MIXED FARMING – HISTORIES AND FUTURES

Final Report

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Lead partner:	**ecodyfi**
Author:	**Chris Higgins**
Contact:	***chris* AT *ecodyfi* DOT *cymru***

Project website address:

https://www.dyfibiosphere.wales/mixed-farming-histories-and-futures

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Executive summary

Starting from the proposition that the climate and biodiversity crisis are real and merit the urgent attention demanded by the scientific community and the various declarations of climate emergency, this LEADER funded pilot project advocates a transition to sustainable mixed farming in Wales based on agroecological principles.

Based in the UNESCO designated Dyfi Biosphere Reserve in mid-Wales, the project marshals a selection of online geographic information (maps) to show that sustainable mixed agriculture is possible in many places in Wales and brings multiple social, economic and environmental co-benefits, including jobs and a more vibrant rural economy.

Working at the level of individual farm fields, we show, with reference to historic data (principally, the tithe maps of Wales), that **historically**, mixed farming (growing crops as well as raising livestock) was commonplace in the lower lying areas of mid-Wales. The method used for comparison with the **contemporary** situation dramatically illustrates the radical changes that have taken place in the Welsh landscape over the last 200 years. The negative consequences for biodiversity are graphically illustrated by the almost complete loss of traditional meadows. A glimpse into the **future** is provided by maps showing the suitability of land in the area for supporting a range of crops under different climate change scenarios – low, medium and high greenhouse gas emission.

From the outset, the project was informed by the position that the small, Welsh-speaking family farms that have been the cornerstone of Welsh rural economy for generations should be front and foremost in considerations of what sustainability means in Wales. In envisaging a future, ecologically sustainable Welsh society, far greater emphasis is needed on relocalisation and encouraging biologically diverse, highly productive, highly skilled, labour intensive, small scale agricultural enterprises.

In keeping with the agroecological principle of *building on the past, looking to the future,* we collected **oral histories** from a number of older generation farmers (and their wives) in the Bro Ddyfi area who have witnessed the decline in mixed farming. In the audio files accessible via the project website, the farmers describe the more vibrant and diverse rural economy of their youth, where more people worked on the land and there was greater reliance upon the help of your neighbours at critical times of the year.

As a signpost to the kind of sustainability related research and development we think is needed, we implemented a map based decision-support tool that allows users to explore the available data (carbon storage, susceptibility to erosion, prior land use) and identify opportunities for reinstating arable cultivation.

The report concludes with some recommendations for how the work of this pilot project could be taken forward and a plea that innovative digital technology be applied with greater consideration as to the urgency of our situation and the need for systemic change.

1 Introduction

This was a 21 month LEADER programme funded pilot project that ran from the 1st of April 2019 to the 31st of December 2020. Set in the context of the UNESCO Dyfi Biosphere, the project was a small local contribution in response to some large national and global issues.

At the time of writing, agriculture in Wales is going through a period of intense flux; we have exited the European Union, the trading environment has significantly changed, the European agricultural subsidy system is being replaced, and the pandemic caused by the novel coronavirus has highlighted, in the most dramatic way, just how fragile long complex food supply chains are. On top of all this, we are faced with the existential challenges of global heating, ecosystem degradation, resource depletion, world hunger, and a growing population that needs feeding.

This project adopted a positive stance, and set out to show, using geographic information (maps) as the main communication vehicle, that sustainable mixed agriculture (growing crops as well as raising livestock) is possible in many places in mid-Wales and brings multiple social, economic and environmental co-benefits, including jobs and a more vibrant rural economy.

The need to produce food sustainably is one of the grand challenges of our age. However, although awareness of the challenge is widespread, what sustainable farming means in practice is widely debated. In this project, we advocated from the outset that the principles of agroecology should be followed and a more diverse range of food should be produced locally using agroecological practices.

We have demonstrated an innovative use of geographic information and digital technology – providing evidence that, historically, mixed agriculture was the norm in mid-Wales, and to help counter the perception that growing more locally is infeasible.

The main tangible project outputs are available through the maps on the project website[1] and provide information on what was grown in the past in the Biosphere area, what is grown now, and what could be grown in the future. From the outset, we committed to using open source software, open data, and open standards. Where possible, we have provided appropriate information in the material below.

2 Why agriculture is so important

The title of this section may sound like an oxymoron, but serious voices in recent Brexit related trade discussion have pointed out that, technically, agriculture is a small part of

[1] https://www.dyfibiosphere.wales/mixed-farming-histories-and-futures

the current UK economy[2] as conventionally measured, signposting a future economy focussed on services.

From the outset, the thinking behind the Mixed Farming project has always been that agriculture is the central and most significant component of any future sustainable Welsh economy. Given the pressures we are under, getting sustainable farming right is crucial in making the transition to an ecologically sustainable society. How we manage our land has direct and profound implications for basic, inalterable, biological needs: where we live, our health and well-being, the water we drink, the air we breathe, the food we eat. This is why we have advocated the more holistic agroecological approach to sustainable farming.

2.1 Agroecology

This is a globally recognised term[3] that encompasses a:

- Science
- Set of practices
- Social movement

As a science, it is the study of ecological processes applied to agricultural production systems. As a set of practices, agroecology is about farming with nature and relying upon natural processes or "ecosystem services" to provide the essentials for food production, i.e. nutrient cycling, pest regulation, disease control, soil formation, pollination, etc. The key to the concept is understanding that sustaining the productive capacity of agriculture in the long term (100's or 1000's of years) is entirely dependent upon the continued existence of intact, functioning, healthy ecosystems.

The term 'nature-based solutions' has become an important part of Welsh Government policy in recent years, not least in the Environment (Wales) Act 2016. We would argue that an agroecological approach to food production embodies this concept.

As a social movement, agroecology is characterised by an emphasis on farmer's knowledge, local solutions, local economies, short supply chains to local markets, decentralisation, regeneration. It seeks to shift the locus of control of our food systems towards producers and consumers, it is a positive movement as it holds that if we farm in a genuinely sustainably way we can create jobs, regenerate our rural economies, feed ourselves, draw down carbon through the use of natural processes for soil fertility, and address the biodiversity crisis – none of the above is possible unless we have intact, functioning, healthy ecosystems.

2.2 Food, agriculture and climate change

[2] https://www.theguardian.com/politics/2020/mar/01/treasury-adviser-farming-and-fisheries-are-not-important

[3] http://www.fao.org/agroecology/overview/en/

Following publication (in 2018) of the UN Intergovernmental Panel on Climate Change Special Report[4] on Global Warming of 1.5°C, climate emergency was declared at national[5] and local levels.

Agriculture is directly responsible for approximately 10% of the Greenhouse Gases produced by the UK economy. However, if the entire food system is taken into account, it is closer to 30%[6]; with several analyses[7] making a useful distinction between emissions due to the **supply chain** (manufacture, packaging, refrigeration, transport, etc), and emissions due to **land use change** (cutting down forests abroad to grow soya, palm oil, etc) in order to service UK import demand.

Relocalisation – a shift towards short supply chains and a greater volume of more diverse food produced locally - helps both reduce emissions, increase resilience, improve food security and make the transition to sustainable life styles.

As mentioned above, agroecology relies upon biodiversity for nutrient management and the maintenance of the fertility required to sustain food production. In the context of climate change, this is important as soil and the biosphere are major carbon sinks. For example, the worlds soil stores 2 to 3 times more carbon than the atmosphere[8]; this means that even relatively small increases in the quantity of the soil organic matter (and hence carbon) that agroecological practices rely upon for fertility disproportionately improves the effectiveness of soil as a means of sequestering carbon.

In short, transitioning to agroecological practices not only feeds human populations, it also addresses the biodiversity and climate crises.

The **pandemic** that is currently afflicting the entire human global population was not caused directly by climate change - although there is a strong link. The evidence[9] is that the constant human pressure on the remaining wildlife habitat is increasing the risk of transmission of zoonotic diseases. Climate change is exacerbating this problem and a continued increased risk of vector borne diseases is forecast[10].

The pandemic highlighted how insecure our food supply chains are - in the early days, serious food shortages were are a real possibility and the supermarkets (with their long just-in-time supply chains) came under strain. There was an upsurge in demand for local produce as people attempted to secure reliable supplies of food.

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[4] https://www.ipcc.ch/sr15/download/

[5] https://gov.wales/welsh-government-makes-climate-emergency-declaration

[6] IPCC (2019). Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [Shukla et al (eds)]

[7] https://landworkersalliance.org.uk/wp-content/uploads/2018/10/Farming-Food-and-the-Climate-Crisis_v2.pdf

[8] https://www.4p1000.org/

[9] https://www.theguardian.com/environment/2020/apr/08/human-impact-on-wildlife-to-blame-for-spread-of-viruses-says-study-aoe

[10] https://www.ipcc.ch/sr15/download/#full

Climate change is happening and we may expect more perturbations (such as that caused by the novel coronavirus) to global supply chains, e.g. reduced crop yields in major grain supplying areas, extreme weather events, geopolitical instability.

Many commentators[11] have observed that the insecurity of the UK's food system is a strategic vulnerability and that there is no physical reason why we cannot grow more of our own food.

3 Historic sources of land use information

3.1 Welsh tithe maps

The digitised tithe maps of Wales were one of the main inspirations for the Mixed Farming project.

Tithes are an archaic kind of tax formerly paid to the church based on quantities of local produce. In the nineteenth century, surveys were conducted and detailed maps were produced in Wales to better quantify how much was owed. Each map was accompanied with statistical data - held in books called apportionments - often at the level of individual fields.

The National Library of Wales's (NLW) website[12] *Welsh Tithe Maps*, was the main output from an earlier Archives and Records Council Wales project managed by NLW called *Cynefin* that used a crowdsourcing approach to digitise the apportionment data accompanying each parish tithe map – scanned, georectified and now available online.

It was during crowdsourcing associated with the *Cynefin* project that the progenitors of the Mixed Farming project first became aware just how much the agricultural landscape of the lower lying areas of Bro Ddyfi had changed in the recent past.

3.1.1 Capturing the 1840 field boundary polygons

One of the most significant outputs from the Mixed Farming project is the demonstration of just how powerful it is to be able to communicate agricultural land use change in Wales using chloropleth maps. In other words, the ability to use colours associated with areas (agricultural fields categorised according to land use) rather than relying purely on point data. Compare the 3 figures below – an area of land around Aberystwyth University's Gogerddan campus at the Southern border of the Dyfi Biosphere Reserve:

- Fig 1 shows land use in 1830 – the bright green and brown areas show the extent of meadow and arable respectively
- Fig 2 shows land use now – note there is little arable and no meadow

[11] Lang, Tim. *Feeding Britain – Our Food Problems and How to Fix Them*. Pelican Books, 2020
[12] https://places.library.wales/

- Fig 3 shows original point data available via the *Welsh Tithe Maps* website

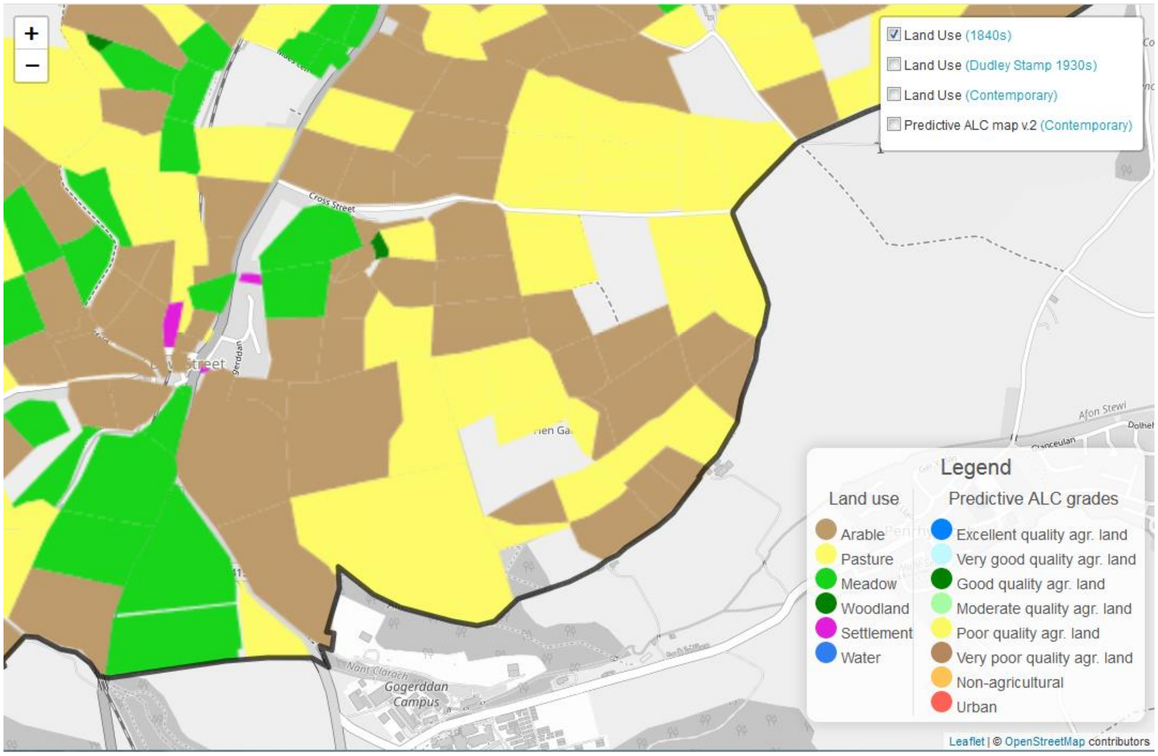

Fig 1: 1830's land use tithe map data displayed by area (individual fields)

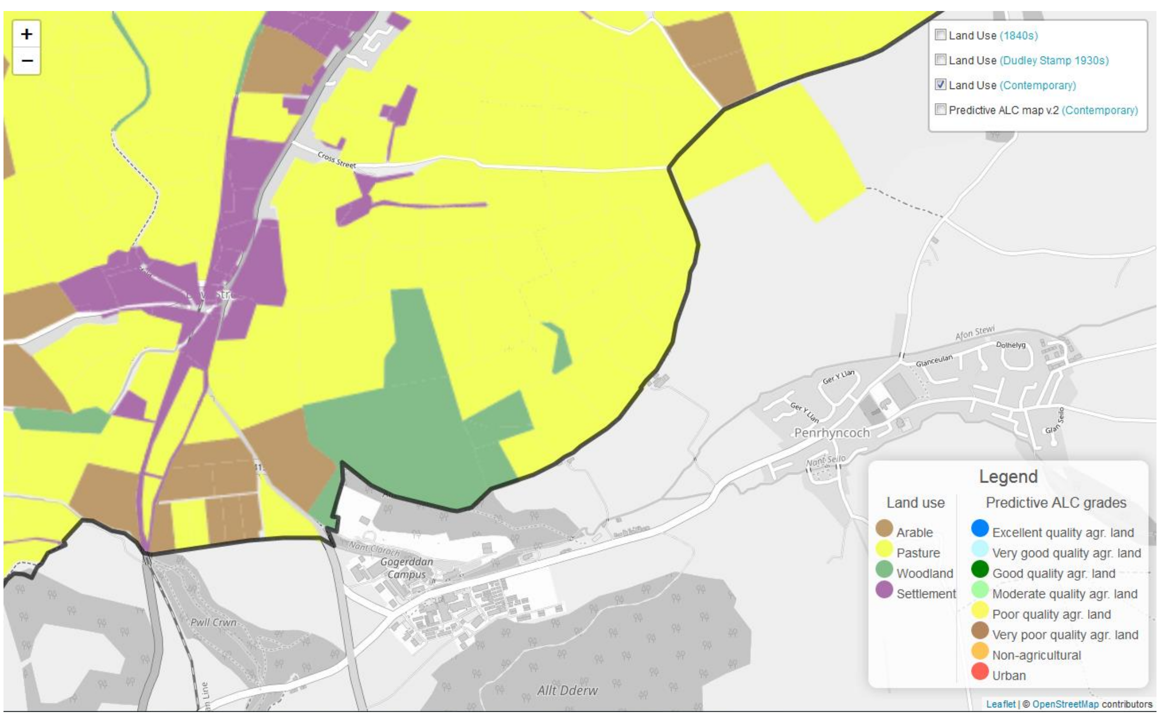

Fig 2: Contemporary land use displayed by area (individual fields)

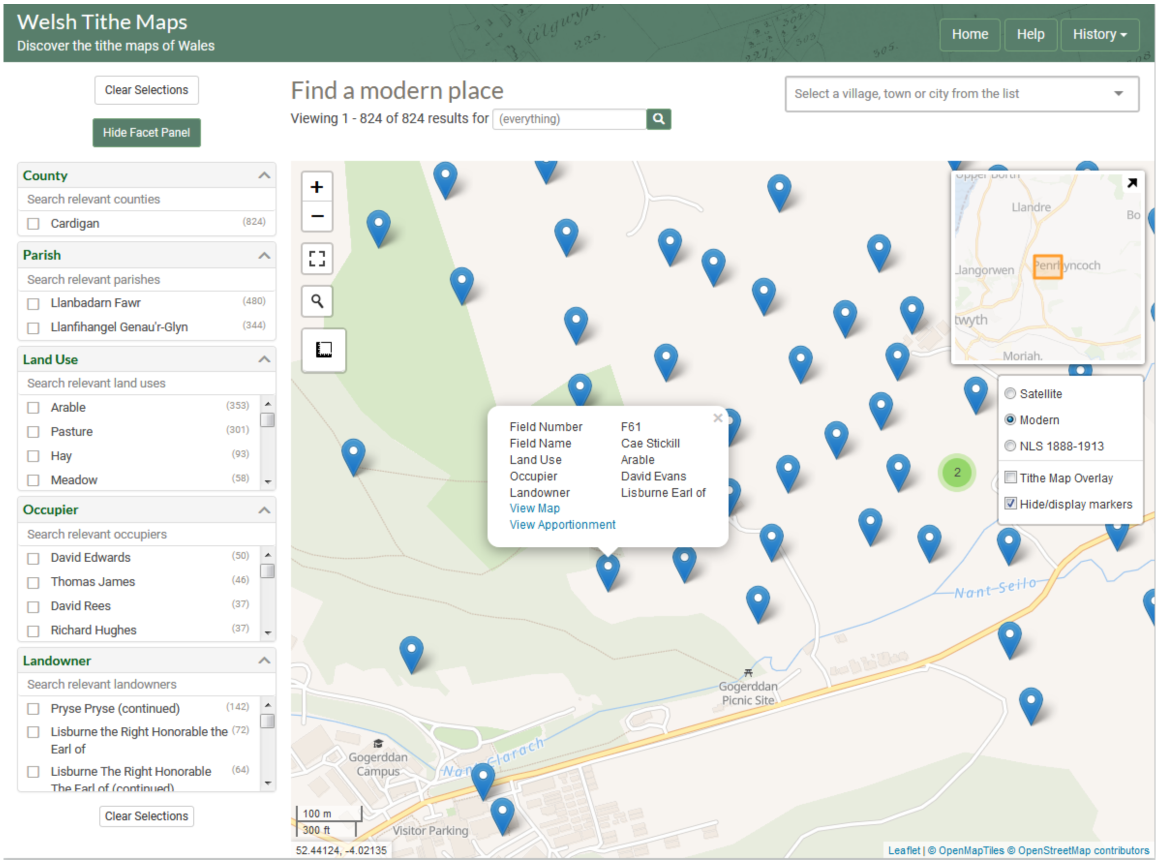

Fig 3: Tithe map data displayed by point (individual fields)

It is immediately apparent from the above that there is a lot less arable and that meadows have almost completely disappeared. Similar results pertain across Wales[13] and are a major factor[14] in the cataclysmic decrease in biodiversity in Wales in recent years – it is important to note that agricultural practices in the 19th century did not have the same reliance on agrochemicals and often used locally adapted varieties of plants.

Project partner Environment Systems Ltd (ENVSYS) led the team tasked with digitally capturing the 1840 field boundaries and making the above possible.

The contemporary national field boundary dataset for Wales is not publically available. As this dataset has multiple uses beyond its main purpose - rural payments, ENVSYS had created their own contemporary field boundary dataset prior to the Mixed Farming project.

The approach devised for capturing the 1840 field boundary polygons involved segmenting the Dyfi Biosphere area and allocating volunteers different segments in a process that used:

- base topographic mapping

[13] https://www.fuw.org.uk/images/pdf/fuw-cynefin-study-preliminary-findings-to-date-27th-July-2016.pdf
[14] https://www.wwf.org.uk/updates/state-nature-wales-2019

- the contemporary field boundaries for that segment
- the relevant section of the scanned 1840 tithe map
- training in the use of QGIS software to enable the volunteers to follow the 1840 field boundaries, digitise them and "snap" to the contemporary field boundaries where appropriate. The latter is useful as often, the field boundaries have not changed and the modern boundaries have been captured more accurately.

The process manifestly works but is labour intensive: approximately 220 hours of volunteer time went into capturing polygons just for the Dyfi Biosphere area. Data quality varies depending upon the skill and experience of who is doing the digitising and there is significant amounts of missing data.

3.1.2 Gaps in the tithe map data

During the execution of the Mixed Farming project, the team got to know the tithe map data intimately and it became clear that the dataset was incomplete and of variable quality. Of particular concern was that land use at the level of individual fields was not recorded in the apportionment data (*'State of Cultivation'* in the tables) in all parishes.

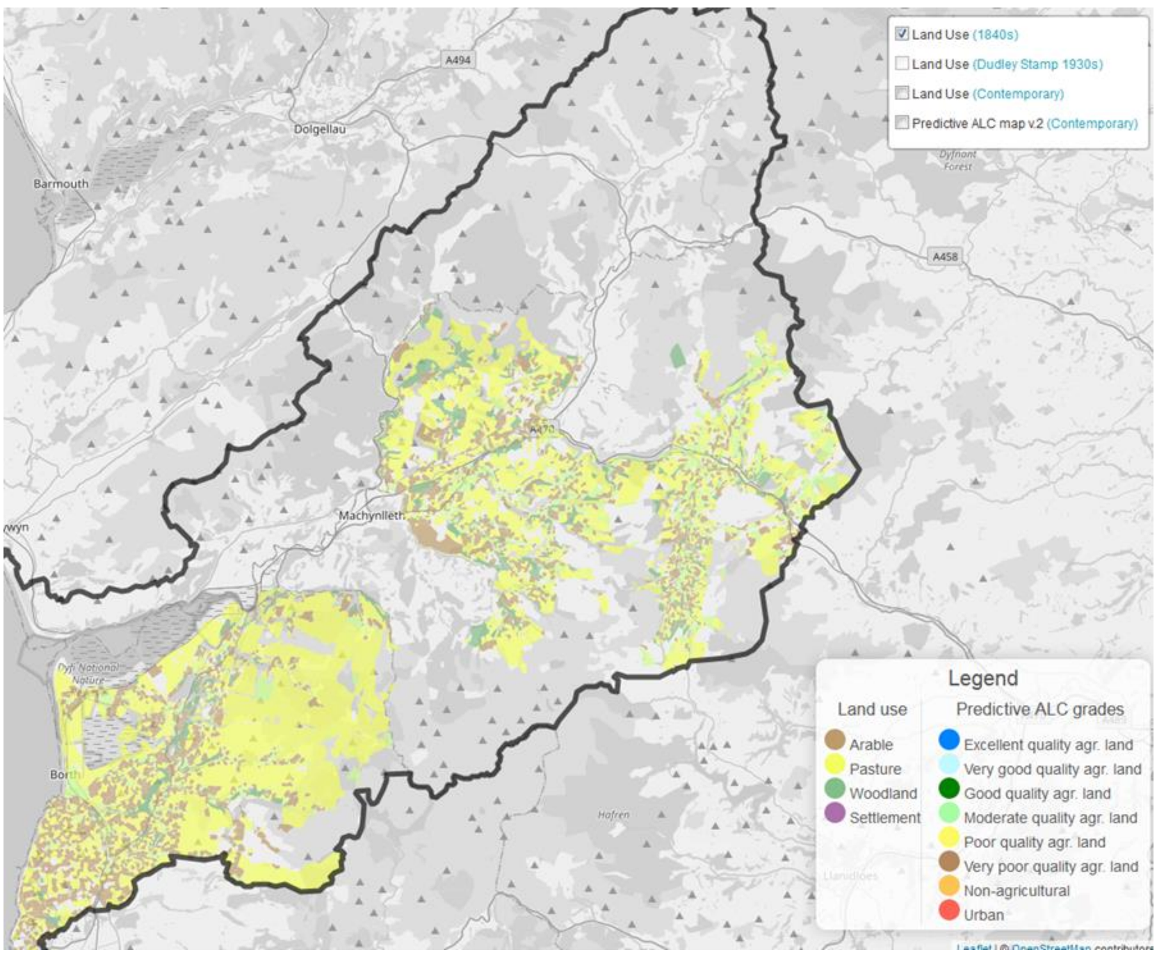

Fig 4. <u>Missing tithe map land use data in the Dyfi Biosphere</u>

The presence of large areas of grey within the Biosphere boundary (fig 4 above) indicates substantial missing data; specifically, *'State of Cultivation'* was not recorded in seven parishes in our area of interest.

Fortunately, as part of a separate project looking at place names which reference past habitats and species, Coed Cadw / the Woodland Trust in Wales was willing to collaborate with ecodyfi to explore ways of filling these gaps.

Two approaches were investigated:
1. Analysing the **field names** recorded in the 19th century. Unlike *'State of Cultivation'*, the column *'Name and description of lands and premises'* in the apportionment tables is complete for every parish and carries information of interest; including, potentially, what the field was used for. We devised a means of automating the analysis of these data.
2. Landed **estates** create maps and **records** for their ongoing management and these can be an important source of data concerning historic farming practices – many predating the 19th century tithe surveys. We devised a means of inputting data sourced from estate maps.

Both these approaches have potential for helping fill the gaps in land use information at field level – detail is provided on the appropriate area of the Mixed Farming website[15].

3.2 1930 Land Utilisation Maps

The first Land Utilisation Survey of Britain was led in the 1930s by L. Dudley Stamp of the London School of Economics. Using volunteer surveyors, mostly schoolchildren and their teachers, field level land-use data was recorded on 6-inch (1:10,560) Ordnance Survey maps.

A simple classification was used, similar to that used by the Tithe Maps: meadow and grass, arable land, hill pasture, woodlands, gardens, and unproductive land. The resulting dataset was published using 1-inch (1:63,360) Ordnance Survey sheets as a base map.

The granularity of the data collected by the first Land Utilisation Survey, almost a century after the tithe map data was collected, made this a suitable comparator to enable visualisation of the differences over the 90-year period between the 2 surveys[16].

This data was readily available for reuse by Mixed Farming via The Environment Agency funded raster digitisation and georeferencing of the 1-inch derivative sheets by the Great Britain Historical GIS Project at the University of Portsmouth in the early 2000s. These digital derivatives are now made freely available for download and reuse

[15] https://www.dyfibiosphere.wales/coed-cadw
[16] Higgins, Sarah. *D5.2 Historical Agriculture Data Report*. 2021

(with appropriate attribution) on their Vision of Britain website[17]. This made it relatively straightforward for the digitised Land Utilisation Survey maps to be integrated into the Gateway (fig 5).

Fig 5. <u>1930's Dudley Stamp data in the Information Gateway</u>

3.3 Other sources of historic data

Led by project partner Aberystwyth University, the Mixed Farming project conducted a study[18] of what other sources of historical agricultural data exist for this area of mid-Wales. For example: agricultural statistics, home office returns, land surveys, aerial photographs, farm sales catalogues, etc.

It is entirely feasible that the approach piloted in this project be used to create a rich and more extensive dataset providing evidence of changes in land use at the level of individual fields. The discussion below (section 9) considers the utility of extending this work.

4 Contemporary land use data

[17] https://www.visionofbritain.org.uk/ [accessed Feb 2021]
[18] Higgins, Sarah. *D5.2 Historical Agriculture Data Report*. 2021

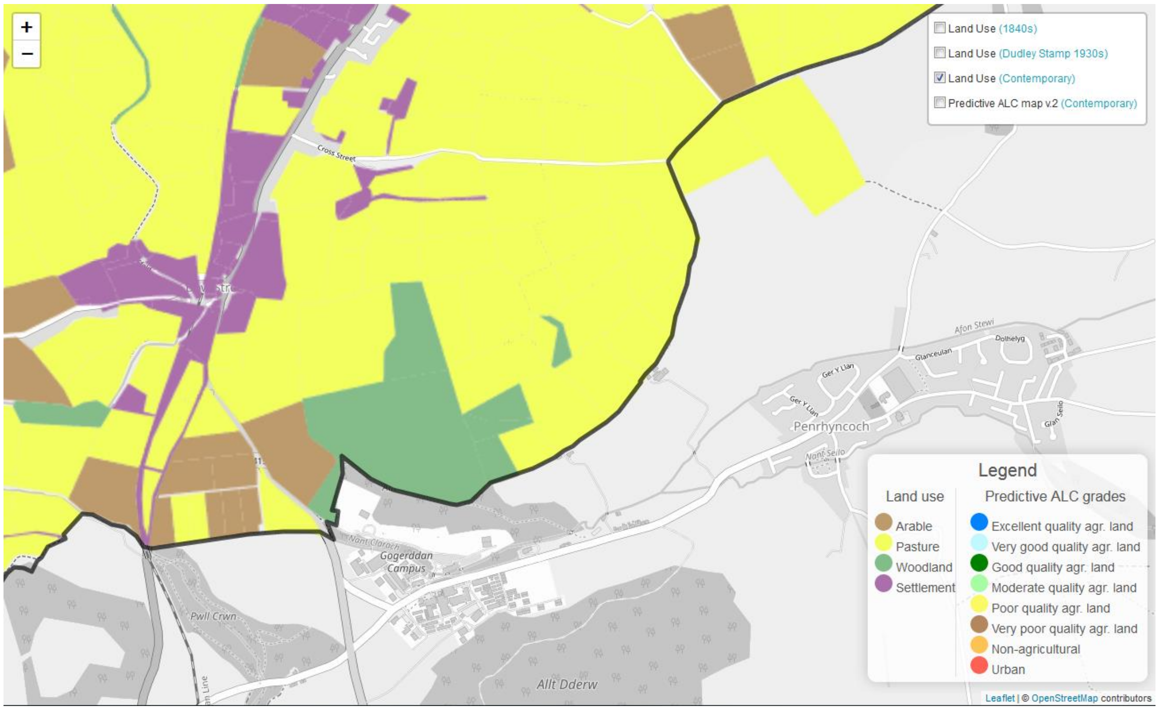

Fig 6. Contemporary Land Use in the Information Gateway

The contemporary dataset used in the Information Gateway (Fig 6) for comparison purposes was prepared by project partner ENVSYS from a variety of different primary data sources, eg, satellite data, aerial photographs.

5 Oral histories

As emphasised at the beginning of this report; agriculture is important and getting it right is crucial in making the transition to a sustainable society. Other sectors of the economy currently driving much contemporary political and economic calculations are human constructions and can change, but the fundamental biological need for clean air, water and food is absolute and has not changed throughout human evolution.

This is part of the reason why agriculture is so deeply rooted in many nations’ history, identity, language and culture. This is true in Wales as elsewhere and it is no coincidence that Welsh language and culture is strongest in the farming community[19]. The Mixed Farming project has held from the outset that the small, Welsh-speaking family farms that have been the cornerstone of Welsh rural economy for generations should be front and foremost in considerations of what sustainability means in Wales.

[19] https://www.nfu-cymru.org.uk/nfu-cymru/documents/nfu-cymru-brexit-and-our-land-consultation-summa/

Following the agroecological principle of *building on the past, looking to the future* [20], much may be learned from listening to older generation Welsh farmers (and their families) who remember when agriculture in mid-Wales was more diverse.

Consequently, project partners ecodyfi, Aberystwyth University Department of Information Studies and NLW led a work package which equipped volunteers to record oral histories (in Welsh) from a number (11 were recorded in the end) of older generation farmers across the Dyfi Biosphere area. The results were catalogued, partially translated into English and are accessible via the project website (Fig 7).

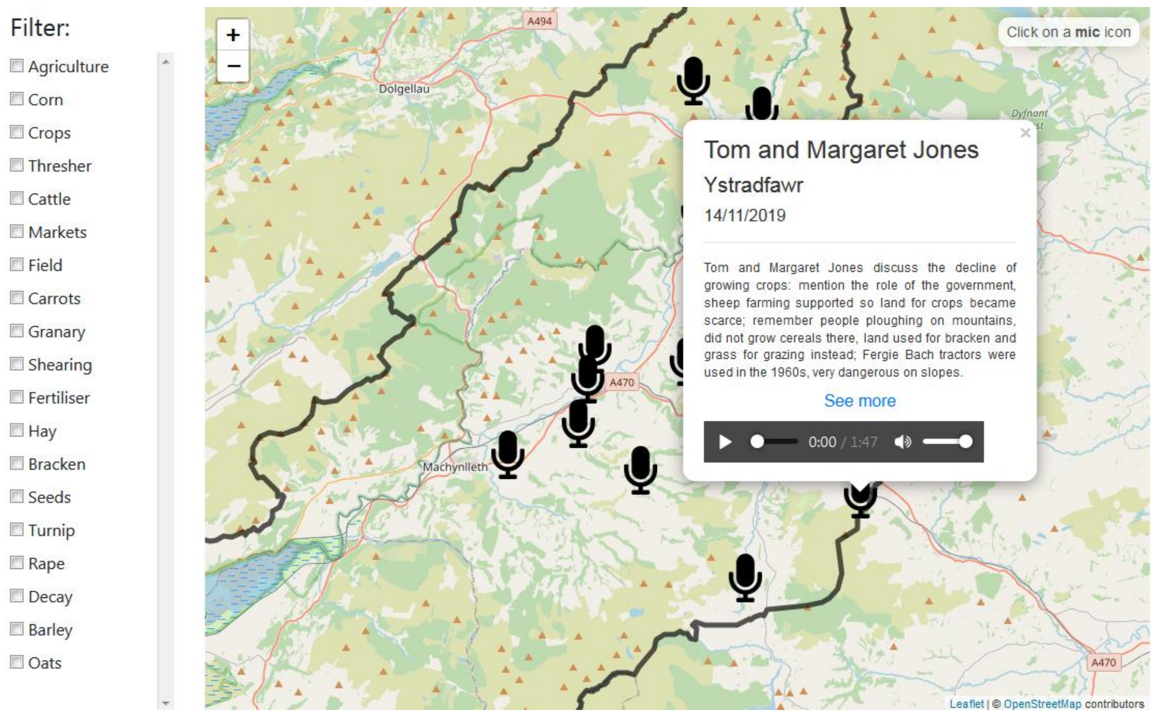

Fig 7. Oral histories in the Information Gateway

What these farmers describe is a more vibrant rural economy, a world where more people worked on the land and there is greater reliance upon the help of your neighbours at critical times of the year. Within living memory; mixed agriculture, where farms kept a variety of livestock, arable in the lower lying areas and horticulture, was commonplace.

As a contribution to the cultural and agricultural heritage of Wales, these oral histories have been deposited for posterity at the NLW. We would encourage any readers inclined to replicate any or all of the oral history related work described here to do so, and do so quickly, the generation that remembers first-hand the details of mixed farming in much of Wales is passing on.

[20] https://www.foodsovereignty.org/wp-content/uploads/2015/02/Download-declaration-Agroecology-Nyeleni-2015.pdf

6 Mid-Wales crops of the future in a changing climate

The Mixed Farming project was fortunate in gaining early access to outputs from the Welsh Government led Capability, Suitability and Climate Programme (CSCP) project.

In particular, through project partner ENVSYS, we gained access to the outputs from modelling which assessed the suitability of land for growing individual crops under different climate change scenarios. Through consultation with farmers representatives (Farmers Union of Wales, NFU Cymru and the Landworkers Alliance) we selected 10 of the 120 crops modelled, concentrating on crops that were traditionally grown in the area, e.g. barley, oats, potatoes, wheat. These datasets were integrated into the Information Gateway to allow users to explore how the crop growing capability of Welsh land in the Biosphere area will change in the future (over the next 80 years) depending upon the amount of GreenHouse Gases (GHG) society emits – see Fig 8.

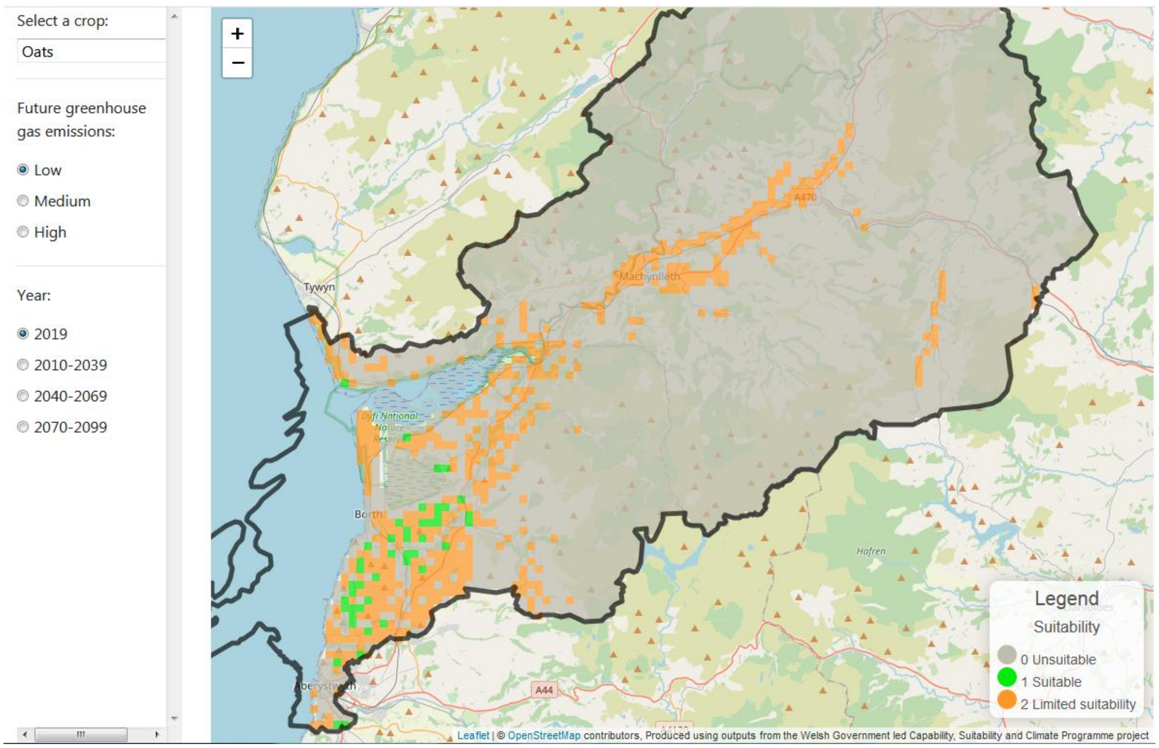

Fig 8. What crops can be grown now and in the future

Irrespective of which GHG emission scenario (low, medium or high) comes to pass, it is now inevitable that human induced climate change will continue; the main changes in mid-Wales are predicted to be average temperature increase, sea level rise, more extreme weather events, wetter winters and drier summers.

The effects on suitability for crop growing vary. Exploring the data reveals that some crops gain ground and some lose, what is particularly notable is that if the high emission scenario comes to pass then drought conditions will become prevalent and overall land capability for growing a wide range of crops will decrease significantly.

7 Opportunity maps - reinstating arable

At the level of individual fields, and based upon:

1. whether the field was under arable cultivation in the past, i.e. at the time of tithe map survey, or not
2. current carbon storage
3. the field's susceptibility to erosion

We provided mapping that indicates the opportunity for reinstating arable cultivation. Fig 9 below is a screenshot from the website's information gateway.

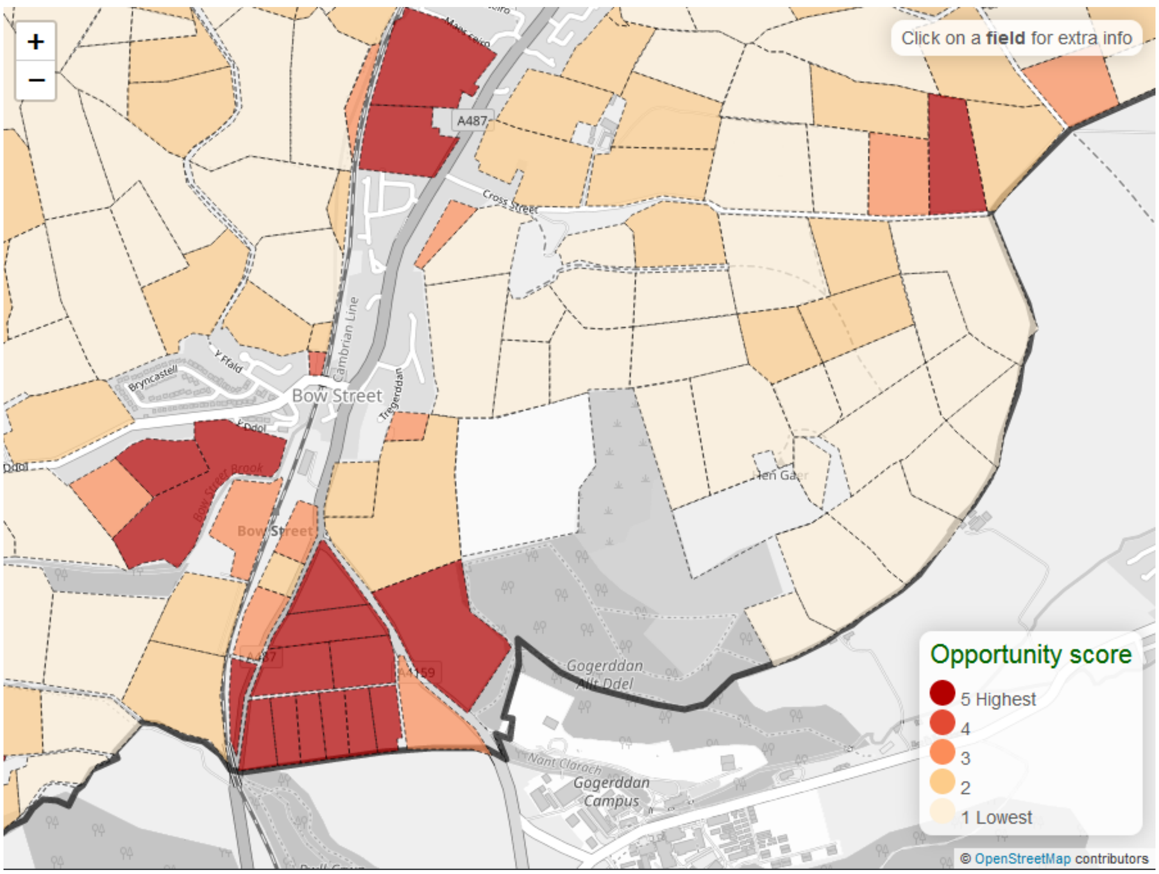

Fig 9. Opportunities for reinstating historical agricultural activity

This web mapping application is interactive and tools (slider bars) are provided to allow users to vary the weighting they put upon the 3 variables listed above. For example, if maintaining current high carbon storage is a priority, then a higher weighting would be assigned to this variable. The main stakeholder group we were envisaging in creating this tool are *'Policy makers and fund managers'* although our hope is that the application and concept is of wider interest. The intention was not to provide a definitive statement about how land should be used, but rather provide a means of exploring data visually to support understanding and decision making.

Appendix A provides more detail on the implementation of the opportunity map.

8 The Covid-19 crisis

The novel coronavirus pandemic arrived in the UK at the start of 2020 - a crucial time (about half way through) for the Mixed Farming project. The main effect on the project was to stymie much of our plans for stakeholder engagement. For example, we (ecodyfi, the university students who prepared the oral histories for the public, and NLW) had arranged a 'Community Digitisation Day' in Machynlleth to attract elderly farmers on market day to share their stories and artefacts with us. We also planned to personally invite all the farmers (and their wives) who completed oral history interviews with us to see what we were doing with the material they donated. With regret, we had to cancel this event; especially sad as the students had been looking forward to meeting the elderly farmers under convivial circumstances.

Our main response to the coronavirus crisis was twofold:

- extend the project by 3 months
- engage with Planna Fwyd![21]

8.1 Planna Fwyd - mapping local producers and distributors

In early 2020, all over the UK and usually of their own volition, local communities organised themselves and created grassroots initiatives in various ways to respond to the pandemic. With some gusto, Planna Fwyd! was created in the Machynlleth area to increase the amount of food grown locally – especially apposite as the pandemic had resulted in lockdown, panic buying, perturbations in global supply chains, and real societal fears concerning food security.

Under these circumstances, the Mixed Farming project refocussed stakeholder engagement and engaged with this initiative. This was to our mutual benefit; in effect, we helped further Planna Fwyd aims and used the opportunity as a source of requirements and an interoperability Use Case (see Appendix B) for the project.

The main Planna Fwyd requirement was to provide online a map showing local retailers, distributors and businesses who focus on local produce. Making available relevant details and contact information in order to:

- provide a good visual presentation to assist people in making connections between the various components of the local food system
- helping make it clear there are markets and opportunities in the local economy

[21] https://plantfood.machynlleth.wales/

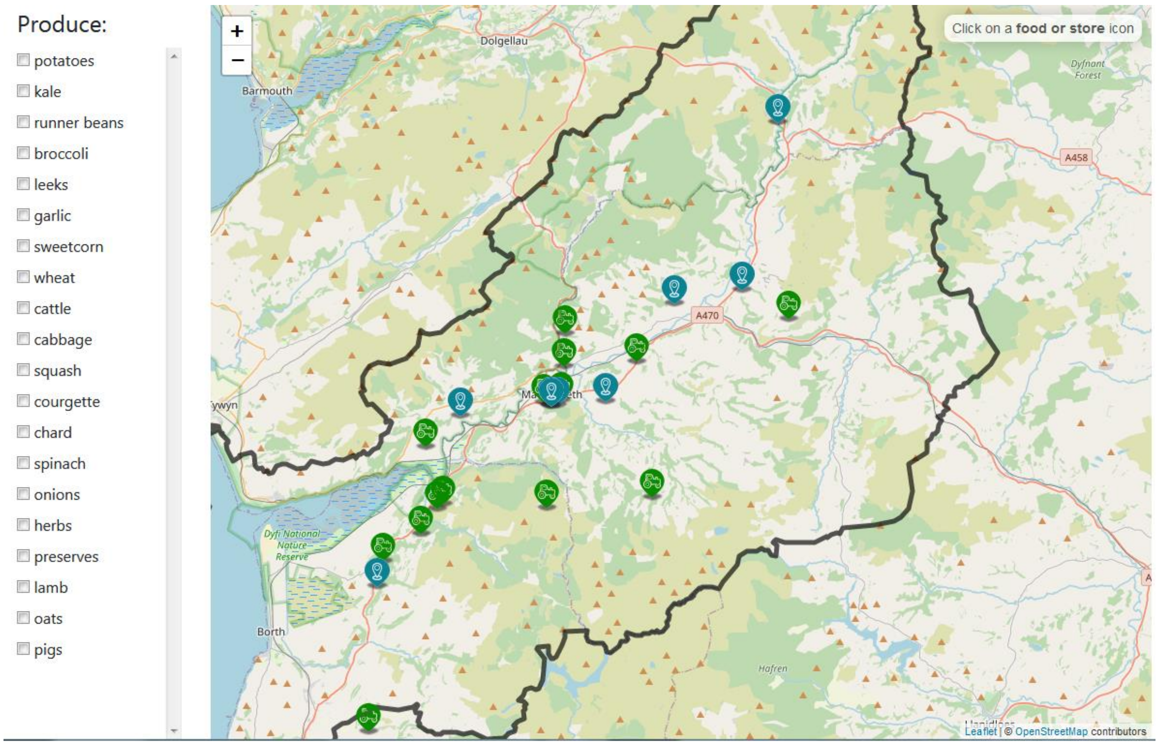

Fig 9. Producers and distributors of fresh local produce in the Dyfi Biosphere area

This dovetailed with the overarching Mixed Farming aim of encouraging movement in Wales towards sustainable mixed agriculture and a more resilient local food production economy. The results can be viewed on the Information Gateway: Fig 9 is a screenshot – if any of the icons (in the live map) are clicked on, more details are provided.

This aspect of the project also succeeded in demonstrating how the technical architecture we adopted allows the data services we created to quickly be repurposed to meet the needs of similar initiatives. In this case, a local food system community group whose main objective is to increase the amount of food grown in the local area as a response to the coronavirus.

8.2 Engagement with schools

While not the primary focus of the project, education is important in any project touching on the welfare of future generations, and effort was expended during the project to engage with schools interested in agricultural practices, how the latter have changed and the environmental, social and cultural consequences.

All schools in the Dyfi Biosphere area were contacted by the education facilitator during the course of the project: with some schools showing particular interest and willingness to be involved in the project.

Unfortunately, the pandemic severely constrained the options for direct interaction. Prior to Covid-19, teachers were consulted in person; subsequently, all contact was via email, phone or web conference. Engagement with schools included:

- Drawing on project outputs and local source material, an article[22] was written to assist with making what can seem a formidably complex subject more comprehensible and tractable.
- Activities around 'Discovering Local Food' including use of geospatial resources; Mixed Farming maps, mapping local food and land use
- A particular interest in association with GCSE Science.
- Interest in running a practical soil science and growing project
- Meetings took place with the Aberystwyth University (IBERS) Prosoil project: interest in developing soils based activities, e.g. earthworm counts, measures of soil organic matter
- ENVSYS expressed interest in developing educational material based on Land Use scenarios
- List of curriculum links compiled
- Some crop-growing activities planned, e.g. comparing heritage low-input wheat growing with modern high-input wheats
- Demand identified for teaching materials such as video clips, photographs, oral histories, etc

When some semblance of normality returns (at the time of writing we are still in lockdown and schools are closed) we hope to pick up on the above and find ways of furthering the plans we worked up with the local education community during the project.

9 Discussion

Assuming that the need to transition to an ecologically sustainable society is no longer a matter of debate, but rather a given; it is the opinion of the author of this report that the Mixed Farming project made a small positive contribution encouraging movement towards sustainable mixed agriculture and a more resilient local food production economy. The project is also a statement about where we believe food and farming related research and development effort should be concentrated.

As noted in the introduction, the need to produce food sustainably is one of the grand challenges of our age, and any serious consideration of food systems needs to be interdisciplinary and multi-dimensional. This project concentrated on the application of geographic information technology in an agroecological context. However, before narrowing the scope to discuss specific project outputs, it is first necessary to set additional context.

[22] https://foodmanifesto.wales/2020/01/14/lessons-loaf-of-bread/

9.1 Economic context

The current market based global economic system is predicated on continual growth and high consumption. That the underpinning theory is outdated and increasingly divorced from the physical reality of a finite planet is evident from the widespread ecosystem collapse current society is experiencing.

This is not a remote rarefied theoretical discussion – it has very real and immediate short term local consequences: for how we manage our land, the food we produce, what is available in the supermarkets for us to buy, and the economic viability of Welsh agricultural enterprises. Especially the kind of small scale, agroecological, diverse, highly productive, labour intensive, enterprises that we want to encourage.

To a large extent, Wales has specialised in producing livestock because the climate, soils and vegetation, i.e. grasses, make it particularly suitable for extensive grazing. Put simply, we have a 'comparative advantage'[23] when it comes to livestock, we trade the excess meat we produce and import the majority of the other foodstuffs we require from countries whose local conditions make them suited to whatever grows best there, e.g. horticultural produce from Spain.

The problem is that the market based system is divorced from ecological reality – true costs are not included in the cost of production; the additional, unaccounted for costs are considered as 'negative externalities'. Examples of the latter include: biodiversity loss, climate change, soil degradation, resource depletion, loss of genetic diversity, pollution, and social costs such as less rural employment, rural isolation, etc.

In effect, what has happened is that the many people (by no means all) who are fortunate enough to not live in poverty in "developed countries" like Wales are experiencing high consumption lifestyles, but at the expense of nature and future generations. In other words, we are borrowing from the unborn, and future generations are subsidising our unsustainable lifestyles as we consume and deplete the planets natural and social capital,

It is an understatement to say this civilizational level problem is widely recognised[24], though the extent, urgency and consequences are still not widely understood within the general population. At the time of writing, political and economic strategies that are not founded upon never ending continual growth of Gross Domestic Product are still not mainstream. The diagram below (fig 9) is indicative of the kind of paradigm shift that is taking place in 21st century economic thinking.

[23] https://en.wikipedia.org/wiki/Comparative_advantage
[24] https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review

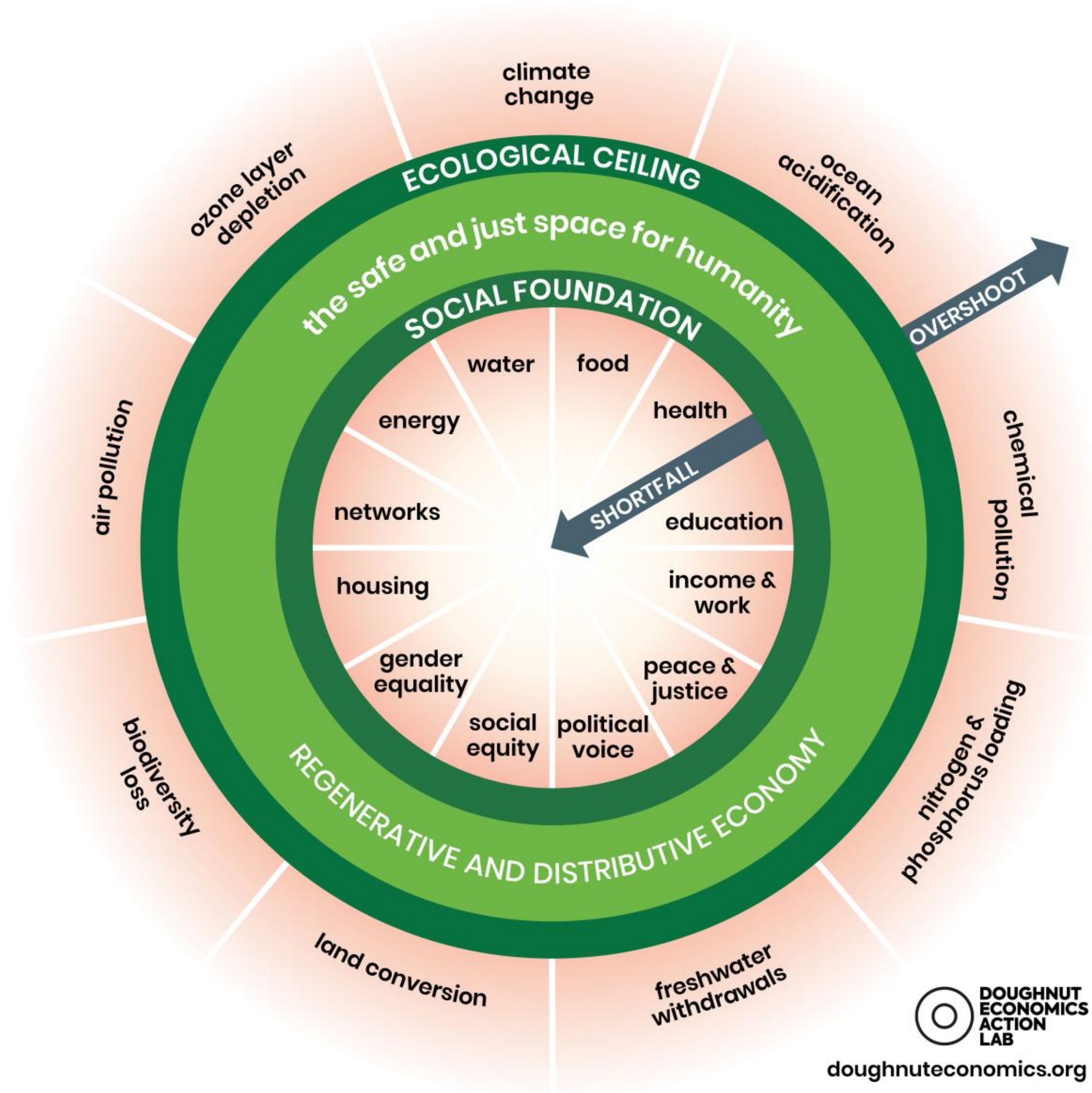

Fig 9. A doughnut-shaped space that is both ecologically safe and socially just

The core message behind the above doughnut diagram[25] is that we urgently need to take steps to ensure that no one is left falling short on life's essentials (the social foundation boundary) at the same time as not overshooting the Earth's carrying capacity (the ecological ceiling). Note the centrality of food and agriculture – it is core to at least 5 of the 12 dimensions of the social foundation (water; food; health; income & work; energy), but has implications for every single one of the nine planetary boundaries.

While we wait for the necessary leadership to transition to an ecologically sustainable society, we still live day to day immersed in an omnipresent unsustainable economic system. In the context of this project, a major consequence is that our economic system

[25] Raworth, K. (2017), *Doughnut Economics: seven ways to think like a 21st century economist*. London: Penguin Random House.

is weighted against exactly the kind of small scale, agroecological, diverse, highly productive, labour intensive, agricultural enterprises that we set out to encourage.

At the moment, it is notoriously difficult for the latter to make a living. The two main economic issues that small scale agroecological producers face are:

- constantly being undercut by artificially low food prices, e.g. in supermarkets
- area based subsidy systems that favour intensive agroindustrial practices and landowners with extensive holdings.

There is obviously not much a small local project like Mixed Farming can do to address global macroeconomic issues like those touched on above, what we did was try to make a contribution within the scope of the project.

9.2 Encouraging movement towards sustainable mixed farming

As a result of Brexit, the subsidy system is changing in the UK and while we do not yet know the exact shape of the new Welsh agricultural subsidy system (a devolved matter in the UK) the indications are that the Welsh Government (WG) at least understands many of the issues. Early on in the Mixed Farming project (Oct 2019) we responded[26] to a WG consultation on proposals for supporting Welsh farmers after Brexit, in the process laying out many of the arguments for why the project took the position it did. This was part of our plan for **stakeholder engagement** with *'Policy makers and fund managers'*.

9.2.1 Stakeholder engagement

As reported in section 8, the project's stakeholder engagement plans were significantly impacted by the pandemic – especially in respect of engaging with farmers and education. This was a matter of some regret, especially as following agroecological principles, it is important to co-create knowledge[27] and take steps to support local control[28] of food systems by food producers.

Oral histories

The oral histories we collected may turn out to be the most significant long term contribution this project makes to Welsh agricultural and cultural heritage. It was a real privilege being in a position to collect these and we would urge any readers in a position to conduct similar exercises to do so fast. With their intimate hard won knowledge of the land they manage, it is a national tragedy that the generation of farmers that remembers first-hand how to engage in more diverse mixed farming in Wales is passing on.

[26] https://ff434530-7747-4340-b305-03c7ed5a8557.filesusr.com/ugd/f2889b_e82a6244cbe0448591d23cd5f8b4a98f.pdf
[27] http://www.fao.org/agroecology/knowledge/10-elements/co-creation-knowledge/en/
[28] https://www.agroecology-europe.org/our-approach/principles/

Collecting oral histories is also an excellent way of building bridges and engaging with all generations of the farming community – the social, cultural and ethnographic implications are not insignificant. The difficulty of finding suitable people to conduct and record the interviews (the interviewers) should not be underestimated. An ideal interviewer needs to talk Welsh fluently, preferably with a grasp of the local dialect and, in this case, have a knowledge of agriculture.

The Mixed Farming project was fortunate in that we had a number of excellent volunteer interviewers – two of which had lived locally for most of their lives and had extensive networks of contacts in the farming community. The volunteers had to be trained by People's Collection Wales[29], equipped with sufficiently high quality recording equipment, and primed with the questions to ask – see Appendix C for more detail.

Use of historic maps

Even with the limitations imposed by the pandemic, all the feedback we have had indicates that being able to show land use change over time at the level of individual fields is an excellent communication tool. This is true of a much wider constituency than the farming community – though it is to be expected that farmers will be particularly interested in any information on the land they know so well, especially when presented in a form readily recognisable to them in the shape of their fields with their familiar names.

With the various challenges society faces, it is imperative that ways are found to encourage thinking imaginatively about how we manage our land in the future. Even with the relatively rapid (decades is fast in geological/scientific terms) rate of change, it is a feature of the human condition that we find it difficult to imagine our familiar everyday natural environment differently – this is sometimes referred to as 'shifting baseline syndrome[30]'.

Consequently, any communication tool that communicates gradual environmental change and which can be understood by significant numbers of people (expert and non-expert) is of value. Maps fall into this category and maps showing land use change at the granularity of individual named fields are even more valuable – too often public interest is lost through showing maps at too coarse a resolution to be meaningful or too obfuscated in scientific jargon to be comprehensible.

9.2.2 Geographic information as an enabling technology

From the outset, the Mixed Farming project has taken the position that the climate and biodiversity emergencies are real, urgent, and that we should act accordingly. In other words, business as usual is not an option. This applies as much to technology and data as any other area of human activity. In this domain, what this means in practice is that we should:

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[29] https://www.peoplescollection.wales/
[30] https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/fee.1794

- target resources and effort on researching, developing and applying the most useful and promising technologies
- lower any barriers that restrict the use of any technology or data that can help address the crises

In the Mixed Farming project, wherever possible, we have used open source software, open data, and open standards. Appendix D provides technical architecture detail.

9.3 Monitoring effectiveness of interventions

This section is more of a look forward and a plea to the public sector in respect of how we monitor the effectiveness of future interventions.

Anticipating a shift towards sustainable farming, either as a result of changes to the agricultural subsidy system, in response to other policy levers being applied, consumer demand, or changes to the macroeconomic system - there will be an increase in the need for improved monitoring of the effectiveness of interventions resulting in land use changes. For example, agroecological systems are more diverse and rely upon high biodiversity to provide the ecosystem services that make sustainable food production possible. If producers are rewarded for using agroecological practices then it is reasonable to expect a quantifiable increase in biodiversity as a consequence.

Multiple technical solutions to monitoring biodiversity are increasingly available, and technology similar to that used in this project can help. For example, satellite data is now available at a resolution (temporal, spatial and spectral) to make time-series analysis a realistic proposition, drones are commonly available, smartphones and citizen science are ubiquitous, Internet of Things technology is becoming commonplace.

It is still too often the case though, that valuable data and information is getting locked up in silos. There are multiple reasons for this:

- Open data policies are lacking
- The data has commercial value and many business models are predicated on being able to licence and sell access to data
- Data is not structured, i.e. it is not FAIR (findable, accessible, interoperable, reusable)
- The data is private, e.g. personal information on families and their landholdings
- The data needs to be secured, e.g. information on the location of protected species

With enough political will, there are solutions to overcoming all or most of these issues, often based on the principles of open data, open source software, and the use of open interoperability standards. A consideration of these solutions needs to be baked in at the time of contract negotiation to make it as easy as possible for as wide a range of effective actors as possible to access and take full advantage of what these technologies can offer in helping address the emergency situation we find ourselves in.

10 Conclusion

10.1 Did the project meet its aims and objectives

The most straightforward answer to this question is – partially. The overall aim of this pilot project was to *encourage movement towards sustainable mixed agriculture and a more resilient local food production economy.*

This is difficult to quantify. However, notwithstanding the difficulty of providing scrupulously auditable evidence under every circumstance, we believe we met, or exceeded, all the Case Level Indicators we enumerated at the start of the project:

- Number of stakeholders engaged: 90
- Number of participants supported: 200
- Number of businesses benefitting: 10

More anecdotally, we are pleased to note that references to agroecology as the preferred way forward seem to have become more widespread, e.g. Food Policy Alliance Cymru MANIFESTO 2021 – Our Priorities for a Food System Fit for Future Generations[31]. It is interesting to note the clear call in this document for:

"… establishing what proportion of our Veg requirement is sensible to produce locally given our land and what additional skills and infrastructure is required to produce it sustainably."

This is obviously a sentiment the Mixed Farming project wholeheartedly concurs with and we sincerely hope our project helps make the case.

The pandemic had a major impact on the project, especially on stakeholder engagement and education related activities, though the shift towards engaging with, and supporting, the *Planna Fwyd!* community initiative helped ameliorate some of these effects.

Finally, some of the project outputs are being sustained and the project is having some immediate discernible impact in that members of the project team have been successful in winning related follow-on grants:

- *Tyfu Dyfi - food, nature and well-being*: Enabling Natural Resources and Well-being (ENRaW) funded project scheduled to start 1st April, 2021. This project is about increasing the number of growing sites in the Dyfi Biosphere area for food, nature and well-being.
- Bilateral co-operation project between Wales and the Basque Country. Ecodyfi is being funded for a study visit to the Urdaibai Biosphere Reserve. The intention is to compare the local food systems from an agroecological perspective with a view to future substantive collaboration.

[31] https://www.foodsensewales.org.uk/pdf/FPACManifestoEnglish_091120.pdf

Neither of the above would have happened without the Mixed Farming project.

10.2 Some recommendations for follow-on work

The starting point for our recommendations is that the climate and biodiversity crises are real and that identifying transition pathways towards sustainable food systems should be treated with the urgency the various climate emergency declarations demand.

There is a debate in agroecological circles[32] concerning the role of digital technologies in advancing the sustainable development agenda.

Often, in agriculture as elsewhere, innovations that claim to be driven by sustainability concerns are principally motivated by the objective of creating and expanding markets in order to generate shareholder value.

This is why the agroecological emphasis on local control of the means of food production is so important. If local farmers and consumers have control then wealth, jobs and the rich knowledge necessary to farm sustainably stays in-country. The alternative is what has become depressingly familiar. The so called 'negative externalities' listed in section 9, and socially, a loss of local knowledge, loss of expertise, less resilience and an increased dependency upon global commodity markets and costly technologies controlled by distant companies whose principal objective is to maximise yields in order to generate profit for their shareholders. This is the opposite of sustainable development.

This project takes the view that there are a vast number of ways in which digital technology can assist the transition to sustainable food systems, but that it is important to analyse decisions through the lens of agroecological principles and set sustainability objectives accordingly.

There will always be grey areas; for example, the technology we have employed in this project depends upon cloud platforms – a distant, highly complex technology predominantly controlled by a USA based technocratic elite. On the other hand, not engaging with digital technology is not an option - the Ugandan smallholder will use the convenience of mobile telecommunications to check crop prices whether it is encouraged or not.

It is better to consciously try to identify appropriate technology and take what steps are possible to build capacity and retain local control; for example, by requiring the use of open source software, open data, and open standards.

The potential number of agroecological applications of digital technology is vast and probably constitutes an entire discipline with associated R&D programme.

[32] http://www.agroecology.gr/ictagroecologyEN.html

In many ways, to date, for all their sophistication, the majority of agricultural applications of technology have been relatively crude and reductionist. Within a market based economic system that externalises true costs and in pursuit of comparative advantage, we have simplified ecosystems in every major biome. In arable systems, the pursuit of ever higher yields has been characterised by the large scale application of agrochemicals, plant varieties bred to respond to these agrochemical conditions and the use of large scale machinery.

Digital innovations such as precision farming have improved the situation; but are still relatively crude; granted, less agrochemicals are applied more selectively, but it is still intensive farming reliant upon the unsustainable use of agrochemicals.

Agroecological use cases are potentially much more sophisticated. Consider the information needs flowing from an understanding of the biophysical complexity inherent in the release of nutrients to plants under natural conditions. Compare with applying inorganic fertiliser.

Here are some recommendation for further work flowing from this small pilot project.

Create a national historic land use change at field level dataset

As noted in section 3, a dataset that shows – at the granularity of individual fields - how land use has changed over the last 200 years or so has multiple applications. This is important during a period of time where people are being asked to imagine a different future. Such a dataset could be crowdsourced with provenance clearly indicated using open geospatial interoperability standards. It should be openly available, at no cost, over the internet.

Collect more oral histories

As mentioned in section 5, this is urgent as the generation that remembers, first-hand, diverse mixed farming in mid-Wales is elderly. If scoping such a project out, note that wider social, cultural and linguistic considerations need to be taken into account, e.g. you may be recording someone using rare Welsh dialect words for agricultural implements. Collaboration with farmers representatives, e.g. the unions, would be a good idea, especially if concerted effort is taking place to understand how in the past crops were grown without agrochemical inputs and with more genetically diverse plant varieties.

Improve Capability, Suitability and Climate Programme (CSCP) project outputs

This is an excellent project producing valuable data and information. As stated in section 6, we were fortunate to gain early access to the data. If there are future iterations of this project, it would be useful if finer grained information could be generated, i.e. not just the 3 categories indicating whether land is unsuitable / limited / suitable for crops. Is higher spatial resolution possible? Greater clarity on the underlying assumptions would be appreciated. For example, it is clear from the historical data that farmers in the past, with an intimate knowledge at the scale of metres, knew what would grow where; this is not always in accordance with CSCP outputs and it would be useful to have greater exposition of the underlying CSCP assumptions. Similarly, when it comes to crop requirements, it would be good to understand the distinction between the requirements of high yield varieties dependent upon agrochemical inputs, and genetically diverse varieties adapted to local conditions and not dependent on agroindustrial practices.

Opportunity maps

As indicated in section 7, this type of work accords strongly with the kind of audit the Food Policy Alliance Cymru is calling for. There is a need for detailed information on what will grow where, and what the trade-offs are. Information tools that operate at the appropriate granularity should be accessible and easy to use.

The approach piloted in this project illustrates the trade-offs between carbon storage and susceptibility to erosion. This work could be built upon in several ways, e.g. the interface could be more sophisticated and integrated with the rural payments geographic information system that farmers are familiar with. Additional variables could be included, e.g. is there information on the amounts of carbon stored under various crops in mid-Wales grown using agroecological practices?

Education

During the course of the project it became apparent there was significant demand for online resources such as the following in support of teaching the complex relationships between food, agriculture, environment, history, culture and economics.

- Videos, photos, oral histories, excerpts from oral histories.
- Access to historic information on exactly what, ie, specific crops, were grown where.
- Presentation of information in various ways to facilitate teaching, exploration and understanding, e.g. mapping at the field level, visualisations such as pie charts or bar graphs.

Being able to localise these resources and make them relevant to the children by referencing places and people they can relate to is important.

Encourage more collaboration

In respect of food systems, much of the drive in responding to the climate and biodiversity crises is coming from the bottom up - from community initiatives such as Planna Fwyd! It could be argued that it is the combined response of individuals, organising in their villages, towns, cities and regions that are our best hope of making a difference. We would therefor recommend that resources and tools be made available to enable groups of people to organise themselves in innovative ways in response to 21st century realities. In respect of food systems, this would include green economic activity centred around agroecological needs. In respect of digital innovations, we would recommend the encouragement of business models aimed at generating profit to realise environmental and social benefits, and built around open source software, open data, and open standards.

11 Acknowledgements

The *Mixed farming – histories and futures* project was a collaboration between the following four organisations and Jane Powell, as independent education facilitator. The individuals named below all worked on the project; opinion expressed in this report is that of the author.

https://www.ecodyfi.wales/

Chris Higgins
Andy Rowland
Michael Koutroumpas

https://www.aber.ac.uk/en/dis/

Dr Sarah Higgins, Department of Information Studies

https://www.library.wales/

Einion Gruffudd

https://www.envsys.co.uk/

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https://www.arwain.wales/

http://www.cynnalycardi.org.uk/english/

https://www.arloesigwyneddwledig.cymru/en/

https://ashleyfamilyfoundation.org.uk/

Appendix A – Some implementation details on the opportunity maps

To summarise, the “opportunities map” web application is an interactive map implemented on top of the Information Gateway backbone showing the opportunities for growing crops in the Dyfi Biosphere, field by field. The darker the field colour, the greater the opportunity. A sample screenshot of the public website is shown in Fig 9.

A high opportunity score favours cultivation, based upon the combination of three factors:

1. **Historic use**: If a field was under cultivation in 1840, that suggests it might be suitable again and would increase the opportunity.
2. **Carbon storage**: This refers to the carbon that is stored in vegetation, whether grass, crops or woodland. For example, cereals hold very little carbon compared to woodland. The map therefore gives a high score to fields that would not negatively affect carbon storage if they were lost or converted to arable. The dataset used in the application is owned by Natural Resources Wales and was used with permission.
3. **The risk of soil erosion**: Steep slopes that have little to no vegetation cover present a greater risk of soil erosion compared to shallow slopes with good vegetation cover, such as woodland and shrubland. Ploughing grassland (or felling trees) to grow crops exposes the soil to wind and rain, leading to erosion and increasing the risk of flooding. Fields that have a lower risk from soil erosion will have a higher opportunity score.

Algorithm

Figure 10 provides an overview of the Opportunity maps algorithm, which was designed by ENVSYS and implemented as open source by the project[33].

The process for calculating the opportunities score based on the flowchart above can be summarized as follows:

1. The raw carbon risk and erosion risk data are fetched from the data provider. The data must linearly represent the risk of carbon storage reduction and the risk of soil erosion.
2. Additional input data are also fetched, which could include any numerical or boolean values. Currently there is only one extra boolean variable: “Was the field previously arable?” which is assigned the value 1 if the answer is yes and 0 otherwise.
3. The carbon risk and erosion risk data are grouped into 10 clusters using the “Jenks natural breaks”[34] classification method as shown in Figure 4.

[33] Opportunity maps backend module is available as open source on Github: https://github.com/xmichael/opportunity-maps

[34] Jenks, George F. 1967. "The Data Model Concept in Statistical Mapping", International Yearbook of Cartography 7: 186–190

4. The classes are assigned an “opportunity status score” as follows: classes 1-5 are classified as not an opportunity and get a score 0, while classes 6 to 10 are assigned the score 1 to 5 respectively, representing increasing opportunity.
5. Optionally, extra customization can be added to the workflow, depending on policy decisions. For example, if one of the above scores is zero then the output opportunity score is 0 and no further calculations are made.
6. Finally, non-negative weights are optionally assigned to each opportunity by the user of the interactive app. If no weights are assigned they are assumed to be equal to 1.

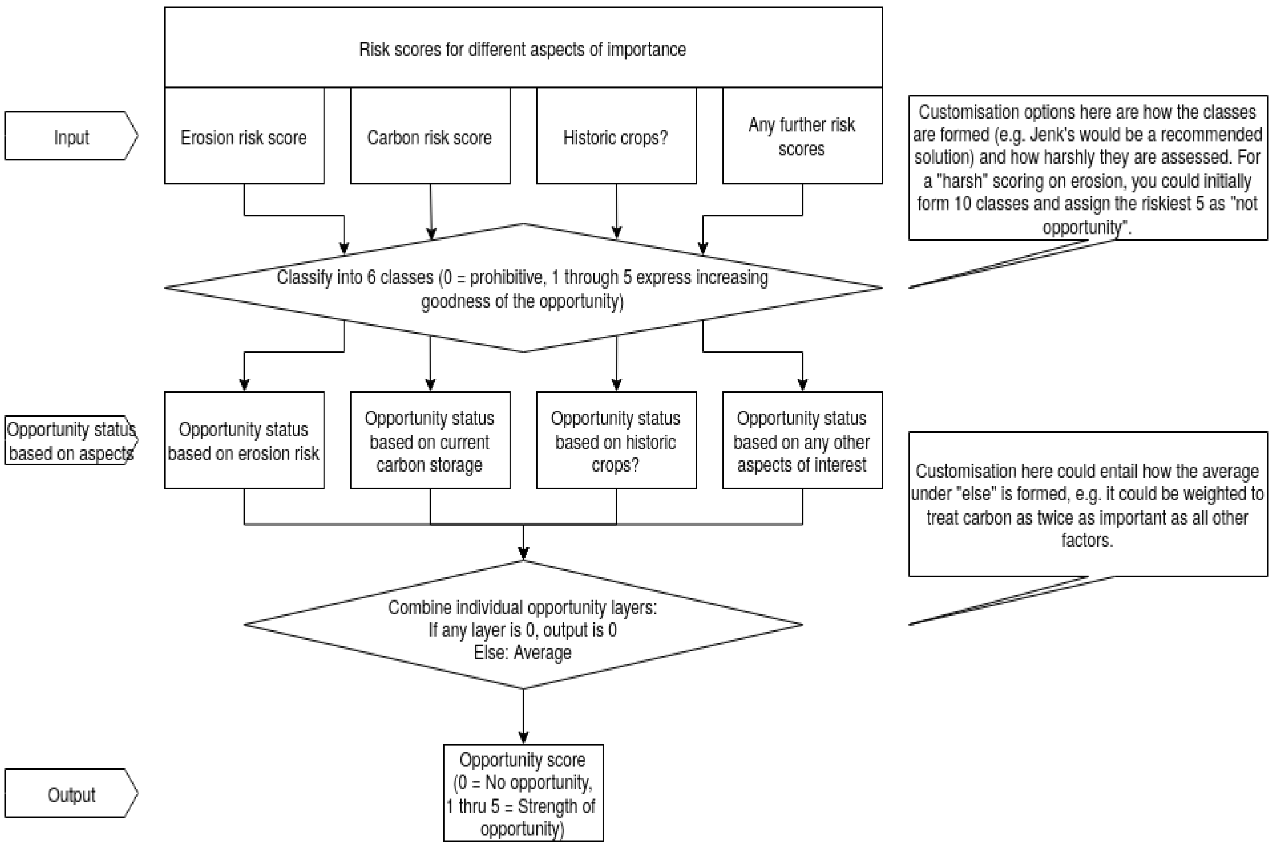

Fig 10: Opportunities calculator flowchart

Assuming the output opportunity score is not zero due to step 5, then the output score is calculated as the weighted arithmetic mean of all the individual scores:

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

where w_i are the non-negative weights assigned in step 6 and x_i are the individual scores.

In the current implementation, the user is allowed to change interactively:

- the weights of the variables carbon risk score, erosion risk score, previously arable score
- whether the output opportunity score should zero if one of the individual scores is zero

As a final note, figure 11 shows a sample of Jenks natural break classification of carbon risk. The 12000 sample values corresponding to different fields are sorted with a carbon risk score from 6 to 75. The natural breaks clustering method seeks to separate values into groups so that the variance **within** classes is minimized and the variance **between** classes is maximized.

The resulting clusters are shown below. The range of values within a pair of dashed lines belongs to a cluster, so for example, values 50-70 belong to class 1, 42-49 to class 2, etc.

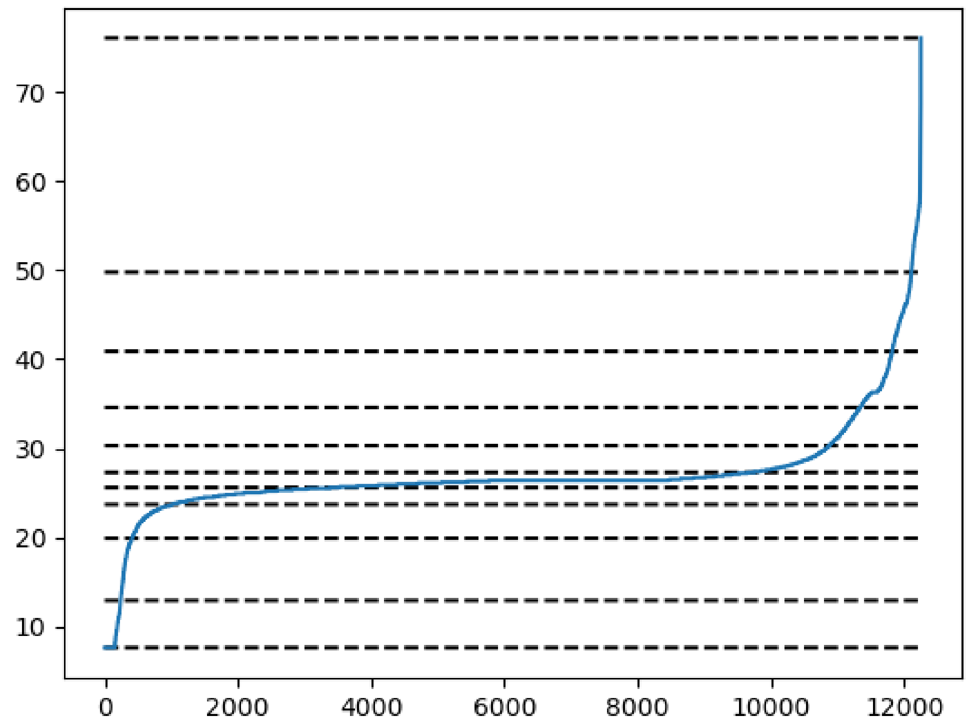

Fig 11: Plot showing the classification of carbon risk data into 10 clusters (delimited by dashed lines) using the Jenks natural breaks method

Appendix B – Use Case: local food system community group

Name:	**009**: Interoperability – local food system community group
Actors:	Community group
Description:	An interoperability use case. This community group has an immediate need for mapping in order to further the aim of the initiative – increase amount of food grown in the local area as a response to the coronavirus. We should be able to identify their requirements, match where possible to what we can offer and make our web mapping available quickly, seamlessly and at low cost within their website in a way that is compatible with their own particular circumstances
Trigger:	Community group has a need for a range of web mapping showing what is been grown where (with photographs) and local opportunities to help organise and disseminate information about the local food system
Notes:	• Planna Fwyd! example https://plantfood.machynlleth.wales/

Appendix C – Briefing for oral history volunteers

Author: Chris Higgins
Email: chris@higgins.myzen.co.uk
Date: 2nd Sept, 2019
Title: **Mixed farming – histories and futures. Briefing for oral history volunteers - interviewers**

Project background

This LEADER funded cooperation project started in April 2019 and will run till the end of September 2020. The area of focus is that of the UNESCO designated Dyfi Biosphere[35] – encompassing part of Powys, Gwynedd and Ceredigion.

This pilot project will illustrate that, historically, mixed farming - the growing of crops as well as the raising of livestock – was much more common in mid-Wales than it is now. We will use a variety of web based resources to demonstrate the feasibility and broader social, ecological and economic benefits of mixed agriculture. Educators will be provided with local source material on the history of land-use and agriculture.

[35] https://www.dyfibiosphere.wales/

Challenges such as climate change, species extinction and a turbulent political and economic environment mean that this is a particularly important period in the evolution of Welsh agriculture. This project aims to make a small agroecological contribution and help make the case for supporting sustainable mixed agriculture and a more resilient local food production economy. The project is predicated upon the recognition that small, family farms are the cornerstone of Wales' past, current and future rural economy, culture and landscape.

Main project outputs

1. An information gateway integrating a variety of web based resources to illustrate the potential for mixed agriculture in the Dyfi Biosphere
2. Mapping showing the development of agriculture in the Dyfi area
3. Improved maps illustrating land use in the 19^{th} century
4. Geospatial data showing 21^{st} century arable farming opportunities and information on associated ecosystem service benefits
5. A network of farmers in the Dyfi area interested in sustainable agriculture
6. Oral histories collected from older generation farmers

Oral histories

We believe this is important information we are collecting and in danger of being lost forever unless we move fast. The idea is to concentrate on collecting memories of when farming in the area was more mixed; specifically, arable cropping in the greater Dyfi Biosphere area was relatively common (especially in the lower lying areas) up until the post war years.

The aim is to collect a minimum of 25 oral histories between July and Dec 2019. Volunteer interviewers must be fluent Welsh speakers, preferably with local knowledge, have an interest in farming and have good social skills.

Key questions to ask

The following seven questions are of core interest to the project. Some digression is inevitable, this is not to be discouraged; especially, for example, were an anecdote being collected that improved the storytelling aspect of the recording, or if it offered broader social, economic, cultural or linguistic insight. Interviewers are expected to use their discretion and lead interviewees:

1. Were more crops grown in the area (on your farm) in the past?
2. Do you remember what crops and where they were grown?
3. Could you talk a little about how they were grown; from sourcing the seeds, to planting, growing and harvesting?
4. Were they forage crops or grown for human consumption? (try to get an idea of how the entire farm worked when farming was more mixed).

5. How were the crops processed, kept, sold?
6. Who was involved at the various stages: the farmer, family, the local community?
7. Do you have recollections of when arable farming became less common or ceased? Why?

Use of props

If possible, interviewers will be equipped with maps of the areas they are visiting and are invited to use these to facilitate the conversation. It is suggested that when subjects are being approached, they are invited to bring their own material in support of their recollections, eg, photos, hand tools, documents, etc. Interviewers should be prepared to photograph these as part of the 'story' the subject is telling. All media can be then be bundled together with the oral history recording and made available.

Who to interview

Several of the volunteer interviewers have extensive networks in the farming community and will have their own ideas about who best to interview. The project will also reach out over the next few months to identify additional interviewees.

Follow-on meeting

During recording of the oral history (maybe towards the end), volunteers are asked to use the opportunity to request if members of the farming family would agree to additional interaction with members of the project team.

This could take the form of return visit to the farm, eg, by another project member and a photographer or an invitation to a meeting with a number of local farmers. The opportunity is sought to engage in discussion with the current farmer on the broader aims of the project - encouraging movement towards sustainable mixed agriculture and an increased local food economy

Appendix D – System architecture

Figure 12 below is a block diagram providing a high level overview of the Mixed Farming architecture.

Building Blocks Characterization

The key components of the architecture are characterized as follows:

Cloud Storage

The term "cloud storage" is loosely defined as non-physical computer data storage provided by a cloud provider (e.g. Amazon AWS or Google Cloud). The actual implementation of that storage is generally not known as it depends on the cloud provider implementing it.

This is a key component that hosts all the data coming in and out of the system. It must satisfy all data access requirements for speed and integrity, provide redundancy and version control and be cost effective.

The reason that cloud storage was favoured among other storage solutions was because it provides the flexibility of managing costs according to the performance and capacity requirements of the project. It is crucial to be able to prove through the Information Gateway (IG) demonstrator that what is now achievable with a limited budget, will be able to scale seamlessly as demand increases.

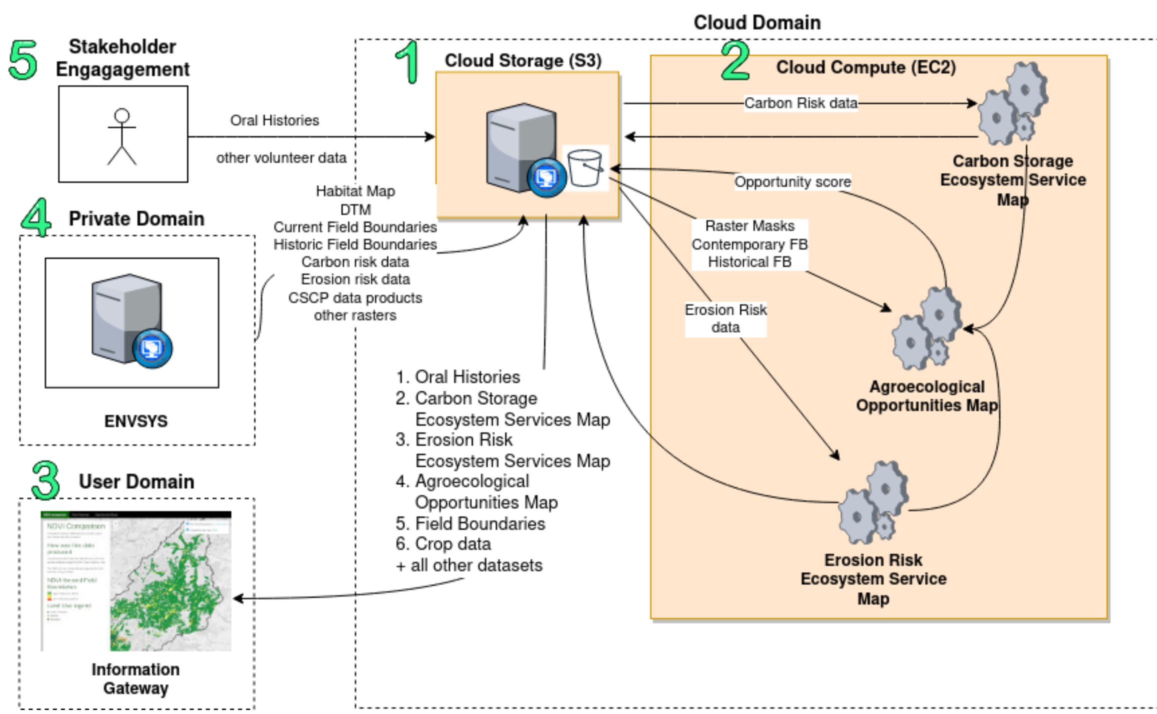

Fig. 12: Mixed Farming Architecture Block Diagram

Cloud Compute

Another cloud-specific term is "cloud compute" which refers to virtualized computer processing services. All geospatial processes are carried out within this service e.g. the opportunity maps generation. The project used Amazon AWS but it is possible at any time to move this component to a different provider like Google Cloud or a traditional physical data centre.

The implementation of the Mixed Farming architecture strives to **avoid vendor lock-in** by implementing all geospatial operations inside a generic self-contained GNU/Linux distribution configured from scratch for the purposes of the project. All software components in the cloud compute are chosen to be stable open-source software. This allows the same virtual machine to operate on different cloud providers as well as traditional physical servers which makes the architecture **compatible with different cloud providers**.

A major advantage in using cloud-based computing is **on-demand scalability** — as the project matures, more complicated processes and a greater number of users can dramatically increase the processing requirements. By using a cloud-based processing and storage services the cost of the project can be kept to exactly what is necessary for the current usage without having to invest extra resources in preparation for a potential usage surge.

It is expected that requirements, data products and algorithms will keep evolving. Therefore, while this component of the architecture is documented as having clearly defined processes and interfaces, it is also designed to be generic enough to be **adaptable to future changes** in technology and project requirements.

User Domain

The user domain includes all component blocks that are **visible to the end user** of the system, i.e. i) the web browser user-interface and ii) the different visualization components which are part of the user-interface. The exact definition of the interface and visualization is left intentionally abstract as it is expected to continuously adapt to user-feedback with continuous incremental software releases.

The user domain is the public-facing part of the information gateway and i**s accessible from the Dyfi Biosphere website**.

All the applications available via the website have a diverse scope in functionality and target user base. They all, however, use the same underlying system architecture.

Private Domain

This domain includes all black-box components i.e. components that provide open data to the system but the processes that produce them are proprietary and not visible.

It should be noted that the technical architecture is deliberately designed to use both proprietary and open source components by adopting the popular 3-clause BSD open source licence. This way the project itself can be open-source while optionally leveraging valuable third-party components that come under a more restricted licence without any conflicts.

The private domain currently encompasses the ENVSYS proprietary processes that generate carbon risk and erosion risk data. These datasets are made available to Mixed Farming projects under their respective licences, but the internal processes that produce them are the intellectual property of ENVSYS.

Other third-party datasets from external providers are also considered to come from this domain and have their own respective licences.

Stakeholder Engagement

The stakeholder engagement domain is loosely defined as the group of external activities that produce useful input to the MF architecture by direct engagement with the MF community, education and other MF stakeholders.

The most visible example is the oral histories dataset that is stored in the cloud storage alongside other data products and is accessible from the information gateway.

This domain also includes all other volunteer contributed data that are utilized by the project e.g. expert input for identifying gaps in existing data products and to provide educated guesses about missing land-use information.

Generic Workflow

The high level block diagram above illustrates the principal parts of the proposed architecture. The main user workflow is deliberately generic and flexible to support a variety of different user requirements. Two typical workflows that are summarised below are **map generation** and **user access**:

Map Generation

Map generation is initiated when new input data become available from one of the external data providers e.g. those under "Private Domain" or "Stakeholder Engagement":

1. Input data products are initially delivered to the cloud storage instance.
2. Cloud processing instances detect the new data and trigger an update for the associated service. Currently this applies to the erosion risk and carbon storage map generation for the production of opportunity maps.
3. Once the above maps are updated, the agroecological opportunities map is generated.
4. The opportunities map along with its two input maps (erosion risk and carbon storage) are uploaded to the cloud storage component and become accessible from the Information Gateway (IG).

User Access

1. The user initiates access to the system from the web-based user interface to access one of the many MF outputs. The actual data and visualization components vary and depend on evolving input from the relevant work packages (WP2, WP3, WP5). Currently, the following datasets are accessible from the IG:
   a. past and present tithe map datasets
   b. oral histories
   c. carbon storage ecosystem service maps

    d. erosion risk ecosystem service maps
    e. agroecological opportunity maps
2. The IG accesses the requested maps using asynchronous Javascript requests to the cloud storage and presents the results to the user.
3. At any time the map data can be updated through the process of "Map Generation" described above. The new data are detected by the information gateway and are seamlessly made available to the end user.

TECHNICAL FEASIBILITY AND CHALLENGES

The technical feasibility of the service has largely depended on its ability to adapt to ever-changing stakeholder requirements, the reliability of its functional components and the robustness of the overall architecture.

The following approach has been taken to prevent or mitigate the following technical risks that commonly exist in large software projects.

- **Vendor lock-in**. Definition: relying on a component that is supported by a single vendor without being able to easily switch alternative solutions due to licence terms, patents, use of proprietary technology instead of open standards, etc. To prevent this, the architecture is exclusively based on widely adopted components that adhere to open standards and use open source software. The whole system is designed to be self-contained and portable, meaning that it can seamlessly switch to a different cloud provider or a physical server infrastructure.
- **Failure of system components to deliver desired functionality**: To minimize that risk our technical team will only select robust, tried and trusted software components that have been proven to work for their intended purposes. All software libraries, database backends, cloud services, GIS tools used have been extensively used by the team and relied upon over many years.
- **Failure for technology to match user requirements and time constraints**. This is the most serious risk that encompasses all aspects of the business strategy and can have many different causes. To minimize that risk an agile, rapid prototyping development approach will be used throughout the development lifecycle to ensure that user requirements match technological solutions.

Technical Requirements:

The core platform will be based on the cloud and as such the following technical requirements regarding performance, reliability and availability are strongly desirable in order to prove that the system is production-strength:

- The final system should be available at least 99% of the time for any one-month period of project activity.
- The system should be scalable to support (when necessary) hundreds of simultaneous users by dynamically expanding its use of cloud resources
- Redundancy of system and user data should be guaranteed through the use of automated backups and disk mirroring (e.g. RAID 1)

- The reliability of the production system should be constantly monitored with automated system testing.

METHODOLOGY

The project followed an iterative and agile approach to the engineering of the broad framework. This entails a rapid prototyping approach with early releases occurring in parallel with the core software development effort. Requirements, as identified under Work Package 2 – stakeholder engagement (WP2), have been incrementally incorporated into the evolving architecture as the WP2 use cases were crystallising.

These requirements have formed throughout the project by using early-access demonstrators, which will in turn, represent the tangible metric through which the architecture can be assessed functionality-wise. Early releases of these demonstrators allow feedback from the stakeholders through which their desired functionality, and implicitly that of our architecture, may be reassessed. As well as the explicit user requirements, subjective issues such as usability can also be investigated.

Agile Development

A simple and effective Agile development lifecycle was used within the project – a rapid prototyping approach with early releases occurring in parallel with the core software development effort.

Capturing user requirements relies heavily on the concepts of test-driven development and continuous integration:

- Early releases (demonstrators) help in establishing a feedback loop with project partners to ensure that the correct user requirements are captured.
- **Requirements and their implementation status are continuously tracked** on Github[36]
- Test cases are written prior to code which effectively guarantees a direct trace between code, tests and user requirements
- The test cases can be used to test that previous functionality still works (**regression testing**) and that the components of the architecture are correctly orchestrated from a top-down perspective (**system & integration testing**)

Multiple language support

The IG is currently available in both English and Welsh languages using the project internationalization infrastructure. It is designed to potentially support any number of languages by using a token for each sentence or term and by dynamically looking up the translation when the webpage is loaded.

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[36] The Mixed Farming project open source code repository, which includes issue-tracking for user requirements, is available on Github: https://github.com/xmichael/mf_client

This internationalization infrastructure has been implemented within the project from scratch rather than depending on an existing web service or application — translators and volunteers were not expected to understand any web programming at all and were not required to learn a new web service or translation framework. They were provided with a spreadsheet containing the original text in English and an empty column for Welsh. This method can potentially include other languages.

The Spreadsheet is then exported to CSV and loaded by the webapp to provide the translation to the user on-the-fly.