean Patch size (m^2)	Habitat and Woodland	8135	8743	7047	8829	9828	+	=	=
Habitat condition	Arable[1]		2.0	2.7	1.7	2.1	=	=	=
	Improved Land[2]		1.97	1.95	1.76	2.55	=	+	=
	Habitat Land[2]		5.60	5.65	5.26	6.09	=	+	=
	Woodland[3]		2.04	2.10	1.85	2.22	=	=	=
	Wales[4]		4.44	4.40	3.97	4.65	=	+	=
Plant species richness [5]	Arable		6.85	8.75	4.95	7.61	=	=	=
	Improved Land		9.80	10.80	9.31	11.97	+	+	=
	Habitat Land		11.44	11.17	10.58	12.37	=	+	=
	Woodland		11.9	12.0	11.1	11.0	=	=	=

[1] Number of annual forbs per $4m^2$ in arable fields.
[2] Number of positive Common Standard Monitoring (CSM) indicators per $4m^2$ random plot for any of the habitats listed in JNCC guidance notes. Improved Land is defined as vegetation mapped as Improved Grassland or if Neutral Grassland then with >=25% summed cover of *Lolium perenne, L.multiflorum* and *Trifolium repens*. Habitat Land comprises all vegetation with <25% cover of Improved Land indicators if Neutral Grassland and excludes Broad Habitats mapped as woodland, arable, improved land, linear features, rivers, open water and canals, inland rock or urban.
[3] Number of Ancient Woodland Indicators per $4m^2$ random plots located in all areas (small and large) mapped as broadleaved woodland Broad and Priority (sec 8) Habitats. The indicator is under development and will change. At present it is based on an indicator species list largely defined for England and we hope to replace these counts with a Wales-only indicator in the near future.
[4] Numbers of positive CSM indicator species summed across all published lists and counted in $4m^2$ plots in all habitats.
[5] Vascular plant species richness per $4m^2$ plots classified to the same habitats as for Habitat condition categories.

TABLE-GMEP-BD-OUTCOME-D-2: Trends in Bird and Pollinator Diversity and comparison of diversity of land in scheme compared to the national average

Indicator	Sub-category	BBS								
		1994-99	2000-04	2005-09	2010-12	2013	2014	2015	2016	Trend
Bird diversity	Farmland Lowland	0.98-1.17	1.00-1.03	0.83-1.03	0.80-1.00	0.89	0.91	0.84	Available 2018	Recent increase (2 years)
	Farmland Upland	0.76-1.08	0.95-1.02	0.97-1.09	0.79-0.96	1.03	1.11	1.08		Recent increase
	Diversity of all species[1]	28.60	30.46	30.21	27.49	27.42	28.51	29.52		No consistent trend
						GMEP				In scheme compared to national average
						2013	2014	2015	2016	
Bird diversity	Diversity of all species[1]					0.88 (0.85-0.92)	0.91 (0.90-0.93)	0.91 (0.88-0.93)	0.89 (0.86-0.91)	Baseline data
Pollinator numbers per site	Butterfly, bees and hoverflies[2]					193 (149-251)	159 (132-193)	138 (114-166)	122 (92-160)	Baseline data[3]

[1] Simpson's diversity index calculated using data for all bird species recorded in survey squares, averaged across all squares in the sample.
[2] Mean count of numbers of individuals recorded per GMEP 1km square based on a Poisson GLMM (+/-95% confidence interval).
[3] Pollinator abundance is summarised at the 1km square level and so cannot be meaningfully separated into fractions associated with land in or out of Glastir. Future analysis will explore whether counts recorded at particular transect locations can be associated with the management status of adjacent habitat.

TABLE-GMEP-BD-OUTCOME-B-3: Trends in Priority species.

Indicator					**GMEP 2013**	**GMEP 2014**	**GMEP 2015**	**GMEP 2016**	**In scheme compared to national average**
Butterfly species: mean number of individuals per site[1]					6 (3-11)	3 (2-5)	4 (3-5)	1 (0-1)	Baseline data
	BBS								
	1994 -99	**2000 -04**	**2005 -09**	**2010 -12**	**2013**	**2014**	**2015**	**2016**	**Trends**
Total abundance of bird priority species[2]	28.60	30.46	30.21	27.49	27.42	28.51	29.52	Available 2018	No consistent trend
	199 4-99	**2000-04**	**2005 -09**	**2010 – 2015**					
Priority bird species index (% of species with increasing or stable populations) [3]	67.6	60.0	48.6	64.7					No consistent trend
					GMEP 2013	**GMEP 2014**	**GMEP 2015**	**GMEP 2016**	**In scheme compared to national average**
Priority bird species[4]					0.884	1.229	1.063	0.826	Baseline data

[1] The following section 8 butterfly species were found in GMEP 1km squares between 2013 and 2016: White-letter Hairstreak, Wall Brown, Grayling, Small Heath and Large Heath.
[2]The total abundance (sum of maximum counts per species) of all Section 8 species, averaged across all survey squares in the sample.
[3] Data for Bar-tailed Godwit, Tundra Swan, Common Cuckoo, Eurasian Curlew, Common Scoter, Dunnock, Dark-bellied Brent Goose, Common Grasshopper Warbler, Golden Plover, Hawfinch, Herring Gull, Hen Harrier, House Sparrow, Kestrel, Northern Lapwing, Common Linnet, Lesser Redpoll, Marsh Tit, Greenland Greater White-fronted Goose, Pied Flycatcher, Reed Bunting, Ringed Plover, Ring Ouzel, Sky Lark, Spotted Flycatcher, Common Starling, Song Thrush, European Turtle Dove, Tree Pipit, Eurasian Tree Sparrow, Twite, Wood Warbler, Yellowhammer, Yellow Wagtail; data taken from BBS, WeBS and other sources (see Appendix 5.3 in the GMEP Year 2 report for more information)
[4] Data are available for Bullfinch, Cuckoo, Curlew, Dunnock, Grasshopper Warbler, Herring Gull, House Sparrow, Kestrel, Lapwing, Linnet, Lesser Redpoll, Lesser Spotted Woodpecker, Marsh Tit, Pied Flycatcher, Reed Bunting, Skylark, Spotted Flycatcher, Common Starling, Song Thrush, Tree Pipit and Yellowhammer.

TABLE-GMEP-BD-OUTCOME-E-1: Habitat suitability for 6 priority species in scheme compared to out of scheme

Indicator	No. indicators	No. indicators where habitat in-option more beneficial / total indicators	No. indicators where habitat in-option less beneficial / total indicators	Overall comparison in option versus out of option[1]
Dormouse	6	0	0	50 out of 60 tests for a test set of 6 species indicated no difference between in and out of option habitat
Marsh fritillary,	24	1	1	
Lapwing	6	1	1	
Curlew	6	1	1	
Rare arable plants	3	0	0	
Lesser Horseshoe Bat	24	4	0	

[1] Differences between habitat which has come into relevant Glastir species options versus that outside were analysed in terms of 54 habitat condition indicators across six section 8 species; Marsh fritillary, Lapwing, Curlew, Dormouse, rare arable plants and Lesser Horseshoe Bat. When repeat data are available we will report tests of change in ecological impacts between land in-option versus ecologically equivalent baseline land out-of-option. See Annex 12 for further details.

TABLE-GMEP-BD-OUTCOME-C-3: Trends for condition of 12 Priority Habitats and comparison of condition of land in scheme relative to national average. Metrics only available for 5 habitats currently. Additional analysis required to align with past data from NRW Phase I Survey for the remaining 6 we hope to report against namely: Arable rare plants by count of annual forbs per 1x100m plots located at random on the cultivated margins of arable fields. For Upland heath; Lowland Heath; Fen; Lowland hay meadow - count of positive Common Standard Monitoring (CSM) indicator species per $4m^2$ random plot. Priority Woodland by count of Ancient Woodland Indicator species per $4m^2$ random plot summed across Lowland Mixed deciduous woodland; Wet Woodland; Upland Oak Wood; Upland mixed Ashwood.

Significant differences over data series and latest period are indicated by: + significant increase; - significant decrease; = no change; n/a not available. Significant differences between land in scheme compared to all Wales is also shown.

Priority Habitat	Indicator	CS				GMEP	Significant differences		In scheme compared to land outside of scheme
		1984	1990	1998	2007	2013-16	Overall	Latest	
Blanket bog	CSM		1.7	2.4	3	4.5	+	+	=
Purple Moor grass and rush pasture	CSM				2.7	3.6		+	=
Hedgerows	Woody species richness[1]			5.8	6.7	5.4	=	-	-
	Less than 2m high (%)[2]			60.7	63.7	73.4	+		=
	Managed (%)[2]			75.9	84.9	88.2	+		=
	% newly planted (%)[2]			7.4	4.6	2.3	-		=
	Layed and coppiced (%)[2]			7.1	5.4	1.5	-		=
Small streams	Reported under Water Outcome								
Ponds	Reported under Water Outcome								
Other PHs[3]	Additional analysis required to align with past data from NRW Phase I Survey. Analysis of condition indicator richness within vegetation plots assigned to groups of Priority Habitats showed no significant differences between habitat in scheme versus the national average for the habitat group.								

[1] From vegetation plots aligned to hedgerows

[2] From mapping of hedgerows

[3] Before comparisons can be made within individual priority habitats, differences in definitions need to be harmonised so that NRW and CS/Gmep data can be jointly analysed and evaluated in the knowledge that subsets of quadrats are referenced to the same kind of vegetation. This process of alignment requires ongoing collaborative work. In the interim we analysed vegetation plots assigned to the following habitat groups and individual priority habitats; woodlands (Lowland Beech & Yew, Lowland mixed deciduous, Upland mixed Ash, Upland Oak, Wet woodland), Fen, Upland plus Lowland heath, Arable field margins (1x100m cultivated margin plots), Lowland hay-meadow. In all other habitats, plots were 2x2m in size. Condition indicators were as follows; woodlands (Ancient Woodland Indicator plants), arable field margins (annual forbs), all other habitats (positive CSM species counting only those species listed in JNCC Guidance as relevant to the habitat).

4.6 Freshwater

Outcome: Improving water quality and managing water resources

Agriculture can increase the input of nutrients, contaminants and fine sediments to streams, with negative impacts on water quality and ecology, therefore reducing these inputs is a goal of Glastir. Changes in land management can also change the rates of rainfall runoff and thus potentially contribute to flood mitigation. We need to know whether Glastir has a beneficial effect on freshwaters, considering all measures whether they are primarily targeted at freshwaters or not.

Modelling has been used to explore the likely future impacts of Glastir on freshwater resources at a national scale. Models used were the ADAS Farmscoper and UVW/CEH LUCI models in combination with data from the GMEP Farmer Practice Survey and uptake data from Welsh Government respectively. Future assessments of actual impacts would most likely use a combined approach of baseline GMEP data, other data sources and modelling as recently reported for the TIr Gofal scheme[25]. The GMEP field survey has been used here to assess long term trends and also to report on baseline differences in headwater stream quality and their relationship to the amount of land upstream which has come into Glastir.

GMEP field data for freshwater is focussed on headwater streams are there are an estimated 9.5 to 16 thousand kilometres of headwater streams in Wales as larger rivers and lakes are reported by Natural Resources Wales as part of the Water Framework Directive (WFD) reporting requirements. The quality of small streams is important because they feed larger river systems upon which we rely for human usage. Small streams also have conservation value (they are a priority habitat) in their own right, providing habitat for a range of characteristic plant and animal species.

Ponds are also included in the GMEP field survey as they are important to the Welsh landscape and provide important habitat for biota. They act as stepping stones for biota to disperse over wide distances while also providing refuges for wildlife, and are priority habitats under the EU habitats directive. There is a substantial amount of pond habitat in Wales. GMEP estimates the number of ponds to be 57800 for the whole of Wales, at a density of 2.78 per km^2. Ponds in agriculture areas can accumulate excess nutrients, contaminants and sediments leading to poor water quality and negative impacts on the ecology. Glastir has a number of measures directly linked to ponds or that could influence pond ecological quality. Future field surveys will be able to directly evaluate the impact of land coming into scheme on pond quality using the GMEP baseline data. For now, GMEP has examined whether ponds on land coming into the scheme are of a different quality compared to ponds outside of the scheme.

A small subset of high level indicators was selected to capture the condition of freshwater resources not captured through other monitoring schemes and to explore the relationship between the quality of water and amount of land in Glastir upstream. For streams we used ecological indicators based on macroinvertebrate diversity and an indicator of habitat condition, examining long term NRW records as well as GMEP field results. For ponds, GMEP field data were used in conjunction with the PSYM model, a multimetric tool to classify pond condition based on habitat structure, plant and invertebrate communities. We defined streams as first or second Strahler order flowing water

[25] Jones, J. I., Murphy, J. F., Anthony, S. G., Arnold, A., Blackburn, J. H., Duerdoth, C. P., Hawczak, A., Hughes, G. O., Pretty, J. L., Scarlett, P. M., Gooday, R. D., Zhang, Y. S., Fawcett, L. E., Simpson, D., Turner, A. W. B., Naden, P. S. and Skates, J. (2017), Do agri-environment schemes result in improved water quality?. J Appl Ecol, 54: 537–546. doi:10.1111/1365-2664.12780

bodies within 2.5 km of their sources and ponds as standing water bodies between 1 m^2 and 2 ha in area, that hold water for at least 4 months of the year. For all field methods for headwater streams and pond sampling see Annex 16. Diatom results are also available (Annex 17). Area of land contributing to flood mitigation is the area of land in Wales (%) helping to slow down the amount of rainfall running off the land which will help reduce rainfall runoff and thus flood risk and the transfer of contaminants to streams and rivers (Annex 10). Modelling results are reported as % change to national loadings of nutrients and sediments in freshwaters (Annexes 5 and 10).

Glastir Impact

Postive Impacts

In scheme farms had the following improvements relative to non-scheme farms based on the GMEP Farmer Practice Survey (Annex 3):

- 10% increase in the likelihood of calibrating fertiliser spreaders (from 62% to 72%)
- 29% more likely to have fenced off streams
- 26% more likely to have established vegetation and uncultivated buffer strips
- 9.4% decrease in the use of phosphate fertiliser on grassland fields
- 15% more likely to have left stubble in fields to provide over-winter cover (from 44% to 59%).
- 6.8% more farms covering manure heaps and 8% increase in calibration of manure spreaders and more likely to increase the size of slurry store

Areas of concern / need for further action

- The modelled net impacts of Glastir, on pollutant losses from all agricultural land (i.e. including land not in Glastir) are small and reductions are significantly lower than first projected in Year 1 at around 1% from all agricultural land in Wales. Reductions are approximately double (i.e. 2%) on the land managed by farms in Glastir, with greater reductions possible at more localised scales. The effect of the Glastir scheme is limited by both the number of participants in scheme and the amount of land under prescription within individual land holdings. However it should be remembered that local benefits can make a significant contribution to changing individual streams and rivers WFD Status.
    - Projections based on the ADAS model Farmscoper using changes in land management reported by farmers in the Farm Practice Survey (Annex 3). Changes are lower than those originally estimated in Year 1.
    - Glastir agreements do not correlate with areas where leached and runoff losses of nutrient from the soil, particularly nitrate, are most intensive[26] (e.g. Pembrokeshire, Anglesey) FIGURE-GMEP-FW-OUTCOME-D-1**.** The most effective mitigation methods according to the Farmscoper model are a few of the options for 'within field' measures such as establishing cover crops (1.4%,

[26] Anthony, S., Jones, I., Naden, P., Newell-Price, P, Jones, D., Taylor, R., Gooday, R., Hughes, G., Zhang, Y., Fawcett, L., Simpson, D., Turner, A., Fawcett, C., Turner, D., Murphy, J., Arnold, A., Blackburn, J., Duerdoth, C., Hawczak, A., Pretty, J., Scarlett, P., Laize, C., Douthwright, T., Lathwood, T., Jones, M., Peers, D., Kingston, H., Chauhan, M., Williams, D., Rollett, A., Roberts, J., Old, G., Roberts, C., Newman, J., Ingram, W., Harman, M., Wetherall, J. and 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 Climate Change (Ecosystems), No. 183/2007/08, Final Report, 477 pp + Appendices.

2.7% and 6.5% reductions in nitrate, phosphorus and sediment respectively), in-field and riparian buffer strips (c. 2% reductions in sediment) and fencing off streams from livestock (1.5% reduction in phosphorus) (Annex 5). The likely additional reductions for these individual methods are significant despite estimates of current implementation already being high (e.g. 50% for fencing off streams from livestock) i.e. there is not a decline in benefit as uptake increases which can be the case for some interventions.

    - The overall combined impact of all of these methods being raised to 100% implementation are reductions in national agricultural loads of 4.3% for nitrate, 8.4% for phosphorus and 11.1% for sediment. The scheme could potentially have a significant local effect if options were more intensely focussed (TABLE-GMEP-FW-OUTCOME-C-1; Annex 4).

- Modelling using the UVW/CEH LUCI model projected a potential increase of 11,641 ha in mitigated land for flood risk, nitrogen and phosphorus delivery to rivers. This was delivered by land use changes included in Glastir contracts which created 4,120 ha of additional mitigating land. Therefore, on average for every 1 ha of change in landcover, around 3 has of land are mitigated (TABLE-GMEP-FW-OUTCOME-D-1; Annex 10). This represents 3.25% more land potentially mitigated from flood risk at a national scale. Modelling also showed a 6,066 ha (1.6%) reduction in the area classified as having high concentration of overland flow i.e. potentially contributing to flash flood risk. Reductions in N and concentration were very similar to those projected by the Farmscoper model at 0.5% for N and 1.5% for P providing greater confidence in the overall results of a 1-2% likely future impact. These benefits are delivered at the cost of reduced intensity on 0.44% of higher agricultural intensity land; this area was downgraded from high and very high production to moderate production or less (TABLE-GMEP-FW-OUTCOME-D-1; Annex 10).

Baseline differences between Glastir land and land out of scheme

- Visual assessment in the GMEP field survey indicated a higher proportion of streams were near-natural or predominantly unmodified on land coming into the scheme (TABLE-GMEP-FW-OUTCOME-A-3). The use of benthic diatoms also indicated lower rates of anthropogenic enrichment in streams draining land upslope of the GMEP sample square where there was a greater proportion of land in scheme. However they had a greater tendency to show the effects of acidification, with 22% having assessments of less than good status assessed by benthic diatoms, compared to 10% for those outside the scheme (Annex 17). These results are likely to be largely due to the greater vulnerability of these small headwater catchments to acidification as samples tended to have lower alkalinity and conductivity. This, in turn, suggests a bias towards less productive upland catchments in scheme. There was no difference in the ecological condition of small streams in relation to the area of upstream catchment as indicated by macroinvertebrates indices which may suggest benthic diatoms may be a more sensitive indicator.
- There was no difference of pond quality relative to whether the surrounding land in the GMEP sample square was in or out of Glastir (TABLE-GMEP-FW-OUTCOME-A-3; Annex 16).

- The percent of land mitigated for flood was similar in scheme compared to land outside of the scheme (18.3% compared to 21.6% respectively) (TABLE-GMEP-FW-OUTCOME-A-3; Annex 10).

Past AES

- A recent paper published by the team involved in Tir Gofal/Tir Cynnal assessment project [27] has indicated a combined field survey and modelling approach was able to identify an effect of scheme entry on water quality.

National trends

Positive Outcomes

- There are an estimated 9.5 - 16 thousand kilometres of headwater streams in Wales. Using GMEP invertebrate data, nearly 83% of the headwater streams have good or high diversity (FIGURE-GMEP-FW-OUTCOME-C-3). Comparison with results from 2007 reported by Countryside Survey indicates an increase in biodiversity but a slight shift towards species more tolerant of degradation.
- There has been a general ongoing improvement in the condition of small streams sampled by NRW since 1990, based on macroinvertebrate communities and nutrient levels (FIGURE-GMEP-FW-OUTCOME-A/B-1). This improvement has continued since 2007 and is greater than that observed for the CS/GMEP samples (TABLE-GMEP-FW-OUTCOME-A-3). One explanation may be the NRW sampled streams drain much larger areas of land (1776 ha compared to 96ha in GMEP) although the percentage of improved land is lower (38% compared to 53%) as is built up areas and gardens (1.3% compared to 2.5%) compared to GMEP. Future analysis could explore the reasons for the difference in improvement rates between the two sample populations.

Areas of concern / need for further action

- GMEP estimates there are approximately 57,800 ponds in Wales but only 13% of ponds sampled by GMEP were judged to be in good ecological condition, with 38% in poor or very poor condition (FIGURE-GMEP-FW-OUTCOME-C-3).
- Poaching, by which livestock are allowed to access streams, is the key cause of stream habitat modification and was observed in 55% of GMEP streams (TABLE-GMEP-FW-OUTCOME-B-1). This will increase the risk of potential transfer of pathogens to humans and/or shellfish beds and increases the risk of bank damage and associated sediment levels in streams.

[27] Jones, J. I., Murphy, J. F., Anthony, S. G., Arnold, A., Blackburn, J. H., Duerdoth, C. P., Hawczak, A., Hughes, G. O., Pretty, J. L., Scarlett, P. M., Gooday, R. D., Zhang, Y. S., Fawcett, L. E., Simpson, D., Turner, A. W. B., Naden, P. S. and Skates, J. (2017), Do agri-environment schemes result in improved water quality?. J Appl Ecol, 54: 537–546. doi:10.1111/1365-2664.12780

FIGURE-GMEP-FW-OUTCOME-A-1: Long term trends in invertebrate indicators in small Welsh streams derived from NRW monitoring. Figures indicate: WHPT score (left; an index of eutrophication and general degradation), Ntaxa (middle; the number of water quality sensitive taxa that contribute to the WHPT score) and ASPT (right; the sensitivity of the taxa to water quality which contribute to the WHPT score

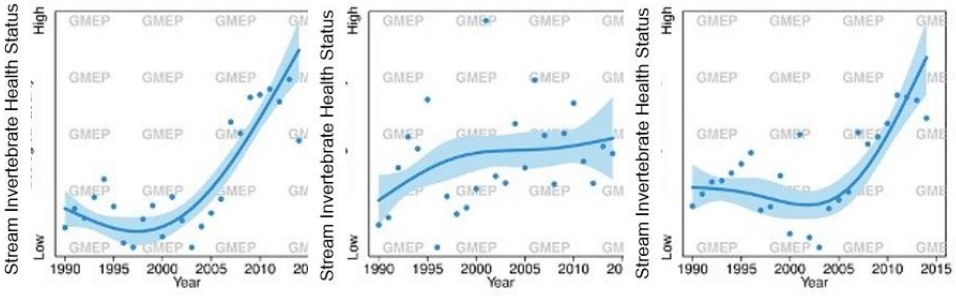


FIGURE-GMEP-FW-OUTCOME-B-1: Long term **t**rends in nutrient status of small Welsh streams derived from NRW monitoring. Figures indicate: soluble reactive phosphorus (mg/L) and total dissolved nitrogen TDN (mg/l). Note that the average area of drained land for these small streams is 20 times greater than streams sampled in GMEP (1776ha compared to 96ha in GMEP)

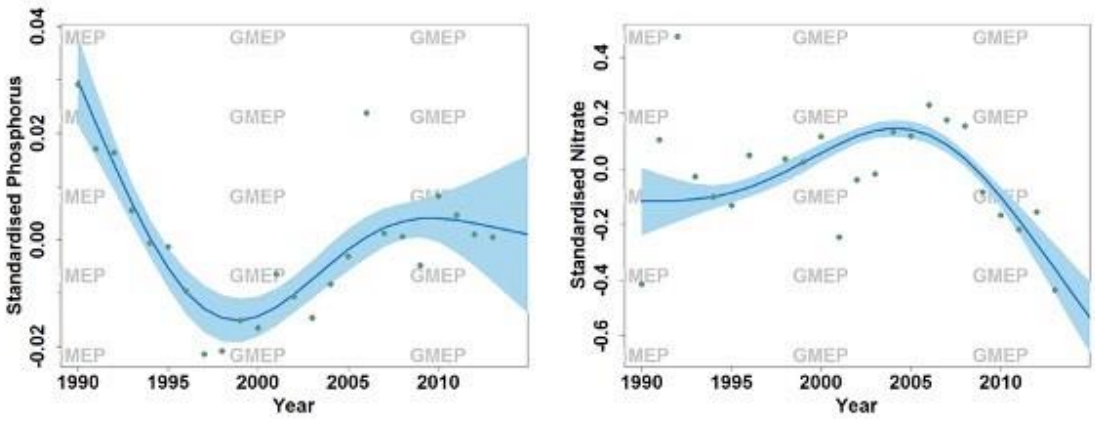


FIGURE-GMEP-FW-OUTCOME-C-3: Quality of freshwater habitats in GMEP small streams and ponds (2012 – 2016). Figures indicate a) stream diversity of macroinvertebrate communities, b) stream habitat modification classes and c) pond ecological condition. Note the classification of stream and ponds have different classes and numbers of classes and are not comparable.

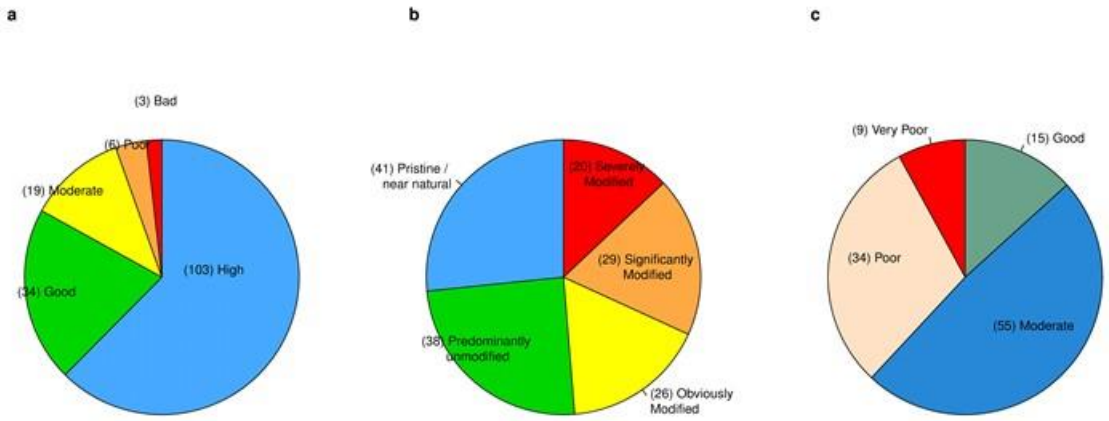
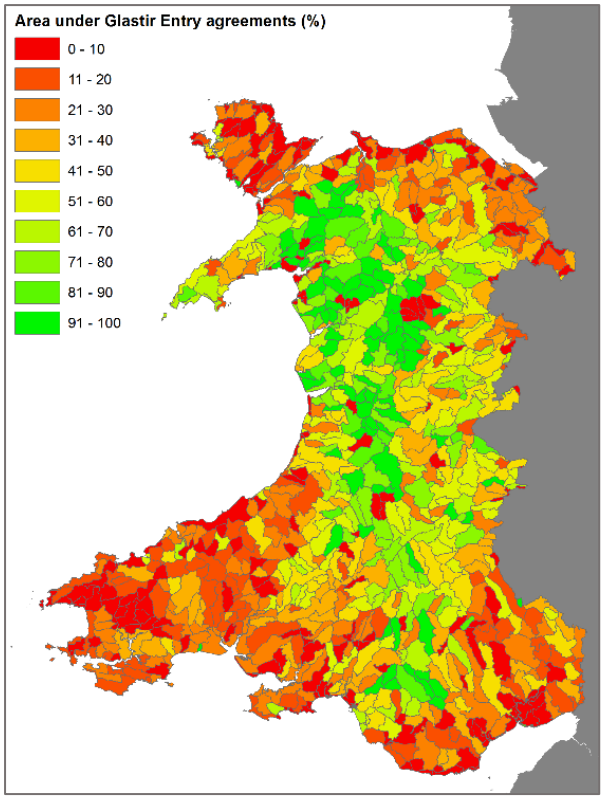


FIGURE-GMEP-FW-OUTCOME-D-1: Percentage of the farmed area (excluding commons land) within each WFD waterbody that is managed by a farm in Glastir Entry or Advanced. (Annex 5)



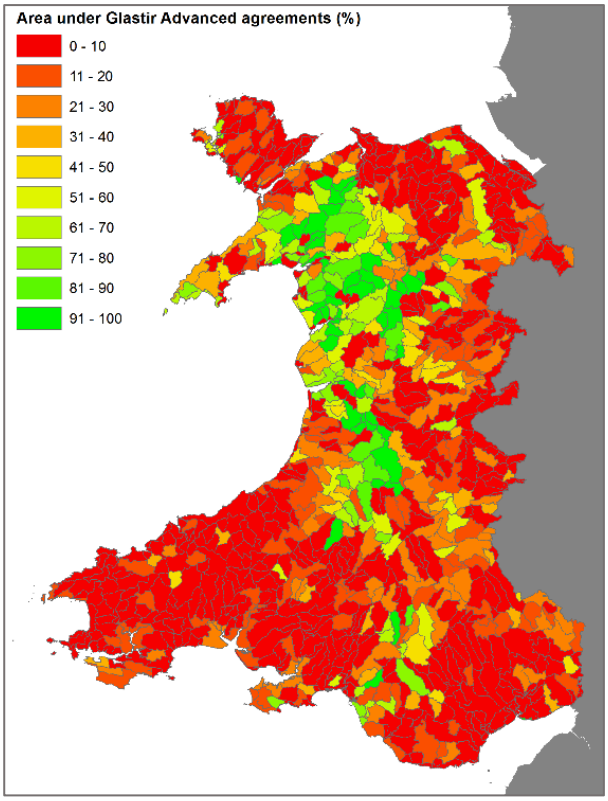


TABLE-GMEP-FW-OUTCOME-A-3 Trends in headwater stream and pond quality and area of land mitigated for runoff/flood.

Significant differences over data series are indicated by: + significant increase; - significant decrease; = no change; n/a not available. Significant differences between land in scheme compared to all Wales is also shown.

Comparison of quality in versus outside of scheme is determined from whether there is any relationship to % land upstream of sampling point which is in Glastir with the exception of pond quality and stream modification which are based on relationship to % land in scheme for the 1km sample square only. (Diatom data is also available Annex 17).

Habitat	Indicator	Countryside Survey		GMEP				Significant differences	In scheme relative to outside
		1998	2007	2013	2014	2015	2016		
Headwater streams	Macroinvertebrates index for eutrophication & general degradation: Sensitivity of taxa[1, 2] (O/E ASPT – mean observed v expected taxon sensitivity)	0.99 (high)	0.97 (high)	0.96 (good)	0.94 (good)	0.96 (good)	0.98 (high)	=	=
	Macroinvertebrates index for eutrophication & general degradation: Number of sensitive taxa [1, 2] (O/E NTAXA – mean observed v expected number of scoring taxa)	0.85 (good)	0.83 (good)	0.91 (good)	0.96 (high)	0.94 (high)	0.96 (high)	=	=
	Invertebrate diversity metric for stream health (%)[3]			83				Baseline	=
	Near-natural or predominantly unmodified (%)			51.3				Baseline	+
Ponds	Good ecological condition (%)[4]			13.3				Baseline	=
Land-water interface	Area of **in scheme** land mitigated for runoff /flood (%)[5]			18.31				Baseline	-
	Area of **out of scheme** land mitigated for runoff /flood (%)[5]			21.58					

[1] The Average Score per Taxon (ASPT) is a measure of how sensitive invertebrate taxa are to water quality based on their individual Whalley Hawkes Paisley Trigg (WHPT) score. NTAXA is the number of macroinvertebrate taxa found that score on the WHPT sensitivity scale (note that not all observed taxa contribute). The WHPT score is an index of eutrophication and general degradation .The techniques deployed in rivers are all the accepted biomonitoring standards as adopted at the UK and EU level, thus our results can be directly compared to Environment agency and NRW WFD monitoring data. The survey techniques used in the above table were RiVPACS (macroinvertebrates), and River Habitat Survey (habitats). The RIvPACS model uses environmental variables to predict the invertebrate community without any degradation (in its reference state), and generates expected values of the biomonitoring scores. The ratio of observed value to expected value is then calculated, with a ratio of 1 indicating the best condition.

[2] Water Framework Directive metrics are not available for small streams from NRW. If developed it would include many more metrics than invertebrates alone. In the absence of any formal method, we provide some indicator of stream quality we used O/E thresholds based on WFD status reporting: ASPT high >0.97, good > 0.86, moderate >0.75, poor >0.63, bad <0.63; NTAXA high >0.85, good > 0.71, moderate >0.57, poor >0.47, bad <0.47 (these categories do not correspond in any way to the categories used for ponds, they are different assessment systems). Note it is likely any WFD method would significantly reduce the number in high and good classes with most falling into the moderate class.

[3] This statistic is calculated by examining the status derived from ASPT and from NTAXA at each site, and attributing the lowest of the two statuses to the site. The numbers of site in each status class are then expressed as a percentage of the total number of sites

[4] There is no national standards for pond monitoring. We used the PSYM model developed by the FHT, a multimetric tool based on plant and invertebrate communities, and habitat features, which classifies ponds as Good, moderate, poor and very poor (these categories are not related to the WFD categories used for streams)

[5]This is calculated using the LUCI model for survey squares recorded that year. Impact of change in land use and management will be used to calculate a change metric in the 2nd cycle of survey (Years 5-8). See Annex 10 for method.

TABLE-GMEP-FW-OUTCOME-B-1 Types of stream modification from 164 GMEP survey sites.

Modification	Number of streams where observed	% of streams where observed	Notes
Poaching	91	55.5	Indicates free access to stream by livestock
Culverts	57	34.8	-
Bank modifications	54	32.9	Artificial materials, reinforcement, resectioning
Channel modifications	24	14.6	Artificial substrate, deepening, resectioning
Bridges	23	14	-
Fords	19	11.6	-
Weirs	15	9.1	-
Outfalls	9	5.5	Excludes field drains
Embankments	8	4.9	-

TABLE-GMEP-FW-OUTCOME-C-1: Percentage potential reductions in national agricultural pollutant loads (nitrogen (N), phosphorus (P) and sediment (Z)), assuming that each mitigation method in the ADAS Farmscoper library that was associated with a Glastir option, or which was found through the survey to be higher on scheme farms, was separately fully implemented on all relevant land across Wales, plus the percentage reduction due to implementing all the mitigation methods at once. (See Annex 5 for full methods and results).

Farmscoper Method		N (%)	P (%)	Z (%)
4	Establish cover crops in the autumn	1.39	2.65	6.48
13	Establish in-field grass buffer strips	0.02	0.62	1.92
14	Establish riparian buffer strips	0.15	0.73	2.16
21	Fertiliser spreader calibration	0.06	-	-
22	Use a fertiliser recommendation system	1.06	0.15	-
26	Avoid spreading manufactured fertiliser to fields at high-risk times	0.11	1.26	-
52	Increase the capacity of farm slurry stores to improve timing of slurry applications	0.18	0.54	-
62	Cover solid manure stores with sheeting	0.06	0.23	-
67	Manure Spreader Calibration	0.44	-	-
76	Fence off rivers and streams from livestock	0.25	1.48	-
79	Farm track management	0.00	0.01	-
102	Management of woodland edges	0.02	0.04	0.06
107	Beetle banks	0.02	0.24	0.77
108	Uncropped cultivated margins	0.09	0.17	0.37
113	Undersown spring cereals	0.29	0.54	1.27
114	Management of grassland field corners	0.47	1.00	1.42
115	Leave over winter stubbles	0.28	0.83	0.81
	Combined Impact	**4.26**	**8.43**	**11.14**

TABLE-GMEP-FW-OUTCOME-D-1: Change in land mitigated for flood and a range of other services modelled by the UVW/CEH LUCI model due to landcover changes included in Glastir contracts. (See Annex 10 for full methods and results.)

Service	Projected change in ecosystem service or quality	Percentage change
Carbon storage in vegetation and top 1m of soils	Average of 2.5 t yr^{-1} sequestration over 150 years	0.074 % increase once soils have reached equilibrium
Area accessible to broadleaved woodland species	12,674 ha increase (plus habitat increase of 3,923 ha)	2.8% increase
Area of "mitigating" land: this is the area classified as increasing infiltration into soil, which can help reduce the risk of flash floods and water quality issues	4,120 ha increase	0.97% increase
Area of "mitigated" land for flood and diffuse pollution: this is the area upslope of mitigating land, which benefits by being less connected to the watercourse	11,641 ha increase	3.25% increase
Area of land "accumulating flow": this is the area where the topography of the land concentrates runoff water increasing the risk of flash flood	6,066 ha decrease	1.6% decrease
Mean in stream N concentration	0.013 mg/l reduction	0.52% decrease
Mean in stream P concentration	0.001 mg/l reduction	1.55% decrease
Agricultural intensity	4,451 ha downgraded from high and very high production to moderate production or less	0.44% of high and very high production land was downgraded

4.7 Climate Change Mitigation

Outcome: Combating climate change

The Land Use, Land Use Change and Forestry (LULUCF) and Agriculture Greenhouse Gas Emission Inventories provide a good national overview of ongoing trends but are relatively insensitive to changes in land management supported under Glastir. GMEP therefore reports the overall trends from the Inventories as background information but also a series of more relevant and sensitive metrics. These include; embodied emissions for 15 'typical' farm types in Wales which includes indirect greenhouse gas emissions associated with e.g. fertiliser production not included in national inventories; an assessment of the condition of peat soils due to their importance as a carbon store; the increase in carbon storage in soils and biomass due to Glastir agreements now in place; and the potential for on-farm renewables to offset agricultural greenhouse gas emissions. The potential impact of future climate change to change greenhouse gas emissions from soil and vegetation was also explored as was the potential for new mobile flux tower technologies to improve our assessment of N_2O and CO_2 fluxes using continuous high density measurements at the field scale. Finally, reductions in ammonia emissions which reduce air quality and increase risk of eutrophication are reported as although not directly relevant to climate change mitigation, the same footprinting tool is used for their calculation.

Glastir impact

Positive Outcomes

- The Bangor Carbon Footprinting Tool was used to calculate the impact of the 'Glastir Efficiency Scheme' on greenhouse gas emissions. Over a three-year period following receipt of GES grants, there was an average reduction of 4.9% in greenhouse gas emissions per hectare across 15 farms for which detailed repeat "carbon footprints" were calculated (Annex 8). The average carbon footprints expressed per kg of lamb live weight and milk produced on surveyed farms declined by 9.5% and 18%, respectively, indicating an improvement in production efficiency[28].
- In addition to GHG emissions, livestock farms are a major source of ammonia emissions to air and nutrient losses to water. Across the 15 surveyed farms, nitrogen and phosphorus footprints per kg of product were reduced by an average of 18% and 8%, respectively, in the three years to 2015. Ammonia emissions declined by 11% over the same period. (Annex 3)
- The University of Aberdeen ECOSSE model was applied to determine if future climate change scenarios would significantly increase the direct emissions of greenhouse gas emissions from soil and vegetation. The results indicate the change was small (ca. 2%) relative to the likely indirect effect from change in land use and management and animal numbers due to economic and policy change[29].

[28] These results include embedded emissions resulting from the production and transport footprints of materials bought and used by the farm (such as animal feeds, fertilisers and plastic sheeting). These emissions are not included in current national inventories but are important to consider if emissions are not to be exported which has relevance for the Well Being of Future Generations Act goal of a Globally Responsible Wales.

[29] Abdalla, M., Richards, M., Pogson, M. et al. Reg Environ Change (2016) 16: 2357. doi:10.1007/s10113-016-0958-7

Areas for concern / need for further action

- Modelling using the Farmscoper model suggest the impacts of Glastir agreements for methane and nitrous oxide emissions will result in reductions of 1.4% and 1.8% respectively for Glastir farms which scales to 0.6% and 0.8% for Wales as a whole. Even if all mitigation methods in the Farmscoper library that was associated with a Glastir option (or which was found through the survey to be higher on scheme farms), was fully implemented on all relevant land across Wales together, modelling suggests a potential of only a 2.2% reduction at the national scale (TABLE-GMEP-FW-OUTCOME-B-1; Annex 5**).**
- The UVW/CEH LUCI model was used to simulate the benefits of increased woodland cover due to all Glastir agreements for carbon sequestration at a national scale. A total of 2.5 t yr^{-1} extra sequestration of carbon (equivalent to a 0.1% increase) and 12,674 ha increase in area accessible to broadleaved woodland species (a 2.8% increase) was calculated to be delivered at the cost of reduced agricultural intensity on 4,451 ha. The agricultural land was downgraded from high and very high production to moderate production or less. Limited reduction in actual production may be expected, since it is likely that less productive land was chosen for reductions in intensity of farming (Annex 10).
- The potential for on-farm renewable energy generation to off-set the national carbon footprint for grazed livestock products in Wales was estimated from the GMEP Farmer Practice Survey (Annex 3). Current on-farm renewable energy generation was calculated to off-set 1.1% of net greenhouse gas emissions, and a highly optimistic future scenario results in an off-set of 6.6%. It is optimistic as only 5% of farms presently have a wind turbine and the scenario requires 66% of farms to do so. Only 35% of the survey respondents either had a wind turbine or expressed an interest in wind power.

National trends

Positive Outcomes

- The National Inventory for Land Use, Land Use Change and Forestry (LULUCF) indicate soil and plant biomass was a net sink of GHG emissions from 1990 (base year) to 1995 and from 2003 to 2014 (FIGURE-GMEP-DPCCM-OUTCOME-A-3; TABLE-GMEP-DPCCM-OUTCOME-A-3). The size of the sink (CO_2e removal) grew more than 900% between 2003 and 2014 from -28ktCO_2e to -296 ktCO_2e. This was mainly due to a reduction in emissions from land converted to cropland and settlements. A transient switch to a net source was observed between 1995 and 2003.
- National Agricultural Greenhouse Gas Inventory indicates emissions have reduced by 14% between 1990 and 2014 (from 6,170 kt CO_2e to 5,278 kt CO_2e). N fertiliser consumption across Wales reduced by ca. 42% between 1990 and 2014, from 132,336t to 76,545t which contributed to this decrease as has the reduction in cattle and calf numbers by 19% (from 1.363M to 1.103M), and sheep numbers by 11% (from 10.935M to 9,739M) (FIGURE-GMEP-DPCCM-OUTCOME-A-3; TABLE-GMEP-DPCCM-OUTCOME-A-3). Note: the GHG values reported for 1990-2014 used country specific N_2O emission factors, so values are lower than previously reported. Agriculture emissions values exclude CO_2 emissions from mobile and stationary combustion used in agriculture.
- Improvement in the Blanket Bog as indicated by increased cover of *Sphagnum* (an important bog forming plant) is reported by combining CS and GMEP data. This suggests peat stores of carbon may be better protected perhaps in response to the extensive activity to restore this important habitat across Wales by many organisations.

Areas for concern / need for further action

- The LULUCF Greenhouse Gas inventory indicates a decrease in the sink by 19% between 2013 and 2014 due predominantly to a reduction in the carbon stock in forests (FIGURE-GMEP-DPCCM-OUTCOME-A-3; TABLE-GMEP-DPCCM-OUTCOME-A-3).
- The Agriculture Greenhouse Gas Inventory indicates a small increase in emissions (220 kt; 4%) between 2013 and 2014, as a result of increased nitrogen fertiliser use, and dairy cattle and sheep numbers (FIGURE-GMEP-DPCCM-OUTCOME-A-3; TABLE-GMEP-DPCCM-OUTCOME-A-3).
- Based on a new 'unified' Welsh peat map developed by GMEP, peat soils are estimated to cover over 90,000 ha of Wales (4.3% of the total land area) of which 75% is in upland areas, and 25% in lowland areas (FIGURE-GMEP-DPCCM-OUTCOME-B-1; Annex 15). Overall, around three quarters of the Welsh peat soil area is thought to have been impacted by one or more land-use activity, including drainage, overgrazing, conversion to grassland and afforestation with only 30% in 'good condition' with 25% 'modified' into grassland and 10% into woodland. As a result of these activities, Welsh peat soils are currently estimated to be generating 'anthropogenic' emissions of around 400 kt CO_2-equivalents per year (equating to around 7% of all Welsh transport-related emissions). This compares to an estimated natural 'reference' condition (i.e. if all the currently mapped peat area was natural bog or fen) of approximately 140 kt CO_2-eq yr^{-1}.

Underpinning work and exploitation of new technologies

Carbon footprinting baseline data:

The Bangor carbon footprinting tool identified the largest proportion of total greenhouse gas emissions from farms come from methane (CH4) accounting for, on average 50% (36-61%) of emissions per ha. Methane emission rates correspond to the number of ruminant livestock, and were primarily a function of ruminant livestock enteric (gut) fermentation. Nitrous oxide (N2O) accounted for, on average 27% of emissions. This was largely from direct emissions (from soil management, peaty soils, and manure handling) with the remainder coming from indirect emissions (N deposition, leaching and runoff on soils, and volatilisation from stored manure). Emissions from inputs averaged 22% (9-40%) of emissions per ha and were dominated by mineral N fertiliser, feed concentrates, and bought-in stock. The CO2 footprint from liming was small on all farms, ranging from 0.5-2.2 kg CO2/ha/yr. (Annex 8).

Very few significant associations were found between footprints of livestock and farm size, stock numbers in winter and summer, or peat soils which mean they cannot be used as simple proxies of emissions (Annex 8). There was a high variability in the footprint of lamb for slaughter varied from 11 kg CO2e/kg LW to 29 kg CO2e/kg LW and 2,400 to 18,500 kg CO2e/ha (average 7,200) indicating the wide range of efficiency across farms. This will reflect both the high variability in land quality but also opportunities for management to improve. Dairy has the highest embodied GHG missions on an area basis followed by mixed, beef and sheep farm businesses (Annex 8).

Carbon sequestration ranged from 853 to 1,648 kg CO2/ha/yr (averaging 1,008 kg CO2/ha/yr). Most sequestration (average 85%, range 51-100%) was in the form of carbon storage in grassland soils. Woodland contributed on average 9% (ranging from a net carbon loss of 5% to a net carbon gain of 25% of whole farm sequestration). Isolated trees sequestered on average 4% (range, 0.5-21%), and

hedges 4% (range, 0.4-7%). Farm type and size had a negligible effect on total sequestration per hectare. The average carbon balance (total footprint minus sequestration) of the ten farms was 6,221 kg CO2e/ha/yr, varying from 1,103 to 17,571 kg CO2e/ha/yr. Sequestration accounted for an average of 21% of the emissions footprint, but this varied widely between 5% and 60% of farm emissions. None of the farms sequestered more carbon per hectare than their total footprint (Annex 8).

Method development to improve GHG flux estimates:

The potential for developing mobile flux tower systems to further improve greenhouse gas flux measurements which are highly variable both spatially and temporally was tested. The technology and specifically power requirements were found to severely limit their current deployment at the scale intended (Annex 18). The results did however confirm a recent report of a strong diurnal cycle for nitrous oxide which could lead to underestimation of fluxes by ca. 20% with the bias switching during high and low flux periods30. Their other main advantage is the reduction in the high spatial variability resulting from their whole field assessments rather than small plot measurements using chambers. The latter generally deliver results with standard errors of ca. 50% of the mean which limit our current ability to detect differences between grassland types and the impact of the relatively subtle effects of some Glastir interventions.

GMEP aligned additional studies using chambers to assess differences between intensive and extensive grassland systems with respect to carbon dioxide (CO2) exchange. Results indicated higher drawdown of CO2 during the day time but also greater release at night in the improved grassland meaning no net different in carbon dioxide balance. This again illustrates the importance of intensive continuous data capture if accurate assessments are to be made. (Annex 18).

[30] Shurpali, N. J. *et al.* Neglecting diurnal variations leads to uncertainties in terrestrial nitrous oxide emissions. *Sci. Rep.* **6**, 25739; doi: 10.1038/srep25739 (2016).

FIGURE-GMEP-DPCCM-OUTCOME-A-3 Long term trends in; annual GHG emissions from the Land Use, Land use Change and Forestry and the Agriculture sector for Wales. Sources are: LULUCF - Emissions and Removals of Greenhouse Gases from Land Use, Land Use Change and Forestry (LULUCF) for England, Scotland, Wales and Northern Ireland: 1990-2014; Agriculture – subset of UK Agriculture Greenhouse Gas Emissions Inventory 1990 – 2014 excluding emissions from mobile and stationary combustion.

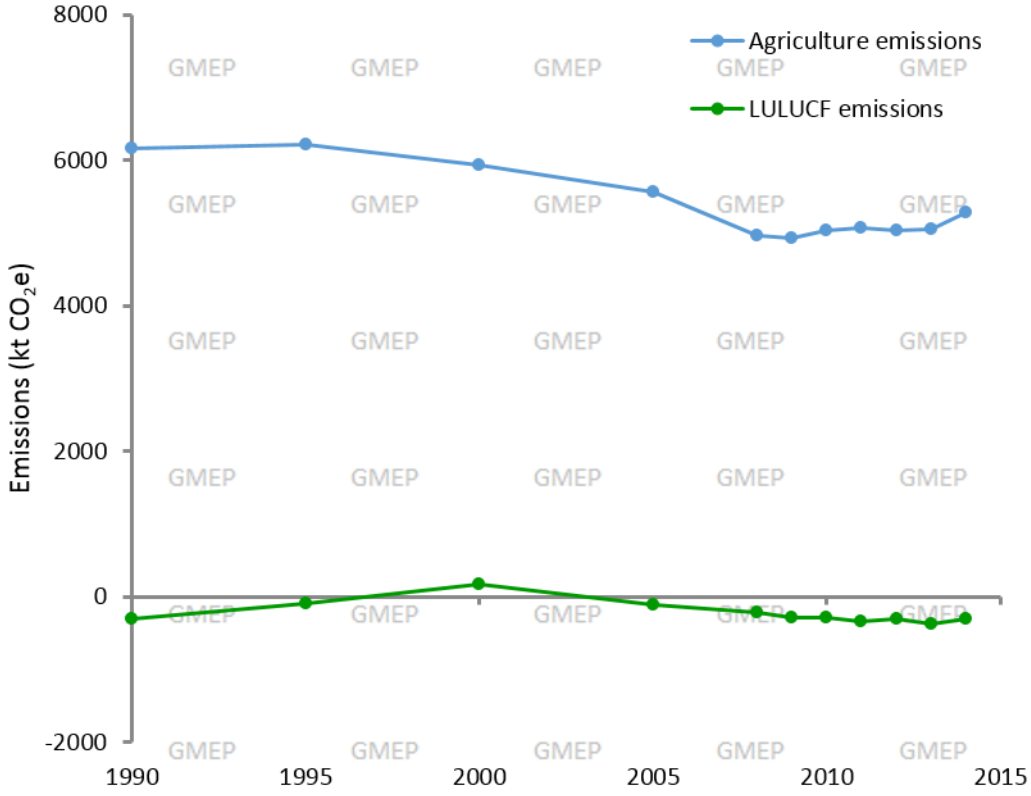
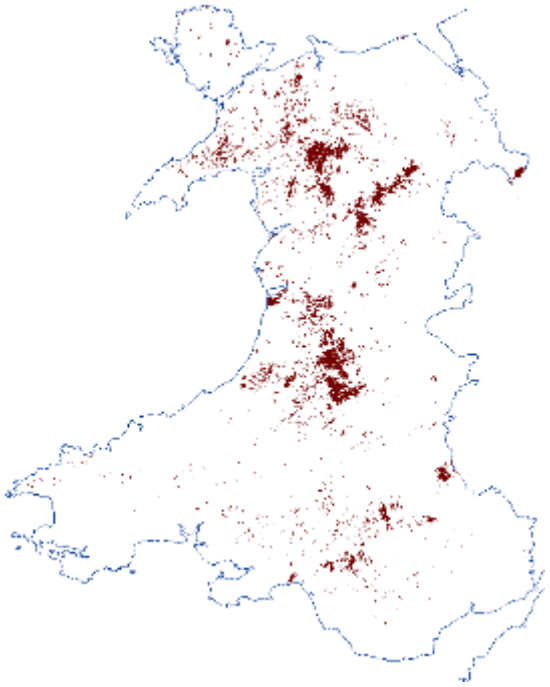


FIGURE-GMEP-DPCCM-OUTCOME-B-1 Peat coverage and greenhouse gas emissions; a) A new unified peat map for Wales and b) the estimated contribution of different peat land-use/condition categories to total greenhouse gas emissions from Welsh peats under a natural 'reference' condition, in 1990, and at present day. The size of each pie chart is illustrative of the overall level of emissions. (See Annex 15 for full report)

a)



b)

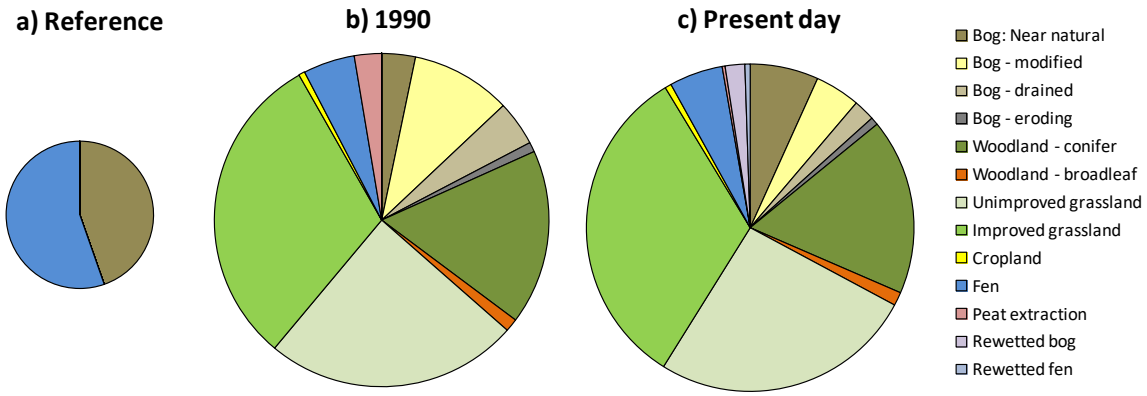


TABLE-GMEP-DPCCM-OUTCOME-A-3: Long term trends in greenhouse gas emissions related to agriculture and land use, land use change and forestry; the impact of Glastir Efficiency Grants on whole farm carbon footprints; and the condition of peat in and out of scheme.
Differences are indicated by: + significant increase; - significant decrease; = no change; n/a not available.

Indicator	National Greenhouse Gas Inventories									Long term / Recent trend
	1990	1995	2000	2005	2010	2013	2014	2015	2016	
Contribution by land use and land use change ($ktCO_2e\ yr^{-1}$) (excludes peatlands)[1]	-295	-99	173	-108	-281	-365	-296	n/a		=/+
Agriculture Emissions (CO_2eq ($kt\ N_2O + CH_4$))[2]	6170	6208	5940	5565	5039	5059	5278	n/a		-/ +
				Bang or Uni		GMEP				Change due to GEGs
Agriculture emissions including embodied emissions (typical average farm data only tCO2e/ha)[3] Beef Dairy Mixed Sheep				6.46 11.23 8.33 1.70		n/a				-
	GMEP									
Peatland condition ($ktCO_2e\ yr^{-1}$): Estimated total emissions[4]	577				546[4]					
	CS					GMEP				Trend
Indicator	1990	1995	1998	2005	2007	2013 – 16				
Peatland condition: Blanket bog *Sphagnum* % cover[5]	1.38		15.54		11.78	34.45				+/+ In versus out of scheme =

[1] Data underlying Figure 13, Emissions and Removals of Greenhouse Gases from Land Use, Land Use Change and Forestry (LULUCF) for England, Scotland, Wales and Northern Ireland: 1990-2013 Salisbury et al (2015). http://uk-air.defra.gov.uk/assets/documents/reports/cat07/DA_GHGI_1990-2013_Report_Appendices_v1.pdf
Net emissions from the LULUCF sector in Wales have changed slightly from those in the 1990-2012 inventory but there is no clear pattern of net increase or decrease. The differences are due to a combination of changes in all sub-categories. The 2013 inventory methods has ben backcast to 1990.
[2] Using IPCC 2006 Guidelines, backcast to 1990. 2000 GL were used in previous reporting on the GMEP portal, and the two methodologies will give different totals (and different proportional contributions of CH4 to N2O,)
[3] The Bangor Carbon Footprinting Tool outputs include: soil direct N_2O, indirect N_2O associated with nitrate leaching and N deposition, enteric CH_4, manure CH_4, CO_2 associated with electricity and energy use, embedded greenhouse gas emissions associated with feed and fertiliser production, agricultural productivity. Above and below ground carbon stocks are also included.
[4] Emissions estimate for the Welsh peat area as defined from British Geological Survey and Natural Resources Wales (NRW) mapping, using peat condition data obtained from the NRW Phase 1 Habitat Survey augmented by drainage ditch maps digitised from aerial photographs, and CO2, CH4 and N2O emission factors taken from the IPCC Wetland Supplement (IPCC, 2014) and Peatland Code (Smyth et al., 2014). Note that total emissions have a high uncertainty where it has been necessary to use IPCC .Tier 1. emission factors based on non-UK flux measurements (notably for grassland, forest and near-natural fen); these estimates will be revised in future as new UK-specific measurements become available. For more information see Evans et al. (2015)
[5] Sphagnum cover data are taken from the 1990, 1998 and 2007 Countryside Surveys, and the 2013/16 GMEP surveys (2m x 2m plots), as an indicator for CO2 sequestration by blanket bogs (1998 and 2007 CS data are assigned to the relevant five-year reporting periods in the table). There was a significant increase in *Sphagnum* cover between the 2007 CS and 2012/16 GMEP surveys. Note however that the sample size was lower in the CS dataset (n = 3, 12 and 15 in the 1990, 1998 and 2007 surveys respectively) compared to GMEP (n = 97). Note also that this metric applies only to blanket bogs under semi-natural vegetation cover, i.e. it should not be taken as an indicator of CO_2 emissions/removals by other peatland types (fens or raised bogs), and does not represent areas of former blanket bog that have been converted to other land-use such as forestry or grassland.

TABLE-GMEP-FW-OUTCOME-B-1 Percentage reductions in greenhouse gas emissions assuming that each mitigation method in the Farmscoper library that was associated with a Glastir option, or which was found through the survey to be higher on scheme farms, was separately fully implemented on all relevant land across Wales, plus the percentage reduction due to implementing all the mitigation methods at once.

Farmscoper Method		**CH_4 (%)**	**N_2O (%)**
4	Establish cover crops in the autumn	-	0.15
13	Establish in-field grass buffer strips	-	0.00
14	Establish riparian buffer strips	-	0.06
21	Fertiliser spreader calibration	-	0.01
22	Use a fertiliser recommendation system	-	0.69
26	Avoid spreading manufactured fertiliser to fields at high-risk times	-	0.01
52	Increase the capacity of farm slurry stores to improve timing of slurry applications	-	0.02
62	Cover solid manure stores with sheeting	-	0.01
67	Manure Spreader Calibration	-	0.05
76	Fence off rivers and streams from livestock	-	0.03
79	Farm track management	-	0.00
102	Management of woodland edges	-	0.04
107	Beetle banks	-	0.00
108	Uncropped cultivated margins	-	0.09
113	Undersown spring cereals	-	0.03
114	Management of grassland field corners	-	1.05
115	Leave over winter stubbles	-	0.03
	Combined Impact	**0.00**	**2.22**

4.8 Soil

Outcome: Improving soil quality and management

Soil properties measured are related to soil and ecosystem function and are important for determining the soil resilience and the impact any environmental or Glastir changes may have on broad habitats and biodiversity. Specifically the GMEP soil measures contribute to the following Glastir strategic outcomes;

- combating climate change through assessment of carbon storage in soils;
- improving water quality through assessment of soil nutrient and acidity levels which indicate potential risks due to runoff and leaching but are also important for maintaining productivity;
- halting the decline in biodiversity through assessing change in specific soil quality requirements of many native plant species and quantification of levels of biodiversity in the soil itself.

All soil properties selected are indicators which were proposed and tested by the UK Soil Indicators Consortium for specific functions including environmental interactions which include hydrological filtering by soils, habitat support and carbon gas exchanges with the atmosphere. As the sampling and analytical methodology used for topsoil in GMEP is identical to that used in Countryside Survey these datasets can be combined to look for long-term national trends as well as providing a robust baseline for assessing future impacts of Glastir payments. All methods used are available in Annex 19.

Results presented here include headline results summarised for Whole Farm Code habitat groups as requested by the GMEP Steering Group although data for Broad Habitats and individual soil types are available and can be used in future assessments. The field survey also enabled the condition of soil of land in scheme to be compared to the national average. In addition to the field survey data, the GMEP Farmer Practice Survey provides farmer reported assessment of soil drainage systems. With respect to Glastir impacts, no modelling work has specifically focussed on the potential change in soil condition in response to Glastir interventions other than that reported for soil carbon stock change by UVW/CEH LUCI modelling which is reported in Section 4.7. Reported lag times in the response of soil nutrient and acidity status to management change underpinned much of the biodiversity modelling work reported in Section 4.5 but is not reported here. See a review of these known lag times from past studies in Annex 9. The peatland work deployed a mix of aerial photography, emission factors from past studies and peat coring. Methods and full results are available in Annexes 15 and 20. All results are presented in FIGURE-GMEP-S-OUTCOME-A-3 and TABLE-GMEP-S-OUTCOME-A-3 unless otherwise indicated**.**

Glastir impact

Positive Outcomes

In scheme farms had the following improvements relative to non-scheme farms:

- 10% increase in the likelihood of calibrating fertiliser spreaders (from 62% to 72%)
- 10% increase in the likelihood of carrying out soil nutrient testing (from 51% to 61%).
- 15% more likely to have left stubble in fields to provide over-winter cover (from 44% to 59%).
- 9.4% decrease in the use of phosphate fertiliser on grassland fields
- 6% reduction in breeding ewe numbers for farms in the Advanced level

Baseline assessment of soil condition of land coming into the scheme compared to the national average

- There is no difference if the condition of soil coming into the scheme due to the high variability of soils in the four high level categories requested by the GMEP Steering Group. Future comparisons will benefit from this robust baseline assessment and reporting by more specific Broad Habitats and soil types.

National trends

Positive Outcomes

- Soil carbon has been stable in improved land for 30 years.
- After recent increases in woodland systems soil carbon is now stable.
- Soil nitrogen levels are stable in improved land and woodland. A decline in soil N in habitat land is likely to be beneficial for native vegetation. The reasons for this decline require further analysis.
- After recent declines in soil phosphorus, levels in improved land are stable and within the zone appropriate for sustainable production whilst presenting a lower risk to waters.
- There is no consistent pattern in soil mesofauna numbers. Values are now back to those observed in 1998. Further work is needed to understand inter-annual variation together with an analysis of the species present.
- A significant increase in *Sphagnum* cover since 1990 has been seen, suggesting a trend toward gradually improving conditions in Welsh blanket bog. See Biodiversity section for additional data relating to blanket bog including a significant increase in Common Standard Monitoring positive indicator plants and plants indicative of wet conditions.

Areas for concern / need for further action

- There has been significant decline in soil carbon in habitat land over the last 10 years. This is primarily due to a reduction in soil carbon in acid grassland. Further work is needed to identify possible reasons for this.
- Soil acidity declined for all habitats up until 2007 reflecting the rapid reductions in acidic deposition over the last three decades. This has now reversed in improved land with increased acidity observed perhaps reflecting low levels of lime usage. However on average soil pH remains above recommended levels for sustained production in improved land.
- Farmers reported 40% of drains in arable and improved grassland are in need of repair or replacement. This has implications for production, greenhouse gas emissions and animal health.

Underpinning work and exploitation of new technologies

Soil biodiversity: We used a mix of eDNA to assess diversity of bacteria, fungi and and visual counting for diversity and numbers of mesofauna in soil. Contrary to expectation, both soil bacterial and fungal diversity are greatest in the arable and horticultural soils and decline across the land intensification gradient (FIGURE-GMEP-S-OUTCOME-B-1). The relationship is most likely related to strong trend in soil pH across the same gradient which is known to be the primary factor explaining soil bacterial diversity. Alternatively, it may relate to the higher diversity of niche space in the more intensive and fertile systems. Interestingly, these relationships are contrary to those observed for mesofauna. Mesofauna diversity has previously been shown in CS to have a characteristic ‘hump’ as

seen for mesofauna numbers here at intermediate acidity and land use intensity types (FIGURE-GMEP-S-OUTCOME-B-1 and diversity data in Maskell et al. 2013[31]). This 'hump' is also seen for vegetation and freshwater macroinvertebrate diversity (Maskell et al. 2013). Is microbial diversity determined by acidity whilst soil and water mesofauna are determined by plant diversity? These and other questions relating to the implications of the diversity relationships for resilience of soil function is being explored by NERC-BBSRC funded [32]aligned PhD studentships.

Soil sampling: A comparison of the GMEP soil corer and a commonly used halfmoon soil auger for soil sampling was carried out to determine if standardisation was important. Critically, the commonly used halfmoor auger under-estimated soil carbon in organo-mineral soils (FIGURE-GMEP-S-OUTCOME-C-1). This simple difference in sampling methods indicates how important it is to consistently use a volumetric sampler as done in CS/GMEP to avoid biased reporting. Important mis-reporting of texture by a commercial laboratory has also been identified which illustrates the importance of using laboratories which are able to provide a good quality analysis across the wide spectrum of national soil types (i.e. not just nutrient-rich improved arable and grassland soils which is the basis for most commercial analysis) for programmes such as GMEP.

Peat accumulation rates: Peat accumulation rates from a range of blanket bogs across Wales were estimated using 'speroidal carbonaceous particle analysis'. The results represent historic carbon accumulation for differing management conditions. Near-natural peatlands accumulated ca. 30-40 g C m^2 yr^{-1} more than afforested and drained sites. However, surprisingly the largest reduction in carbon accumulation occurred where grasses dominate the bog (Annex 20). The invasion of bogs by grasses may reduce carbon accumulation as dead grass material is less resistant to decomposition than primary peat forming taxa (e.g. *Eriophorum vaginatum*, *Sphagnum*). This suggests grass-invasion of blanket bogs are at greatest risk of carbon loss.

[31] Maskell, L.C., Crowe, A., Dunbar, M.J., Emmett, B., Henrys, P., Keith, A.M., Norton, L.R., Scholefield, P., Clark, D.B., Simpson, I.C. & Smart, S.M. (2013) Exploring the ecological constraints to multiple ecosystem service delivery and biodiversity. *Journal of Applied Ecology,* **50,** 561-571.
[32] http://www.starsoil.org.uk/

FIGURE-GMEP-S-OUTCOME-A-3: Long term trends in topsoil (0-15cm) condition for Habitat, Improved Land and Woodland for the following properties:

a, b and c) topsoil condition for carbon
d, e and f) acidity
g, h and i) nutrient levels -nitrogen
j, k and l) nutrient levels - available phosphorus
m, n and o) soil mesofauna numbers

Countryside Survey data is indicated by a solid line and GMEP by a dotted line. Grey line when present indicates CS Great Britain average 1978 – 2007) to provide national context. Red lines indicate thresholds which are to be avoided exceeding. Green lines indicate thresholds not to fall below.

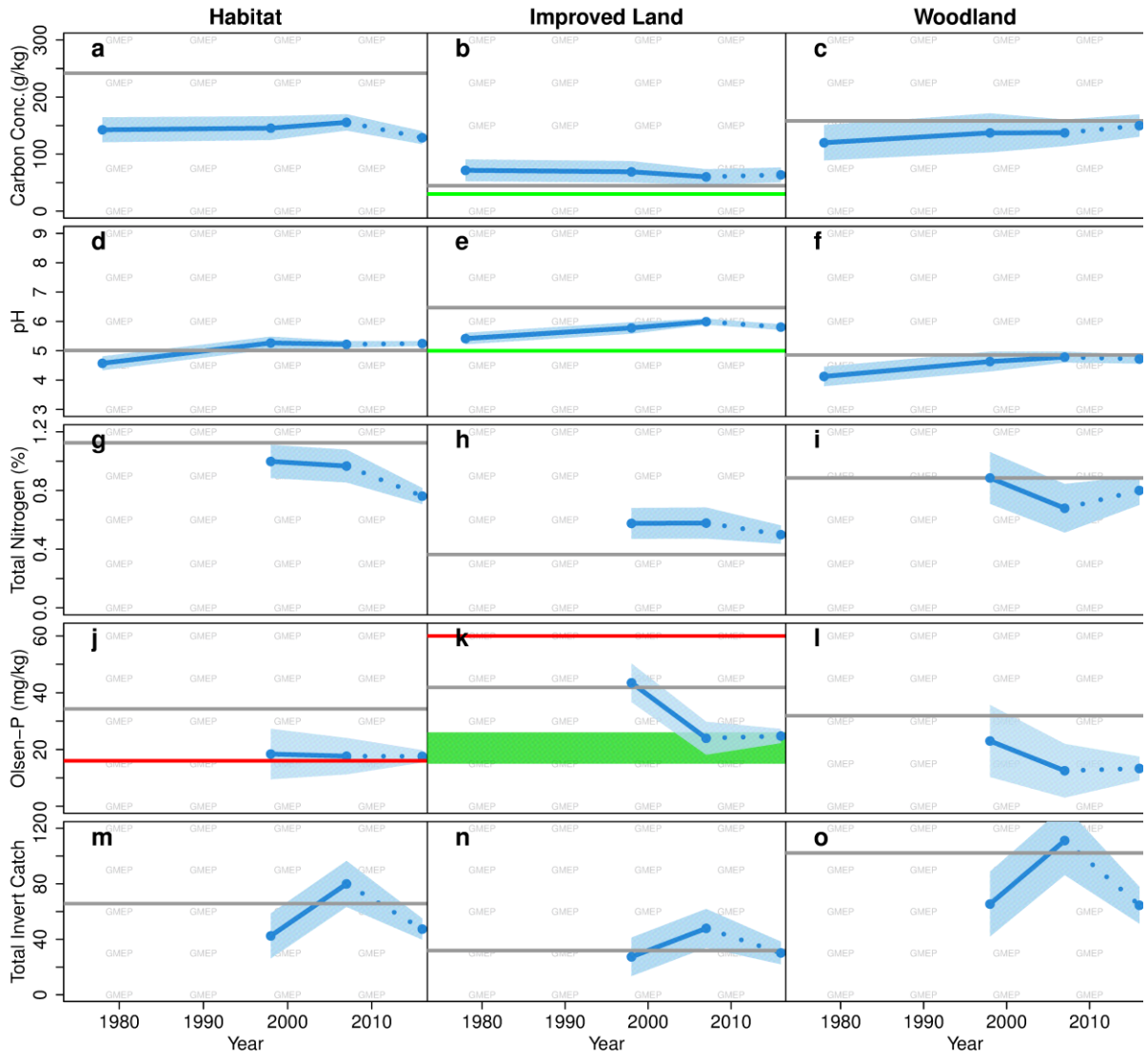


TABLE-GMEP-S-OUTCOME-A-3: Long term trends in topsoil (0-15cm) condition.
Significant differences over data series and latest period are indicated by: + significant increase; - significant decrease; = no change; n/a not available. Significant differences between land in scheme compared to all Wales is also shown.

*Note the decrease in phosphorus is considered a positive outcome for improved land and all Wales as it indicates less risk for diffuse pollution. Levels are still above those recommended for production.

Habitat Groups	Indicator	Countryside Survey[3]				GMEP	Significant differences		In scheme compared to national average
		1978	1990	1998	2007	2013-16	Overall	Latest period	
Improved Land	Carbon (g/kg, from LOI)	71.6		69.0	60.2	63.7	=	=	=
	pH	5.42		5.78	5.99	5.81	+	-	=
	N (g/100g dry soil)			0.58	0.58	0.50	=	=	=
	Phosphorus (Olsen P mg/ kg)			43.5	24.0	24.8	-*	=	=
	Soil biota (Total invert catch)			27.4	47.9	30.2	=	-	=
Habitat	Carbon (g/kg, from LOI)	142.6		145.5	155.6	128.8	=	-	=
	pH	4.57		5.27	5.22	5.25	+	=	=
	N (g/100g dry soil)			1.00	0.97	0.76	-	-	=
	Phosphorus (Olsen P mg/ kg)			18.4	17.6	17.6	=	=	=
	Soil biota (Total invert catch)			42.5	79.9	47.4	=	-	=
Woodland	Carbon (g/kg, from LOI)	120.0		137.3	137.3	150.0	+	=	=

Habitat Groups	Indicator	Countryside Survey[3]				GMEP	Significant differences		In scheme compared to national average
		1978	1990	1998	2007	2013-16	Overall	Latest period	
	pH	4.12		4.63	4.78	4.72	+	=	=
	N (g/100g dry soil)			0.89	0.68	0.80	=	=	=
	Phosphorus (Olsen P mg/ kg)			23.0	12.5	13.3	=	=	=
	Soil biota (Total invert catch)			65.4	111.2	64.5	=	-	=
Wales	Carbon (g/kg, from LOI)	104.7		107.4	108.1	107.6	=	=	=
	pH	5.02		5.42	5.54	5.39	+	-	=
	N (g/100g dry soil)			0.78	0.74	0.67	-	-	=
	Phosphorus (Olsen P mg/ kg)			32.4	19.7	19.7	-*	=	=
	Biodiversity (Total invert catch)			41.0	69.9	43.1	=	-	=
Peatland	Peatland condition (Estimated total emissions $ktCO_2e\ yr^{-1}$) [1]	577			546[4]				=
	Peatland condition: Blanket bog *Sphagnum* % cover [2]		1.38	15.55	11.78	34.45	+	+	=

[1] Emissions estimate for the Welsh peat area as defined from British Geological Survey and Natural Resources Wales (NRW) mapping, using peat condition data obtained from the NRW Phase 1 Habitat Survey augmented by drainage ditch maps digitised from aerial photographs, and CO2, CH4 and N2O emission factors taken from the IPCC Wetland Supplement (IPCC, 2014) and Peatland Code (Smyth et al., 2014). Note that total emissions have a high uncertainty where it has been necessary to use IPCC .Tier 1. Emission factors based on non-UK flux measurements (notably for grassland, forest and near-natural fen); these estimates will be revised in future as new UK-specific measurements become available. For more information see Evans et al. (2015)

[2] Sphagnum cover data are taken from the 1990, 1998 and 2007 Countryside Surveys, and the 2013/16 GMEP surveys (2m x 2m plots), as an indicator for CO2 sequestration by blanket bogs (1998 and 2007 CS data are assigned to the relevant five-year reporting periods in the table). There was a significant increase in *Sphagnum* cover between the 2007 CS and 2012/16 GMEP surveys. Note however that the sample size was lower in the CS dataset (n = 3, 12 and 15 in the 1990, 1998 and 2007 surveys respectively) compared to GMEP (n = 97). Note also that this metric applies only to blanket bogs under semi-natural vegetation cover, i.e. it should not be taken as an indicator of CO2 emissions/removals by other peatland types (fens or raised bogs), and does not represent areas of former blanket bog that have been converted to other land-use such as forestry or grassland

[3] As estimates are obtained via a model-based approach with a correlation structure to account for repeated measures, there is the possibility that estimates change at each reporting occasion as the correlation structure is re-estimated. The change in estimated correlation structure affects the estimated parameters in the model and hence yearly estimates. See Scott, W. A. 2008 Statistical Report. CS Technical Report No. 4/07 for further details.

FIGURE-GMEP-S-OUTCOME-B-1: Topsoil bacterial and fungal species diversity and mesofauna numbers under a range of broad habitat classes. (GMEP mesofauna diversity numbers are still being analysed. CS data are available in Maskell et al. 2013). The habitats are ranked from those of highest productivity on the left to those which are less productive on the right.

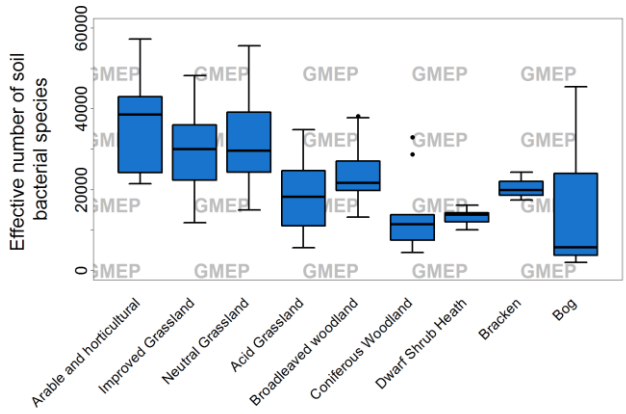


FIGURE-GMEP-S-067-A-1: Boxplots showing the distribution of topsoil microbial diversity across different broad habitats sampled in the GMEP field survey

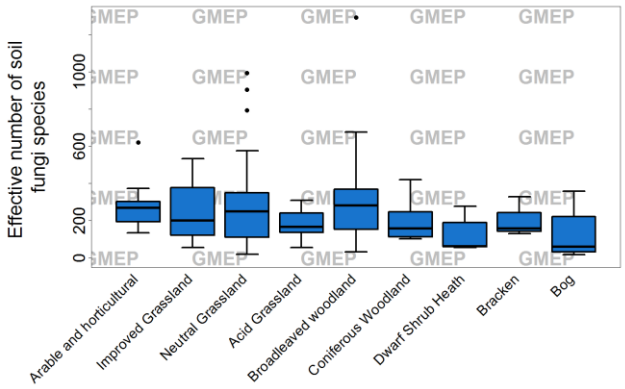


FIGURE-GMEP-S-070-A-1: Boxplots showing the distribution of topsoil fungal diversity across different broad habitats sampled in the GMEP field survey

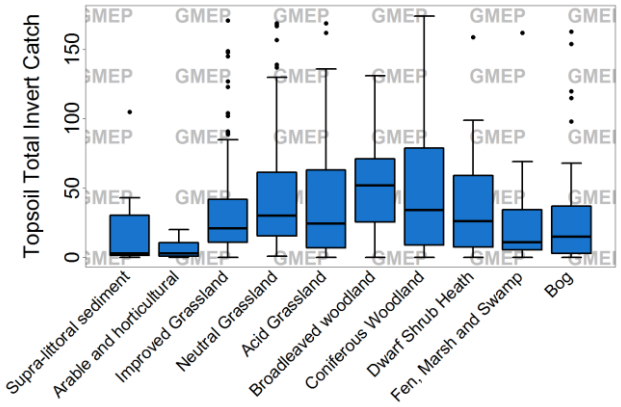


FIGURE-GMEP-S-048-A-3: Boxplots showing the distribution of topsoil mesofauna abundance (total invertebrate catch) across different broad habitats sampled in the GMEP field survey

FIGURE-GMEP-S-OUTCOME-C-1: A comparison of the GMEP core cutter and half-moon auger for sampling soil and resulting carbon concentration results.

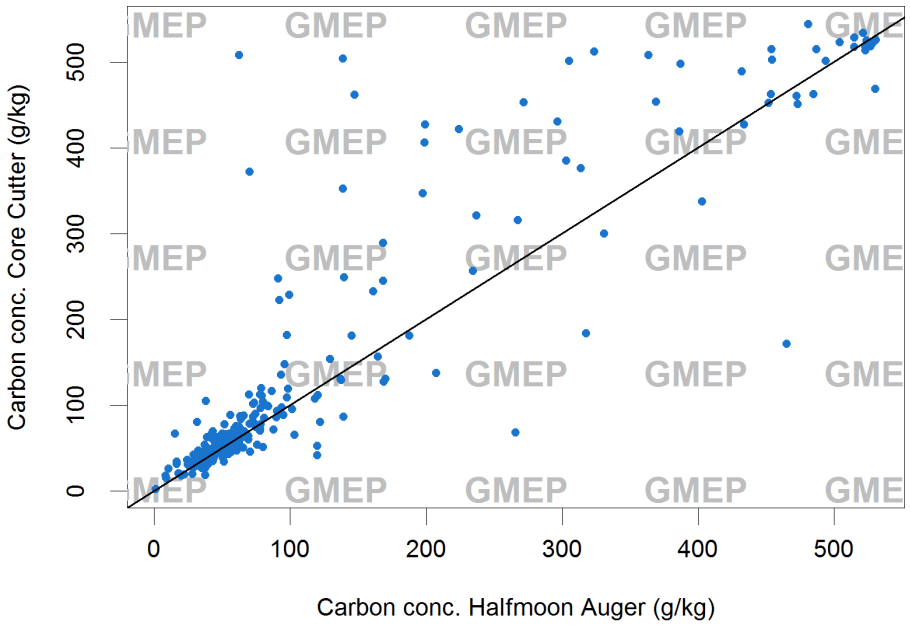


FIGURE-GMEP-S-065-A-1: Relationship between carbon concentration estimated from halfmoon auger verus carbon concentration as estimated by core cutter.

4.9 Landscape and access

Outcome: Managing landscapes and historic environment and improving public access to the countryside

Three high level indicators have been selected which will enable the future impacts of Glastir to be assessed for landscape, historic features and access and thus potentially how a broader section of the community may benefit from Glastir. As many visitors to the countryside tend to be concentrated around urban and coastal setting it is important to note that GMEP squares include coastal land and land surrounding our towns and cities (so called peri-urban).

Indicators presented include a new index developed by GMEP to provide a robust, tested and repeatable metric for assessing aesthetic quality as perceived by the public [33] (Annex 21). Plant species richness, amount of water and green spaces have all been found to be positively related to the VQI suggesting there is a link between ecological and landscape quality. Future assessments will be able to quantify change over time and the link to Glastir payments, and the relationship between ecological and landscape quality using other metrics such as the new High Nature Value index (see Section 4.5). Other indicators requested by the GMEP Steering Group include the condition of Historic Environment Features and condition of public rights of way.

National trends

Positive outcomes

- 66% of public rights of ways are easy to use. This appears to have increased steadily over the last 10 years from a baseline of around 40%.
- Land inside protected areas has a higher Visual Quality Index compared to land outside.

Comparison of land in scheme compared to land out of scheme

- Land in Glastir has a mean higher visual quality index relative to land outside of scheme. Future assessments will be able to quantify the change due to Glastir interventions

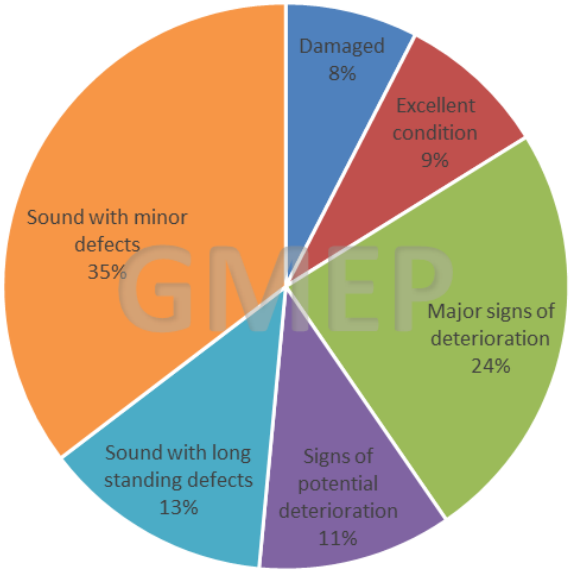
Areas for concern / further action needed

- 57% of Historic Environment Features are in 'Sound' or 'Excellent' condition. This is lower than assessments made by Cadw for listed buildings and scheduled monuments perhaps reflecting their larger number and thus greater challenge to protect. The greatest threats identified on site were vegetation encroachment (50%); stock damage (25%) such as poaching, burrowing, path wear; and agricultural operations (13%), such as rutting, ploughing, drainage, stone clearance, pasture improvement etc.

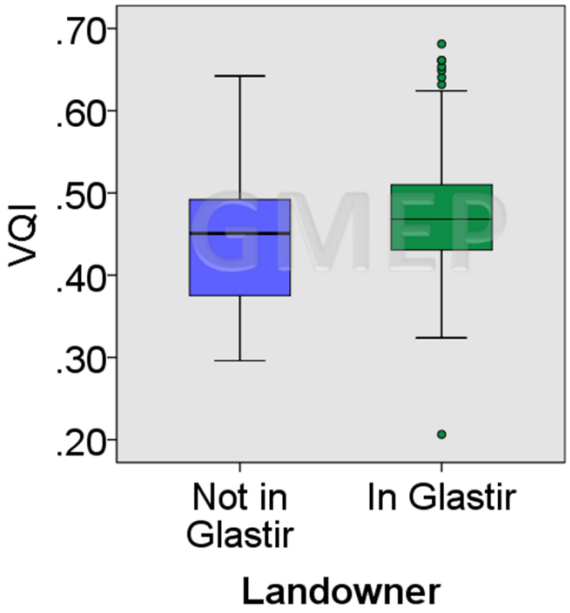
[33] R.D. Swetnam, S.K. Harrison-Curran, G.R. Smith, Quantifying visual landscape quality in rural Wales: A GIS-enabled method for extensive monitoring of a valued cultural ecosystem service, Ecosystem Services, Available online 21 November 2016, ISSN 2212-0416, http://dx.doi.org/10.1016/j.ecoser.2016.11.004.

FIGURE-GMEP-L-OUTCOME-A-3: a) Condition of Historic Environment Features (HEFs) from GMEP, b) the difference in the Visual Quality Index (VQI) of land which has come into Glastir compared to that outside the scheme, c) the difference in the VQI inside a protected areas compared to those outside and d) the relationship between plant species and the VQI.

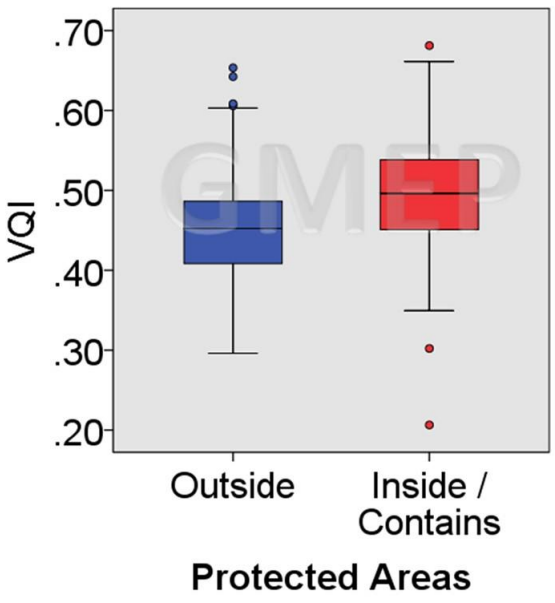
a)



b)



c)



d)

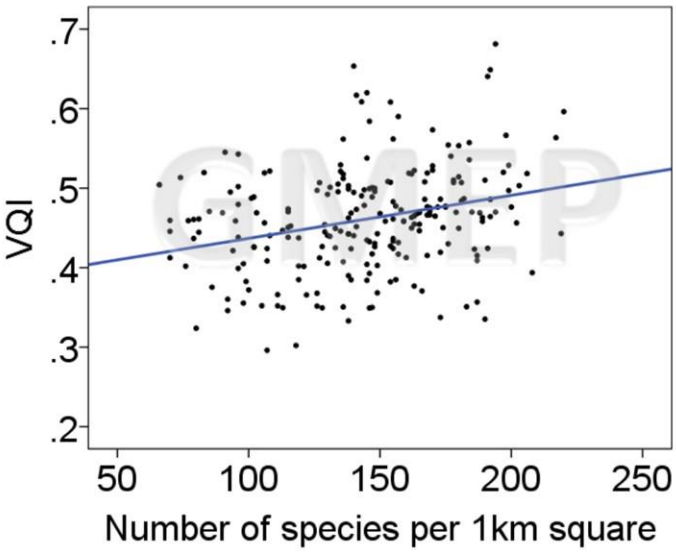


TABLE-GMEP-L-OUTCOME-A-3: Indicators of landscape quality, historic feature condition and condition of Public Rights of Way.

Significant differences over data series and latest period are indicated by: + significant increase; - significant decrease; = no change; n/a not available.

Habitat	Indicator	Other data sources						GMEP 2013 - 16	In versus out of scheme
Landscape quality [1]	Median Visual Quality Index (index from 0 – 1.0): In scheme	No comparable data						0.468	+
	Median Visual Quality Index (index from 0 – 1.0): Out of scheme							0.451	
Habitat	**Indicator**	**Cadw Year**							
Historic features	Historic environment assets (% in stable or improved condition[2]	78 - 79							**n/a**
								GMEP 2013 - 16	
	Historic Environment Feature Condition (% in 'Sound' or 'Excellent' condition)[2]							57	**n/a**
		StatsWales[3]						**GMEP**	**Trend**
		2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	**2013 -16**	
Public Rights of Way	% of footpaths and rights of way which are easy to use	41.0	50.6	51.0	49.3	54.9	55.0	66.0	+

[1] This is a combined scoring of five key components from the GMEP survey squares: topography (how rugged / varied the landform is); .blue-space. (water features in the landscape); .green-space. (habitat diversity, vegetation complexity); anthropogenic (built components); historic / cultural (including presence of Scheduled Ancient Monuments etc). The validity of the index has been tested in an array of web-based and social surveys and has been found to reflect values actually attributed to quality of landscape as perceived by a broad section of the population (Swetnam et al. 2016).

[2] Data from Cadw as presented in the Programme for Government, Indicator OU095. This data is based on listed buildings and Schedule Monuments (SAMs) so is not comparable to GMEP which are for sites including undesignated Historic Environment Features (HEFs).

[3] https://statswales.gov.wales/Catalogue/Environment-and-Countryside/State-of-the-Environment/Our-Local-Environment/PercentageOfFootpathsAndOtherRightsOfWayWhichAreEasyToUse-by-LocalAuthority-Year

5. How does land in the Glastir scheme differ to the national average overall?

Assessment of the initial difference between land which has come into scheme is essential to provide a robust baseline for future assessments of Glastir payments. Of particular importance for reporting to the European Commission, is the impact of Glastir on High Nature Value (HNV) farmland which combines various indicators relating to biodiversity. GMEP was tasked with developing a new approach to characterising HNV land with some key stakeholders (see HNV report in Section 4.5). It may have been expected that Glastir would capture a higher than random percentage of HNV land to ensure continued protection of land with high levels of biodiversity.

Results indicate that the amount of High Nature Value farmland (HNV Type 1) with a high proportion of semi-natural land is higher in scheme than out of scheme which has a higher Visual Quality Index than the national average. However, the Glastir survey does not appear to have captured areas with a mosaic of habitats and/or land uses reflective of HNV Type 2. (Further consultation is required to agree on HNV Type 3 land relating to land important for rare species to exploit latest information.) It is perhaps surprising that the capture of HNV Type 2 related to mosaic of habitats has not come into the Glastir scheme. This may relate to early priorities by Welsh Government to prioritise payments in Years 1 and 2 to water quality and climate change.

There are no differences in condition of land coming into scheme. This is likely to be due to the wide variety of land in both populations and the diverse land and farm types targeted by Glastir.

In summary, land in scheme had the following differences compared to the national average:

- 54% of land in scheme is semi-natural habitat compared to the national average of 41%
- 27% of land in scheme is High Nature Value Type 1 farmland which is characterised by having a high proportion of semi-natural land. This compares to 14% Type 1 HNV for all of Wales.
- There was little difference in Type 2 HNV, which is characterised by having mosaics of habitats, with 18% in scheme compare to 15% in the national average. Habitat diversity was also similar in scheme and for all of Wales.
- Wetlands, grassland and heathland are all more connected in scheme compared to national average (189%, 135% and 154% respectively) whilst broadleaved woodland is less connected (73%). There is also lower hedge density in scheme compared to all of Wales (75%).
- Streams have less physical modification and lower rates of anthropogenic enrichment but more impacted by acidification as indicated by benthic diatoms.
- Land in scheme has a higher mean visual quality index compared to the national average.
- Little difference in plants indicative of good condition were observed between land in scheme versus that out of scheme or the national average. This includes no difference in presence of plant species indicative of good condition, soil properties, pond quality and most woodland condition metrics.

Many of these results are included in TABLE-GMEP-NRM-OUTCOME-A-1 where we apply the data to explore resilience of land in scheme compared to the national average.

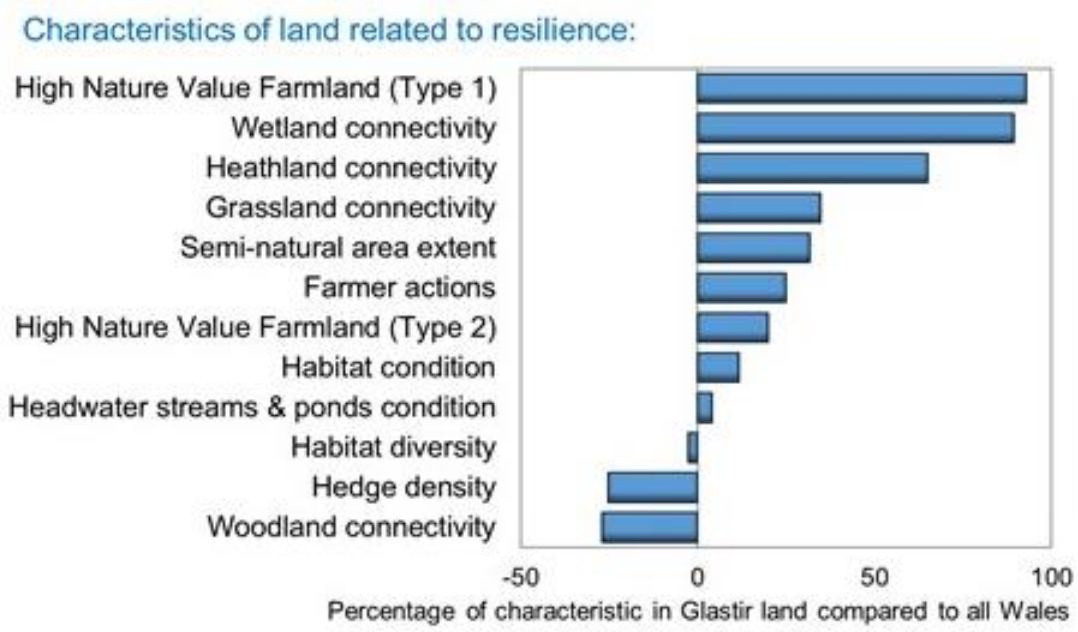
6. Can GMEP results be used to explore resilience?

Many of the results captured by GMEP are relevant to assessing the area, condition, diversity and connectivity of the Welsh countryside which are considered underlying features for understanding and monitoring ecosystem resilience. Promoting the resilience of the countryside is a new duty required of public authorities which is embedded in the new Environment (Wales) Act and the Well-being of Future Generations (Wales) Act.

To explicitly quantify this for land in scheme compared to national average we identified 12 high level indicators for area, condition, diversity and connectivity. We used data from the GMEP field survey, CEH's Landcover map 2007[34] and modelled metrics combining the two (Annex 11). We also included an indicator relating to the resilience of the farming system identified by the GMEP Farmer Practice Survey.

Results indicate land in scheme has more attributes relating to resilience compared to the national average (FIGURE-GMEP-NRM-OUTCOME-T-1; TABLE-GMEP-NRM-OUTCOME-A-1). This approach with additional metrics particularly relating to social and economic features could be used to assess future outcomes of Glastir and its contribution to increasing the resilience of the countryside for both people and nature.

FIGURE-GMEP-NRM-OUTCOME-T-1: Comparison of land in Glastir compared to land across all Wales for metrics of resilience.



Positive values indicate land in Glastir may be more resilient than land across all Wales. Negative values indicate land in scheme may be less resilient compared to all Wales.

[34] https://www.ceh.ac.uk/services/land-cover-map-2007

TABLE-GMEP-NRM-OUTCOME-A-1: Differences in metrics which may promote resilience of land in scheme compared to the national average.

Resilience features	Metric	Source of data and method	In scheme	All Wales	% in scheme compared to all Wales
Area[1]	% Semi-natural land	CEH Landcover map 2007	54	41	132
Diversity[1]	Habitat diversity	Number from GMEP survey squares	0.61	0.63	97
	Habitat diversity	Number from CEH Landcover map 2007	1.01	1.05	96
Connectivity[1]	Wetlands	Modelled from GMEP field survey data to all 1km squares for Wales.	10,485	5,538	189
	Grassland		102,556	76,100	135
	Heathland		39,520	23,961	165
	Woodland		28,407	38,929	73
	Hedge density	Modelled from GMEP field survey data to all 1km squares for Wales. Length added across habitats (km)	2620	3506	75
High Nature Value Farmland	Type 1	HNV maps (Annex	27	14	193
	Type 2		18	15	120
Condition	Common Standards Monitoring species across all habitats	Number of indicator species in permanent vegetation plots in GMEP Wider Wales survey squares	5,19	4.65	112
	Headwater streams and ponds condition	GMEP survey combined data			104
Farm diversification and efficiency	Number of farms undertaking actions	Number of actions taken by farmers in scheme from the GMEP Farmer Practice Survey	20	16	125

[1]These three features could be replaced by the HNV Type 1 and 2 indicators. HNV Type 3 which is indicative of land supporting rare species could also be added.

7. Legacy of past agri-environment schemes

Attempts to extract the legacy effect of schemes such as Tir Gofal are challenging due to different selection criteria and prescriptions, different methodologies, and lack of baseline data for some components e.g. species. However some examples are available:

Legacy in farmer action:

The GMEP Farmer Practice Survey (Annex 4) indicated:

- No increase in fertiliser use attributed to farmers exiting the Tir Cynnal or Tir Gofal schemes suggesting a positive legacy effect. However, results for animal numbers were more variable. For example, for farms having exited the Tir Cynnal or Tir Gofal schemes there was a net increase of 3.7% in dairy cow and a decrease of 5.8% in suckler cow numbers. There was no significant change in the dairy adult and dairy follower numbers. In comparison, for farms participating in the current Glastir scheme, changes were limited to a net decrease of 3.9% in breeding ewe numbers, and a small net increase of 1.5% in beef finisher numbers.
- Participation in the previous Tir Cynnal scheme was associated with 11.3% more farmers increasing the proportion of manures spread during the growing season when risk of runoff is reduced, and 16.7% more farmers completing a manure management plan.
- Participation in the previous Tir Cynnal scheme was associated with 9.4% more farmers using professional advice.
- Overall there was a persistent effect of previous participation in the Tir Cynnal and Tir Gofal schemes in 2009 on the uptake of selected management actions surveyed on farms that had not entered Glastir in 2016. Furthermore, 34% of participants in the Glastir Entry and Advanced schemes agreed that participation in an agri-environment scheme had 'changed my management of the farm' compared to 61% of participants in the Tir Cynnal or Tir Gofal schemes. One explanation for this may be under the Tir Gofal scheme, participants had to adhere to the mandatory Whole Farm Section which strictly controlled stocking rates in order to reduce soil erosion. In order to meet Tir Gofal's requirements, some participants had to reduce stock density considerably. In contrast, optional management agreements under the current Glastir scheme include a number of prescriptions that restrict stocking on habitat land. Therefore, participants were only required to reduce stocking rates if they signed up to certain options, unless they were participating in the Glastir Commons, where they were required to achieve a sustainable stocking level (Annex 5).

Past effect of AES schemes and their Legacy on ecosystem condition:

Preliminary analysis of early GMEP data identified better condition of upland heathlands that had been maintained under Tir Gofal option 5 compared to heathlands that had never been in Tir Gofal. There was no evidence for a legacy effect for 7 other Tir Gofal options explored. However, the analysis only included Year 1 and 2 GMEP data and this initial analysis needs to be repeated as many benefits will take 10 -20 years to be realised, highlighting the need for both consistency in management and monitoring approaches.

In addition to this legacy effect, work has continued by the organisations involved in Tir Cynnal and Tir Gofal evaluation to explore the original evidence base for scheme impacts. New results published include:

- New analysis of data from BTO/JNCC/RSPB Breeding Bird Survey in Wales for GMEP identified a series of Tir Gofal options for which positive associations were much more

common than negative ones. This was particularly strong for woodland and hedgerow management, followed by arable seed provision and scrub management (FIGURE GMEP-BD-OUTCOME-E-1).

- A recent paper published by the team involved in Tir Gofal/Tir Cynnal assessment project[35] has indicated a combination of field survey and modelling was able to identify an effect of scheme entry on water quality.

8. Ecosystem functions, services and opportunity mapping

Many ecosystem services are the combined outcome of the combination of several ecosystem functions which derive from the quantity, condition and spatial configuration of our natural resources within landscapes. As traditional monitoring most effectively captures the quantity and condition of natural resources, modelling is often used to bring these together to map ecosystem functions and services ideally taking into account how they align in the landscape. In GMEP we have used the UVW/CEH LUCI model to explore ecosystem functions and services as LUCI is able to explore the concepts of connectivity (e.g between woodlands for focal species) and flows (e.g. topographical flow of water and effects of barriers/buffers) for seven ecosystem services derived from the interacting effects of air, soil, water and biodiversity. As LUCI operates at a 5m scale, it is able to simulate the impacts of small scale interventions such as wetland and riparian area creation which are an important part of agri-environment schemes such as Glastir.

The LUCI (Land Utilisation Capability Indicator) model was one of a suite of models applied as part of the GMEP project. LUCI models ecosystem services and trade-offs between services enabling it to be used for landscape planning for targeting of interventions to maintain existing good service. The methodology and a wide range of modelled outputs for the seven services is available in Annex 10. Opportunities and their trade-offs explored here are:

- Change in agricultural production to better match land quality
- Woodland creation
- Optimising carbon stocks and sequestration
- Improving flood mitigation and diffuse pollution

Headline findings

- Opportunity mapping by our ecosystem service model has identified 81,389ha of land in Wales which potentially have significant opportunity to enhance multiple services with few apparent trade-offs. This provides a basis to help target more locally based assessments incorporating local data sources and stakeholder priorities.
- We explored opportunities for woodland planting identifying 616, 067 ha of land where there are opportunities to do woodland planting to extend current woodland and/or reduce rainfall runoff without impacting on a range of conservation, cultural, water quality and climate services
- We identified potential target areas to increase soil and biomass carbon sequestration.
- We assessed whether land whether has come into the Glastir scheme was identified by LUCI as having high opportunity to improve multiple ecosystem services. Overall, land identified as

[35] Jones, J. I., Murphy, J. F., Anthony, S. G., Arnold, A., Blackburn, J. H., Duerdoth, C. P., Hawczak, A., Hughes, G. O., Pretty, J. L., Scarlett, P. M., Gooday, R. D., Zhang, Y. S., Fawcett, L. E., Simpson, D., Turner, A. W. B., Naden, P. S. and Skates, J. (2017), Do agri-environment schemes result in improved water quality?. J Appl Ecol, 54: 537–546. doi:10.1111/1365-2664.12780

having high opportunity to improve multiple services has not come into the scheme. This mismatch should be explored further as there should be good potential for modelling to help inform spatial planning and targeting.

- Ecosystem service models have different strengths and weaknesses, and the selection of model for the specific application purpose is essential.

For each service output is considered in terms of existing service provision and opportunity to improve. It should be remembered that any mapping approach serves only to help target follow-on exploration of potential opportunities which should involve incorporation of any local data sources not embedded in the national scale data used in models such as LUCI and a range of stakeholders familiar with the areas identified.

8.1 Comparison of Ecosystem Service models

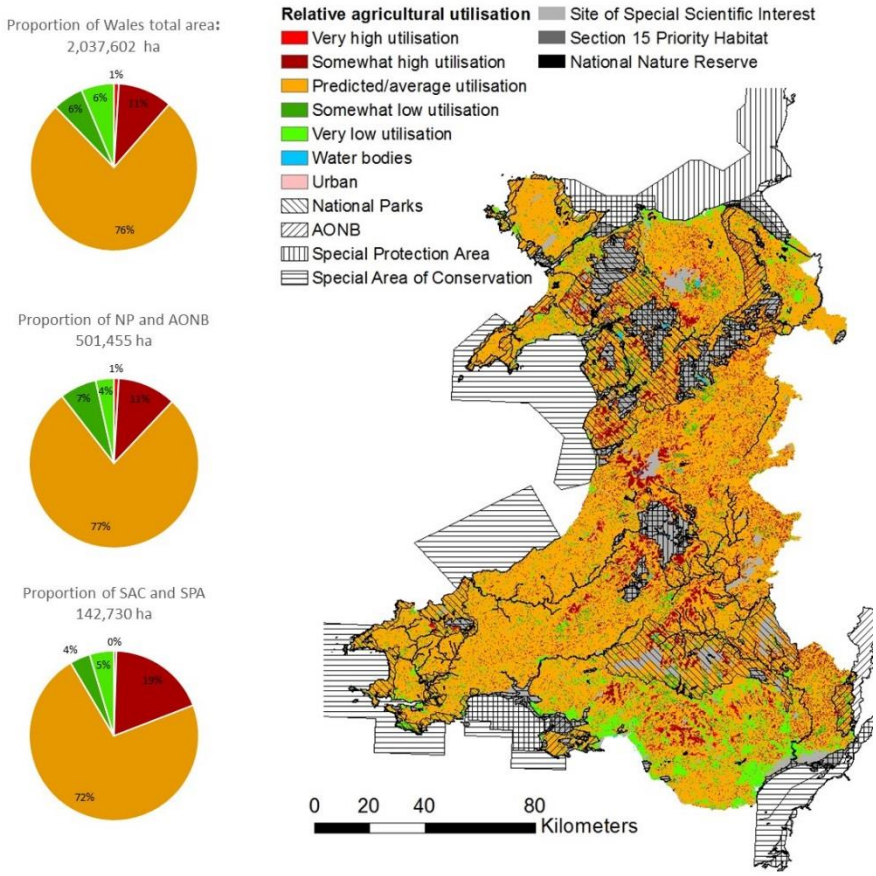
The LUCI model has been explicitly tested against 2 other well used ecosystem models in a data-rich catchment in Wales (the Conwy) as part of the NERC Biodiversity and Ecosystem Services Programme in a project led by CEH Bangor. The resulting results now published in the peer-reviewed literature[36] indicates the relative good performance of the LUCI model relative to the other two models but also highlighted the need to recognise the different models simulate apparently similar services (e.g. water flow and flood) which on inspection are fundamentally different and thus which cannot be directly compared.

8.2 Opportunities to improve agriculture and the management of designated land

The LUCI Agricultural Productivity Tool can be applied to identify areas of more productive land which should not be targeted for habitat creation. The tool can also be applied to identify areas which may be currently over utilised, which should be assessed for any possible degradation of the land or environmental impacts. These can be considered in the context of areas which may require protection for environment and biodiversity. The results suggest 76% of the country is optimally utilised for agriculture. For the areas covered by National Parks and Areas of Outstanding Natural Beauty, again land is mostly appropriately utilised. However, for Special Protection Areas and Special Areas of Conservation, a slightly greater area is shown to be over utilised (FIGURE-GMEP-NRM-OUTCOME-O-1). This may warrant further assessment, to ensure that land is being effectively utilised without unintended consequences on these areas of national importance.

[36] Sharps, K., Masante, D., Thomas, A., Jackson, B., Redhead, J., May, L., Prosser, H., Cosby, B., Emmett, B. & Jones, L. (2017) Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment. Science of the Total Environment 584-585:118-130.

FIGURE-GMEP-NRM-OUTCOME-O-1: Modelled estimate by LUCI of relative agricultural utilisation mapped across Wales, with a statistical breakdown for the country as a whole, and protected areas of national importance. Note: These results should be used to target for further exploration at a local level as they have not been ground-truthed.



8.3.Opportunities for woodland expansion and creation whilst protecting and enhancing other services

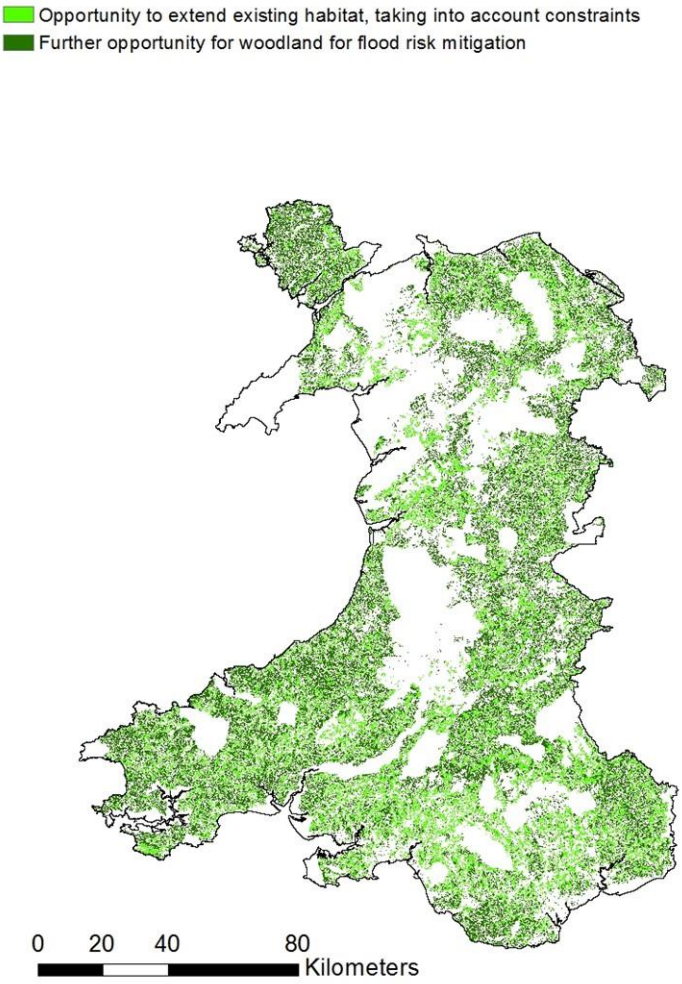
The LUCI woodland connectivity tool can be applied for identification of suitable areas for habitat expansion and protection. This enables new planting to be targeted to areas where it would be accessible to existing biodiversity, without damaging other important habitats. The tool follows a cost-distance approach to evaluating habitat connectivity, following the approach outlined by Forest Research's BEETLE project (BEETLE stands for Biological and Environmental Evaluation Tools for Landscape Ecology). LUCI automates this approach, and uses Forest Research's parameters for focal woodland species. This identifies a potential area of afforestation of 462,231 ha. However, if other factors which may affect suitability of land for afforestation, such as Section 15 priority habitats, historic landscapes, red squirrel habitats, urban areas and areas of more than 2 Ecosystem Services with existing good condition are used as masks, the potential area for afforestation is reduced to 356,828ha.

Woodland planting can have added benefits in terms of flood mitigation where trees increase infiltration to soils in areas where accumulating surface water is routed to the river. All areas with potential for afforestation to extend woodland and/or to reduce flood risk, amounts to a total of 616,067 ha without planting in the unsuitable areas (FIGURE-GMEP-NRM-OUTCOME-P-1).

FIGURE-GMEP-NRM-OUTCOME-P-1: Opportunity for afforestation to extend woodland or reduce flood risk by 616,067 ha excluding areas which would include inappropriate trade-offs.

Exclusions are: Section 15 priority habitats, historic landscapes, red squirrel habitats, peats, urban areas, areas of more than 2 Ecosystem Services with existing good condition, protected areas such as national nature reserves, national parks, areas of outstanding natural beauty, sites of special scientific interest, special protection areas, special areas of conservation and acid sensitive areas.

Areas where trees could provide added benefits in terms of flood mitigation by increasing infiltration to soils in areas where accumulating surface water is routed to the river is also indicated.



Note: These results should be used to target for further exploration at a local level as they have not been ground-truthed.

8.4 Areas to target for protection of carbon stocks and maximise carbon sequestration

The LUCI carbon tool can be used to identify areas with significant carbon stocks which should be protected, and areas where there is potential for sequestration. This can help to avoid emissions from agriculture, and has potential to help offset emissions from other sectors. The model applies a "space for time" substitution to calculate potential for emissions or sequestration, in assuming that any change in carbon storage in soils following landuse change can be estimated based on comparison with data from other sites with the same soils where the new land use is already established. The new unified peat map developed by GMEP has already been integrated with the Natmap soil data for the modelling presented here, and work is underway to calculate and map the impacts of changes in GHG inventories for peats and wetlands. Carbon is estimated according to IPCC tier 1 protocols. We calculated total carbon in biomass and top 1m of soils as 382 Mt C for all of Wales. When converted into CO_2 equivalents, this is 1400 Mt; over 30 times the total GHG emissions

from Wales in 2014[37]. The calculations seem reasonable in comparison to previous calculations of 340 Mt C in the top 1m of Welsh soils[38] and 114 Mt C in all vegetation across the UK [39]; although this is unsurprising as these calculations are based on the same underlying data.

The model then calculates potential to increase carbon storage over the landscape, by comparing a value of potential carbon stock at equilibrium under a different landcover with the current carbon stock. The "best" landcover for storing soil carbon has been identified for each soil type based on national datasets. Sequestration potential is mapped as a rate per year, assuming consistent rates over 150 years to reach the new equilibrium. Positive values mapped for carbon change indicate potential to store more total carbon in soils and biomass if landcover is changed. Where values are negative, this shows that although soils are able to store more carbon under a different landuse, the reduction in biomass carbon would be expected offset any benefits, resulting in lower total carbon storage in the landscape.

If this potential were realised, it would represent a 45% increase in carbon storage after 150 years, and a total of 637 Mt (or 4 Mt per year) in CO_2 equivalents. This would be enough to offset annual residential emissions 2014. It is of course unrealistic to suggest that land-use change would occur on this scale- however the map may be useful in targeting areas where land use change may be able to achieve carbon sequestration benefits.

[37] E. Salisbury, K. H., R. Brook, G. Buys, R. Bailey, G. Thistlethwaite, C. Walker, D. Wakeling, P. Brown, Y. Pang, L. Cardenas, M. Broomfield, P. Henshall , E. Kilroy, K. King, H. Malcolm, R. Matthews , T. Misselbrook, J. Moxley, T. Murrells, N. Passant, A. Thomson, N. Webb, K. Young (2016). Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 - 2014.

[38] Bradley, R. I., R. Milne, et al. (2005). "A soil carbon and land use database for the United Kingdom." Soil Use and Management **21**(4): 363-369.

[39] Milne, R., and T. A. Brown. (1997). "Carbon in the vegetation and soils of Great Britain." Journal of Environmental Management **49**(4): 413-433.

FIGURE-GMEP-NRM-OUTCOME-B-2: Map of estimated current stocks

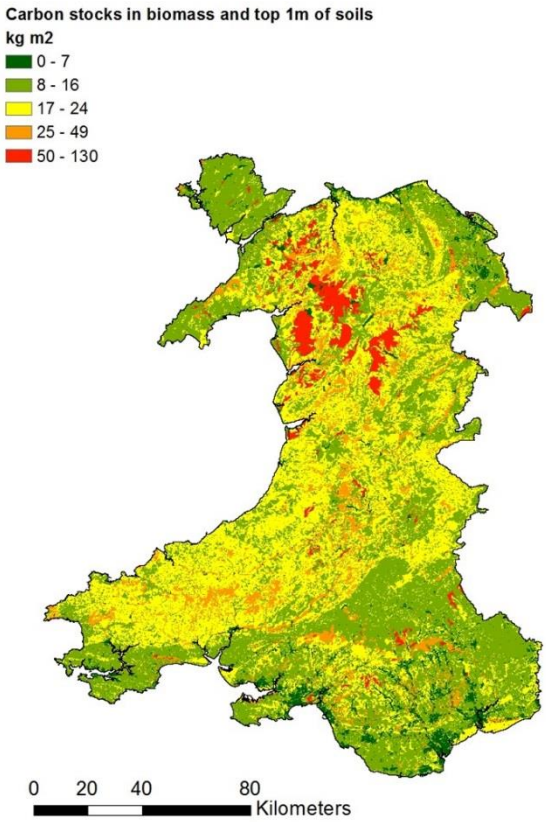
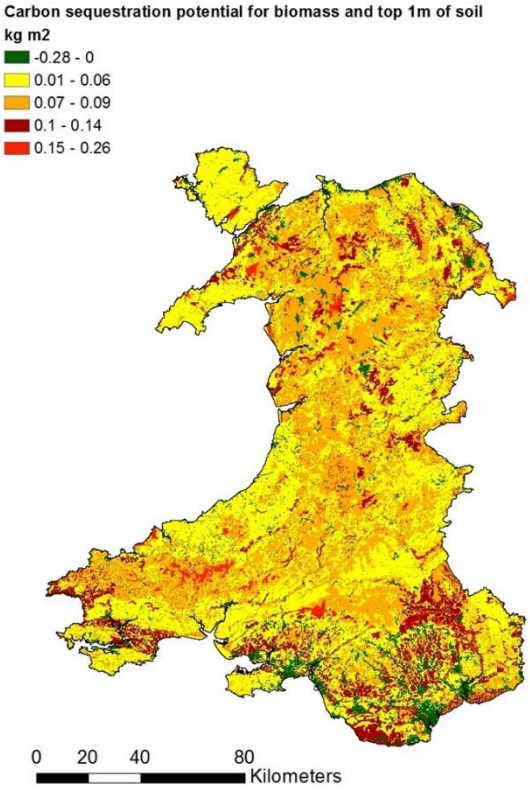


FIGURE-GMEP-NRM-OUTCOME-B-2: Map of carbon sequestration potential for biomass and top 1m of soil (kg/m^2)



8.5 Areas to target for flood mitigation

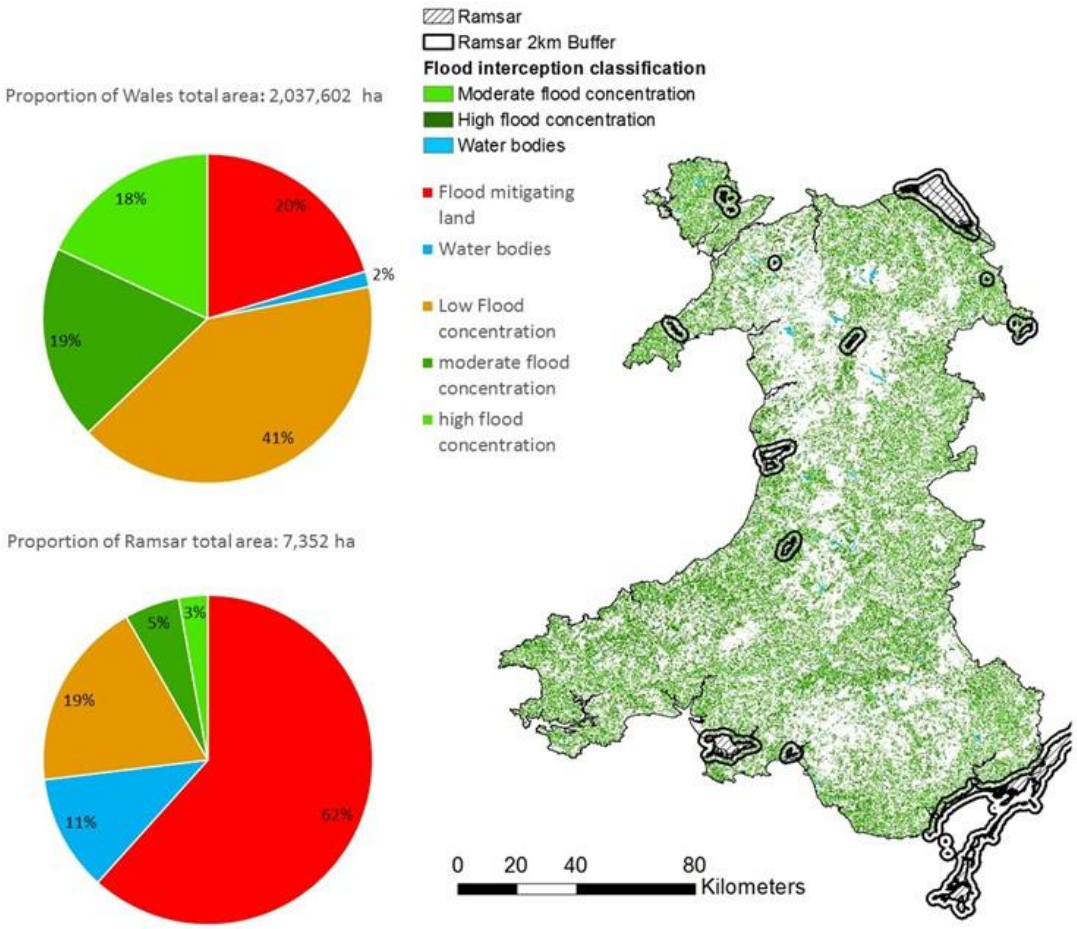
LUCI modelling for flood mitigation can be used to identify where creation of habitats such as wetlands and forests may also help to reduce risk of flash floods downstream. All land use or types that provide flood mitigation are treated as having high existing values; these include woodland, wetland, bog, marsh, scrub and similar natural cover. Areas where a large amount of unmitigated flow may occur may be treated as priority areas for change in landcover to reduce runoff.

There are 3 main outputs for flood mitigation; “mitigating” land, “mitigated” land, and land “flood concentration”. “Mitigating” land is where land use (e.g. forestry or wetlands) acts to increase water infiltration. This can help to mitigate downstream flood risk by acting as a sink for fast moving overland flow and near-surface subsurface flow; either storing this or routing the water more slowly through subsurface routes. “Mitigated” land is the area of land upslope which benefits from this mitigation and therefore is less likely to be contributing to flash floods and water quality issues. Land with moderate or high “flood concentration” is where the topography of the land concentrates runoff water increasing the risk of flash flood downstream. Creation of habitat types which provide mitigation in these areas could thus help to reduce this flood risk.

There may be added benefits to biodiversity from habitat creation in these areas, but it is also necessary to be cautious of potential unintended consequences. It is also necessary to consider constraints on habitat creation from designated Historic landscapes, existing good condition for other ecosystem services and urban areas. We would also expect wetland sites of international

importance designated under the Ramsar Convention (1971) to provide good mitigating service for runoff. The pie charts indicate that these sites are modelled as providing flood mitigation services, as would be expected (FIGURE-GMEP-NRM-OUTCOME-Q-1).

FIGURE-GMEP-NRM-OUTCOME-Q-1: Areas which may benefit from creation of woodland or wetland are mapped with “Ramsar” areas, currently protected for wetland habitat, highlighted. The pie charts show a breakdown of LUCI flood mitigation output for all of Wales, and a comparison for the Ramsar areas.



8.6 Land with multiple opportunities for service improvement and the relationship to land which has come into Glastir

LUCI Trade-off maps combine information from the separate tools to identify where opportunities exist to improve delivery of these services whilst protecting areas which currently delivery a high level of service. An opportunity map for Wales with a breakdown of statistics by county provides the outcome of this approach (FIGURE-GMEP-NRM-OUTCOME-R-1). There are no counties which do not have at least some area with multiple opportunities to improve ecosystem service provision through landcover change, and all counties also have at least some area with multiple services in good condition, which may benefit from other Glastir measures for conservation.

An exploration of how Glastir uptake aligns to the LUCI opportunity and trade-off mapping indicates there was a 50% reduction (16% to 8%) in Glastir interventions involving landcover change on land with significant or existing multiple services (red and dark red) relative to the rest of Wales (FIGURE-GMEP-NRM-OUTCOME-S-1). However, it may have been expected that more of the 17, 040 ha of landcover change undertaken as part of Glastir would have aligned more strongly with the 81,389 ha identified as having significant opportunity to enhance multiple services.

The potential of modelling approaches such as LUCI which directly model the importance of topographically influenced services such as flood mitigation and simulate sub field-level interventions enable sub-national identification of locations to look for these opportunities. If used in combination with other models such as Farmscoper and Multimove as we have done in GMEP to cross-check findings and produce a more holistic output, confidence is gained in model outputs and important messages re lag times and dynamics of systems are highlighted. Nevertheless all modellers should emphasise the importance of local-level assessments as national data on which most models mean they are a useful targeting approach for follow-up work.

A more formal coupling of these models and other models could provide a capability similar to that developed by the European climate change impacts community [40] to explore a range of future scenarios and opportunities. This coupling of models enables the cross-sector (agriculture x forestry x water etc) interactions to be captured and models are selected which include dynamic processes, this would also ensure the effects of climate and feedbacks are included ensuring decisions are not made based on the atypical 'average' climate year.

[40] Harrison et al. (2016) Nature Climate Change 6: 885 – 890. doi:10.1038/nclimate3039

FIGURE-GMEP-NRM-OUTCOME-R-1: Opportunity mapping by LUCI for 7 ecosystem services (agriculture production, flood mitigation, water quality mitigation for N, water mitigation for P, woodland connectivity, carbon storage and carbon sequestration) by county

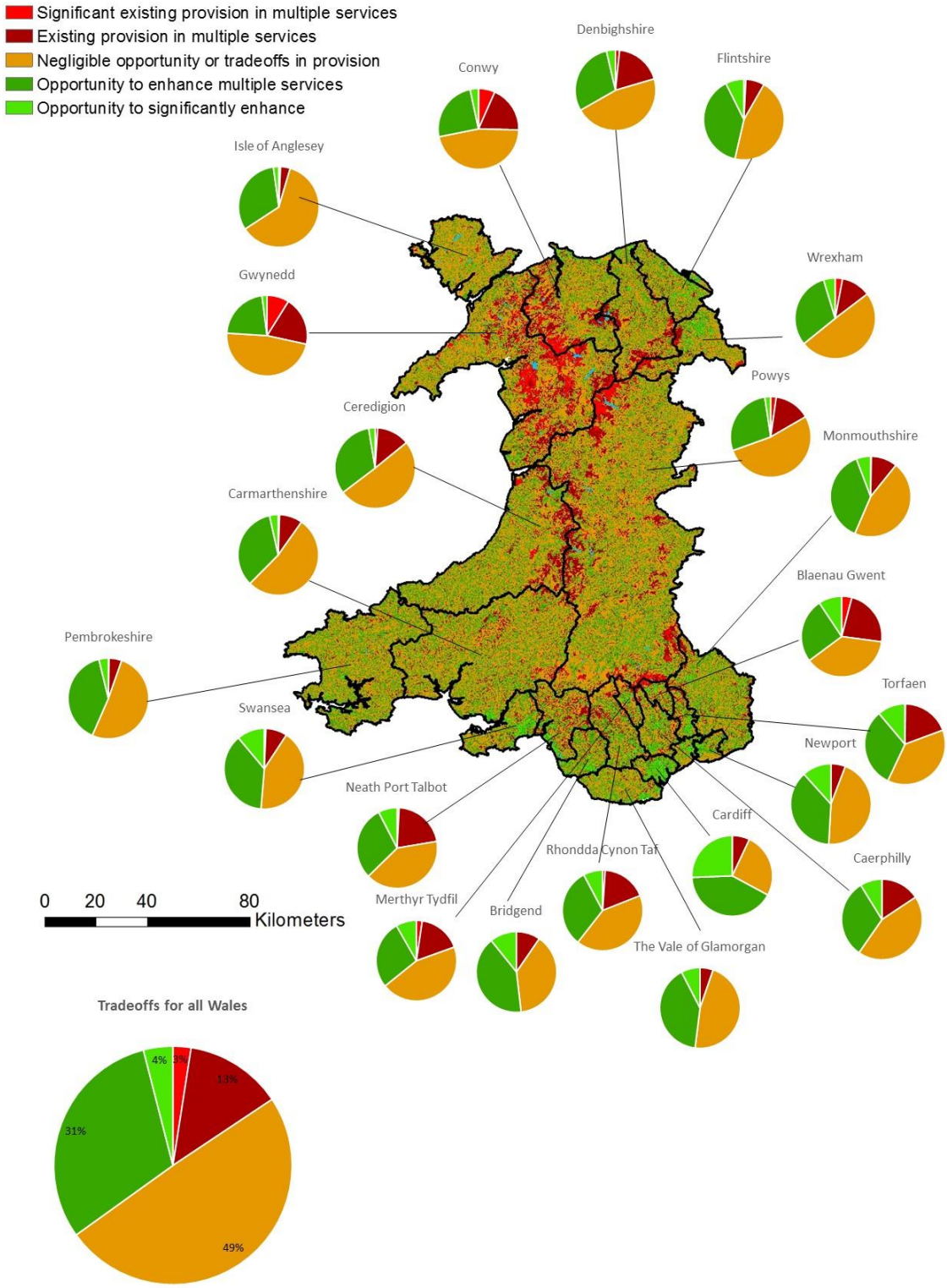
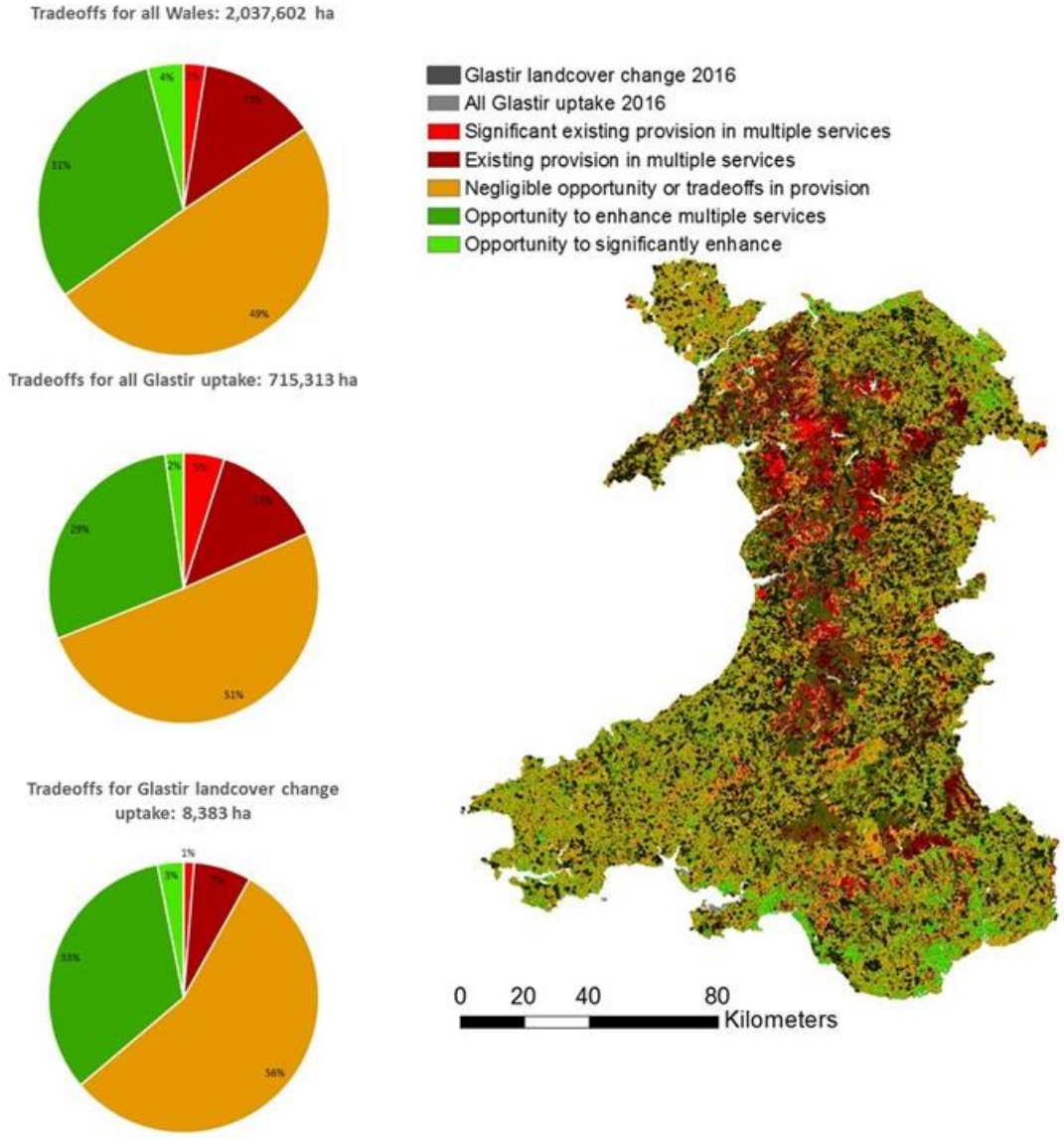


FIGURE-GMEP-NRM-OUTCOME-S-1: Opportunity mapping by LUCI of Ecosystem service provision with statistical breakdown for areas managed under the Glastir scheme.



9. International activities and other outputs

GMEP has successfully delivered on all requirements working in close partnership with a wide number of stakeholders. It has been used by the European Commission as an exemplar of good practice and as a demonstration dataset of national biodiversity data in a United National Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC) step-by-step guide for biodiversity accounting[41].

GMEP data is being used for both National and European reporting requirements. It is the sole source of data for reporting against Indicator 13 'Concentration of carbon and organic matter in soil' as required by section 10(1) of the Well-being of Future Generations (Wales) Act 2015 and is also being used for other wider RDP reporting requirements. The GMEP team met with authors responsible for the State of Natural Resources Report and provided early access to data and bespoke synthesis reports of GMEP data. GMEP data is being converted into a series of scientific papers (8 to date) and the data has been successfully used as leverage to win additional RCUK and Defra funding into Wales.

The GMEP team have presented the programme at 10 EU/International meetings and conferences, engaging with individuals from across the EU, China and the USA, including presentations of the Wales policy framework and the GMEP monitoring, modelling and mapping approaches at the United Nations Statistical Division in New York in 2013 and 2015. The Welsh Government GMEP contract manager, James Skates also presented the GMEP approach and findings multiple times at various European Union events. Closer to home, GMEP has been presented at almost 70 meetings, conferences and workshops in the UK, building an engaged stakeholder community with over 80 individual organisations.

To help train the next generation of researchers and explore additional aspects of the data which were not an essential part of the contract, GMEP has supported one PhD student directly and two through access to data. There is clearly an opportunity to increase these numbers in the future, however constraints about security of personal data can constrain use in some circumstances. Whilst anonymised data can circumvent this problem, experience from Countryside Survey is that frequently students and academics prefer free use of all data which cannot be delivered under the GMEP terms of the contract. It should also be noted that PhD dissertations are not an appropriate or timely route for producing deliverables which are a requirement of a contract such as GMEP. It would be unfair on the student who is undertaking a training programme, there is a risk of non-delivery if the student fails to complete, and a student, however competent, is unlikely to meet the level of quality assurance / accreditation most government departments now require. Future activity should therefore be targeted on more exploratory topics rather than activity leading to official government statistics.

[41] The published Species Account Manual can be found here: http://wcmc.io/Species_Accounting.

10. Next steps

The GMEP team was commissioned by the Welsh Government to identify options and develop recommendations for an integrated natural resources monitoring framework for Wales reflecting the ambitions and integrating principles of the Environment (Wales) Act 2016 and Well Being of Future Generations (Wales) Act 2015[42]. More than 71 individuals and 25 organisations were involved in the 'Future Options' project activities over during the 4 months of activity. Overall the final recommendations were to exploit, improve and integrate monitoring methods and technologies and rebalance resources to enable data to be 'collected once–reused often' through more effective sharing of data. A need for a modelling and scenario testing component to underpin data interpretation and provide a predictive capacity was also highlighted. The potential to increase levels of engagement across the Welsh Government, public and private sectors to promote Wales' position at the forefront of collaborative and innovative working should be realised in future initiatives.

Many of these findings supports the approaches developed in GMEP such as our multi-partner team; re-analysis and combining of data from multiple sources; exploitation of new technologies and the use of modelling to integrate and provide future projections.

The Welsh Government has now indicated their intention[43] to commission a new Environment and Rural Affairs Monitoring and Modelling Programme Monitoring and Modelling Programme guided by the ten recommendations with the stated intention of "enhancing the methodological approach and data time series of GMEP".

Any future work should also explore the many opportunities to analyse GMEP data further to gain even more insights into ongoing drivers of change and help inform future policy development. Examples include:

Drivers of change

- What is driving the change in national data reported? Priorities include:
    - Decrease in soil carbon habitat land and increase in acidity in improved land?
    - Further exploration of evidence of improvement in blanket bog – can we align this with activities on the ground?
    - The difference in freshwater trends in NRW and GMEP stream samples
    - Role of farmer segmentation characteristics in socio-economic changes reported
    - What is the evidence for change in individual broad habitats which have been reported at a higher aggregated level at the request of our Steering Group.
- How are the spatial and temporal trends observed in soil, vegetation, pollinators, birds and water linked? What are the indirect effects of change in one resource on another and what are the lag times? How do these relationships change across scale from field to catchment/landscape?

[42] Emmett, B.A., Bell, C., Chadwick, D., Cheffings, C., Henrys, P., Prosser, H., Siriwardena, G., Smart, S., Williams, B., (2016) Options for a New Integrated Natural Resource Monitoring Framework for Wales; Phase 1, Main Report to Welsh Government (Contract reference: C147/2010/11; Agreed Additional Work Requirement Dated 8th March 2016). NERC/Centre for Ecology & Hydrology (NERC CEH Project: NEC05945)

[43] https://www.sell2wales.gov.wales/search/show/search_view.aspx?ID=MAR191568

- What is driving these changes? Can we untangle a climate change and air pollution signal from changes in land management driven by changing economic drivers?

Mapping and tracking change in 'resilience'

- There is a need to integrate the GMEP and other data on diversity, area, connectivity and condition for our habitat and woodland land to better visualise change in ecological stability and resilience? How does this compare to social and economic stability / resilience of the farms and rural communities?
- What is the relationship between the area and condition of our natural resources as indicated by the GMEP survey and the health and well-being of the wider?

More efficient monitoring and evaluation

- How can we identify land which should be targeted for future monitoring as they are undergoing rapid change and/or at significant risk of future risk whilst maintaining an overall surveillance programme to capture unexpected changes and tracking improvements to demonstrate value for money from incentive schemes?
- Can new technologies tested and exploited in GMEP be accepted by the wider community and regulatory framework?
- Can we exploit the GMEP to provide an assessment of the general condition of designated lands benchmarked against national trends average e.g. is soil condition above or below that of the national average? Are there more or less Common Standard Monitoring species expected for the habitat relative to the national average? This could provide evidence of a co-benefit of designation beyond that of the condition of features for which the land was designated which would require a specific assessment.

More integrated working for new regulatory frameworks and incentive schemes

- How do social and economic drivers, constraints and benefits interact with our natural resources
- Can we build on our modelling work to develop an even more ambitious integrated modelling framework to help inform direct and indirect cross-sectoral interactions between agriculture, forestry, water and tourist industries and the environment? Work in the climate change impacts community has indicated that both the magnitude and direction of change could be missed if these unintended cross-sector impacts are not considered (e.g. Harrison et al. 2016[44])?
- Can we exploit the wealth of data, models and knowledge from GMEP to help the Welsh Government tackle new challenges such as the United Kingdom's withdrawal from the European Union which is likely to require the development of new regulatory frameworks and incentive schemes?

[44] The published Species Account Manual can be found here: http://wcmc.io/Species_Accounting.

11. Conclusions: 'GMEP at a Glance'

Glastir impacts

The Glastir Monitoring and Evaluation Programme (GMEP) provides a robust, comprehensive programme to establish a baseline against which future assessments of Glastir can be made. GMEP has used methods from past surveys so results can be evaluated within a longer term perspective and national trends also reported. The use of models and farmer surveys provides early indicators of the likely direction, magnitude and timing of future outcomes and are presented here. The results indicate variable changes in farmer behaviour and modest benefits to those natural resources for which models are available. Opportunities to improve these outcomes include simplification of the woodland scheme, better targeting of other scheme offerings, and consistent support through time across all schemes to allow for lags in ecological responses.

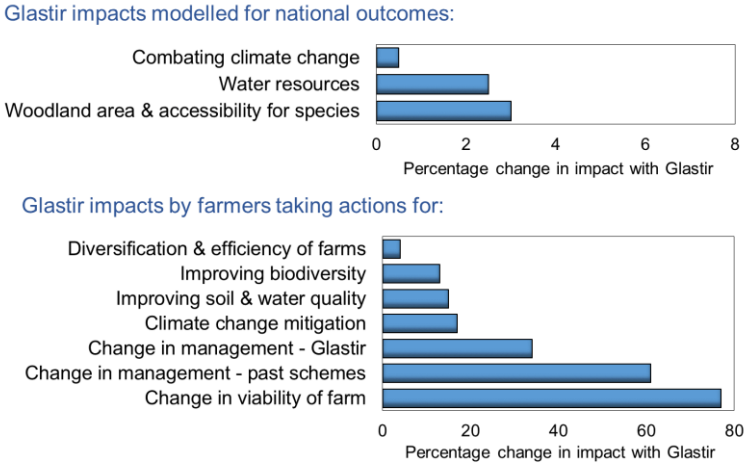


Figure Explanation: Early indications of Glastir impacts were captured by a mix of the GMEP Farmer Practice Survey to assess self-reported changes in farmer behaviour, and GMEP modelling of four Glastir outcomes at the national scale. (Note: Only three outcomes are shown because modelling to assess benefits for biodiversity cannot be scaled to national impact, although results suggested that for 75% of the 26 species explored benefits to habitat suitability would be delivered).

Characteristics and resilience of land in the Glastir scheme

Documenting the differences in the type and condition of land in Glastir compared to all of Wales is essential for benchmarking future changes resulting from the scheme. Field survey and earth observation techniques have been used to capture these differences. The results show land in the scheme is more heavily dominated by semi-natural habitat than Wales as a whole, but there is little difference in overall condition and habitat diversity. Habitats in the scheme are generally better connected with the exception of woodlands. These landscape characteristics are thought to underpin ecosystem resilience and these results suggest land in the Glastir scheme may be more resilient to disturbance and stresses.

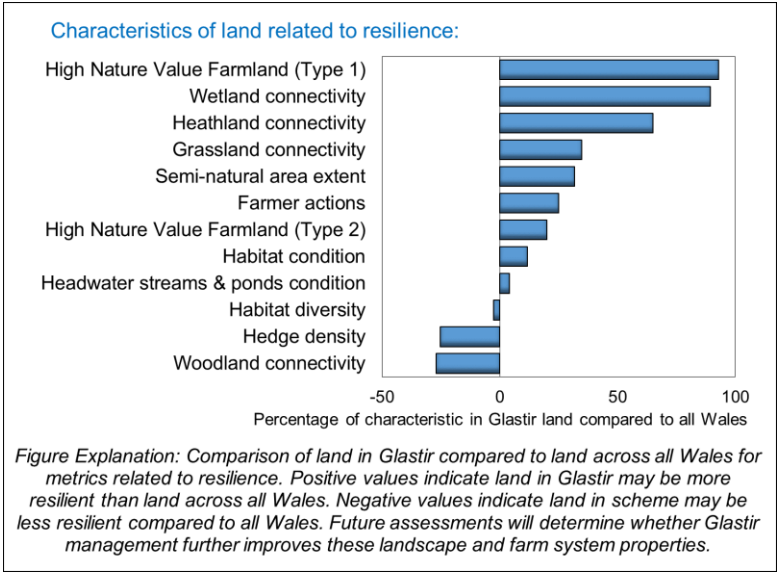


Figure Explanation: Comparison of land in Glastir compared to land across all Wales for metrics related to resilience. Positive values indicate land in Glastir may be more resilient than land across all Wales. Negative values indicate land in scheme may be less resilient compared to all Wales. Future assessments will determine whether Glastir management further improves these landscape and farm system properties.

National trends

GMEP sampling strategy and methods have built on past surveys which allow long and short term trends to be assessed for a range of indicators for each Glastir Outcome. The indicators selected were considered the most relevant and appropriate for Glastir reporting by the GMEP Steering Group. The overall the picture is one of stability and some improvement, although some areas for concern remain. The report found there are two to three times more indicators improving (26-30%) than declining (8-14%) in the short and long term, with the remaining 60% showing no change.

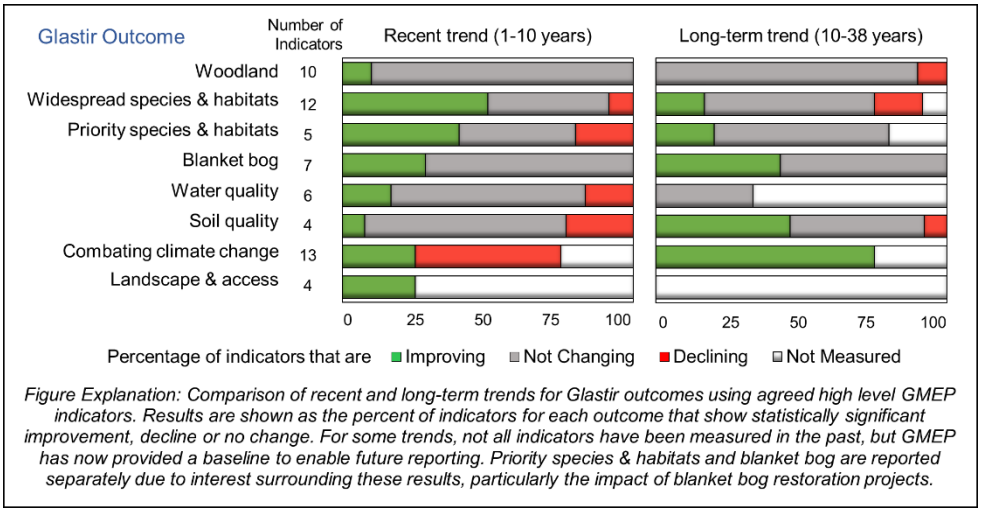


Figure Explanation: Comparison of recent and long-term trends for Glastir outcomes using agreed high level GMEP indicators. Results are shown as the percent of indicators for each outcome that show statistically significant improvement, decline or no change. For some trends, not all indicators have been measured in the past, but GMEP has now provided a baseline to enable future reporting. Priority species & habitats and blanket bog are reported separately due to interest surrounding these results, particularly the impact of blanket bog restoration projects.

12. Acknowledgements

Finally, the GMEP team would like to thank the Welsh Government for their support and input during the 4 year programme in particular the input from the Project Officer James Skates. We are also indebted to our GMEP Advisory group and Stakeholder Group who gave up many hours to provide valuable advice and constructive feedback. Finally our thanks to the many landowners who provided access to their land and their enthusiasm and support for our collective endeavour to provide independent and objective evidence for the state of our natural resources and provide a baseline for future assessments of the impact of the Glastir scheme.

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