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Approaches for spacially explicit negotiation of impacts of land use change on ecosystem services

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APPROACHES FOR SPATIALLY EXPLICIT NEGOTIATION OF IMPACTS OF LAND USE CHANGE ON ECOSYSTEM SERVICES

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ABSTRACT

There is increasing policy interest in valuing a broader range of ecosystem services in environmental management. Engagement of local people in ecosystem management is fundamental to making operational approaches viable. Development of decision support systems capable of operating in complex, data sparse non-linear multi-component systems is challenging. This thesis explores approaches for spatially explicit support of negotiation of land use change to manage ecosystem service provision across a range of ecosystem services. Initial research on the impacts of farmer interventions on ecosystem service provision in the Pontbren Catchment in mid Wales were used to identify operational requirements and knowledge gaps. Initial findings highlighted the importance of taking a spatially explicit approach and revealed significant gaps in data to inform decision making at local levels. Research revealed that local stakeholder's ecological knowledge suggested significant complementarities with scientific understanding of ecosystem function in the catchment that was useful for addressing data gaps and for validation of high resolution spatial datasets. Existing approaches for mapping ecosystem services were then reviewed to explore the extent to which they could be used to inform on the ground decision making. This revealed significant gaps in relation to mapping flows of ecosystem services and for informing decision making at finer scales. An iterative process was used to develop specifications for spatial tools focused at field, farm and immediate landscape scales connecting field level decisions about land use change (e.g. addition or removal of tree cover) with impacts on landscape scale processes (e.g. flood risk and habitat networks). The approach was then tested and adjusted following a scoping study in the Elwy catchment. The specifications resulted in Polyscape, a participatory methodology and geographic information system (GIS) mapping tool which integrates the knowledge of local and technical experts with readily available spatial environmental data to facilitate negotiation of land use change to manage ecosystem service provision. Polyscape offers a means for prioritising existing features and identification of opportunities for land use change to improve ecosystem service provision. It meets a key need for models and visualisations that it can be widely applied as it uses readily available data for parameterisation. Deficiencies in the data can be reduced by incorporating local stakeholder knowledge (which, in turn, increases stakeholder participation in the negotiation process). The Polyscape approach was applied in the Cambrian Mountains where output was evaluated by a range of local stakeholders (including farmers and ecologists). The feedback suggested that the approach delivered credible results at local landscape scales and provided a reasonable basis for the negotiation of ecosystem service provision. Requirements for implementing policy at local scales for effective ecosystem management were identified. Achieving this would require decentralised and integrated governance structures amongst agencies and training in participatory methodology. Polyscape provides a tangible framework for doing this

Keywords: *Stakeholder engagement, ecosystem Services, local scale, visualisation, negotiation, landscape, GIS*

DEDICATION

This thesis is dedicated to my family:

My wife, Sas, and my children, Laney, Ned and Mili,

My mum, Hetta, and my brother, Jooch

In loving memory of my dad
(who would have enjoyed this as much as I did)

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I would just like to add some personal thanks to my neighbours and friends who have helped look after the kids and keep my spirits high: My mum, Esther and Matt, Nat and Jas, Miles and Joel and Susie and a nod to Mr Keiron Hebdon.

And, finally, a huge heap of thanks and love to my wonderful wife, Saskia 'Flowed'.

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ABBREVIATIONS AND ACRONYMS

ALP	Adaptive Landscape Project
AES	Agri-environment schemes
ARIES	Artificial Intelligence for Ecosystem Services
AKT	Agro-ecological Knowledge Toolkit
BAP	Biodiversity Action Plan
CEH	Centre for Ecology and Hydrology
CCW	Countryside Council for Wales
Coed Cymru	A national welsh initiative that offers free help and advice on the management of woodlands and the sustainable use of woodland products.
CMI	Cambrian Mountains Initiative
Defra	Department for Environment, Food and Rural Affairs
DTM	Digital Terrain Model
EA	Environment Agency
ESA	Environmentally Sensitive Area
FC	Forestry Commission
FCW	Forestry Commission Wales
FRMRC	Flood Risk Management Research Consortium
GIS	Geographical Information Systems
Glastir	A 5 year whole farm sustainable land management scheme available to farmers and land managers across Wales.
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IPCC	Intergovernmental Panel on Climate Change
LFA	Less Favoured Areas
MA	Millennium ecosystem assessment
NSRI	National Soil Research Institutes
PAWS	Planted Ancient Woodland Sites
PES	Payments for Ecosystem Services
SAC	Special Areas of Conservation
SPA	Special Protection Areas
SSSI	Sites of Special Scientific Interest

TEEB	The Economics of Ecosystems and Biodiversity
Tir Cynnal	Tir Cynnal was an entry-level agri-environment scheme run by the Welsh Government. The scheme was funded by the Rural Development Plan for Wales 2007-2013
Tir Gofal	Tir Gofal was a Welsh agri-environment scheme (2000-2013). It is due to be replaced by the Glastir scheme in 2013
Tir Mynyedd	Less Favoured Area (LFA) scheme for Wales
UNESCO	United Nations Educational, Scientific and Cultural Organization
WAG	Welsh Assembly Government

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND TO THE ECOSYSTEM SERVICE APPROACH

Agricultural practices began to appear on earth over 9000 years ago (Lev-Yadun *et al.*, 2000). Farming evolved primarily as a means for securing the supply of food, fibre and fuel. The shift from hunter-gatherer to agricultural systems was one of the critical developments that enabled civilisation to develop. In turn the associated growth of human population resulted in increased requirements for these resources. Substantial areas of the planet have been modified to enable increased food production; a process where complex ecosystems have been converted into ecologically simplified and more heavily managed agro-ecosystems (Foley *et al.*, 2005; Kareiva *et al.*, 2007 - see Figure 1.1).

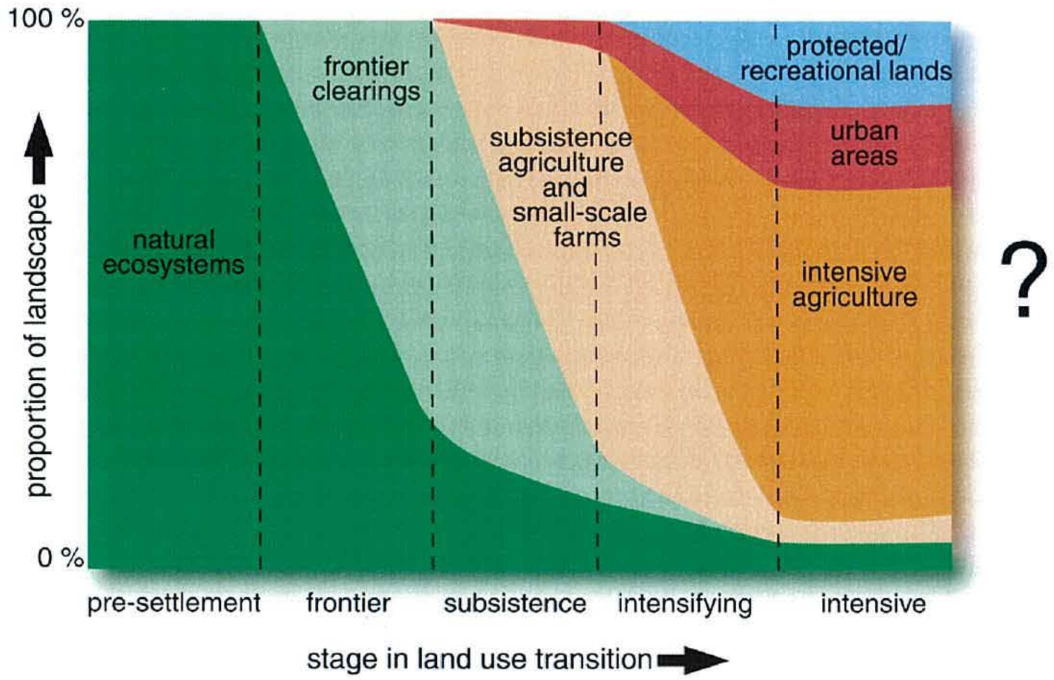

Figure1.1: The transition of ecosystems into agro-ecosystems (from Foley *et al.*, 2005)

Agro-ecosystems now account for over a quarter of the terrestrial land surface (Bruinsma, 2003). Over the last 50 years the pace of change has increased with significant, and often detrimental, impacts on the ability of these systems to provide the broad range of benefits (such as water supply and quality and climate stabilisation) required for human well being (Sanderson *et al.*, 2002; MA, 2005). These ecological processes and associated goods that contribute and sustain human wellbeing are known as ecosystem services (Daily, 1997; MA, 2005) It has been argued that to sustain their productivity and delivery of other ecosystem services, there is a need to modify how agricultural landscapes are managed (Scherr and McNeely, 2007). Achieving these objectives is likely to require the restoration of the some degree of ecological complexity that underlies the delivery of ecosystem services into agro-ecosystems. This presents a significant challenge as there are substantial gaps in scientific knowledge about ecosystem function (Kremen and Ostfeld, 2005), the understanding of which are necessary for effective management strategies; particularly at the finer scales at which modifications are made to the landscape

Since its genesis in the 1970s (Holdren and Ehrlich, 1974) the ecosystem approach has evolved rapidly both as a scientific discipline and as a paradigm for environmental policy (Fisher *et al.*, 2008; Norgaard, 2010). The major milestone for the wider adoption of the approach was the publication of the Millennium Ecosystem Assessment (MA , 2005). The MA built on a number of influential studies at the end of the 1990s (including works by Daily (1997) and Costanza *et al.* (1997); who provided an initial valuation of global ecosystem services at US$ 33 trillion per year). The MA provided, for the first time, a comprehensive summary of the state of ecosystem health for the 14 major terrestrial biomes and made explicit the linkages between the health of these systems and human welfare. The MA concluded that whilst modifications to many ecosystems had contributed to net gains in human well-being and economic development, this had come at considerable cost in the form of substantial degradation of 15 of the 24 ecosystem services assessed. Arguably the MA's most significant impact was in framing the approach in a format that was utilisable by policy makers (largely through the greater use of economic valuation tools). The impact of this was that the approach was widely adopted, initially by the World Bank, World Wildlife Fund, The Nature Conservancy, and Conservation International (Fisher *et al.*, 2008) and then increasingly by national governments (including the EU and the UK (Defra, 2007). Whilst the approach has not been without controversy, particularly in relation to the role of economic valuation (Norgaard, 2010; Spangenberg and Settele, 2010), its underlying utility is widely recognised in relation to enabling more holistic approaches to land management

1.2 MOVING ECOSYSTEM SERVICES FROM THEORY TO PRACTICE

Importantly the framework developed by the MA did not deliver the tools necessary to make ecosystem service conservation operational (Armsworth *et al.*, 2007). The steps required to do this has been the focus of much of the continued and rapidly expanding research into ecosystem services (Cowling *et al.*, 2008a; Daily *et al.*, 2009; de Groot *et al.*, 2010; Harrington, 2010)

From an operational perspective both the term 'ecosystem' and 'service' present problems. Ecosystems can be defined as complexes where biological and physical components come together in a place, essentially acting as stocks of natural capital (Vira and Adams, 2009, Crossman and Bryan, 2009). As such they exist at many scales ranging from a grain of sand up to the Earth itself. Much of the literature on ecosystem services stresses the need for working at 'landscape' scales but largely fails to define what a landscape is from a management perspective (Hein *et al.*, 2006a; Jackson *et al.*, 2007). The natural processes and goods that arise from these systems are defined as services once they affect human needs or values. Thus an ecosystem service is an output derived from an ecosystem from which people derive benefits (MA, 2005). Given the interdependencies inherent within ecosystem functions, modification to components of an ecosystem (as a result of management) will likely impact multiple ecosystem services simultaneously. At operational scales stakeholders managing a landscape are potentially buffered from this as there is spatial and temporal variation in where effects of service changes are manifest (MA, 2005). Ecosystem managers need to help land owners to understand the rationale for making changes and balance the needs of land owners with the needs of those reliant on public goods derived from the ecosystems they manage.

There is substantial heterogeneity both in the natural systems that provide ecosystem services and within the political and social systems responsible for their management (Helming and Perez-Soba, 2011). Given this, the management of ecosystem services should be tailored address the ecological, economic and social needs of these local systems. Developing management strategies capable of addressing these local variations whilst still supplying public goods requires interdisciplinary understanding of all three dimensions, including variations across spatial and temporal scales.

In order to address these issues ecosystem services research needs to move from a conceptual to an operational framework for decision making (Harrington *et al.*, 2010). Fisher *et al* identified (Fisher *et al.*, 2008) three main barriers to progress along this path. The first was the considerable gaps in ecological understanding, particularly in relation to the mechanisms and underlying structure within ecosystems required to sustain a continual flow of services. The second was in the development of appropriate methods for valuation of these services. Much of the recent research emphasis has been on valuation tools (Boyd and Banzhaf, 2007; Cornell, 2011). The final hurdle was the development of decision support systems that address the complex social, spatial and temporal dimensions of ecosystem service delivery. This forms the focus of the present research.

1.3 The roles for spatial tools

This research focuses on two of the elements, outlined above, which are required for decision support; specifically the social and spatial components. Where features (such as tree cover) are located in a landscape may have a significant influence on the nature of the services that they can supply (Morse-Jones, *et al.*, 2011). A number of studies have suggested a need for more spatially explicit typologies (see Boumans and Costanza, 2007; Fisher *et al.*, 2009). Given this spatially sensitivity spatially explicit approaches are likely to be helpful for engaging local stakeholders in decision making (deGroot *et al.*, 2010). The use of visualisation tools potentially offers a means for collective exploration of synergies and trade-offs between ecosystem services resulting from management decisions. Part of the inherent value of mapping approaches is that the output is intuitive for many stakeholders. Decision making is also a participatory process involving dialogue between stakeholders.

1.4 Aims and Objectives

The research presented in this thesis explores the requirements for spatial tools aimed at facilitating negotiation between the multiple stakeholders involved with the management of ecosystem services at field to landscape scales. The research draws on experimental work conducted on small scale changes to ecosystem functions from a collective of farms in mid Wales to develop specifications for mapping approaches. The key research objectives addressed in this thesis are as follows:

1. To what extent can land use change be used to manage ecosystem service provision in agricultural landscapes? **(Chapter 2** and **Chapter 3)**
    a. What are the current gaps in knowledge associated with the management of ecosystem services on farmed land?
    b. To what extent can generally available environmental data be combined with scientific knowledge and local knowledge to bridge these gaps?
2. To review the extent to which existing mapping approaches can be used to inform local decision taking about land use change and its impacts upon ecosystem service provision. **(Chapter 4)**
    a. What are the appropriate scales for management of ecosystem services in relation to impacts of land use change on ecosystem services?
    b. What are appropriate scales for measuring impacts on recipients?
3. What are the requirements for supporting negotiations about land use change in relation to managing ecosystem service provision? **(Chapter 5)**
    a. What are requirements for appropriate engagement of local stakeholders in ecosystem management?
    b. What resolution of spatially disaggregated data are required for developing representations to inform management decisions and are these data available?
4. To what extent is the mapped output produced from adopting the Polyscape approach to visualising impacts of land use change on ecosystem service provision legitimate to stakeholders? **(Chapter 6)**
    a. How plausible is the output to local stakeholders?
    b. To what extent does it address local stakeholder needs?

1.5 Structure of the Thesis

The thesis is structured as follows:

In Chapter 2 an analysis of the impacts of farmer interventions on ecosystem service provision is presented for the Pontbren Catchment in mid Wales. This provided a starting point for research on negotiating land use change and it's impact on ecosystem services from different stakeholder perspectives ranging from those of the farmer to those of agencies influencing how land is used. The case study at Pontbren was used to identify gaps in knowledge and issues likely to be encountered in operationalising an ecosystem services approach in Wales.

Engagement of local people in ecosystem management is fundamental to making operational approaches viable. Local stakeholder's ecological knowledge is a potentially useful resource for validating spatial datasets and for increasing engagement and ownership. In the third chapter local ecological knowledge of ecosystem function held by farmers in the Pontbren catchment was compared with the scientific understanding of ecosystem function resulting from research in the catchment. The aim of this work was to explore the extent to which local knowledge systems could be used to address knowledge gaps inherent in ecosystem management.

The forth chapter reviews current approaches for mapping ecosystem services. The aim was to clarify the potential roles of mapping in ecosystem service research and identify the extent to which existing approaches could be used to inform on the ground decision making was explored

The fifth and sixth chapters describe the specification and application of a spatially explicit approach for negotiating ecosystem service provision. The specifications for the approach were developed to span spatial scales from field to 1000 km^2). The initial research was conducted at Pontbren, a 10 km^2 sub catchment in the Severn catchment in mid Wales (Figure 1.2). The approach was then tested and adjusted following a scoping study in the Elwy catchment (270 km^2). As a result of this a spatial tool (Polyscape) was developed. In the sixth chapter the Polyscape approach was applied in the Cambrian Mountains, an area used for testing agri-environmental approaches in Wales. Initial output generated by the approach was evaluated by local farmers, ecologists and members of the local community. The research focussed on the Leri, Ceullan, Clararch & Clettwr and Rheidol catchments (a total area of 380 km^2). In all cases catchment boundaries were used as the system boundaries (this is discussed in the relevant chapters – see also Figure 1.2)

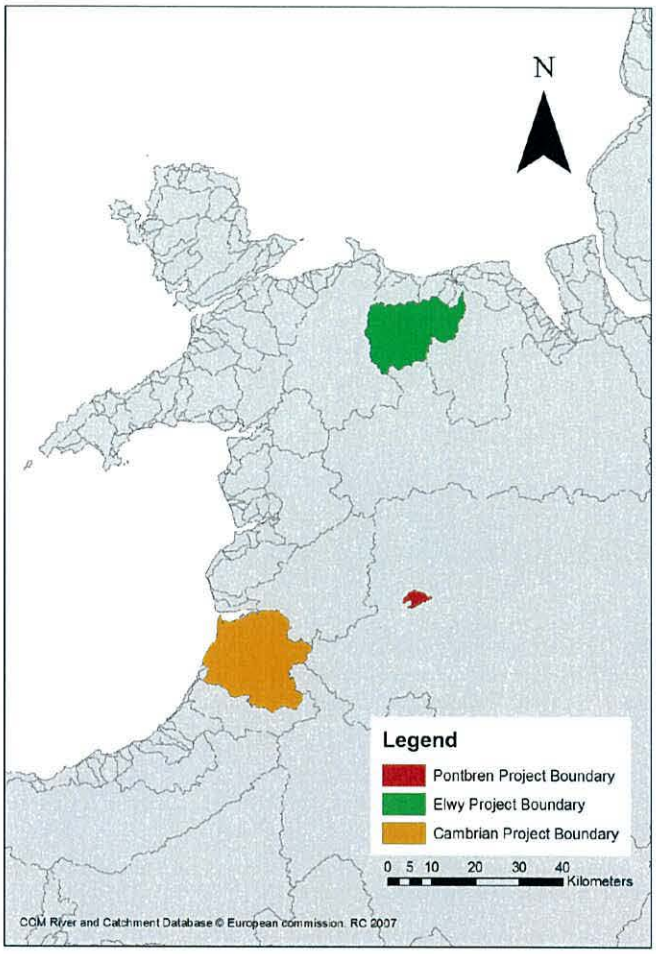

Figure 1.2: Map showing the location of the three study sites in Wales

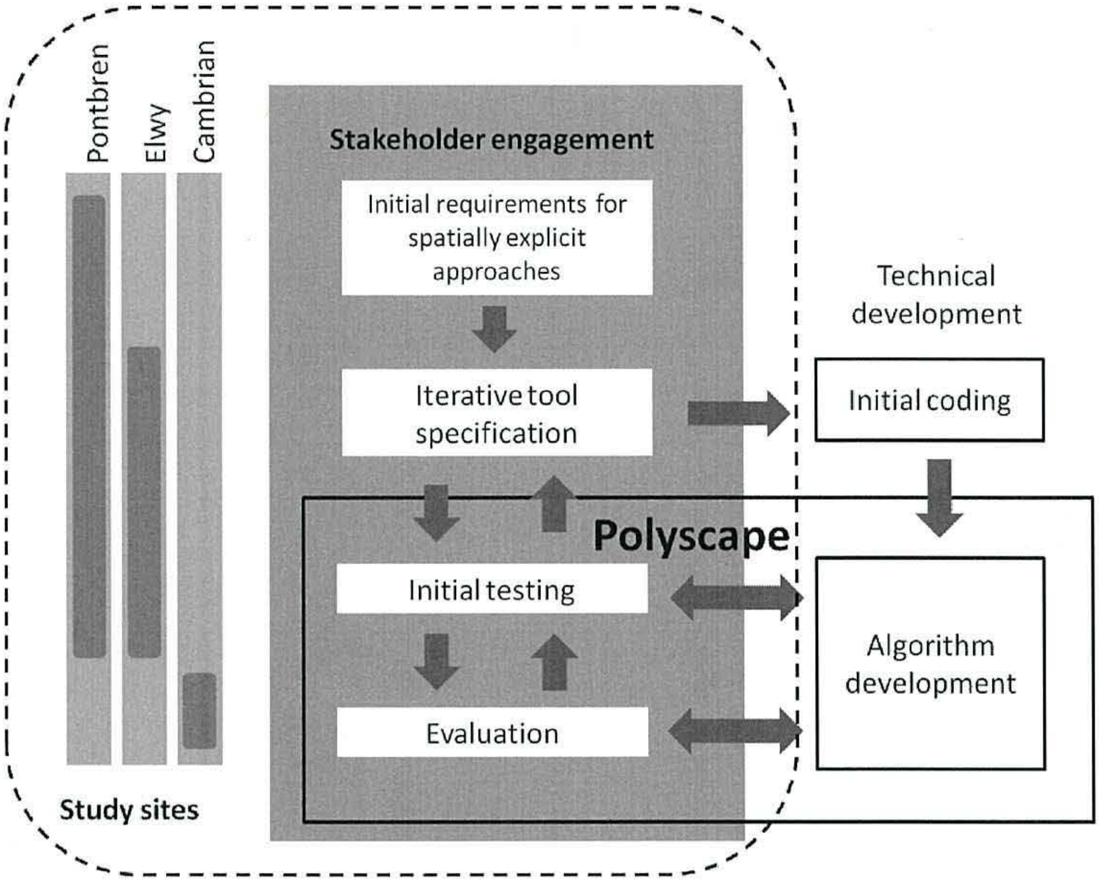

Figure 1.3: Methodology framework for the PhD (within the hatched line). White nodes represent the core components of the PhD. The gray bars on the left indicate the locations where research took place and correspond with the white nodes. The Polyscape tool developed as part of this thesis is represented by the node with the black outline

Given the requirement for interdisciplinary cooperation embodied by ecosystem service research a number of people have been involved in the initial development of the Polyscape tool (described in Chapters 5 and 6). The general requirement for a spatially explicit tool for ecosystem service management bridging field to landscape scale, emerged from the author's research on stakeholder engagement in flood risk management at Pontbren as part of Flood Risk Management Research Consortium (FRMRC) phase 1 (see Figure 1.3). The need for the tool arose through the early discussions with the Pontbren farmers (described in Chapter s 2 and 3). The ability to realise this in GIS terms came through collaboration with Bethanna Jackson (who was also working on the FRMRC project) then working at Imperial Collage and now works at Victoria, University of Wellington. In line with the stated methodology, a number of other people were involved with the development of the initial individual GIS layers used in Polyscape. The initial specifications are described in Chapter 5. The specifications for the agricultural layer were developed by the author based on interviews with the Pontbren farmers. The specifications for the water regulation layer were based on discussions between the author and Bethanna Jackson and drew on the hydrological modelling work conducted by Imperial collage at Pontbren as part of the FRMRC project (Jackson *et al.*, 2008). The habitat connectivity layer was based on the UK Forest Research's habitat network modelling approach which was applied at Pontbren by the author and Amy Eycott from Forest Research (Eycott *et al.*, 2007) as part of the EU Robinwood project. In chapter six the approach was expanded to include a priority habitat layer (with the specifications provided by the author) and a carbon sequestration layer adapted from work done on mapping carbon sequestration for Polyscape in New Zealand (described in O'Leary, 2010) as part of her MSc dissertation. The GIS coding for the Polyscape tool was done by Bethanna Jackson and various research assistants working under her supervision and is described in Jackson *et al.*, (in review). The stakeholder engagement component of the research was conducted by the author as an EPSRC PhD research fellow attached to the FRMRC phase two.

CHAPTER 2

IMPACTS OF LAND USE CHANGE ON ECOSYSTEM SERVICE PROVISION AT LOCAL SCALES: A CASE STUDY IN THE PONTBREN CATCHMENTS, MID-WALES

2.1 INTRODUCTION

This chapter provides an assessment of changes to ecosystem service provision resulting from land use change implemented by farmers in the Pontbren catchment in mid-Wales. The analysis was primarily concerned with identifying changes to ecosystem function at local scales, and indentifying the impacts of this on the regulating and cultural services both within and beyond the catchment. The first section documents the back ground to the research at Pontbren. The results of multidisciplinary research on changes to ecosystem function arising from the farmer led initiative were then analysed. The implications of these finding are then discussed in relation to land use planning at operational scales aimed at delivering more holistic ecosystem service provision.

2.1.1 Background

Increasing human requirements for natural resources (such as food and fibre) have led to substantial modifications to many of the earth's ecosystems. Several global assessments have described these impacts (Foley *et al.*, 2005). Since the late 1990's the ecosystem service approach has been increasingly used as a conceptual framework for describing these changes, reaching a critical mass after publication of the Millennium Ecosystem Assessment in 2005 which provided a compelling summary of the current state of global ecosystems and the implications of this for future human well being. Since its publication there have been substantial increases both in research into ecosystem services (Vihervaara *et al.*, 2010) and political awareness of the concepts (Fisher *et al.*, 2008). This had led to increasing calls for conversion of the conceptual framework into an operational model for adapting land management approaches to include more holistic assessments of the impacts of change (Cowling *et al.*, 2008; Daily *et al.*, 2009; de Groot *et al.*, 2010).

In the UK the Department for Environment, Food and Rural Affairs (Defra) released an Action Plan ((Defra, 2007b)) which detailed approaches for embedding an ecosystems approach into UK environmental policy. A number of studies have followed exploring the potential of implementing an ecosystem approach (Defra, 2007a; Defra, 2007b; Haines-Young *et al.*, 2008). In 2011 a synthesis of the first UK National Ecosystem Assessment was published (UK National Ecosystem Assessment, 2011). In line with these initiatives the Welsh Government began to explore opportunities to explicitly manage the Welsh countryside to secure and ultimately enhance the delivery of the broad range of ecosystem services it provides (Defra, 2007b; Welsh Assembly Government, 2006). Key drivers for this have been increased concern about the threats posed by climate change, and tighter EU legislation associated with revisions to the Common Agricultural Policy (CAP) (Welsh Assembly Government, 2008). There were also significant new legislation relating to water management (under the Water framework directive (European Union, 2000)) and biodiversity (amongst others the EU Habitats Directive (produced in 1998) and the EU Biodiversity Communication and Action Plan (produced in 2006). The main policy instruments to deliver on the ground changes to rural green infrastructure in Wales are the agri-environment schemes (AES). Since their inception, and in line with European policy at the time, AES have focused almost exclusively on biodiversity objectives (Whittingham, 2007; Whittingham, 2011). Up until 2013 the two main agri-environment schemes in Wales were *Tir Cynnal* (an all Wales entry level scheme) and *Tir Gofal* (a higher level scheme). Both schemes were voluntary farm based schemes designed to encourage environmental management to prevent loss of bio-diversity through conserving and creating wildlife habitats on farms (National Assembly for Wales, 2011). In response to changes in priority introduced under the CAP health check (Welsh Assembly Government, 2008) the Welsh Government announced plans to develop a new agri-environment scheme, *Glastir*. The new scheme was designed to broaden its scope to include adaptation to climate change, carbon capture, water management as well as bio-diversity. To meet these policy goals requires a greater focus of on sustaining the regulating capacity, of the rural landscape. Translating these policy objectives to local land management plans presents a number of challenges: A principal concern is that objectives for the delivery of public goods are likely to conflict with the livelihood objectives of local stakeholders, which are primarily focused on the provisioning capacity of the landscape. This is reflected in the way that the land was and is managed. Additionally addressing issues such as water regulation and adaptation to climate change requires coordinated changes across landscapes. This will require greater collective action on the part of local stakeholders, the prescriptions for which are currently absent from Welsh agri-environment schemes. Finally there is the virtual absence of data on the baseline delivery of ecosystem services at local landscape scales (Everard, 2009) making it difficult to monitor and evaluate changes to ecosystem service provision.

Given these tensions ecosystem assessments are likely to play an important role in providing knowledge to inform land use strategies (Cowling *et al.*, 2008). Currently the policy focus in the UK has been on implementing national scale studies (UK National Ecosystem Assessment, 2011). There have been relatively few small scale assessments of ecosystem service provision conducted across the UK. Those that have been conducted have been largely based on economic inventories of ecosystem services exploring relative values (or marginal values). Examples of this include the Dartford Marshes (Collingwood Environmental Planning and GeoData Institute, 2007), an appraisal of the creation of salt marshes for coastal realignment schemes (Luisetti *et al.*, 2008) and the Tamar catchment and the Alkborough Flats managed realignment sites (Everard, 2009). In Wales a study by Chris Dyson (2009) explored the potential of floodplain habitats in the Usk catchments to deliver multiple benefits. Whilst these inventories provide valuable tools for analysis and decision making there is still limited information on the ecological and social dimensions of ecosystem service delivery at these operational scales. These include identification of local management priorities for landscape and the identification of potential barriers or opportunities to developing more integrated approached to land management.

In this chapter we report the changes to ecosystem service delivery arising from modifications made by farmers to the Pontbren catchment in Wales. The Pontbren farms are of interest as they represent a 'grass roots' collective that grouped together independently to alter their farmlands to improve their overall sustainability. To do this they extensified their farming systems by creating more shelter provision and returned to using local hardy sheep breeds that could be left outdoors through winter. The effect of this was to increase tree cover over the catchment. Researchers were invited on to the farms to study many of the resulting changes which provided an opportunity to explore the effects of collective action on ecosystem service provision at operational scales.

2.1.2 Objectives

The main aim of this chapter was to provide an assessment of the changes to the provision of ecosystem goods and services resulting from land use changes in the Pontbren catchments in Wales. The key research questions addressed were:

- What evidence was available of changes to ecosystem processes at the field to small landscape scale resulting from the farmer interventions?
- To what extent were local stakeholder land management objectives synergistic to the holistic approach suggested by the ecosystems approach?
- What were the lessons from the Pontbren experience in relation to informing of an operational approach to ecosystem service management?

2.2 METHODS

2.2.1 Study site

The Pontbren group consists of a consortium of ten farmers based near Llanfair Caereinion in mid-Wales[1]. The Pontbren group take their name from the *Nant-Pontbren*, a stream that flows through the majority of the farms. The genesis of the group was in 1997 when three neighbouring farmers began to work together to plant shelterbelts[2] on their farms. In 2001 this core group invited a further seven neighbouring farmers to join the group having realised the benefits of working

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[1] http://www.pontbrenfarmers.co.uk/index.html

[2] Shelterbelts are linear tree features designed to lessen the force of the wind – in upland farms in Wales this is primarily for the protection of livestock.

together. After successfully seeking funding as a group (with the help of Coed Cymru[3]) the farmers began a major programme of shelterbelt and hedgerow planting in 2001.

Researchers were initially invited into the catchment in 2003, when farmers asked the Centre for Ecology and Hydrology (CEH) and Bangor University to explore the hydrological impacts of their tree planting (Bird *et al.*, 2003; Carroll *et al.*, 2004). The Pontbren group continued to be successful in attracting funded research particularly in relation to studying the impacts of 'soft engineering' approaches in reducing flood risk. Pontbren was selected as a major study site for the Flood Risk Management Research Consortium (FRMRC)[4] between 2004 and 2010 (see Marshall *et al.*, 2009; Wheater *et al.*, 2008; Jackson *et al.*, 2008a and Henshaw, 2009). This work resulted in the implementation of an intensive hydrological monitoring program alongside multi disciplinary research into geomorphologic processes, and associated stakeholder and policy dimensions of the initiative. There have also been a number of smaller studies looking at water quality (Reynolds *et al.*, 2009) and biodiversity benefits at Pontbren (McHugh, 2003; Moro and Gadal, 2007).

The Pontbren farms were interesting for a number of reasons. The changes made by the farmers were spread over 1000 ha of contiguous farmland – representing a potential model for collective landscape level management. The modifications to land use were designed and implemented by the farmers. As such they represented 'grass roots' level decision making to meet local objectives. There were potential synergies between these objectives and national objectives outlined for agri-environmental schemes in Wales (although this was not intentional). Understanding the farmers' rationale for making changes provided an insight on the types of changes that other farmers were more likely to adopt. Finally by inviting scientists into the catchment after they began to make changes, the effects of the interventions could be partially quantified offering provisional evidence on what might be expected from similar approaches.

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[3] Coed Cymru (*Welsh Woods*) is a NGO that assists farmers in Wales with planting and managing farm woodlands.

[4] http://www.floodrisk.org.uk/

The collective farm land covers an area of 1000 ha accounting for approximately 43 % of the Pontbren sub-catchment. The sub-catchment lies in the headwaters of the river Severn and flows into the Severn basin upstream of Shrewsbury. The farms are typical of many upland farming systems in Wales – consisting of enclosed, intensively managed, grazing land, adjacent to more extensively grazed wet heathland. Woodland occupies approximately 1.5% of the total holdings and there is a network of unmapped hedgerows. Most of the catchment (88%) is under pasture of which 66% is improved grassland (Improved grasslands are ecologically defined as grassland with more than 50% cover of *Lolium perenne* and *Trifolium repens.* In management terms it signifies meadows and pastures which have been subject to agricultural improvement, often by the installation of sub-surface field drainage systems, re-seeding with more productive grasses and application of inorganic fertilisers).

2.2.2 Assessment methodologies

The assessment methodology was developed using the same method that was detailed in Defra's "Introductory guide to valuing ecosystem services" (2007). This identified five key steps as part of a systematic approach to appraising ecosystem service provision. This approach provides the basis for the methodology adopted here. The key steps were:

1. Establish the environmental baseline.
2. Identify and provide qualitative assessment of the potential impacts of interventions[5] on ecosystem services.
3. Quantify the impacts of interventions on specific ecosystem services.
4. Assess the effects on human welfare.
5. Value the changes in ecosystem services.

A provisional assessment was made of baseline ecosystem service provision in the catchment. There were substantial limitations on the information available to address this objective, particularly the lack of any form of scientific monitoring in the catchment prior to the farmer interventions. Instead the findings from a workshop

[5] Note the term 'intervention' was substituted for 'policy option' from the original document.

held at the onset of research in the catchments were used to provide a qualitative assessment of the base line condition (see Section 2.3.2 below).

The second stage called for identification of the impacts of changes to ecosystem service provision in the catchments. Information was collected on the nature of the changes made in the catchments through interviews with all ten of the Pontbren farmers. Interviews were also held with stakeholders involved with the plantings (including two members of Coed Cymru). Based on this information an inventory of ecosystem goods and services associated with the interventions were described and a qualitative assessment was conducted.

The published scientific evidence gained from the multi disciplinary work conducted at Pontbren was then synthesised in relation to the inventory to identify which elements could be quantified. Where possible these were translated into ecosystem service outcomes. The impacts upon cultural services were identified through interviews with the Pontbren farmers. Data on provisioning services was not collected as part of the research conducted at Pontbren, although anecdotal evidence was provided by the farmers.

The assessment on the impacts upon human welfare were based on interviews conducted with all the farmers in the catchments.

2.2.3 Typologies

A common problem with ecosystem assessments relates to ambiguity in the manner in which key terms are defined and the variation in typologies of ecosystem services used (Wallace, 2007). At present there is no universally accepted typology of ecosystem services. This makes comparisons between ecosystem assessments problematic (Seppelt *et al.*, 2011). The MA (2005) remains the highest profile typology of ecosystem services and is the most widely used and understood at the present time. Much of the recent research on ecosystem typology has raised concerns about double accounting particularly where multiple ecosystem functions were involved in the production of a single final service (see Boyd and Banzhaf, 2007; Fisher and Turner, 2008; Fisher *et al.*, 2009). To avoid this the typology suggested by Balmford *et al.*, (2011) was used initially to identify changes to ecosystem function, which were then translated into ecosystem services as defined by the MA (where possible) as the typology broadly corresponds with the MA typology (See Appendix 1).

2.2.4 Economic valuation

The final step of the Defra methodology, outlined above, calls for an (economic) valuation of the changes. Whilst economic valuation plays a key (and often central) role in ecosystem service assessments (Seppelt *et al.*, 2011) they were excluded from this study. The reasons for this were that the study focused primarily on understanding bio-physical changes to ecosystem function resulting from small scale interventions (i.e. at the point of provision). As many of the changes were to regulating services it was likely that in effect, many of the service benefits would be realised beyond the catchment boundaries. These non-consumptive ecosystem services are difficult to value (TEEB, 2010), particularly where the extent of the effect of the change was unknown. Instead the focus was on understanding the rationale (i.e. defining the in situ benefits to the farmers) which were used to justify the interventions and explore the positive (or negative) externalities associated with those changes. Although the changes to the provisioning services within the catchments could be more easily measured in economic terms this was not a primary focus of the work. The study does identify some of the cultural non-use values associated with the Pontbren landscape, but not in financial terms.

2.3 RESULTS

2.3.1 A brief overview of historical changes to ecosystem service provision at Pontbren

Wales consists of almost entirely semi natural habitat. Agriculture is the predominant land use over much of Wales, accounting for approximately 81% of the terrestrial surface area (Welsh Assembly Government, 2010b). This compares with approximately 70% across the UK as a whole (Defra, 2011)). Woodland makes up most of the remaining land use (accounting for 14.3% of the land area (Forestry Commission, 2011)) with approximately half being managed as conifer plantations. In the immediate post War period (i.e. 1947 onwards), driven by increased demand for food, the Welsh rural landscape went through significant changes to support enhanced livestock production (Fuller and Gough, 1999). This process of intensification resulted in modification and fragmentation of Welsh habitats (Welsh Assembly Government, 2008). In the 1930s almost 75% of Wales consisted of semi-natural grassland (Stevens *et al.*, 2010). At national scales habitat maps provide evidence of substantial changes with improved grassland covering an area of approximately 1 million ha making it the most common habitat in Wales (Blackstock *et al.*, 2010). Historical land use maps produced as part of the work into understanding geomorphologic processes (Henshaw, 2009) show changes in the area of improved grassland within the catchments since the 1930s (Figure 2.1)

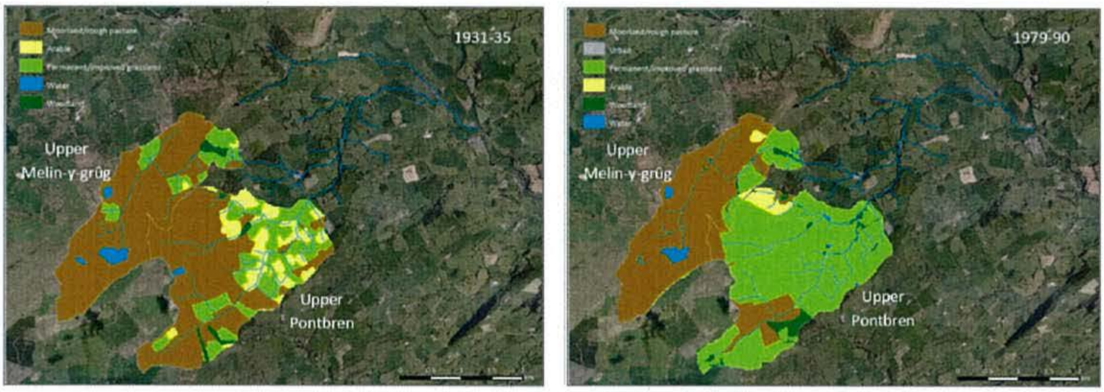

Figure 2.1: Historical land use data showing the conversion of the areas of peat rich moorland and rough pasture (brown areas) to improved grassland (green areas) from a) 1930s to b)1979-1990 (source Henshaw , 2009)

The relatively recent conversion of large areas of peat into improved pasture through improved drainage are likely to have had a significant effect on carbon levels (Berglund and Berglund, 2011) potentially turning much of the land from a carbon sink into a carbon source at the time of the interventions – although there is no formal evidence to support this. At the same time these were likely to have decreased the water regulating capacity of the landscape (Wheater and Evans, 2009) and similarly reduced the area of natural habitat.

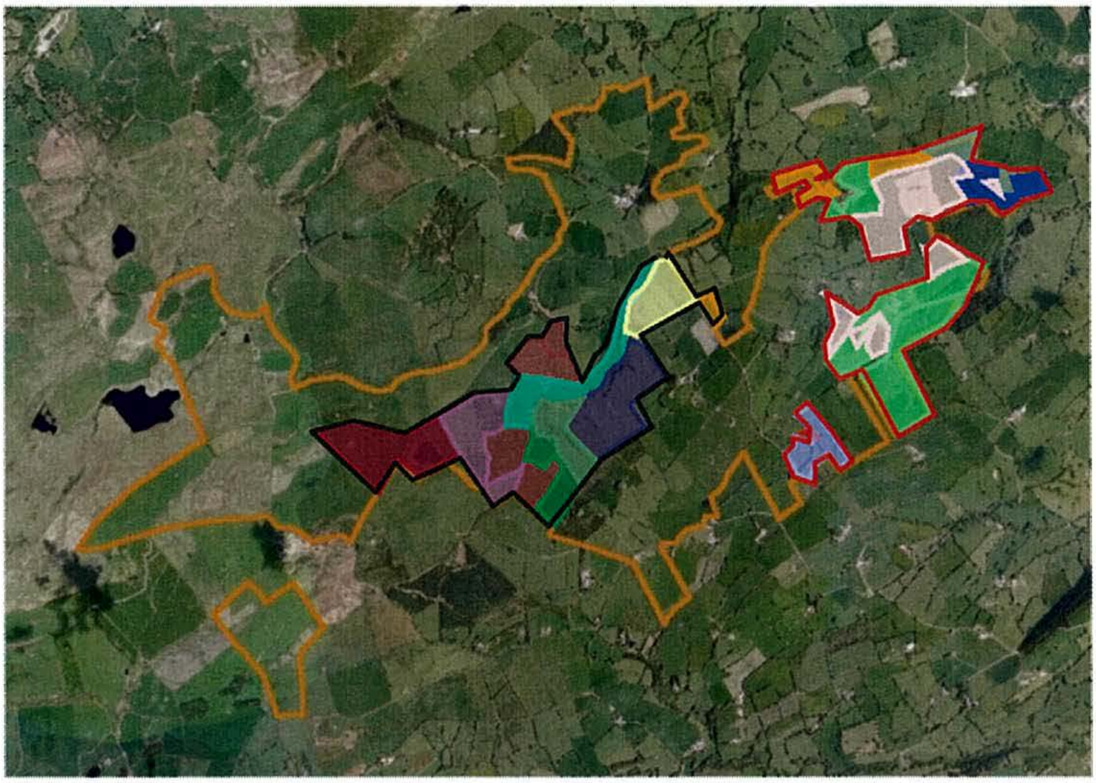

Figure 2.2. Historic farm boundaries (visible here as coloured polygons) from 1851 overlaid over two current farm boundaries – one with a black boundary and one with a red boundary) within the Pontbren farm area (orange boundary)

Similarly there were significant changes in the manner in which the land was farmed, not only in terms of to the technologies employed but also in terms of the social dynamics - with the land originally supporting a higher number of small farms when compared to the present day (Figure 2.2).

2.3.2 Establishment of a baseline for ecosystem service provision

There were no quantitative baseline data available on the provision of ecosystem services from the Pontbren catchment at the time that land use changes were initiated in 2001. The first researchers were invited into the catchment in 2003; two years after the major interventions had been implemented. In these conditions explicit measurement of a baseline position for the broad range of ecosystem services at Pontbren would require substantial assumptions given the data gaps (Everard, 2009). To address this a stakeholder meeting was held at the outset of the research to document the farmers' (and other interested professionals) assessment of the current state of the landscape and their vision for it's future. Two consecutive meetings were held; the first attended by the Pontbren farmers, the second by farmers and local level representatives from Centre for Ecology and Hydrology (CEH), Bangor

University, the Environment agency (EA), the Montgomeryshire Wildlife Trust, Coed Cymru and the Forestry Commission (FC). The initial meeting was held to allow the farmers, as landowners, to discuss and define their views on landscape function ahead of a broader discussion with other interested parties on expectations from the area. Participants at the meetings were asked to outline what they expected from the Pontbren landscape now and over a fifty year time horizon into the future. The meetings were structured around defining i) what the stakeholders thought were important landscape functions, ii) what could be used as indicators for each function and iii) threshold levels of the indicators above or below which the provision of the function was considered satisfactory. During the meetings the key drivers behind the interventions were outlined (see Figure 2.3)

The rationale behind the formation of the group was a desire to collectively change their farming systems to make them "more sustainable and less intensive". The farmers had noted that farming was labour intensive, solitary and an occupation that their children were unlikely to want to follow them into (especially when compared with other professions). Another key driver for the farmers was that housing livestock indoors over winter was becoming very expensive both in time and money so the farmers' initial interest was in increasing the proportion of hardy sheep breeds on their farms to reduce winter housing costs. A return to longer periods of outdoor grazing meant that provision of shelter for the livestock became an important priority.

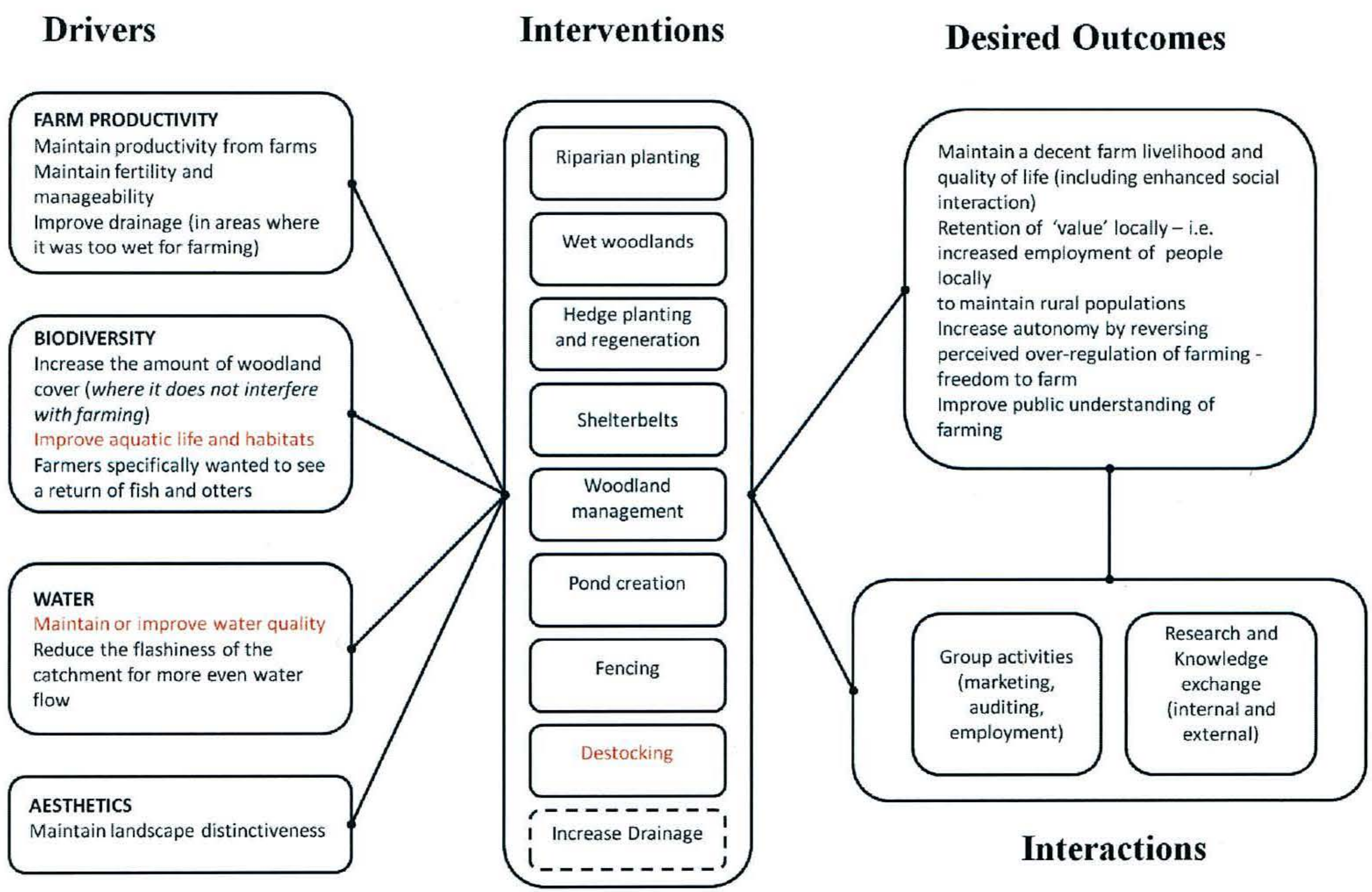

Figure 2.3: Summary of key drivers, interventions, interactions and outcomes. Components highlighted in red indicate externally driven priorities. The node with the hatched edge represents a desired outcome that was not achieved.

The farmers indentified the supply of traditional provisioning services associated with the farms as their management priority. The interventions were designed around, rather than instead of, farming objectives. The farmers were interested in the positive externalities associated with the interventions but not at a cost to farming. Converting these into planned interventions as opposed to incidental benefits would require alternate levers then those that were currently available. None of the Pontbren farmers were eligible for *Tir Gofal* (the Welsh agri-environment scheme) – nor were they overtly interested in its primary objectives (the maintenance of biodiversity) as it would require them to revert land back to habitat. Interestingly the farmers were concerned that farming was viewed negatively by members of the public (and potentially their children). The farmers were sensitive to this and wanted to present farming in a better light by highlighting the positive cultural and environmental aspects of farming.

Within this overall framework, the farmers articulated a number of specific goals (the drivers identified in Figure 2.4) that underpinned the work carried out on their farms. Many of these could be translated into changes in ecosystem functions (see Table 2.1), for example:

The farmers' wanted to enhance the provisioning capability of their farming systems. This was achieved by increasing efficiency through enhanced land husbandry practices such as provision of shelter belts. The primary function of these was in local climate regulation (but they would also impact upon global climate regulation)

Another objective was that the farmers' expressed a desire to see trout return to the catchment – This was associated with past land management practices and an interest in increasing water regulation and biodiversity along riparian corridors (and an implicit acknowledgement that both the water regulating capacity and biodiversity within the catchments had declined over the last 30 years).

In summary the key findings from that meeting were:

1. The changes had been made to provide a more sustainable approach to farming whilst maintaining or improving economic returns (by utilising

woody material, such as woodchip gained from hedgerow management, for use as bedding for housed livestock and firewood).

2. This desire to maintain a livelihood from farming underpinned all other environmental objectives. This included a desire to increase the bequest value of their farms
3. The environmental objectives of the farmers were associated with interventions to improve their farming practice. These benefits were a positive (and valued) side effect but not a principle driver for action in themselves

Table 2.1: Areas of intervention identified by the Pontbren farmers re-cast in terms of ecosystem service objectives. Services highlighted in bold represent farmer priorities.

Drivers	Ecosystem service	Service category
Farm productivity	**Food**	Provisioning services
	Fibre	
	Fuel	
	Soil regulation	Regulating services
	Climate regulation – (Local)	
Water	Water purification	
	Water regulation	
	Water provision	
Aesthetics	Aesthetics	Cultural services
	Recreation	
	Social relations	
Biodiversity	Habitat creation	Supporting services

2.3.3 Interventions

The majority of the interventions were implemented with support from a grant from Enfys[6] in 2001. The interventions were implemented by the Pontbren farmers with the aid of staff from Coed Cymru. Coed Cymru is an all Wales initiative, supported

[6] The Enfys scheme is a UK lottery award programme in Wales. It was a partnership led by the Wales Council for Voluntary Action (WCVA. To deliver Enfys, WCVA came together in a partnership with Prince's Trust Cymru (PTC), Environment Wales (EW), and the Environment Agency Wales (EAW).

by statutory bodies and governmental organisations, to provide free advice on the management, protection and enhancement of predominantly broadleaved woodlands. Staff from Coed Cymru originally offered the farmers a Pontbren scale planting scheme based on biodiversity objectives but this was rejected as the farmers wished to retain autonomy of decisions made within their farm boundaries. Instead a menu of prescriptions was developed and offered to the farmers. Funding was distributed equally amongst the farmers (despite variation in farm size).

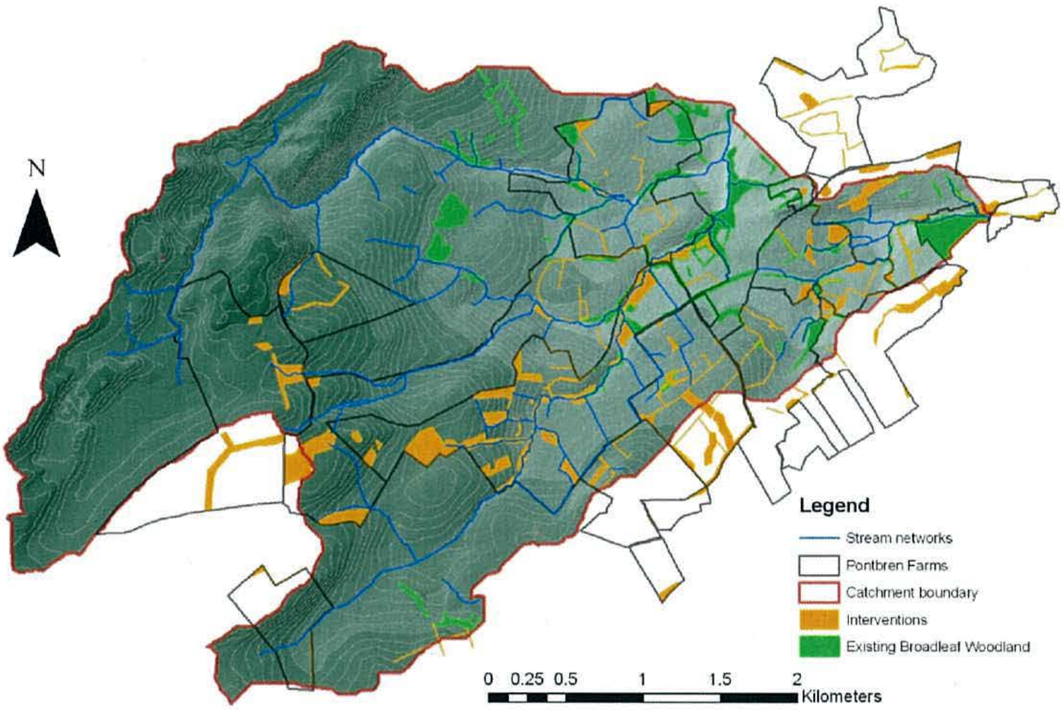

Figure 2.4: Map of the interventions (highlighted in orange) made on the Ponbren farms. Farm boundaries are black. The Pontbren sub catchment is outlined in red. Woodland cover (represented in green) was derived from the Countryside Council for Wales's Phase 1 Maps (© Countryside Council for Wales, 100018813 1979 - 1997)

Farmers made changes in areas that provided direct benefits to their livestock (through shelter provision) or in areas that were considered marginal for farm productivity as they were too steep or too wet for farm machinery. The plantings often took advantage of existing features (for example supplementary planting for shelterbelts were implemented in areas where there were existing hedgerows with standards already present). All the tree material was of local provenance and where possible was grown in a nursery managed by one of the Pontbren group. The major changes to the ecological infrastructure on the farms are shown in Figure 2.4 and described in Table 2.2 below. In total over 120 000 trees were planted across the 10 farms; largely as new hedgerows and shelterbelts

Table 2.2: Main intervention implemented on individual farms at Pontbren

	Intervention	Notes
Tree Features	*Hedge planting and regeneration*	Hedgerows were recognised as valuable components in hill farming systems, primarily for use as barriers and provision of shelter. Hedgerows that provided shelter against the prevailing winds were prioritised. Hedgerows were double fenced (to protect them from livestock). This was the most popular intervention with all ten farms involved. In total 26.5 km of hedgerows were planted or restored. Many of the hedgerows included standards for provision of timber and shade.
	Shelterbelts	Shelterbelts are broader and taller tree structures planted primarily for shelter benefits (for an example see Plate 2.1: page 47). There were mainly sited perpendicular to the main wind (from the southwest) or to provide protection from the less frequent but colder northerly winds. Given the space required they were less common.
	Streamside trees	Streamside planting was implemented on areas where degradation of the banks was occurring. These areas were fenced off and natural regeneration of trees was allowed to occur occasionally enhanced by tree planting.
	Native woodland/ Wet Woodlands	There was very little expansion of existing woodland, the main activity was fencing areas to exclude livestock and so encourage recruitment of new seedlings and ultimately a more mixed age structure of trees
	Pond creation	Four of the farmers created eleven new ponds across the catchment. The main drivers were restoring marginally productive land back to its original wetland status (with associated reductions to livestock disease (liver fluke and foot rot), increased amenity value and provision of wildlife benefits
	Stock change	As part of a trial initiative by the Welsh Assembly Government seven of the Pontbren farmers elected to reduce their flock size by approximately 20%.

A qualitative summary of changes to ecosystem processes resulting interventions in the Pontbren landscape as of 2009 is provided in Table 2.3 below. The assessment is based on discussions with stakeholders working and researching on site. The changes identified are based solely on the interventions identified above (and exclude any other management practices that the farmers may have engaged in). The table sets out likely enhancements to service provision associated with these changes and indicates where measurements of impact are available.

Table 2.3: Matrix showing qualitative assessment of impacts of land use interventions on beneficial ecosystem processes

	Farmer interventions							
	Hedgerow Creation	Stock exclusion	Shelterbelts Creation	Riparian planting	Native Woodland	Stocking Reductions	Wet woodlands	Pond creation
Numbers of participating farms	10	10	9	9	9	7	5	4
Ecosystem processes								
Primary biomass production - Grass	-	+	-	-	0	+	-	-
Primary biomass production - Fibre	+	+	+	+	0	0	0	0
Secondary biomass production	+	0	+	+	0	0	0	0
Pollination	+	+	+	+	+	0	+	+
Formation of species habitat	+	+	+	+	+	0	+	++
Erosion regulation *	+*	++	+*	++	0	+	+	0
Formation of physical barriers	+	+	+	+	0	NA	+	0
Formation of pleasant scenery	++	0	+	+	+	0	+	++
Local climate regulation	+	0	++	+	0	0	+	0
Global climate regulation	+	0	+	+	0	++	+	+
Water regulation	+*	0	+*	0	0	+	+	+
Water purification	+*	+	0*	+	0	+	+	0
Water provision	0	0	0	0	0	0	?	+

Key: ++ = potential significant positive effect; + = potential positive effect; 0 = negligible effect; - = potential negative effect; -- = potential significant negative effect; ? = gaps in evidence; NA = not applicable. * Signifies for feature to have a positive effect must be oriented perpendicular to the direction of flow. The ecosystem processes highlighted in gray were measured as part of the research conducted at the catchments

The table shows that the impact of the interventions on key ecosystem processes within the catchments. For example hedgerow provided positive impacts on 12 ecosystem processes (although three of these services were dependent upon orientation and thus not all hedgerows provided all services). The results demonstrate clear inter-linkages between ecosystem processes and illustrate how changes aimed on one ecosystem service will likely impact others.

2.3.3.1 Tree planting

Research at Pontbren suggests that the degree to which ecosystem processes are influenced linear woody features such as hedgerows and shelterbelts varied significantly depending upon location in the catchment (and orientation when considering water or erosion control). Approximately 50% of the hedgerows planted at Pontbren are with the contour and so would be expected to contribute to water flow regulation and purification and erosion regulation but the extent to which they do so will also vary with their position on the slope (in general, hedgerows lower down a slope were more valuable for these services than those further up because they intercept a larger cumulated flow of water (Wheater *et al.*, 2008). In a similar manner, shelter belts, which were generally larger structures than hedgerows (but were less common within the landscape) provided similar ecosystem services but were more likely to be parallel to the slope – delivering fewer hydrological benefits but as they were taller and broader they provided greater microclimatic regulation and habitat provision.

2.3.3.2 Pond formation

A number of ponds were created at Pontbren. These were all located in naturally wet areas which were low value for farming. All the ponds provided varying levels of enhanced water storage which was valuable for provisioning of water to livestock throughout the summer months. The new ponds allowed some of the farms to fence streamside areas, reducing livestock access to streams which, in turn, reduced both bank erosion and the amount of faecal coliforms entering water courses. Beyond the catchment, the regulation of the *Nant-Pontbren* provided flood regulation through regulation of peak flows. Anecdotal evidence suggests that the ponds were also important wetland habitat areas, with farmers reporting increased sightings of birds including wetland specialists such as Lapwing (*Vanellus vanellus)*, Snipe (*Gallinago gallinago*), Kingfisher (*Alcedo atthis*) and Curlew (*Numenius arquata*) following pond creation.

2.3.3.3 Woodland management

The major intervention associated with existing woodlands at Pontbren was fencing off to reduce livestock access. This is likely to increase the shrub layer within the woodlands leading to an increase in plant and invertebrate biodiversity and associated pollination services. It will also alter the regeneration pattern of tree species present in the wood. Where livestock (particularly sheep) still have access to woods for shelter, high stocking levels have led to low levels of natural regeneration and a consequent decrease in structural diversity (Mayle, 1999). However, complete removal of stock may lead, in time, to more vigorous plant species shading out less competitive species, including mosses, lichens and liverworts on tree trunks Periodic grazing is used as a management tool in semi natural woodlands in some parts of Wales to control vigorous bryophyte growth in the understory (Gritten, 1999).

2.3.3.4 Riparian management

In many areas of the Nant-Pontbren there was evidence of old streamside erosion. In response to this farmers fenced off a number of stream banks and allowed natural regeneration of streamside trees. This provided habitat creation, erosion control and water quality benefits associated with reduction in livestock access to the water course which may lead to lower faecal coliform loading (Kay *et al*, 2008). Stream sides were planted in areas where bank erosion was a visible problem so this was not uniform across the catchment. There was no streamside planting on areas of unimproved grassland (i.e. the *Melun-y-grug* catchment to the north of the Pontbren group – where there was a requirement for livestock to have access to the stream for drinking water. The amount of riparian trees and fencing varied considerably along the water courses and from farm to farm.

The areal extent and spatial configuration of landscape features (such as the trees, ponds or wetlands) was a central factor in their ability to deliver services. The orientation and position of features such as hedgerows and shelterbelts was a significant factor in determining their ability to provide services. For example for ecosystem processes where the movement of water was a key factor (such as soil regulation and water regulation) the ability of features to provide a service was dependent upon the degree to which the features intercepted the water flows. The inference here was that hedgerow features, shelterbelts and other features were potentially keystone features (in that they will impact positively on multiple ecosystem processes) however their capability to deliver services was not equal across the catchment and was highly spatially dependent. Other factors such as age, composition and associated management were also likely to strongly impact the delivery of services.

The main objectives of the farmers were to improve the sustainability of their farming systems. The only potential threat from the interventions was losses of areas of primary grass production to new trees. In most instances trees were planted on land that was low value to the farmers so this was limited. The only interventions sited on higher quality land were new hedgerows where the farmers felt the loss of productivity was offset by the provision of shelter.

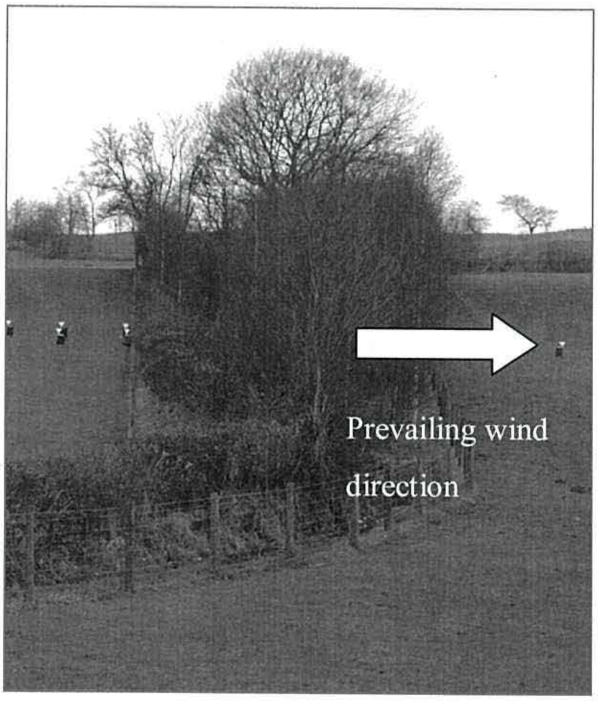

Plate 2.1: An example of a shelterbelt at Pontbren planted in 2001 and photographed in 2007. The tree row is predominantly perpendicular to the contour (with limited ability to intercept water). Note the use of native tree species (including Blackthorn - *Prunus spinosa*, Silver Birch - *Betula pendula* and Oak - *Quercus petraea*) and the fencing to prevent livestock access to the trees (increasing pollination)

2.3.4 Changes to Biodiversity

The farmers were happy to take land out of production in the more marginal areas and allow that land to be managed for wildlife. This provided a broad range of benefits in these marginal areas. The design of the interventions reflected the farmers' values associated with nature (based largely on the (less intensive) landscape they remembered from their childhoods) rather than an externally driven biodiversity agenda. The farmers were explicitly interested in increasing the presence of high profile, charismatic species (i.e species with widespread popular appeal) such as otter (*Lutra lutra)* and trout *(Salmo trutta)*, rather than, for example, invertebrate populations – although the farmers took a keen interest in research related to this. In contrast the farmers were also keen to see reductions in species that were associated with reducing farm productivity such as badger (*Meles meles)* and ravens *(Corvus corax)*.

The farmers were not interested in habitat provision where it had a negative impact on farm productivity as there was no mechanism for compensation for that loss. In many cases there were clear synergies between removing land from agriculture and their farming objectives. For example reducing stock access to wetland areas decreased the likelihood of incidences of fluke and foot rot. As the farming potential of these areas was also low the exclusion of livestock was pragmatic.

2.3.5 Cultural services

In addition to ecosystem function the impact of the farmer interventions on cultural services in the Pontbren catchment was also explored with the farmers.

Table 2.4: Matrix showing qualitative assessment of impacts of land use interventions on cultural services

		Numbers of participating farms	Effect of changes
Beneficial Cultural services	Tourism	0	0
	Recreation	4	+
	Spiritual and cultural well being	?	?
	Aesthetic benefits	10	+
	Nature watching	5+	+
	Research	5	++
	Education	10	++
	Social relations	10	++
	Sense of place	10	+

One of the desired outcomes from their interventions was the desire to maintain rural populations. The increased mechanisation of farming had changed the size of farms and reduced the requirements for labour. This had converted farming into a relatively lonely occupation for farmers, especially where there was limited family support. The Pontbren farmers had relatively close ties prior to group formation. Interviews revealed strong kinship bonds between many of the farmers (see Figure 2.5) and all the members of the group met socially through memberships of local chapels. Prior to group formation some of the farmers assisted each other informally. These bonds were largely present outside farming activity which remained a largely solitary enterprise. There was no sharing of intelligence about the prices for materials, for example, or a point of contact at times of stress. After formation the group held regular social gatherings and provided a support network for each other. This proved particularly important from the outset as the 2001 foot and mouth epidemic (Defra, 2002) effectively shut down the farms soon after the group formed. The farmers valued being able to discuss problems with each other during this time and acknowledged that this was a key component in increasing social capital amongst group members and potentially a significant factor for the sustainability of the group.

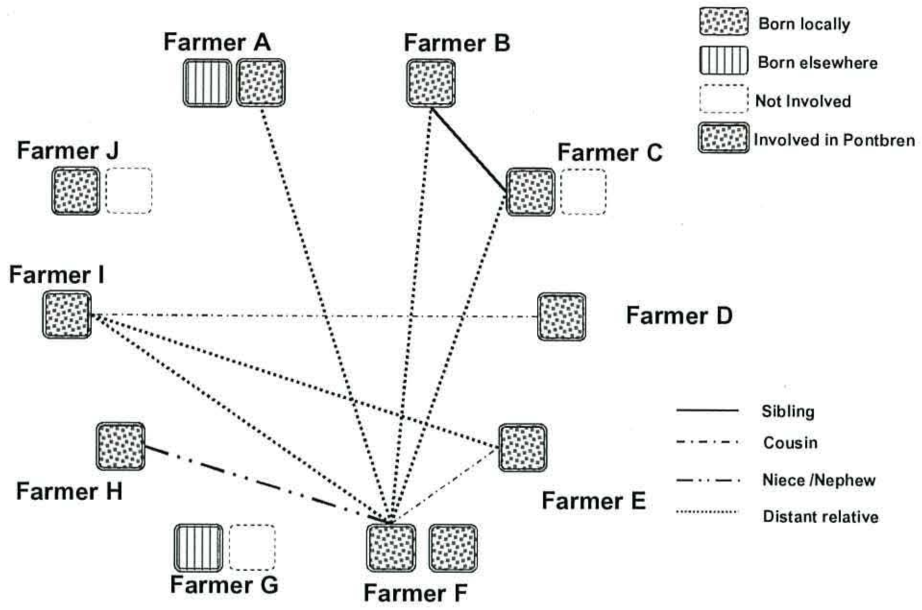

Figure 2.5 A simplified kinship diagram for the Pontbren farmers

After group formation individuals were collectively responsible for administering the Enfys fund. This included taking management of group finances, agreeing standards of work and conducting inspection procedures on each others' farms. All funding was shared equally between participating group members (despite considerable differences in farm size). This process increased the social capital between group members substantially. As the group developed they began to share significantly more information about management practices and even financial decisions with each other. The group also purchased materials for their farms collectively (e.g. fencing) and including altruistic behaviour where, for example, a chipper was brought collectively by nine members of the group (but was only used regularly by three members). The group attempted to market their produce collectively under a Pontbren logo, in the local markets. This involved conducting butchering operations on farm and sharing marketing duties collectively – although this proved unsustainable as the farmers found the transaction costs were high and not all group members could participate meaning that the duties were inequitably distributed.

The farmers felt that working together had substantially reinforced their relationships and led to greater exchanges of ideas and knowledge and improved their individual well being; essentially increasing their social capital. The development of these close social relations between group members was valued highly by the entire group and this was cited as the most important output from the experience to have significantly improved their livelihoods.

2.3.5.1 External links

In discussions with the farmers four external groups were recognised: the farming community, the general public, politicians and the scientific community. The farmers were most comfortable amongst other farmers, particularly once the interventions had been established and they recognised the value of Pontbren as a demonstration farm for other groups of farmers interested in emulating them, The farmers were most happy to host visits to the farms from these groups.

A primary objective for the Pontbren farmers was to retain and increase the degree of autonomy on their farms. They were aware that the politics of farming had changed bringing with it an increase in bureaucracy. This was seen as unwelcome by the farmers. Their rationale for setting up the group was, in part, to decrease the level of involvement of politics in farming. Ironically the nature of the changes (and the involvement of Coed Cymru and the scientists) meant that the Pontbren group developed a high political profile in Wales, which was not always perceived as beneficial by the farmers (due to increased transaction costs)

The scientific community were of relatively low interest to the farmers before the interventions. Once they realised that some of the changes they initiated were having unexpected effects the farmers invited the scientists on to the farms. They were hoping that scientific involvement would strengthen their case for this new direction for farming. The relationship was fairly distant initially as both groups lacked the means/terminology to communicate effectively with each other but this developed as the projects evolved. Interaction was largely limited to 3-5 core members of the group (who had monitored interventions on their land) although update meetings were held where all the members of the group were invited to hear progress.

The final group was the general public which were both a potential hazard but also a potential ally. The farmers felt that farming did not have the general approval from the public that it once did and they were keen to address this – but were also aware that there were potential negative consequences with dealing directly with the public. The farmers were keenly aware of the dangers to bio security posed by increased access to the country side. They were also aware that non farmers had potentially more power over rural decision making then they would perhaps like – illustrated through the passing of emotive legislation such as the ban on fox hunting and resistance to badger culls.

2.3.6 Ecosystem service reception

The qualitative assessment of changes to ecosystem processes and cultural services were combined and provide a qualitative summary of the potential impacts of the farmers' interventions of ecosystem services both within and outside the Pontbren catchments using the MA typology (Table 2.5 below). The principal aim here was to identify potential beneficiaries across scales.

Many changes to the delivery of public goods were incidental rather than planned. For example, water regulation was not a primary concern for the farmers, despite being the focus of research at the site (and a wider Welsh policy objective, Welsh Assembly Government, 2008). All impacts upon water regulation were coincidental (and of relatively low value to the farmers as this was not a flood generating area – although water regulation contributes to other benefits such as reductions of soil erosion). Given the small size of the catchments the distance attribute is likely to be significant and negative i.e. the 'distance decay effect' (see Morse-Jones *et al.*, 2011) which suggests that, when taken in isolation the impacts of these changes were likely to be limited. There was no monitoring of change outside the catchment. This makes it impossible to properly convert the changes to ecosystem function into regulating services at broader scales (as recipients would need to be identified) apart from global climate regulation where the recipients were universal.

Outside of the catchment the strongest available evidence was for increased cultural services, particularly education and research where the farmers' changes were clearly influential (Carroll *et al.*, 2004; Jackson *et al.*, 2008; Marshall *et al.*, 2009; Wheater *et al.*, 2008; Henshaw, 2009; Wheater and Evans, 2009 and McIntyre and Marshall, 2010). In addition the farms acted as an informal demonstration site for other farmers resulting in significant numbers of farm visits. The visitors included members of the farming, research and policy community.

Despite observed changes to the aesthetic qualities of the farms the extent to which these changes could be enjoyed by external stakeholders was limited. Concerns about bio-security meant that farmers were unhappy about allowing open access onto their land and the recreational benefits were largely generated for their own enjoyment (e.g. the ponds).

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Table 2.5: Changes to ecosystem service provision arising from Farmer interventions

Biophysical structure	**Function** (based on Balmford *et al.*, 2011)	**Ecosystem service** (MA, 2005)	**Condition**	**Benefit to Humans**	**Who benefits?**
All tree features	Primary biomass production	Provision of Fuel and Fibre	Increased provision with management for these purposes which may conflict with other service provision	Provision of fuel wood, timber and secondary products	Pontbren farmer
	Global climate regulation	Climate Regulation	Amount of carbon stored will vary across catchment	Reduction in CO_2	All
	Formation of species habitat	Biodiversity associated with tree cover	Planted tree areas may have conflicting biodiversity value with other habitat e.g. important grassland habitat	Greater ecological resilience associated with diverse habitats	Pontbren farmer, Local/Regional
	Pollination	Pollination	Production habitat provision for species of conservation importance Composition and location of tree cover important	Vital supporting service for many ecosystems	Local, Regional
	Formation of physical boundaries/pleasant scenary	Aesthetic Value	Possibly restrictive labour requirements for maintenance	Pleasing landscape, Inspiration, sense of place	Pontbren farmer, Local and Visitors
	NA	Supporting	Increased supporting services include production of oxygen, nutrient cycling , translocation of water and nutrients from depth, primary	Increased resilience	All
Hedgerows	Local climate regulation	Climate regulation	Requires hedgerows oriented perpendicular to the wind and managed to maintain shelter properties	Live weight gains for livestock lead to increased agricultural income	Pontbren farmer

Biophysical structure	Function (based on Balmford *et al.*, 2011)	Ecosystem service (MA, 2005)	Condition	Benefit to Humans	Who benefits?
	Water regulation	Water regulation	Requires hedgerows oriented perpendicular to the slope –unmanaged hedgerows with developed root systems may provide better infiltration	Provision of cleaner water	Pontbren farmer, Downstream
		Natural hazard regulation -flooding	This is a non-linear process and scaling up may mean the effect is diluted	Lower flood risk	Downstream
	Increased sediment trapping(erosion regulation)	Erosion and sediment delivery regulation	Hedgerows oriented perpendicular to the slope will intercept more sediment.	Higher productivity, provision of cleaner water, improved instream habitat conditions, and reduced flood risk	Pontbren farmer, Downstream
	Reduced erosion and sediment transfer in stream channels (erosion regulation)	Erosion and sediment delivery regulation	Controlled by magnitude of reduction in peak stream flow which is, in turn, heavily dependent on the spatial organisation of tree features within the landscape (see above)	Higher productivity, provision of cleaner water, improved instream habitat conditions, and reduced flood risk	Pontbren farmer, Downstream
	Increased habitat connectivity	Biodiversity associated with tree cover	Hedgerows positioned adjacent to woodland areas, composition and maturity	Vital supporting service for general ecosystem function	Pontbren farmer, Local, Regional
Shelterbelt	Local climate regulation	Microclimate regulation	Shelterbelts oriented perpendicular to the wind. Management requirement to maintain efficiency of shelter provision	Live weight gains for livestock lead to increased agricultural income	Pontbren farmer
	Increased sediment trapping (erosion regulation)	Erosion and sediment delivery regulation	Shelterbelts oriented perpendicular to the slope will intercept more sediment.	Higher productivity, provision of cleaner water, improved instream habitat conditions, and reduced flood risk	Pontbren farmer, Downstream

Biophysical structure	Function (based on Balmford *et al.*, 2011)	Ecosystem service (MA, 2005)	Condition	Benefit to Humans	Who benefits?
	Reduced erosion and sediment transfer in stream channels (erosion regulation)	Erosion and sediment delivery regulation	Controlled by magnitude of reduction in peak stream flow which is, in turn, heavily dependent on the spatial organisation of tree features within the landscape (see above)	Higher productivity, provision of cleaner water, improved instream habitat conditions, and reduced flood risk	Pontbren farmer, Downstream
	Increased infiltration of surface water (water purification)	Water regulation	Orientation of shelterbelts predominantly parallel to slope so interception of water is lower. Root systems likely to be more developed. Also greater utilisation of water.	Provision of cleaner water	Pontbren farmer, Downstream
	(water regulation)	Natural hazard regulation -flooding	This is a non-linear process and scaling up may mean the effect is diluted	Reduced flood risk	Downstream
Riparian tree planting/regeneration	Increased bank stabilisation	Erosion control	Unmanaged riparian trees can increase flood risk	Higher productivity and cleaner water. Reduced Flood risk	Pontbren farmer, Downstream
	Sediment/nutrient buffer for watercourses (water purification)	Water purification	Riparian planting provides filter strip – thickness and composition of species will impact on effectiveness	Provision of cleaner water	Pontbren farmer, Downstream
	Shade and organic matter input for streams	Biodiversity associated with rivers	If managed for these purposes.	Increase in fish stocks	Pontbren farmer, Local, Regional
Wet Woodland	Increased storage of surface water (water regulation))	Natural hazard regulation -flooding	Located in sink areas	Reduced flood risk	Pontbren farmer, downstream
	Sediment/nutrient buffer for watercourses	Water purification	Wet woodland provides filter strip – thickness and composition of species will impact on effectiveness	Provision of cleaner water	Pontbren farmer, Downstream

Biophysical structure	Function (based on Balmford *et al.*, 2011)	Ecosystem service (MA, 2005)	Condition	Benefit to Humans	Who benefits?
	Livestock denied access to wet woodland areas	Disease /pest regulation	Fencing required	Healthier livestock decrease economic losses	Pontbren farmer
Fencing wetland	Livestock denied access to wetland areas	Disease / pest regulation	Loss of land utilisable for agricultural production	Healthier livestock decrease economic loss	Pontbren farmer
	Stabilise wetland habitat	Water regulation	NA	Reduction in flood risk	Pontbren farmer, Local/Regional
	Creation of aquatic habitat	Biodiversity associated with water bodies	Loss of land utilisable for agricultural production	Greater ecological resilience associated with diverse habitats	Pontbren farmer, Local/Regional
Pond	Improved Farm Aesthetics	Aesthetic Value	Access generally restricted	Aesthetic Value, Inspiration	Pontbren farmer, Visitors
	Creation of aquatic habitat	Biodiversity associated with water bodies	Loss of land utilisable for agricultural production	Greater ecological resilience associated with diverse habitats	Pontbren farmer, Local/Regional
	Increased storage of surface water	Natural hazard regulation -flooding	This is a non-linear process and scaling up may mean the effect is diluted. Storage capability depends on location and size of pond structure – maintenance required to remove sediment	Increased temporary storage of water	Downstream stakeholders
	Livestock denied access to water course	Water regulation	Requires all water courses to be fenced to be effective. Often restricted by lack of mains water supply to many fields. In addition may provide bio-security benefits	Faecal indicator organisms (FIOs) do not enter water course – Clean water. Biosecurity	Pontbren farmer, Local, Downstream stakeholders

Biophysical structure	Function (based on Balmford *et al.*, 2011)	Ecosystem service (MA, 2005)	Condition	Benefit to Humans	Who benefits?
Fencing water courses	Increase in tree material on river banks (Erosion regulation)	Erosion control	Livestock require fresh water. Fields without mains water require more labour or changes to field infrastructure	Water carries less sediment	Pontbren farmer, Downstream stakeholders
		Biodiversity associated with tree cover		Greater ecological resilience associated with diverse habitats Biosecurity	Pontbren farmer, National/Global
Fencing Woodlands	Modification of tree habitat (through modification of age structure	Biodiversity associated with tree cover	Planted tree areas may have conflicting biodiversity value with other habitat e.g. important grassland habitat	Greater ecological resilience associated with diverse habitats	Pontbren farmer, Local/Regional
Social Processes					
Pontbren Group	Increase in social capital	Social Relations	Trust between group members	Increase in farmer livelihoods through co-operation and shared labour	Pontbren farmers
	Education/ research	Knowledge Systems/ Educational values	Regular interactions between group members and other stakeholders	Knowledge shared with wide range of interested parties	Pontbren, Local, Regional
	Formation of pleasant scenery	Sense of place	Implicit rather than explicit	Attractive location for visitors and local population Increase in local livelihoods	Pontbren farmers, Local, Visitors
	Provision of employment		Short term labour requirements	Increase in local livelihoods	Pontbren Farmers, Local

2.3.7 Measured Ecosystem services

2.3.7.1 Water regulation

Much of the hydrological research at Pontbren has focused on understanding and modelling effects of changing tree cover on water flow and erosion potential associated with alleviating flood risk. The main finding from initial research conducted at the site (using double ring infiltrometers and basic soil assessments), was that the rate of water infiltration was up to 60 times higher in areas where stock had been excluded and trees planted, than in adjacent grazed pasture (Bird *et al.*, 2003; Carroll *et al.*, 2004). The measurements from the more extensive FRMRC research programme (Wheater *et al.*, 2008; McIntyre and Marshall, 2010) demonstrated that tree planting increased interception losses, available water storage within the soil and the infiltration rate into the subsurface layer. A physics-based model of water flow at field scale was developed and calibrated with on site data. A novel catchment scale model was then developed from the field scale model, validated in relation to stream flow measurements and then used to explore a variety of spatially explicit tree cover scenarios (Jackson *et al.*, 2008a). Modelling results indicated that planting tree material over a relatively small area of the catchment by the Pontbren consortium had resulted in a significant reduction of flood peaks at a sub-catchment scale; a potential reduction in peak flows of between 6 to 18 % from the baseline condition. Figure 2.6 shows the effect of four tree planting scenarios on stream flow modeled for the Pontbren catchment. The first scenario (in red) indicates the baseline situation prior to any of the farmers' intervention (2001) and the second scenario (in black) is the modeled output showing the effect of the interventions. This suggests a significant reduction on peak flow within the catchment as a result of the 2001 tree planting (particularly given that the planting was not explicitly designed for this purpose).

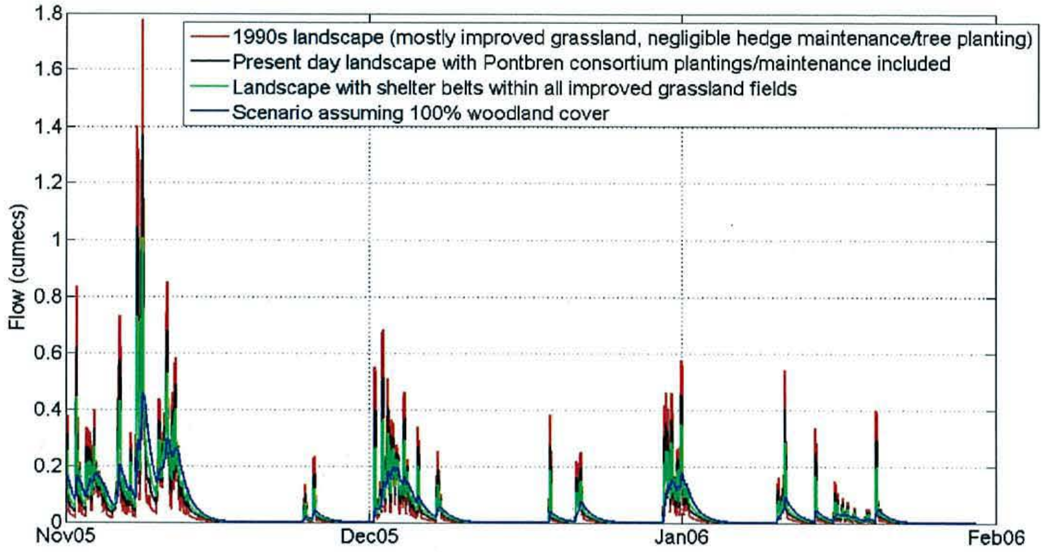


Figure 2.6: Models of four scenarios of tree planting on river flow at Pontbren (Wheater *et al.*, 2008)

Another key finding was the extent to which drainage played a role in catchment runoff processes. Much of the improved grassland at Pontbren has been artificially drained and the drains respond rapidly to rainfall under wet conditions. Drain flow tended to dominate runoff, with overland flow being dependant on antecedent moisture conditions at the soil surface. In large winter rainfall events, overland flow sometimes contributes more than 50% in terms of the total runoff rates at the hill slope scale and is hence an important contributor in peak events. However the annual contribution of overland flow is low, of the order of 10% of annual drain flow. The proportions are highly variable in time- in general grazed grassland infiltration rates and drain flow transmission increased in summer and decreased in winter, with associated reductions/increases in overland flow (see Marshall *et al.*, 2009). This component of the catchment hydrology remains unchanged as a result of the farmer interventions.

Small scale manipulation plot experiments (Wheater *et al.*, 2008) at Pontbren showed that the exclusion of sheep resulted in decreased surface runoff in the immediate area of the changes (by over 40%), which was increased where tree material was introduced (over 70% interception of surface runoff – even under relatively juvenile trees).

2.3.7.2 Soil regulation

The main focus of the geomorphological research at Pontbren was on impacts of land use change on sediment delivery. Tree planting at Pontbren may help to reduce the delivery of fine sediment from fields to surface watercourses by intercepting the overland flow which transports it. The effectiveness of 'buffer" or 'filtration strips' has been investigated extensively over the past 30 years (see Owens *et al.*, 2007 for an overview) but did not receive explicit attention at Pontbren. While their role in preventing fine sediment transfer in other agricultural landscapes (e.g. arable) can be highly significant, the presence or absence of tree planting in grazed pastures was unlikely to have a major impact on stream sediment loads at Pontbren as experimental results and field observations indicate that only small amounts of fluvial fine sediment appear to be sourced through soil erosion in grazed pastures and subsequent transport across the land surface via overland flow (Henshaw, 2009). Despite high levels of surface runoff, good vegetation cover was maintained within pastures due to proactive and reactive management by farmers, thus reducing the extent and intensity of surface soil erosion.

The main benefit of tree planting at Pontbren appears to be through its impact on flood peaks within the natural stream channel network. The peak flow reductions reduced the amount of energy available during floods to erode the bed and banks of streams (which, along with subsurface field drains, were the major sediment sources in the area), and transported the material downstream (where it increased flood risk by aggrading channels).

2.3.7.3 Impacts of farmer interventions on water quality

The Centre for Ecology and Hydrology investigated baseline river nutrient chemistry in the *Nant Pontbren* and *Melin y Grug* to explore the relationship to catchment land use and the role of soil-water pathways in transporting agricultural nutrients to watercourses (Reynolds *et al.*, 2009). Key points in the catchment provided conduits for nutrient enriched runoff into the water course. The research identified point sources where this may be occurring which included areas where livestock accessed the water for drinking (and farm yards where slurry was stored). Mass balance calculations indicated that a proportion of the dissolved nutrients in runoff were retained within the catchment and did not reach the streams. There is incomplete evidence that areas such as wetlands, heavily vegetated ditches and woodlands may be acting as nutrient sinks within the catchment. These areas have been expanded as a result of the farmers' interventions.

In contrast to dissolved nutrients, the annual riverine flux of particulate phosphorus was approximately five times the annual catchment flux which implied that there was a large unaccounted for source of particulate-P within the stream channel (Reynolds *et al.*, 2009). This result was consistent with independent observations that a large proportion of the fine sediments supplied to the *Nant Pontbren* originate from channel bank sources. Farmer interventions which assist in stabilising the banks (fencing and riparian planting) will address this to some extent although livestock poaching around watering areas was likely to be some of the area's most heavily affected.

These findings suggest that in areas of improved grassland at Pontbren subsurface artificial land drains were the primary hydrological pathway for transferring dissolved nutrients from the catchment to the stream. The interventions made by the farmers across the catchment will generally not affect this pathway unless the water emitting from drain outlets was intercepted. The creation of wetland and wooded areas at key points in the catchment may be providing sinks for some nutrients but where drain flow dominates these were unlikely to have a major impact. At certain times of the year, nutrient flushes associated with rainfall after extended dry periods may be intercepted by trees when overland flow dominates. The report reinforces the idea that decisions about changes need to be made at a landscape scale to have effect – where there are patches of unfenced river within a catchment then the likelihood is that there will still be periodic influxes of nutrients and possibly faecal coliforms, although the latter were not measured at Pontbren.

2.3.7.4 Creation of habitat associated with interventions

There have been a number of small scale biodiversity studies at Pontbren. These include baseline plant studies conducted by the Montgomeryshire Wildlife Trust, studies on carabid populations (McHugh, 2000) and small mammal abundance and diversity (Moro and Gadal, 2007). Moro and Gadal's research highlighted the value for habitats of working as a group of farmers (as opposed to individual farm level activity) and that increased habitat heterogeneity was important for small mammal populations.

An undergraduate dissertation by Jeremiah (2009) also indicated that land use changes in the Pontbren area may be beneficial for in-stream ecosystems and riparian habitats. Comparisons of reaches on three streams of contrasting land use and land management histories suggest that while habitat indicator scores and invertebrate species abundance and diversity were lower at sites where riparian fencing and planting had been undertaken compared to 'natural' moorland sites, they were higher than those where grassland improvement had been undertaken and grazing was unrestricted.

Changes in habitat connectivity resulting from farmer interventions were investigated using Forest Research's Habitat connectivity calculations (described in Watts *et al.*, 2008). This resulted in maps showing changes to the functional connectivity of woodland within the Pontbren landscape (presented in Eycott *et al.*, 2007). The baseline habitat network maps were developed using CCW's Phase 1 land use datasets. These were modified by inserting the new plantings (see Figure 2.7). The maps indicated improvements associated with woodland biodiversity from the tree planting that had occurred since 2001. The farmers were unhappy with the output presented. Their concerns were that areas that had been heavily planted, particularly towards the western edge of the catchments had not resulted in the creation of more focal woodland areas. The farmers were unhappy with definitions used for focal woodlands areas (areas > 10 ha) as it did not agree with their observations of improvements to wildlife in those areas that had been modified.

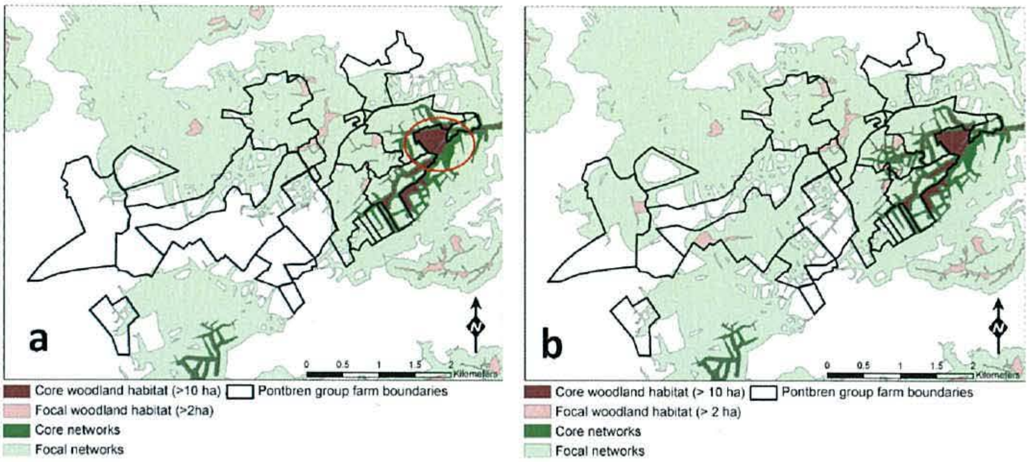


Figure 2.7: Changes to woodland habitat networks before (a) and after (b) changes to tree cover made by the farmers. Coed Cwm-y-llwynog is circled in red.

The farmers were able to identify a number of limitations with the Phase 1 data used to develop the habitat networks. The only core woodland habitat available for the Pontbren farmers to expand their woodland from lay to the south east of the catchment and consisted of the Forestry Commission owned *Coed Cwm-y-llwynog* and *Coed Newydd.* The farmers suggested that the biodiversity quality of these woodlands were low, particularly Coed Cwm-y-llwynog, as it consisted mainly of Red Oak (*Quercus rubra*) which was not native. The farmers were also concerned that hedgerows were treated uniformly across the landscape (i.e. all hedges were given the same permeability score) which did not reflect their observations on the ground. The farmers quickly identified hedgerows on the farms that were much better than others in terms of supporting woodland wildlife and provided an explanation as to why that was so. The farmers indicated that they had high levels of local knowledge that would have significantly improved the maps. The farmers were concerned that the low resolution of the Phase 1 data (then being used in the Better Woodland for Wales grant schemes) and the lack of information on factors such as age of the hedgerow/woodland and its composition (which the farmers were aware of) could result in incentives being offered to improve connectivity to what were, in reality, poor woodlands in terms of actual biodiversity.

The farmers were unsure of the value of 'woodland biodiversity' compared to other biodiversity benefits they had already observed on their land. The habitat connectivity models use generic focal species (Watts *et al.*, 2008). The lack of suitable real life examples of core woodland creatures relevant to the Pontbren catchment meant that the farmers found it difficult to understand the output, especially in contrast to observed changes to biodiversity in the catchments. This included the return of species such as the otters and owls which they felt were more tangible to them then unspecified 'woodland species'. The farmers were also aware biodiversity improvements to their land which had occurred without external influence and questioned the validity and credibility of the modelled output for their farms.

There was a reluctance to accept the need for biodiversity planning at a landscape scales as opposed to the farm scale. The farmers explained that all current changes to the farms had been made by the farmers themselves, including decisions about where trees were planted. This had produced tangible benefits from the farmers' perspective. Decisions made at a landscape scale would need to be externally driven (by organisations such as Countryside Council for Wales (CCW). There was a general suspicion about any form of external agent would force them to make tradeoffs between agricultural productivity and other policy objectives. The farmers had all experienced the effects of fluctuating farm policy and were concerned that the changes may be short term – but have long term consequences for them. They also felt that the data used to drive this external decision making was not robust enough for equitable decision making. This was especially true as biodiversity conservation was not a farmer priority and had no real associated financial benefits for farmers at present (the farmers were not eligible for Welsh agri-environment schemes).

Informal observations by farmers indicated changes in the wildlife present on their farms including increased sightings of European otter (*Lutra lutra*) as well as Hen Harrier (*Circus cyaneus*), Skylark (*Alauda arvensis*) and Linnet (*Carduelis cannabina*) – all birds on the UK Red List of species. The extent to which these sighting could be linked to habitat changes at Pontbren were not measured formally.

2.3.8 Opportunities for future interventions

The funding for the interventions was split equally between the farmers. In all but one case the farmers spent the total amount allocated to their farm. Half the farmers indicated that there was potential for further interventions on their farms (and that they would be prepared to consider working on more coordinated projects if the right incentives were in place) whereas the others were satisfied with the interventions and were reluctant to make further changes. The farmers were uncertain about the rationale for making changes in their catchments in relation to key ecosystem services and were keen to know the 'effect' of further changes outside of the catchment.

The farmers wanted guidance on the best locations to make further changes. The current interventions were mainly located in areas that the farmers identified as marginal to their farms. Further interventions would require taking more productive farmland out of farming which was likely to require significant incentives to offset the loss of livelihood associated with the change (and evidence that it worked for the farmers to agree to the change)

2.4 DISCUSSION

The implications of the research at Pontbren are discussed in relation to land use planning to manage the flow of ecosystem services at operational scales:

2.4.1 Rationales for spatially explicit approaches

Ecosystem services are spatially explicit (Boyd and Banzhaf, 2007; Fisher *et al.*, 2009). The success of operational approaches is likely to depend upon the extent to which ecosystem services production and value can be mapped. The findings at Pontbren suggest that at local scales the ability of features to provide regulating services was dependent upon their position (and orientation) within the catchment. Given this spatial sensitivity land use planning should be implemented at scales that enable these issues to be addressed. Current land use datasets available in the UK do not offer a fine enough resolution to capture many key features such as hedgerows (Figure 2.7) which this study has identified as being keystone features in the Pontbren landscape associated with multiple benefits (see Table 2.5).

The inability to map key features has implications for scientific research and for policy implementation. Morse–Jones *et al.*, (2009) identified the measuring, mapping and modelling of ecosystem service production as a key step required for valuation ecosystem services provision. The current limitations mean that within a semi-natural landscape, such as Pontbren, many key features (including the entire hedgerow matrix and the management associated with it) are essentially invisible beyond the catchment boundaries. Modelling ecosystem service based on existing land use data could potentially distort baseline service provision for the catchments.

Negotiations about land use change will be most effective where decisions are informed by mapped output that enables farmers see their land at fine enough resolution to capture features such as hedgerows in relation to flow pathways for ecosystem services. This is also important at wider scales. Managing landscapes (as opposed to farms) for ecosystem service provision is likely to require collective action from farmers (Swift, *et al.*, 2004; MA, 2005 Defra, 2007b; O'Farrell and Anderson, 2010). Initiating these approaches will be more successful if farmers can make informed decisions both at farm and at 'landscape' scales. To enable this they need to able to see their farm in its landscape context in relation to ecosystem service pathways.

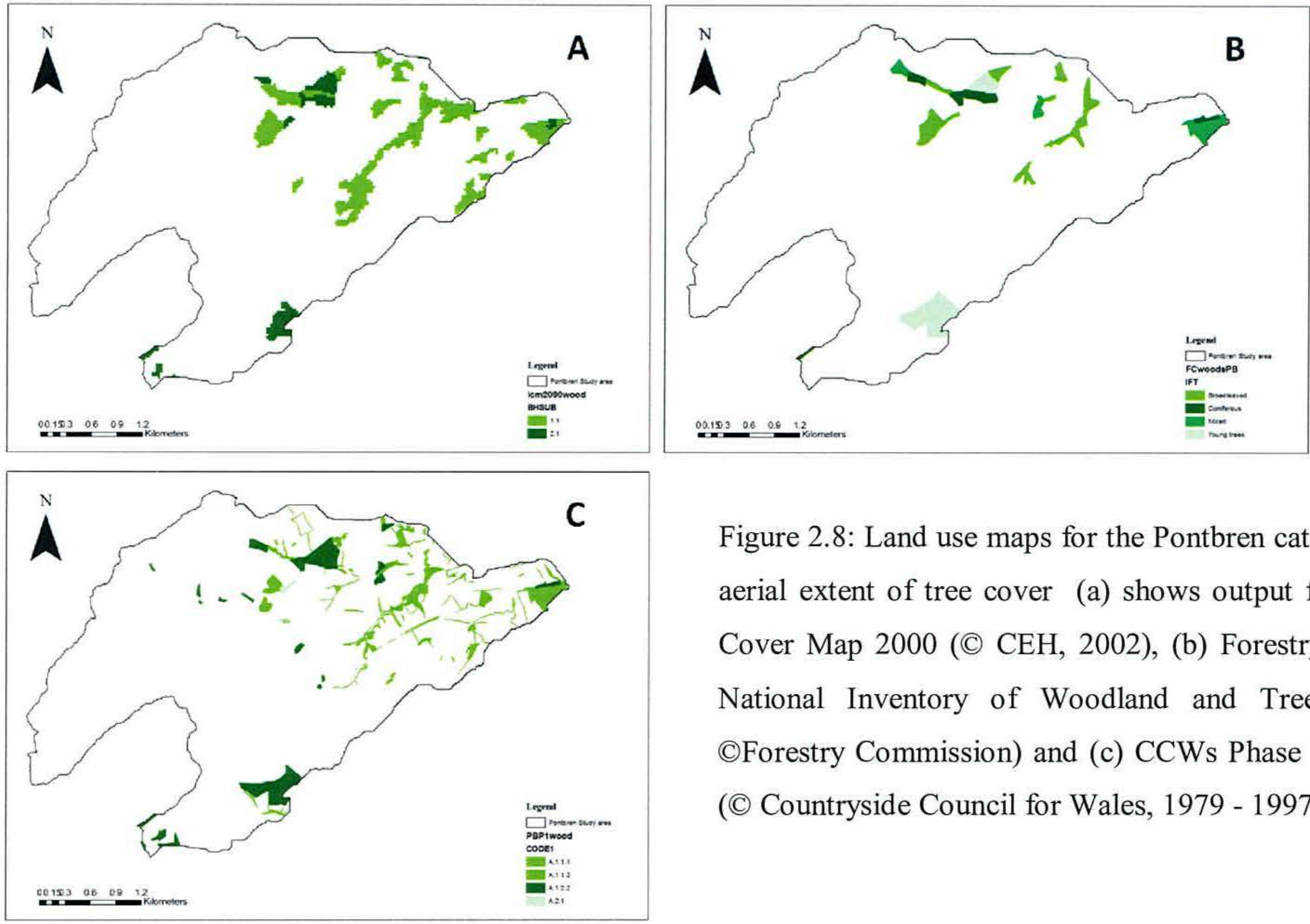


Figure 2.8: Land use maps for the Pontbren catchment showing aerial extent of tree cover (a) shows output from CEH Land Cover Map 2000 (© CEH, 2002), (b) Forestry Commission's National Inventory of Woodland and Trees (Forest data ©Forestry Commission) and (c) CCWs Phase 1 land use data. (© Countryside Council for Wales, 1979 - 1997)

Figure 2.9a identifies the individual decision making units at Pontbren in relation to the wider Pontbren catchment. The maps suggest that to meet water related policy objectives farmers outside the existing collective would ideally need to be involved (i.e. those farmers in the white areas within the red catchment boundary in Figure 2.9a). Figure 2.9b shows the Pontbren catchments in relation to upper Severn area. The Pontbren sub catchments only forms a small component of the 273 sub catchments which potentially contribute to flood risk in Shrewsbury. For soft engineering approaches (such as those described above) to be effective it is likely that large areas of land would need to be modified. For a catchment such as the Severn this might include the areas of high rainfall in the headwater areas (identified as the darker green sub catchments in Figure 2.9b) to decrease flood risk in Shrewsbury. A current issue is the extent to which ecosystem service boundaries can be defined as these are likely to be varied in relation to specific ecosystem services. This is explored in Chapter 4

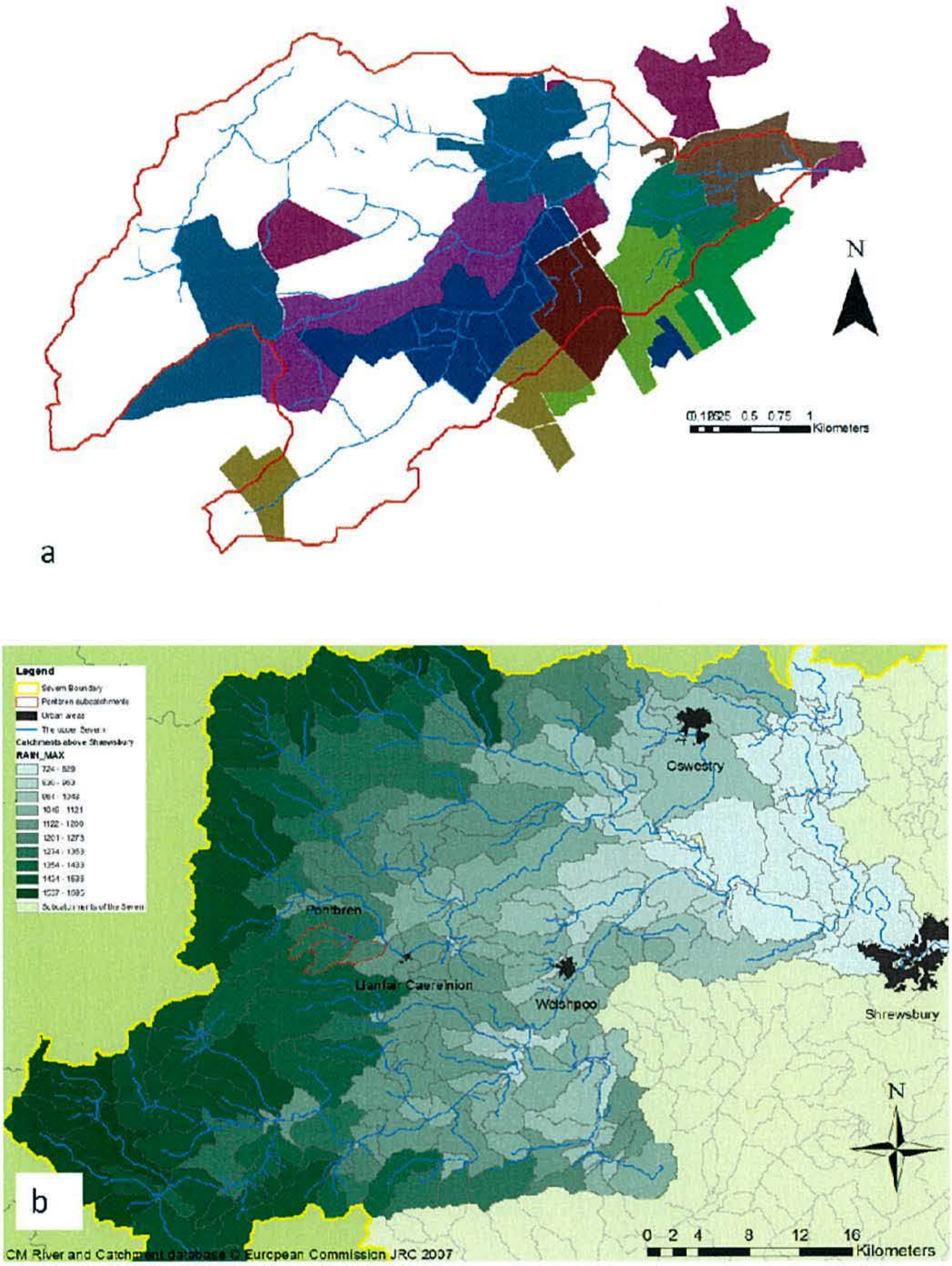


Figure 2.9 (a) shows the Pontbren decision making structure in relation to the sub catchment and (b) shows the Pontbren catchments within the context of the upper Severn above Shrewsbury.

2.4.2 Farmer objectives and ecosystem services

In part the policy interest in Pontbren was associated with understanding the effects of the farmers managing the land at a catchment rather than a farm scale. The driver behind the management decisions of the farmers was based largely on the *in situ* benefits derived from their interventions rather than the delivery of public goods. Although the interventions provided benefits to regulating services these were largely incidental rather than planned (in effect positive externalities). Targeting interventions specifically for the delivery of public goods would require negotiation with the farmers particularly where changes would reduce agricultural productivity (which was the farmers' raison d'être).

As not all ecosystem services can be maximized simultaneously trade-offs are necessary. The explicit identification of synergies (situations in which an increase to one service results in a related increase in another and vice versa) and tradeoffs (where one service increases and another decreases) associated with features in the landscape that farmers have management responsibility for delivery of ecosystem services is likely to important for negotiating changes to land management. This would enable more cost effective, targeted land use planning which can identify locations where interventions will deliver multiple benefits and to ensure that plans were sensitive to local livelihood requirements.

In Pontbren the farmers benefit from the changes they engineered. The farmers would like to have more drainage in the catchments, for example, (see Figure 2.3 above) but these benefits would have limited utility outside the catchments and could lead to increased flood risk. This leads to potentially conflicting views on the management of the area.

The group at Pontbren was formed largely because there were existing ties between them (see Figure 2.5) and the group were resistant to further expansion. Whilst the farmers were happy to work together this was balanced with a strong desire to retain autonomy on their farms (demonstrating resistance to external driven agendas for their land, especially without a compensation mechanism). This identifies a potential problem with the Pontbren model of group formation if the function of the group was to address 'landscape scale issues' such a water regulation and biodiversity (see section 2.6.3.4) which could require cooperation over broader scales.

To enable policy to realise these objectives is likely to require building both binding social capital (between land owners in flood generation areas to coordinate management) and bridging social capital (between the farmers and policy makers and between those who might benefit from their interventions). This is particularly challenging in the Upper Severn catchment context given the transnational issues involved as all the main headwater areas are located in Wales and potentially affect the well being of stakeholders in flood receptor areas in England. There are no existing policy mechanisms in place to deliver agri-environmental changes at these scales. The findings from Pontbren identified the benefits of increased social capital within the group, which was highly valued by the farmers. The evidence presented here suggests that the Pontbren farmers have significantly altered their social support framework and have demonstrated altruistic behaviour towards each other and derived benefits through co-operating with each other. Many of the farmers were prepared to consider more coordinated management in a second phase – but this was not uniform across the group and was dependent upon the farmers 'getting their houses in order' first. A first step towards more coordinated management may be in communicating the social benefits of cooperative action to other farmers and facilitate group formation.

2.4.3 Knowledge Gaps

With no existing baseline data available on existing ecosystem service delivery it was difficult to tell how the supply of ecosystem services from Pontbren (both before and after the interventions) compared with neighboring catchments. In discussing opportunities for increasing tree cover with farmers one of their first responses was to suggest that the area already had significant numbers of trees and to ask if there was a need for more. This was impossible to answer as the degree to which tree cover was providing many ecosystem services was almost completely unmeasured.

The evidence from Pontbren suggests that changes in land use or management affected multiple ecosystem services simultaneously. Although the indications were that the impacts were positive, and despite an unusual level of experimentation within the catchment, many of the changes to ecosystem service provision were unquantified. Monitoring changes to all ecosystem services at these scales is non-trivial and would incur significant transaction costs and it is unlikely that local changes could be monitored if the approach was applied broadly across Wales.

Both these factors suggest that on the ground decision making about ecosystem service provision will be taken in largely in data sparse environments. The Pontbren farmers demonstrated their capability 'ground truth' spatial datasets (see section 2.6.3.4). The degree to which other knowledge gaps related to ecosystem service provision was in Chapter 3.

2.5 CONCLUSION

The assessment of ecosystem services at Pontbren demonstrated that the changes made by the farmers had had a positive impact on the supply of ecosystem services from the catchment. Scientific monitoring in the catchment was able to demonstrate and quantify positive changes to water regulation, soil regulation and biodiversity. The farmers focus on in situ benefits meant that in many instances these regulating benefits were incidental rather than planned. The findings suggest that it was likely that many of the benefits were realised beyond the catchment boundaries although the evidence for this was limited.

In relation to informing operational approaches for the management of ecosystem services the key findings from this research were that given the spatial sensitivity of many landscape features in relation to ecosystem service provision, where interventions were placed matters. Developing operational approaches is likely to benefit from adopting spatially explicit approaches when planning ecosystem service interventions. The resolution of land use data is likely to be an important consideration at operational scales, for identifying key features in relation to service provision and for measurement and decision making.

CHAPTER 3

LOCAL ECOLOGICAL KNOWLEDGE OF ECOSYSTEM FUNCTION HELD BY FARMERS IN THE PONTBREN CATCHMENT

"Effective management of ecosystems typically requires "place-based" knowledge—that is, information about the specific characteristics and history of an ecosystem. Traditional knowledge or practitioners' knowledge held by local resource managers can often be of considerable value in resource management but it is too rarely incorporated into decision-making processes and indeed is often inappropriately dismissed."

(MA , 2005)

3.1 INTRODUCTION

In Chapter 2 the changes to ecosystem service provision arising from modifications made by the Pontbren farmers were assessed. In this chapter a knowledge based approach was used to explore the farmers' local knowledge of the properties of the catchment that would influence water and soil regulation. The first section presents the findings of the study and then the following sections discuss the degree to which the local knowledge complimented findings from the scientific research on the site. The implications of these finding are then discussed.

3.1.1 Background

There is increasing interest in both policy and science in the development alternative land management strategies that address deficiencies in ecosystem service provision (World Resources Institute (WRI) *et al.*, 2005; Cowling *et al.*, 2008a; Fisher *et al.*, 2009; de Groot *et al.*, 2010; Defra , 2007; ICSU *et al.*, 2008). To successfully meet these objectives local stakeholders' participation is likely to be an important prerequisite (Cowling *et al.*, 2008; Dailey *et al.*, 2009). Despite this in many cases local stakeholders are rarely involved in the decisions relating to land use planning in a meaningful manner (Jackson *et al.*, 2007)

The management of multiple interacting ecosystem processes is likely to be complex and requires land use planning across scales (deGroot *et al.*, 2010). Implementing operational approaches at local scales is likely to require interactions between multiple stakeholders with potentially divergent knowledge systems and priorities (Fabricius *et al.*, 2006; Vanclay *et al.*, 2006). One solution to addressing this issue is to explicitly acknowledge local knowledge systems using formal acquisition methodologies (Sinclair and Walker, 1998). Where local knowledge has been collected in this manner it has been demonstrated to increase mutual understanding amongst stakeholders about ecosystem processes and their management (Thapa *et al.*, 1997) The utilisation of local knowledge has also been identified as an important means for increasing stakeholder participation in natural resource management (Reed, 2008).

One of the principal findings from the second chapter was that there were likely to be limited site specific scientific data available to inform decision making in projects or initiatives operating at field, farm and landscape scales. At present this is true generally for scientific understanding of ecosystem function in many ecosystems (Kremen and Ostfeld , 2005). However stakeholders who live and work within landscapes often have detailed local or 'place based' knowledge about their environment (Thapa *et al.*, 1997; Ericksen and Woodley, 2005; Raymond *et al.*, 2010). Local ecological knowledge (LEK) refers to knowledge held by local stakeholders (such as farmers and resource users) that is derived from their daily interactions with their natural environment, in effect based on experience and observation (Sinclair and Joshi, 2000). In areas where there are gaps in scientific understanding of local ecosystem structure and function there is potential value in utilising local understanding of bio-physical (and socio-cultural) conditions to compliment this knowledge (Raymond *et al.*, 2010). This is explicitly acknowledged in Principle 11 of the Convention on Biological Diversity's Ecosystem approach which states that: "The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices". It goes on to state that "information from all sources is critical to arriving at effective ecosystem management strategies" stressing the need for broad stakeholder engagement in land use planning. This is likely to be particularly important as the heterogeneity found within different types of agro-ecosystems limits the extent to which generic solutions can be applied (Hein *et al.*, 2008). Tailoring potential solutions to address local conditions and explicit acknowledgement the livelihood requirements are likely to be more viable for local stakeholders. The acquisition and utilisation of local knowledge offers a potential method to inform decision making and improve stakeholder participation (Sinclair and Joshi, 2000). Interest in the use of knowledge held by local people for research has a long history (Sillitoe, 1998)[7]. Despite wide recognition of its value local knowledge remains a heavily underutilised resource and continues to be largely inaccessible both to science and policy makers. This is largely true within the UK ((Edwards-Jones, 2001; Edwards-Jones, 2001; Ingram , 2008; Ingram *et al.*, 2010). There may be a number of reasons for this including issues associated with the methodologies employed in the acquisition of local knowledge – which can lead to issues of validation (Fabricius *et al.*, 2006). This can stem from uncertainty associated with multiple and varying interpretations of observations which can lead to variation in knowledge between disparate sources (not only at an individual level, but also between and within sectors involved with specific aspects of environmental management (Failing *et al.*, 2007)). The process of knowledge acquisition works best where there is trust and mutual understanding which requires time to generate (Norgaard, 2010). This incurs significant transaction costs which may limit implementation.

The use of interdisciplinary and multi-stakeholder perspectives is important in order to understand the links between ecosystem services and human well-being across scales. An operational ecosystem service approach is most likely to succeed where there is shared vision amongst stakeholders (Vanclay *et al.*, 2006) that is informed by interdisciplinary thinking that encourages flexible and transparent decision-

[7] In literature local knowledge is sometimes referred to as indigenous knowledge (Dewalt , 1994) or traditional environmental knowledge (TEK; (Berkes and Folke , 1998).

making between land users, scientists and policy makers (Robards *et al.*, 2011).Achieving these goals will require greater integration between the diverse knowledge systems and values held by these stakeholders groups (Reed, 2008). By strengthening the flow of knowledge between these three stakeholder groups it becomes possible to identify synergies and gaps in knowledge between the knowledge systems and take steps to address this (see Figure 3.1).

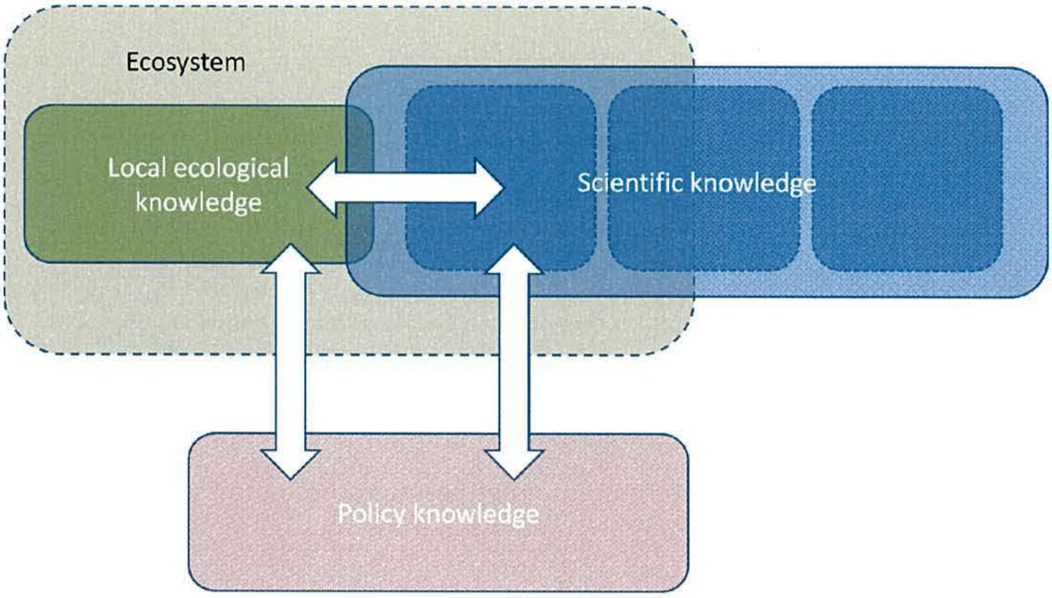


Figure 3.1: Conceptual model of interaction between knowledge systems involved with understanding ecosystem function. The blue squares with in the scientific knowledge node represent the multiple disciplines. The white arrows indicate requirements for knowledge exchange for successful ecosystem management

Scientists have a high level of conceptual understanding about ecosystem function although their knowledge is often compartmentalised within different disciplines, particularly between the natural sciences, economics and social science (Scheffer *et al.*, 2000). Although there are increasingly examples of co-operation across disciplines (Vihervaara *et al.*, 2010) there is often less interaction between scientific and local knowledge systems. Reasons for this may be that knowledge systems can be difficult for non expert stakeholders (including policy makers) to access and understand (Raymond *et al.*, 2010; Pullin *et al.*, 2009). Developing more inclusive and interdisciplinary approaches has been highlighted as key requirement to enable more integrated land use strategies. Meeting the demands of landscape scale management is likely to require increased knowledge transfer between stakeholders and investment in increasing social capital (Cowling *et al.*, 2008b).

3.1.2 Objectives

Whilst the ecosystem assessment at Pontbren revealed knowledge gaps in the scientific evidence of local ecosystem service provision it was evident that the farmers, given their long association with the landscape, had relevant knowledge about local ecosystem function.

The principal research questions were:

1. What do stakeholders know about ecological drivers that affect water flows and flood generation in the Pontbren catchment within a landscape context?
2. To what extent does local ecological knowledge complement scientific understanding of ecosystem processes at small scales?
3. What were the potential gains from using local knowledge in relation to testing land use plans and stakeholder engagement?

3.2 METHODS

3.2.1 STUDY SITE

The Pontbren study area is situated between Newtown and Welshpool in mid-Wales. The farms cover a contiguous area of 1000 ha in the Pontbren catchment adjacent to the town of Llanfair Caereinion. They are situated between 150 and 400 m above sea level and have a mean annual rainfall of over 800 mm. The majority of farms lie within the Pontbren sub-catchment, a small tributary in the upper Severn catchment (known locally as the *Nant-Pontbren*). Livestock are an integral part of farming and the farm enterprises focus mainly on sheep or mixed herds (although one member of the Pontbren group is a dairy farmer). In recent years a combination of higher incidences of TB *(Mycobacterium tuberculosis)* and the increased availability of cheaper foreign beef have had a big impact of beef farming in the local area with many farmers in the Pontbren group finding it difficult; there is a gradual transition away from beef production.

3.2.1.1 Land use in the catchment

The farmers themselves describe the farming practice in this part of mid-Wales as not having altered much over the last hundred years although farming technology has moved on. There is evidence of significant land use change since the Second World War (Henshaw, 2009). Figure 3.2 (below) shows the most land use map for the catchments based on recent (and slightly simplified) Phase 1 land use maps produced by the Countryside Council for Wales (CCW) (Howe *et al.*, 2005). These show much of the *Nant-Pontbren* and the *Gelli Gethin* sub catchments are improved grassland. In the 1930s just over 23% of this land area was improved (Henshaw, 2009). The presence of peat and clay loam soils that dominate the catchment means those improvements to productivity were closely linked to land drainage. Historically there have been two key periods concerns about food security led to government subsidisation of land drainage; the first as a consequence of food shortages immediately after the Second World War and then again in the late 1970's early 1980's when there were substantial grants available again for drainage to stimulate increased production (Wheater and Evans, 2009).

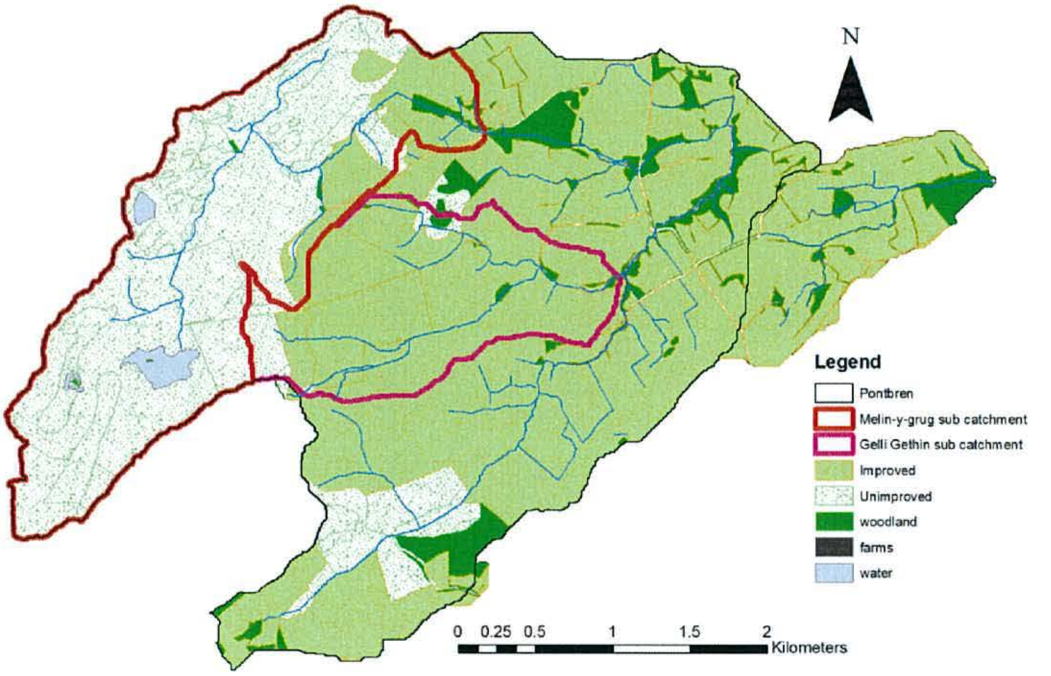


Figure 3.2: A simplified land use map for the Pontbren catchments

The *Melin-y-grug* sub catchment, which lies to the north of the *Nant-Pontbren* (see Figure 3.2) is the only remaining area of largely unimproved grassland, and has not changed substantially since the War.

Most recently the Pontbren farmers began an initiative to increase in the tree cover in the catchments. As part of this program over 120 000 trees were planted across the 10 farms (a contiguous area of over 1000 ha); largely as new hedgerows and shelterbelts (for more detail see Chapter 2; Section 2.3.2). It was the farmers' observations of changes to the catchments' hydrology as a result of these plantings that led to research being initiated in the catchment (Carroll *et al.*, 2004).

3.2.1 KNOWLEDGE BASED METHODS

Local knowledge was acquired from the Pontbren farmers using a knowledge based systems method (Sinclair and Walker, 1998; Walker and Sinclair, 1998). The local knowledge was recorded using the Agro-ecological Knowledge Toolkit (AKT5) software system (Dixon *et al.*, 2001) that involved disaggregation of knowledge into sets of unitary statements represented using a formal grammar (Walker and Sinclair , 1998), with associated contextual information about the definition and taxonomy of terms (Sinclair and Walker , 1998). The knowledge was evaluated for coherence and consistency as it was collected, using a suite of automated reasoning tools (Kendon *et al.*, 1995) and a diagrammatic interface to explore connections among statements (Walker *et al.*, 1995).

The main topic area explored with the farmers was knowledge about ecosystem function within the farm: water and soil regulation. In addition the impact of the farmers' knowledge about the effects of tree planting on biodiversity were explored. These services were selected to complement research taking place in the Pontbren catchments exploring both the impacts of soft engineering approaches on flood risk (see Chapter 2). The Pontbren farmers' knowledge was sought due their long association with the catchments which enabled exploration of changes in historic and present day ecosystem function.

The knowledge base was developed from primary data derived from semi structured interviews with the Pontbren farmers. Other key stakeholders, including researchers, drainage contractors and members of Coed Cymru (a welsh woodland NGO, who facilitated the tree planting on the farms) were also interviewed. Primary data were collected through two ethnographic methods: semi structured interviews and focus group discussions (see Laws *et al.*, 2003). Detailed knowledge was acquired by repeated interviews with members of the Pontbren group. Repeated interviews with the same people were important for obtaining deeper explanatory knowledge and resolving inconsistencies. In addition to the formal interviews and discussions a number of informal meetings and telephone interviews were held with the farmers (and other stakeholders) over the period of the research to clarify specific points raised. Focus group discussions were held with researchers to discuss the degree convergence between LEK and scientific knowledge about ecosystem functions in the catchment.

The Flood Risk Management Research Consortium (FRMRC) used Pontbren as a major field site from 2006-2011. Secondary data, in the form of research output arising from this project was also utilised (Carroll *et al.*, 2004; Jackson *et al.*, 2008; Marshall *et al.*, 2009; Wheater *et al.*, 2008; Wheater and Evans, 2009 and McIntyre and Marshall, 2010).

3.3 Results and Discussion

A summary of the interviews conducted in the catchment is provided in Table 3.1 below).

Table 3.1: Outline of interviews held at Pontbren

Topic	Methods	Stakeholders involved
Discussion of farmer livelihood objectives	Workshop	4 PB farmers plus members of CC, EA, FC, CEH and WG
Past, present and anticipated drivers on land use and impact flood risk	I	6 PB farmers and 4 local farmers
Local knowledge of hydrology	I	10 PB farmers
Impacts of tree planting	I	10 PB farmers and 2 CC
Local knowledge of drainage	FGD	4 PB farmers
Local knowledge of drainage	I	5 PB farmers + local drainage contractor
Local knowledge of geomorphology	I	All 10 PB farmers
Mapping of ecosystem services	FGD	6 PB farmers
Scientific knowledge of hydrology	FGD + I	11 Researchers

I = Semi-structured Interview; FGD =Focus group Discussion; PB = Pontbren

The final knowledge base consisted of 323 statements supplied by 10 sources about the soil and water regulation in the Pontbren catchments (see Table 3.2). There were 384 specific terms, arranged in 11 main taxonomic hierarchies and 84% of the statements were explicitly about causation, indicating considerable explanatory content.

Table 3.2: Contents of the local knowledge base about soil and water regulation in the Pontbren catchments

Number of statements of each type used in the Soil and Water regulation at Pontbren knowledge base		
TYPE	Number of statements	Conditions attached
all	327	40
attribute	43	10
causal	278	30
Comparison	6	0

3.3.1 Farmers' knowledge of water regulation

Most of the farmers interviewed noted that there was little local evidence of any impact from changing farming practice on flooding since the time that they had been farming. Flooding was not a major issue in upland farm areas - as very few upland areas are affected by flooding. The nearest area with any significant flooding was Welshpool, which was subject to floods prior to any of the major land improvements carried out in the 1970s and continues to be flooded today. There has not been a noticeable increase in the amount of localised flooding in the Pontbren area. The farmers generally categorise their farms as 'wet' farms - in that they receive high annual rainfall and the soils remain waterlogged for long periods of the year. However there has been a significant reduction in the response times of local streams and rivers over the years i.e. farmers were aware that their land did not hold the water as well as it used too. This change, farmers suggest, was caused primarily by two factors: intensification of land use (specifically agricultural improvements - improved drainage) and climate change. In the past much of the upland areas potentially available for agriculture were unproductive due to extensive areas of boggy ground. Government incentives, mainly in the forms of grants in the 1970's and 1980's, allowed farmers to drain and farm these areas improving the overall productivity of the land but also decreasing the water storage potential.

Initial scoping discussions about farmers' understanding of the term 'hydrology' indicated that in practical terms the word equated with drainage. The ability to farm in the 'heavy' (i.e. clay rich) soils found in upland areas of Wales required substantial modification to the hydrological functioning of the fields through additions of surface ditches and sub surface drain systems. The differences between the hydrological response of the improved *Nant Pontbren* and the *Gelli Gethin* catchments and the unimproved *Melin-y-grug* sub catchment (see Figure 3.2 above) were a central theme in discussions about the water regulation given the farmers perceptions of differences in hydrological responses between the two subcatchments.

In interviews about the hydrology of the catchment the farmers identified four main areas of influence on catchment response: the influence of climate on rainfall patterns within the catchment; above ground interactions; below ground interactions and processes occurring adjacent to and within the stream channel system. Within each of the terrestrial components the farmers identified key features associated with soil and water regulation within their farming systems. These are visualised in Figure 3.3.

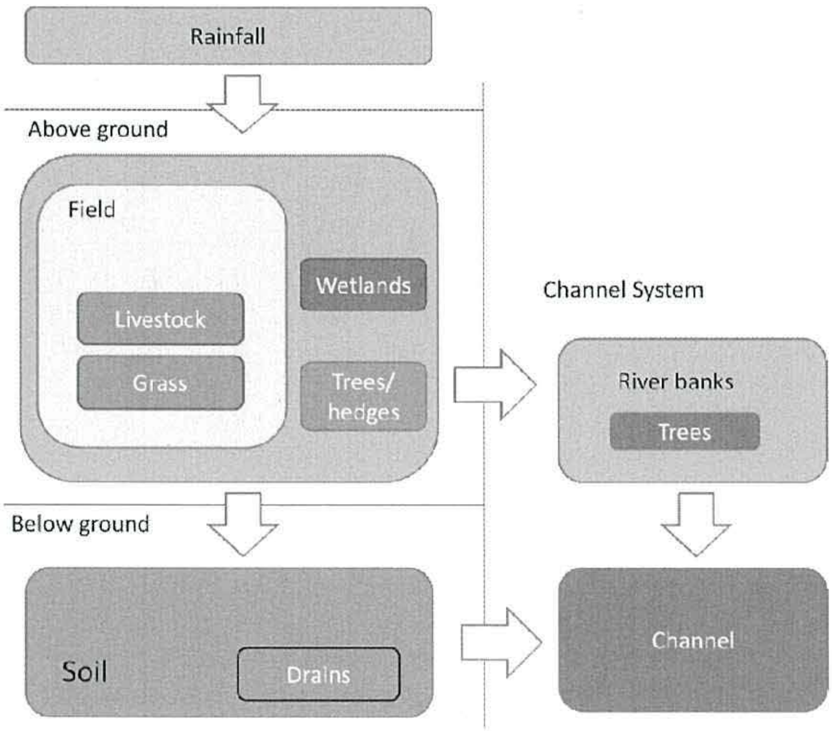


Figure 3.3: The main points of interaction between the farm system and the hydrological system

Whilst the farmers felt that climatic effects were beyond their control within each of the three terrestrial areas of influence the farmers identified key landscape features that affected the movement of water. The effects of each of these components (and associated management) are discussed below:

In identifying and discussing these components the farmers demonstrated detailed knowledge about all the key features. For example as the farmers livelihoods were intimately related to the soils and the farmers had detailed knowledge both of the composition and location of soil types across their farming areas. When discussing tree features farmers were able to identify which species were present, their age and current and historical management practices in detail.

3.3.1.1 The influence of climate and weather

All farmers interviewed both within and outside the Pontbren group noted that local rainfall patterns have changed. There was uncertainty about whether there has been any change in the total amounts of rainfall (although many felt that there had been an increase) but rainfall intensity had definitely increased. Farmers felt that storms were now much more intensive than in the past and that seasonal variation had become less distinct (there was a blending of the seasons), particularly in relation to increased amounts of summer rainfall.

Apart from general observations about changes in rainfall patterns farmers also explained how these changes impacted upon farming practice. For example farmers mentioned 1) the length of time that farmers had to keep animals in over the winter had gone up and 2) The occurrence of frost on their farms had decreased. Both of these issues were beyond the control of the farmers.

The amount and timing of winter rainfall was the main lever dictating when the animals needed to come in and changes in the duration of this winter housing has big potential impacts on the productivity of the farms, especially with regard to dealing with increased slurry storage (especially with potentially tighter regulations linked to this expected to come in force in the near future). The farmers anticipate that if current climate trends continue that they will be faced with housing livestock for increased periods at greater financial costs to themselves

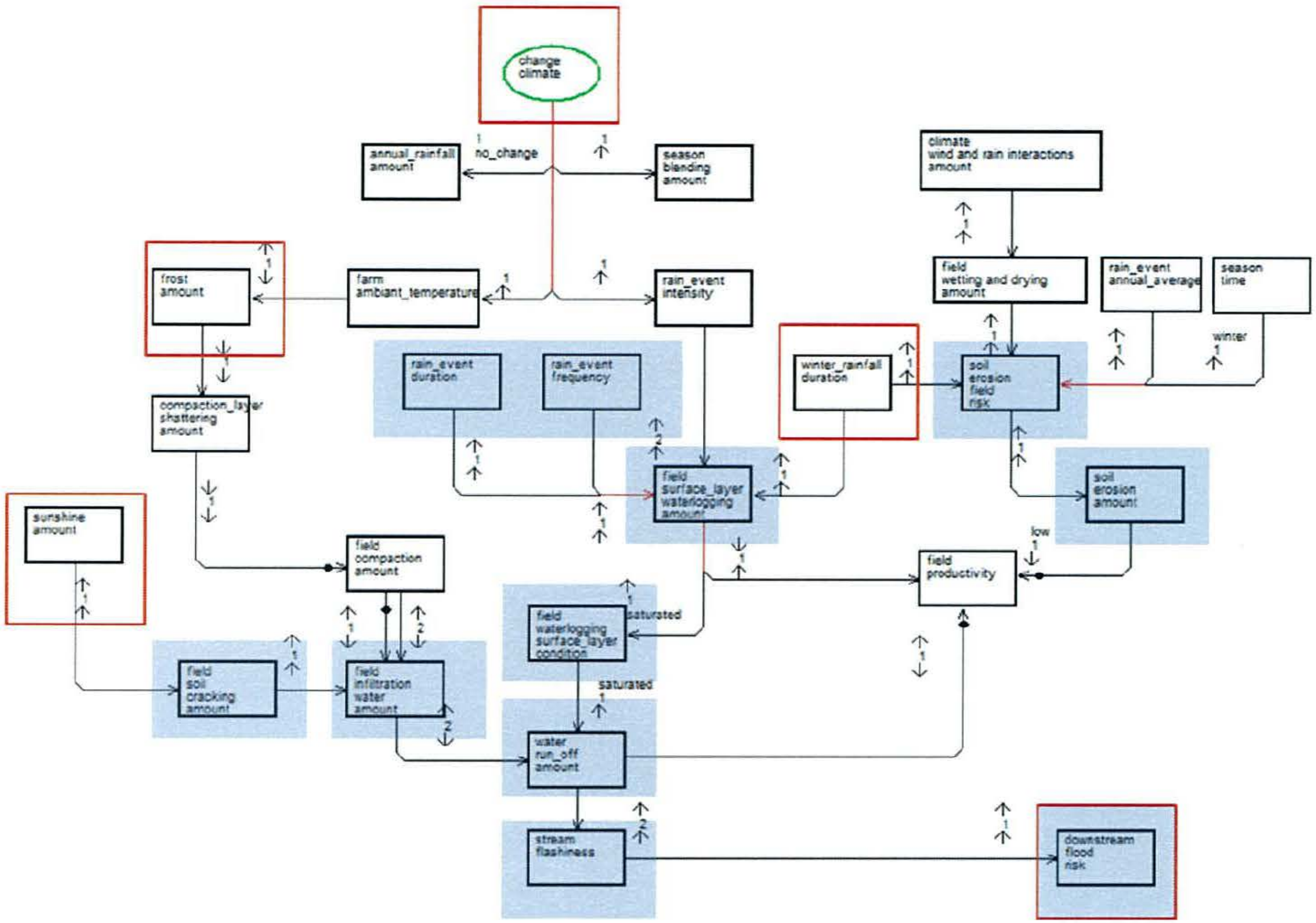


Figure 3.4 Causal diagram representing Pontbren farmers' knowledge of the effects of climate change on catchment hydrology.

Blue fields represent areas farmers knowledge supports instrumented output from the catchment. Red squares represent key nodes

In AKT diagrams Nodes represent human actions (boxes with rounded corners) or attributes of objects, processes or actions (boxes with straight edges). Arrows connecting nodes denote the direction of causal influence. The first small arrow on a link indicates either an increase (↑) or decrease (↓) in the causal node, and the second arrow on a link refers to an increase (↑) or decrease (↓) in the effect node. Numbers between small arrows indicate whether the relationship is two-way (2), in which case ↑A causing ↓B also implies ↓A causing ↑B, or one-way (1), which indicates that this reversibility does not apply. Words instead of small arrows denote a value of the node other than increase or decrease. Nodes representing natural processes are green ovals. A black dot on a causal arrow indicating a negation of the node it is coming from or going to.

3.3.1.2 Above ground *interactions*

Farmers identified four functional units which influenced water regulation above ground: grass cover, tree stock, livestock and wetland areas.

Farmers were aware of variation between the water holding capacities of different grasses. In the *Melin-y-grug* sub catchment the farmers observed that the older lay grass created a dense mat like effect that held water like a sponge. Farmers demonstrated this by pulling up handfuls and 'wringing' them out. On improved parts of the catchments the use of new improved grass varieties meant that this mateffect did not happen. Farmers suggested that new grass lays, especially less than five years old, were likely to associate with greater surface runoff. Farmers were unsure how big an effect this had in reducing overland flow at a catchment scale especially as overland flow was heaviest during the winter when, in general, the sward was depleted. Some farmers did not mention grass at all. The effect of grass on water regulation was not part of the scientific research at Pontbren

The impact of new tree cover on water regulation was more significant. Individual standards that grew near to streams or wet areas (such as willow (*Salix spp.),* ash (*Fraxinus excelsior)*, alder (*Alnus glutinosa)* and to a lesser degree birch (*Betula spp.*)) were all noted as 'thirsty' trees capable of taking up significant quantities of water as mature trees. Areas adjacent to these trees were generally drier than areas without trees. Farmers had noticed young (>2years) hedgerows having an impact upon infiltration during initial tree planting. These observations resulted in the early research into impacts of trees on farm hydrology (discussed in Bird *et al.*, 2003; Carroll *et al*, 2004). Well maintained hedgerows were highly valued by farmers for their shelter properties and ease of maintenance. It was well established that soils were drier near to hedgerows; farmers always drove their vehicles along hedgerows for this reason. Farmers were unsure of whether infiltration increased compared with shelter belts as hedgerows were maintained at lower heights. The main species used in hedgerows at Pontbren were Blackthorn (*Prunus spinosa)* and Hawthorn *(Crataegus monogyna)*. The farmers knew very little about the root architecture and water holding properties of either of these species. The drying effect of hedgerows extended between 5 and 10 m from the hedge.

'Shelterbelts' was a term used by the farmers to describe areas where tree planting had taken place specifically to provide additional protection to livestock from the wind. This was a key objective for the farmers. As this practice required more land then hedgerows they were much less common and often situated on more marginal land/less productive land (see Plate 3.1). In shelterbelts the trees were generally of mixed varieties, including blackthorns, and birch and other standards. The farmers felt that the shelterbelts behaved in a similar way to the hedgerows, having an area of effect which was determined by the size and location of the shelterbelt. The oldest shelter belt feature had dried out soil to at least 10m down slope. Shelterbelts were more likely to follow field boundaries, and tended to be parallel to the slope limiting the amount of potential interception. The effects of shelter belts on catchment hydrology was a central component of the research at Pontbren.

Plate 3.1: The 'Bowl' shelter belt at Pontbren. The area 10 m in front of the shelter belt has dried out considerably as a result of the planting

The farmers established a number of riparian woodland areas but felt that due to their proximity to the streams they had little effect of water regulation other than for soil stabilisation (see section below).

Farmers were unsure of the impact of farm trees on flooding at a landscape scale. None of the trees had been planted for the purposes of influencing local hydrology and the farmers were unsure of the effect if they had been. The farmers also noted that there were already a significant number of trees in the local landscape and there were questions about the impact of planting more. The farmers did note the afforestation programs had had a major effect on catchment hydrology, including the small area of conifer woodland to the south west of the catchment. The large drain systems used in conifer plantations were cited as the major reason for this.

Impacts of Livestock

Farmers were aware of the research interest in compaction but did not identify compaction by livestock as a major factor affecting the hydrology of the farm. Surface runoff was not generated by livestock compaction (soil type and drainage were considered to be more important). During the initial phase of the project many Pontbren farmers did acknowledge their animals may be compacting the soil. This was possibly as a result of interactions with project staff. These farmers felt that de-stocking would potentially have a positive impact on decreasing runoff times; but that they would need to be convinced of the scale of the effect. Compaction studies have not been incorporated in the FRMRC work at Pontbren and the farmers have increasingly challenged this paradigm. On other farms that were less involved with the experiments farmers were either unaware of the impact of compaction or argued that sheep behaviour dictated that compaction would be limited to areas where they congregated and would not be uniform across fields. The role of frost was also mentioned, as it helped to break up compaction caused by livestock over winter when runoff would be highest.

3.3.1.3 Below ground interactions

The nature of soils at Pontbren was fundamental both in terms of the type of farming practise they allowed and their effects on farm hydrology. The farmers categorised their soils into wet and dry soils based on their water holding capacity. The wet soils consisted of peat soils in unimproved areas of the upper catchment (in the *Melin-y-grug*), which blended into clay soils further down the catchment. The peat areas were over impermeable blue clays – and as land was improved the peat soils became more clay like. The most productive areas were where clay soils were dominant (the majority of the Pontbren farm holdings). These areas had been extensively drained over the last 100 years. During the winter months these soils become susceptible to poaching (the process by which soils become muddy or broken up from being trampled by livestock) and farm animals were removed from fields and over-wintered indoors. The free draining areas or 'dry' fields were highly valued as they were resistant to poaching and could often sustain small amounts of livestock throughout the winter. Vehicles could also access these fields over winter so farmers used them for slurry spreading. Dry fields tended to have south facing aspects. In addition farmers mentioned that in parts of the catchment the soil layer was thin between the surface and the bedrock. They suggested that in these areas there was limited water storage potential but that it was not obvious how much area was affected by this.

The addition of drainage systems was identified by the farmers as having the most significant impact of water regulation in the catchment (Figure 3.5 below). Drains were designed to dry out soils to improve their productivity and were an essential component of upland farming systems in Wales. The farmers could see that areas that were undrained typically responded to rainfall in a different manner to unimproved areas. Peat areas, in particular, were noted for their water holding capacity. In the past, prior to improvement, the *Nant Pontbren* would remain full for over a week after a rainfall event. Once the land was drained the response time shortened to hours. In the *Melun-y-grug* the response time was still muted.

Hedgerows and shelter belts both had an effect upon drainage in that 'thirsty' trees such as willow, alder and ash were associated with blocking drains (see Figure 3.5). Farmers laid imporous pipes 10 m either side of a hedgerow if the drain needed to pass near any tree feature. The farmers did not know the extent of roots from blackthorn tree species, the dominant hedgerow species.

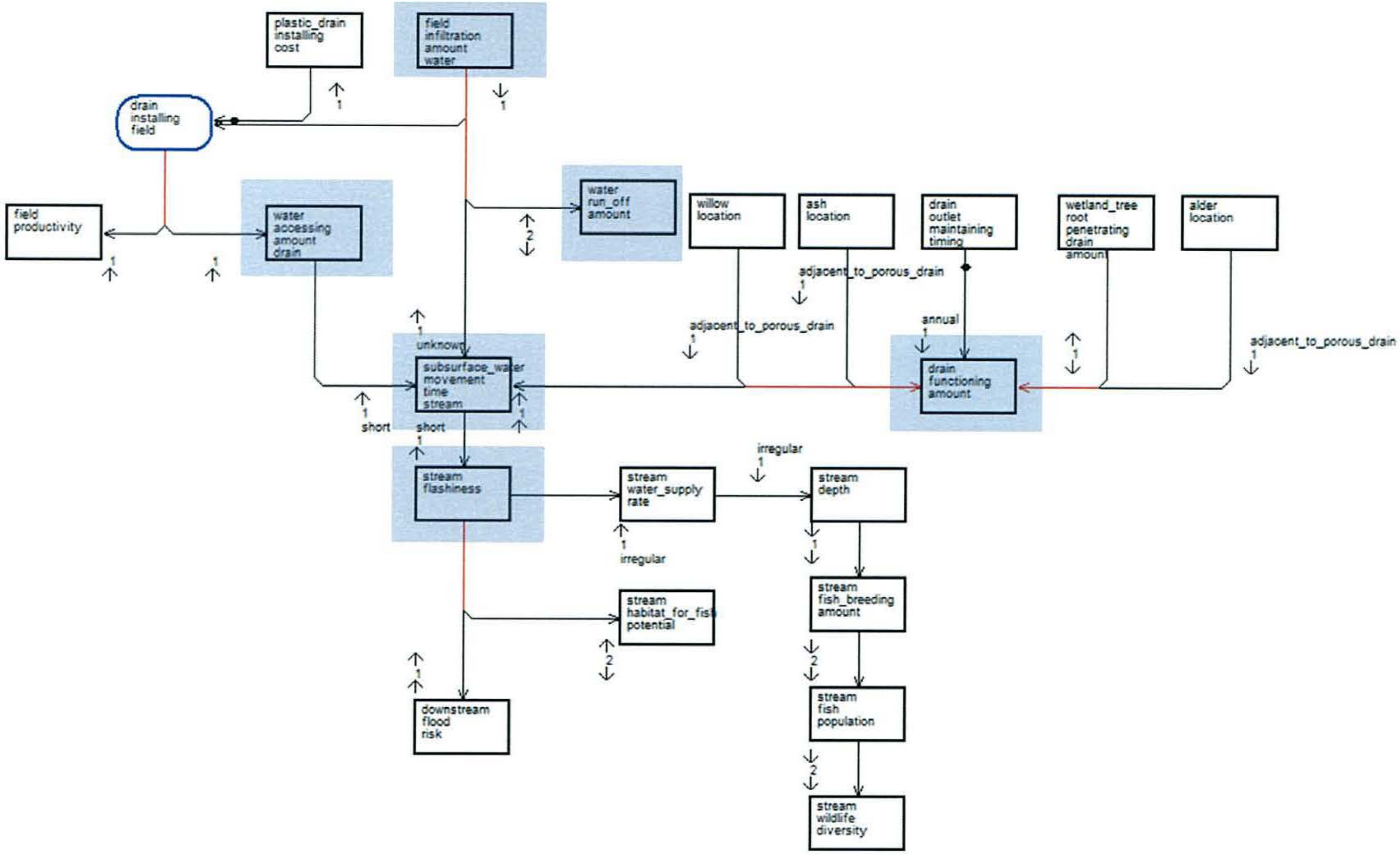


Figure 3.5: Causal diagram representing Pontbren farmers' knowledge of the effects of field drainage catchment hydrology.

Cataloguing the extent of land drainage in Pontbren was complicated. There was no central database of land drained (although farmers did have maps of more recent drainage systems). The farmers were aware where most of their more recent drains were but could not identify the locations of all drains. Some drainage systems required frequent management but a functioning drain could go unnoticed. The farmers were aware of where most drain outlets were but not all. A major tile drainage system was identified through aerial photography on one of the research sites that the farmer was completely unaware of.

3.3.2 Farmers knowledge of soil regulation

The farmers did not consider, under their present management strategies, that field erosion was a major issue in the Pontbren catchment. They were very aware of the potential risks of soil erosion if local soils were unmanaged. In the recent past, when farmers left livestock outdoors over winter poaching was a significant problem. To reduce this farmers occasionally used farm woodlands for sheltering stock. Even in these conditions the land would recover quickly from erosion. The farmers were aware when the soils on improved fields were prone to erosion, and removed stock from fields during heavy rains. The risk of soil erosion from poaching was a winter problem, especially associated with longer duration rain events. On farm visible erosion was limited to gateways, feeding spots and where livestock 'paddled' in the brooks. When poaching occurred there were higher incidences of chicken weed (*Portulaca quadrifida* - see Figure 3.7 below)

Localised problems were dealt with by management (rotating fields) and occasionally remedial measures (chain raking, re-seeding). There was little or no erosion in areas of unimproved grassland because the grass mat protected the soil from the livestock. If there were rushes present then the farmers said that poaching would not occur. The only time poaching was a problem on unimproved land was when livestock were contained in a small area, either for feeding or when administering medicine. Farmers could identify areas that were prone to poaching, based either on soil type, farm infrastructure or animal behaviour

The farmers identified two other processes that enabled sediment to get into the stream network; through bank erosion from livestock and from sediment delivery through the drain systems. These were not thought to be major effects or have a major detrimental impact on farm productivity. The *Gelli Gethin* and *Nant Pontbren* streams carried significant amounts of sediment after heavy rain. Farmers identified practices that exposed the soil, such as ploughing and unmanaged poaching as being the main culprits. As many fields had limited or no access to mains water supply, livestock accessed the river to drink. This resulted in significant bank erosion throughout the catchment. The farmers identified cattle as causing more damage than sheep. Although bank erosion was a generally regarded as a gradual process, and located at regular drinking spots, the farmers could identify two occasions, one after very heavy rainfall and the other after a snow melt, where significant amounts of the banks were lost throughout the catchment. The farmers addressed the issue of bank erosion by planting trees on the river banks and fencing off these areas form livestock. This was effective and the farmers could demonstrate the trees impact on bank stabilisation. Not all farmers were happy with this. Fence posts near the streams were often loosened when the streams swelled – and the maintenance costs were high, and blocking access was not an option if alternate solutions for supplying drinking water could not be found.

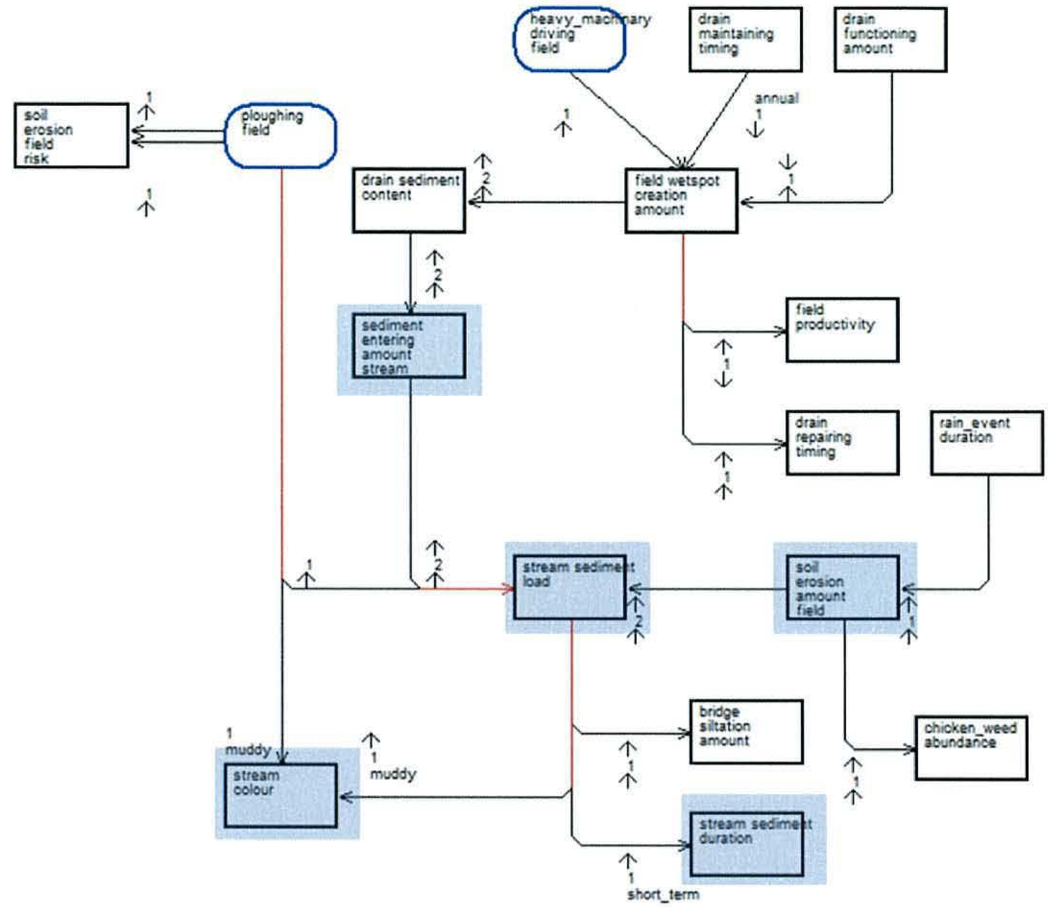


Figure 3.6: Farmers knowledge of factors affecting sediment delivery into the catchment

One farmer in the catchment had recently experimented with a field of winter wheat (*Triticum aestivum*) .There was evidence of rill and gully formation in the field and the farmer did not plan to repeat this as a result.

The drain systems also were responsible for the delivery of sediment to the catchment (see Figure 3.7). As part of farm management the farmers maintained the outlets to clear sediment build up. Farmers were able to identify drains (and fields) that were susceptible to 'wet spots'. Wet spots were created when parts of the drain systems collapsed and as a result sediment entered the system. This was caused by the drains getting old or when heavy machinery, such as tractors, were driven over the drains (farmers preferred to use quad bikes for just this reason). The older tile drains, although more prone to collapse had a vertical orientation and tended to run clearer than the plastic drains. New drain systems were implemented using a herring bone pattern with drains running across the fields, rather than vertically down. This also led to higher build up in sediment. Farmers were able to describe which fields had drains and the type of drains present – although this was not comprehensive. Drains that worked were often forgotten about; it was only areas where drains malfunctioned that received regular attention. The open ditches on the farms silted up (and this would require infrequent and limited remedial work). This varied across the catchment and was influenced by soil type and steepness of the ditch. In the worst cases the ditches were managed on an annual basis but for many ditches management was only required once every three - five years.

3.3.3 Farmer knowledge of catchment scale processes

The farmers were uncertain to the extent to which modern farming practice could be associated with increased flood risk. The farmers had observed clear differences in the response times of the catchments over their lifetimes and noted two key times of change. These were the introduction of conifer plantations in the catchments and the government policy in the 1980s which encouraged farmers to produce more food (see figure 3.7). Both of these factors were essentially driven by external agents. As part of this farmers had been given grants for implementing drainage systems which had brought more land into production. The farmers had observed significant changes in the catchment response times related to this. The farmers recognised that adding extensive drainage systems to waterlogged soil meant that during the winter the farms had a very dynamic and limited relationship with rain water once it arrived on to the farm. The amount of land with potential for water storage has been greatly decreased. This was supported by the relatively slow response time in the *Melun-y-grug* sub catchment which was relatively unimproved. The farmers could observe surface runoff occurring in the catchment under heavy rainfall conditions once the soil was saturated. Increases in surface run-off were related to changes in climatic conditions which the farmers observed.

In terms of erosion the farmers were aware of the risk of sediment loss from fields but felt that this was a minor issue, as they managed their land for it. The major contributor to catchment scale processes was livestock drinking directly from streams (and the associated bank erosion) and limited supply from malfunctioning drain networks)

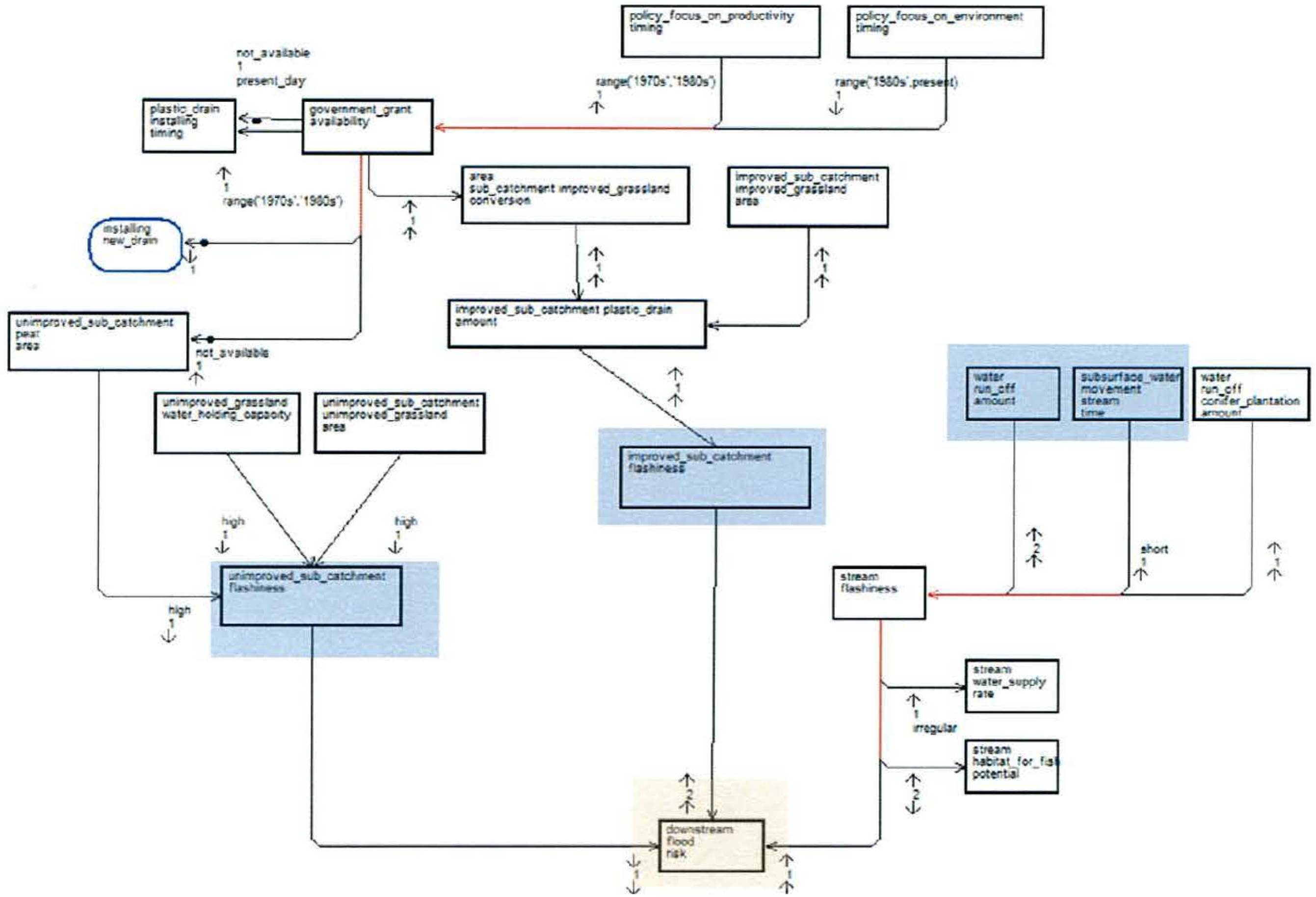


Figure 3.7: Summary of farmer knowledge of catchment scale processes.

3.3.4 Convergence between LEK and scientific knowledge about ecosystem functions in the catchment

There are considerable uncertainties within current research in the UK in relation to the degree to which land use change impacts flood risk (Wheater and Evans , 2009; Defra , 2004; O'Connell *et al.*, 2005). Flood risk continues to rise in Wales (Hall *et al.*, 2005). In upland catchments studies have suggested a link between an increase in flood risk and the grant-aid supported drainage schemes of the 1960s and 1970s (ADAS, 2003) and the sharp increase in sheep numbers during the 1980s (Samson, 1996). However this remains an area of contention in the scientific literature (Wheater and Evans, 2009)

The Pontbren farmers had a detailed understanding of their catchment hydrology as it impacted directly on the way they farmed. The experience with water was based on observations at local scales over a number of years. In particular the farmers were very aware of the nature of interactions with the various soil types with water and had a detailed knowledge of where in the catchments changes in management were likely to impact on water and soil regulation. This was often based on firsthand experience of making changes themselves in these areas. The farmers' understanding detailed understanding of the nature of soil on their land was at very high resolution in relation to existing soil maps. Farmers were very easily able to interpret these soil data and in many cases were able to ground prood them efficiently..l It is currently impossible to get this level of detail from existing soils maps. This level of detail is invaluable when making decisions about interventions designed to address issues relating to water regulation in upland catchments. Not acknowledgeing this knowledge is also potentially dangerous given the degree of inaccuracy with existing soil maps that is indicated by the farmers local knowledge

The farmers' knowledge shared a number of complementarities with the research conducted on the farms. Farmer's local knowledge about hydrological process offered an insight into both the local environmental conditions (including temporal and spatial variations) and the effects of management practice within the Pontbren landscape. The blue fields in Figures 3.4, 3.5, 3.6 and 3.7 identify areas where there was demonstrable complimentarity between the farmer's knowledge and the research findings. At catchment scales the nested stream flow measurements found significant differences in the flashiness of the hydrographs between the unimproved *Melun-y-grug* and the improved pasture in the N*ant Pontbren* sub catchments (McIntyre and Marshall, 2010). Similarly the farmers' identification of the importance of drain flow was confirmed as drainage was found to contribute significantly to rapid field runoff. Examination of the flow records showed clear signals of agricultural intensification (Wheater *et al.*, 2008; McIntyre and Marshall, 2010).

Despite explicit acknowledgement of the value of participatory research, the initial interactions between the farmers and the research team were limited. During the early phases of the work the researchers mainly concentrated on measuring above ground processes (given their focus of the effects of tree material). The farmers were mainly observers in this process. During the initial experimental design the effects of sub surface drains were not properly considered within the research. Early feedback sessions with the farmers led to the farmers suggesting that the drains were significantly more important. After this the shift of the research focussed to integrate the understanding the drainage systems into the research. One PhD student working on the shelterbelts stated that she had spent three years confirming what the farmer had told her in a five minute conversation.

Farmers were unsure of the impact of farm trees on flooding at a landscape scales (although there were observed drying of soils adjacent to new tree cover and hedgerow features). There were only a limited number from the Pontbren group that have deliberately planted trees to try and impact their local hydrology. During interviews there was little mention of any potential local benefits to the farm hydrology from planting trees. Similarly the influence of trees, could not be identified in the research (McIntyre and Marshall, 2010). The wider role of trees in reducing flood risk at broader scales remains contentious (see McCulloch and Robinson, 1993; Alila *et al.*, 2009)

At catchment scales the research into sediment dynamics also confirmed many of the farmers' observations (Henshaw, 2009). Coarse sediment yields in the Nant Pontbren were found to be approximately twelve times greater (and fine sediment yields approximately five times greater), than from the unimproved *Melun-y-grug* sub catchment. Work on soil erosion in Wales (McHugh, 2000) suggests that the farmers are generally less aware of the erosion rates on their fields. Measurements of erosion in the catchment identified significant levels of material moving downstream under storm events, which contrasted with the farmers' observations that there was relatively little movement of materials downstream(Henshaw, 2009). The research did confirm bank erosion as a key source of sediment in the catchments. Research into the impacts of drains for sediment delivery is an area of emergent research, but research suggests that drains may play a significant role in sediment delivery from grasslands (Bilotta *et al.*, 2008)

3.4 DISCUSSION

In Wales, there is an emerging interest in more land use policy involving trees, implemented at a landscape scale, in relation to agricultural policy and agri-environment schemes (National Assembly for Wales, 2011). A key requirement is to address means of integrating the management of a broader suite of ecosystem functions at local scales. This makes it critical to explore how placement of trees for various purposes can impact flood risk, for example, and the consequent implications for development of spatially explicit land use policy. The Pontbren farmers had detailed local ecological knowledge about their land (including an understanding of the hydrological value of key features within their landscape at the resolution appropriate for making changes. The acquisition of this knowledge may provide a rapid method for enhancing land cover data available (and will also potentially increase farmer participation and 'buy in').

There were a number of gaps in the current scientific research that the LEK work identified – particularly the potential role of hedgerows in water function. Despite almost 23km of hedgerows being implemented at Pontbren, and their general popularity in comparison to other tree features, there is still very little known about hedgerows impacts on flood risk (Viaud *et al.*, 2005). The farmers' knowledge offered an insight into the root spread of hedgerow trees, and the likely maximum area of additional water storage gained under new hedgerow systems.

3.5 CONCLUSIONS

Both scientists and policy makers will generally lack knowledge relating to local practices and processes which may affect ecosystem function. One method to address this is the greater use of stakeholders' local knowledge of ecosystem function derived from observation and experience. Research revealed that local stakeholder's ecological knowledge suggested significant complementarities with scientific understanding of ecosystem function in the catchment that was useful for addressing data gaps and for validation of high resolution spatial datasets.

CHAPTER 4

A REVIEW OF THE POTENTIAL USE OF SPATIAL TOOLS FOR DECISION MAKING IN ECOSYSTEM SERVICE PROVISION

4.1 INTRODUCTION

"...in defining what the 'significant' functions of an ecosystem are and what constitutes an 'ecosystem service', an understanding of spatial context (geographical location), societal choices and values (both monetary and non-monetary) is as important, as knowledge about the structure and dynamics of ecological systems themselves."

(Haines-Young and Potschin , 2009)

The Millennium Ecosystem Assessment (2005) demonstrated that anthropogenic changes to natural systems present a significant threat to human wellbeing. Increasing requirements for food, fibre and fuel over the last 50 years have resulted in significant land use change which, in turn, has significantly decreased the capacity of many terrestrial and marine systems to deliver these and other ecosystem services that humans depend upon for their well being such as regulation of water flow and the conservation of biodiversity. Both the direct and indirect drivers of these changes, such as decreased ecosystem resilience associated with climate change, (Schroter *et al.*, 2005; Montoya and Raffaelli, 2010) and increased pressure for resources associated with population growth (Tilman *et al.*, 2001), remain active. These pressures have led to a third of the terrestrial surface area being converted into simplified agro-ecosystems (Bruinsma, 2003). The MA was able to demonstrate that by focussing management on the production of ecosystem goods, the flow of other ecosystem services had been altered, particularly those that provide a regulating capacity (MA, 2005). The conceptual framework offered by the MA, which has been increasingly refined in the numerous studies that have followed it (see, for example, Wallace, 2007; Seppelt *et al.*, 2011; Boyd and Banzhaf, 2007; Fisher *et al.*, 2009), provided a means for more holistic assessments of the impacts of anthropogenic change on the environment and novel methods for valuing ecological assets and for highlighting the importance of sound environmental management within society. Whilst the ecosystem services approach has now been widely recognised in policy (Fisher *et al.*, 2008) the concept has yet to be structurally integrated within environmental planning and management planning (de Groot *et al.*, 2010; Cowling *et al.*, 2008a; Daily *et al.*, 2009).

Managing landscapes for ecosystem services requires spatially explicit understanding of the flows of services from one area to another. This requires clear identification points of provision, flow pathways and the locations of actual (and potential) recipients of these services, in effect the supply and demand chain (Zhang *et al.*, 2007). Given this spatially explicit dimension, mapping ecosystem services is likely to be of fundamental importance in the transition from conceptual framework to operational planning and implementation. Amongst other things, explicit consideration of the scales at which services are manifest and the manner in which a range of stakeholders interact with them are required for valuation (Hein *et al.*, 2006b; Kozak *et al.*, 2011). For governance purposes the mapping of ecosystem services has been recognised as a key element to improve the inter-institutional understanding and for informing both strategic and operational decision making (de Groot *et al.*, 2010; Pettit *et al.*, 2011). Given the requirement for interdisciplinary and user oriented research, envisioned by the ecosystem approach (Cowling *et al.*, 2008a), maps also provide a visual and thus intuitive method for communicating information amongst resource managers and members of the public, about the often complex nature of interactions amongst ecosystem services. However, despite widespread acknowledgement of the importance of adopting a spatially explicit approach (see, for example, Swetnam *et al.*, 2011), methodologies focussing on mapping of ecosystem services have received relatively little attention (Morse-Jones, *et al.* 2011).

Whilst ecosystem planning and management can and does occur at many scales, actual changes on the ground will tend to be delivered by land managers who, in many cases, will be farmers. These people will tend to be non expert in ecosystem management. Instead their management decisions will be strongly influenced by the demands required to meet their livelihoods, which in turn will be driven by societal needs (the requirement for food security will always be a powerful driver with broad support from all stakeholders). Land managers can be insulated, to a degree, from the effects of their management decisions as the impacts may be felt away from the point of change in both a spatial and temporal sense. Changes in the regulating capacity associated with these modifications may impact stakeholders at a range of scales (Hein *et al.*, 2006a).

For an ecosystem approach to be successful there is a need for tools that enable land users to meet their livelihood demands and engage with more holistic decision making that takes into consideration the broad spectrum of ecosystem services potentially affected by their management decisions. This requires greater knowledge exchange between experts and non experts at scales appropriate for the ecosystem services being considered. In most cases farmer level decision making is limited to management within the farm boundary, but an ecosystem centred approach requires decision making that takes into consideration landscape scale processes beyond farm boundaries. For many ecosystem services and land use changes, it is not only scale that is important, but also the position of the farm within the landscape and of possible land use interventions within the farm, that will determine impacts on ecosystem service provision. For example, management changes that affect the water regulating capacity of a feature (such as a forest or field) will only influence ecosystem service delivery downstream from the intervention point. There is, therefore a requirement for spatially explicit and co-ordinated management across sectors (e.g. agriculture, forestry, biodiversity conservation and water regulation) based on shared visions amongst multiple stakeholders (Vanclay *et al.*, 2006). Mapping ecosystem functions at these operational scales will have a vital role in facilitating the negotiation of this process.

The broad aim of this work was to provide a critical review of current approaches to mapping ecosystem services. Firstly, the potential roles for mapping within an ecosystem services approach are identified and outlined, providing a conceptual framework that is then used as the basis to review approaches documented in the peer-reviewed literature. The review identifies which ecosystem services are mapped, the scales at which mapping takes place and approaches to mapping flows of ecosystem services from one land unit to another. The main research objectives were:

To review the extent to which existing mapping approaches can be used to inform local decision taking about land use change and its impacts upon ecosystem service provision.

1. What are the appropriate scales for management of ecosystem services in relation to impacts of land use change on ecosystem services?
2. What are appropriate scales for measuring impacts on recipients?

4.2 METHODS

The review initially drew on materials from an ISI web of Knowledge search using the terms ('spatial' or 'mapping' or 'spatial modelling' or 'visualisation') and 'ecosystem services'. Given its prevalence within policy documents and its profile the MA (2005) provided the current baseline typology for ecosystem services in this study (see also Section 4.2.1 below). The review was confined to publications produced after the publication of the Millennium Ecosystem Assessment, that is between 2005 and July 2011 (when the search was processed). The initial search returned 207 articles covering both terrestrial and marine ecosystems. From this list studies were selected that had produced mapped output that could be used for ecological restoration or to inform decision making either at landscape or at broader strategic scales. Where appropriate other mapped output referenced by these studies was also included. Where multiple studies were linked to one site, they were grouped together (e.g., Egoh *et al.*, 2008; Egoh *et al.*, 2009; Egoh *et al.*, 2011). This resulted in a final set of 52 peer reviewed studies evaluated in the review (see Appendix 2)

Given that much of the ongoing work on mapping ecosystem services remains unpublished, much of the reporting associated with these tools exists as 'grey' literature or appears on websites (i.e. it is does not follow the standard peer review process). Whilst we acknowledge that existing tools may be more capable then represented in current publications, the review here was restricted to published output associated with the tools. Finally, given the focus on Welsh ecosystems the

Countryside Council for Wales's report on mapping of ecosystem services in Wales (CCW, 2010) was also included.

4.2.1 Framework and Definitions+`

Ecosystem service typology

A common problem with ecosystem assessments relates to ambiguity in the manner in which key terms (such as ecosystem good and services) are defined and the variation in typologies of ecosystem services used (Wallace, 2007). Here we give a brief overview of current issues with regard to capturing spatial characteristics of ecosystem services within ecosystem service typologies. The baseline typology was developed by the MA (2005) and divided ecosystem services into four main categories; these are summarised briefly below:

- Supporting services represent long term ecosystem functions that support the delivery of other services (including primary production and long term nutrient cycling),
- Provisioning services represent the goods derived from ecosystems and include food, water, fibre and fuel),
- Regulating services represent the benefits derived from ecosystem functions such as the regulation of flows of water, soil, climate and organisms.
- Cultural services which are the social benefits derived from natural systems, including recreation and enjoyment of aesthetically pleasing features.

Whilst the MA typology was appropriate within the context of a global assessment and an important output in its own right (ICSU *et al.*, 2008) there were recognised issues both in terms of valuation (Wallace, 2007; Boyd and Banzhaf, 2007) and for use in implementing practical approaches for management (Armsworth *et al.*, 2007). More recent typologies (Haines-Young and Potschin, 2009; Fisher *et al.*, 2009; Fisher and Turner, 2008; Morse-Jones *et al.*, 2011) distinguish between stocks of natural capital (which encompass landscape structure and function), the flows of services and finally the benefits derived (see Figure 4.1 below). These are largely to limit double accounting of ecosystem services.

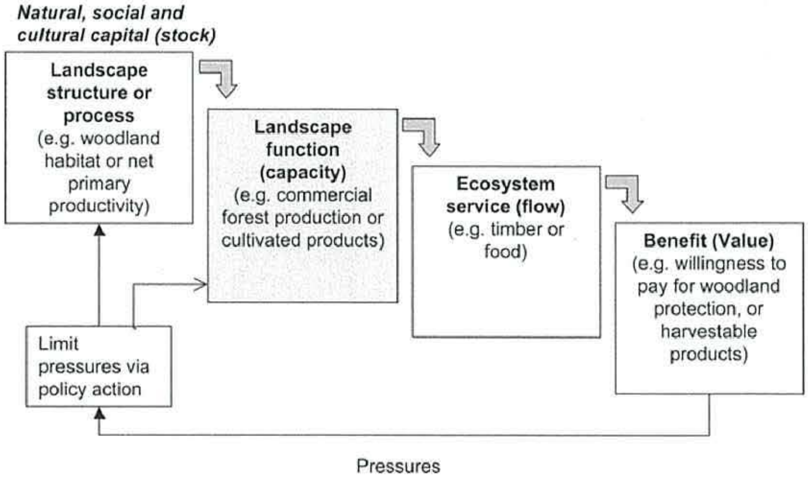


Figure 4.1: Conceptual framework for analyzing landscape functions (from Kienast *et al.*, 2009 redrawn and adapted from Haines-Young and Potschin, 2009)

A number of studies have suggested a need for more spatially explicit typologies (*see* Boumans and Costanza, 2007 and Fisher *et al.,* 2009). In addition, there are inconsistencies in the way that biodiversity is valued. Whilst not seen explicitly a service within the MA biodiversity was considered to underpin ecosystem service provision. More recent typologies have considered it as a cultural service due to its existence value (see, for example, habitat services in The Economics of Ecosystems and Biodiversity (TEEB) reports (Maes *et al.*, 2011) or option use value (Ruiz-Frau *et al.*, 2011). There is an ongoing requirement for an updated more universally accepted typology for ecosystem services (Fisher *et al.*, 2009; Morse-Jones *et al.*, 2011) – see also Section 4.3.4 below. Whilst acknowledging the limitations identified above, the MA typology was used as the baseline typology within this study because it the most widely used and understood at the present time.

4.2.2 Definitions of scale

Ecosystem services are manifest at a range of scales, often with non-linear relationships amongst scales, which makes mapping flow pathways complex for individual services let alone the complex interactions amongst multiple ecosystem services. Decision making associated with ecosystem service delivery also takes place at a range of scales from field level decisions of individual farmers to institutional strategic planning at national scales (Hein *et al.*, 2006a). The resolution at which ecosystem services are mapped is critical for understanding both their impact and their utility to different user groups (Kozak *et al.*, 2011). The concept of 'landscape' scales appears throughout ecosystem service literature (de Groot *et al.*, 2010; Schellhorn *et al.*, 2008). Whilst there is a need for a solid definition of what constitutes a landscape in many respects this term is indefinable (Jackson *et al.*, 2007). In practice, different landscape units can be defined for different purposes, such as watersheds, habitat networks or administrative districts and there will be different overlapping boundaries relevant to different ecosystem services and management units. This study explores the degree to which landscapes were defined within the studies reviewed. For the purposes of this review, we differentiate between three scales at which mapping of ecosystem service provision is likely to be required. These represent the main scales at which decision making about ecosystem service provision are likely to be made:

Local scale: this is the scale at which local level decision making about change in land use occurs by farmers, forest managers or other land users. It encompasses field scale through to immediate landscape scales (10-1000 km^2) at which ecosystem services are manifest and may be managed (e.g. sub-catchments, contiguous farmer co-operatives and habitat networks). Maps generated at these scales would allow farmers to see their land in a recognisable context and them and other stakeholder to see the contribution it makes to ecosystem services manifest at immediate landscape scales.

Regional scale defined here as the scale between local and national. This is the scale at which most policy decisions relating to ecosystem service provision are likely to be made and is generally over 1000 km^2 but sub-national. The resolution required for regional decision making is generally quite coarse.

National scale is defined here as the scale at which strategic decisions about ecosystem services are made including national and in transboundary contexts (e.g. some major lakes and protected area networks), international scales. Assessments at these scales use aggregated datasets based on national scale data and hence very coarse spatial datasets (where system boundaries are based on national borders).

4.2.3 Land use mapping and resolution of spatial data

Currently land use datasets have a fundamental role for mapping ecosystem services;. Scientists have tended to use indicators based on land use/land cover as a proxy for the provision of services (Marion, 2009; Nelson *et al.* 2009). The ability to map, for example, tree cover in an area will allow an approximate measure of the degree of water regulation occurring within a landscape. These relationships remain largely untested for most services (Naidoo *et al.* 2008; Bennett *et al.*, 2009). Despite this mapping the areal extent and the position of these features is fundamental for understanding their role in ecosystem service provision. The resolution of this data will have a significant effect on these calculations, with datasets that pick up, for example, individual trees likely to provide much more accurate data than a dataset that can only register large areas of woodland. Mapping ecosystem services will often require integration of multiple spatial datasets, which may have different resolutions (for example the degree of carbon sequestration will be heavily affected by the soil upon which the trees are growing). Soil datasets are often coarser than land use data for example, the NSRI Soilscapes data which maps soil in the UK is considered relatively high resolution at 1 km^2 (Farewell *et al.*, 2011). The potential variance in resolution between datasets is likely to be a major source of uncertainty. As we move between scales there is a clear tension in transaction costs associated with developing detailed maps and the use of simplified land use datasets that facilitate modelling ecosystem service provision at broader scales.

4.2.4 Stakeholder categories

Ecosystem services, by definition, are explicitly linked to human welfare. For the purposes of this review we recognise three broad stakeholder groups involved in ecosystem service decision making: ecosystem managers, ecosystem service receptors, and intermediaries. These definitions are based on work by Swallow *et al.*, (2007) exploring Payments for Ecosystem Services (PES). *Ecosystem managers* are defined here as entities (an individual, family, group or community) whose actions directly modify the quantity or quality of ecosystem services being generated, either positively or negatively. Ecosystem service receptors are interested and affected parties located in ecosystem service reception areas who are, either explicitly or implicitly, impacted by the ecosystem services generated by an ecosystem. *Intermediaries* are the diverse set of entities (including policy makers, non-governmental organizations, the scientific community and community organizations) that directly or indirectly shape interactions among ecosystem managers, ecosystem service receptors, and the ecosystem itself. As with (Swallow *et al.*, 2007) we recognise that none of these groupings are exclusive, and it is entirely possible for an individual actor to belong to more than one group

4.2.5 Attributes measured

Utility

To explore how maps were currently being used within the ecosystem approach a mapping framework was created. This describes the main roles for mapping. The mapped output from existing studies was then analysed using this framework to identify the current focus of approaches.

The extent to which the tools were useful for local level decision makers was also explored.

4.2.5.1 Scale and resolution

Given the uncertainty associated with terms such as 'landscape' identified above, this review explores how the concept has been approached in the studies and the rationales used for defining system boundaries. Moving between scales requires some degree of simplification of spatial datasets (Seppelt *et al.*, 2011). Even though landscapes can be broken down hierarchically into smaller functional units based on topography the process of ''scaling up from intensive ecosystem studies is not linear because of differences among landscapes and interactions between adjacent land uses" (Costanza *et al.*, 2002). The resolution of spatial datasets has implications both for identification and recognition of functional units within a landscape and decision making associated with their management. The area of effect and the degree to which flow pathways were mapped both spatially and temporally were also considered.

4.2.5.2 Characterisation of ecosystem services

A fundamental requirement for adopting an 'ecosystems approach' to management is that whole ecosystems and their benefits are taken into consideration. The degree to which spatial tools not only consider multiple ecosystem services but also the interaction between them is critical. The ability to map multiple ecosystem services together allows identification of synergies and tradeoffs that are vital for holistic planning. Studies that selected only a limited subset of ecosystem services were likely to be of significantly lower utility within an ecosystems approach (Everard, 2009). The extent to which current approaches addressed this was reviewed, both in terms of types and numbers of ecosystem services mapped. The degree to which services were defined consistently was also assessed – as this has implications for comparative studies

4.2.5.3 Uncertainty and validation

As many ecosystem services are part of complex non-linear multi-component systems there is still considerable uncertainty associated with scale-dependencies and scale–interactions and temporal aspects (Kremen and Ostfeld, 2005). Lack of data is a key constraint for understanding ecosystem process (Kremen and Ostfeld, 2005; Carpenter *et al.*, 2009). In spatial mapping proxies are often used to represent ecosystem service despite reservations about their reliability at different scales (Eigenbrod *et al.*, 2010a). The degree to which uncertainty was represented within mapped output was assessed. Given the interest in using maps for operational purposes it was important to look at how involved different stakeholders were in developing, validating or utilising maps.

4.3 Results and discussion

There has been an exponential growth in research into ecosystem services (Fisher *et al.*, 2009), much of which includes some element of mapping. This study was initially restricted to peer reviewed studies where the provision of maps of ecosystem services was a central focus of the work. Research specifically on the development of spatial tools appears to be following a similar but delayed trajectory with 58% of the studies reviewed here being published within the last two years.

4.3.1 The role of mapping

The conceptual framework for ecosystem service provision provided by Haines-Young *et al* (Haines-Young and Potschin , 2009) translates easily into basic mapping requirements (see Figure 4.1 above). Spatial assessments are a prerequisite both for identification and compilation of inventories of 'functional units' (i.e. assessments of the natural capital). At finer scales mapping the orientation and position of these features will enable identification about the nature and strength of services being provided. Mapping flow pathways is important for determining the area of effect, who will benefit and potential interactions between other ecosystem services (either synergistically or in competition). Linking ecosystem services to human well being requires identification of the receptor areas for ecosystem services; this is fundamental for determining the value of ecosystem services.

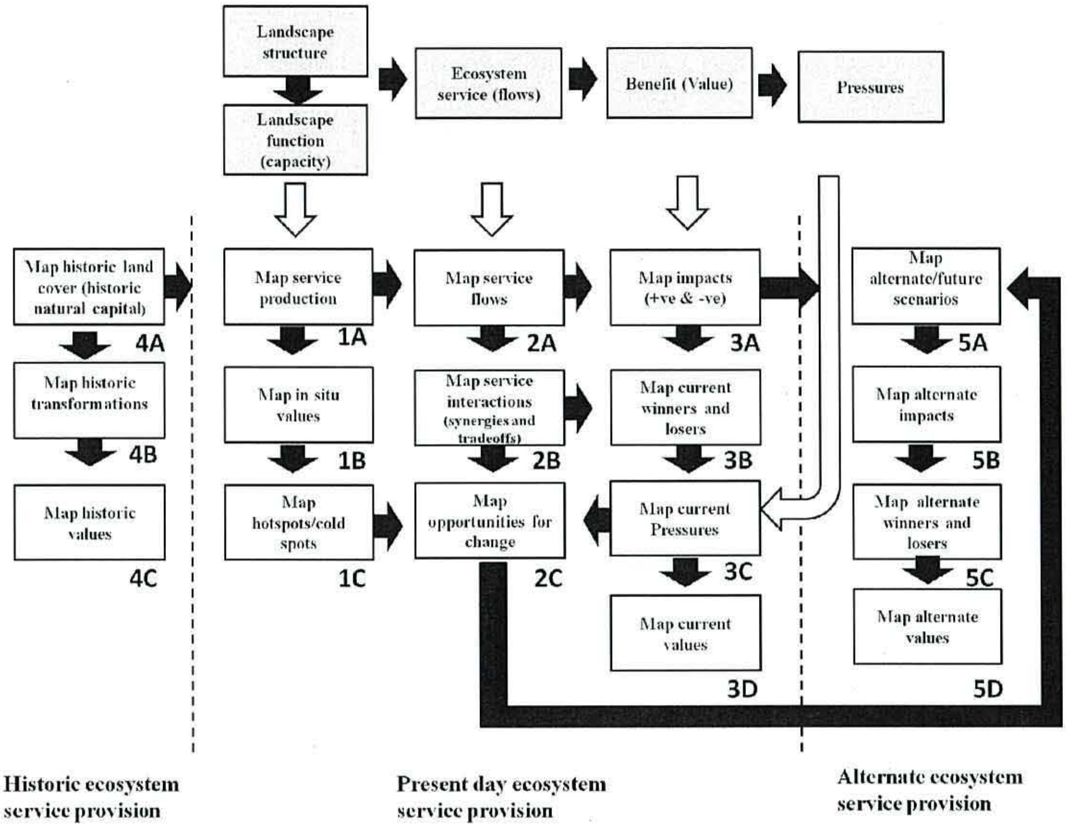


Figure 4.2: Mapping requirements for assessing ecosystem service requirements expanded from the stock-flow-receptor conceptual framework (shaded nodes) developed by Haines-Young *et al.* (2009). Unshaded nodes indicate forms of mapped output, filled arrows show major instances where one form of mapped output is used in the development of another and unfilled arrows show connections between the stock-flow-receptor framework and mapped output.

The mapping framework presented in Figure 4.2 builds on the basic stock-flow-receptor model of Haines-Young *et al.* (2009) and draws on other studies (Fisher *et al.*, 2009; de Groot *et al.*, 2010; Morse-Jones *et al.*, 2011; Cowling *et al.*, 2008b) to identify 16 broad categories of mapped output. They are arranged sequentially. This framework incorporates temporal components and explicitly explores synergies and tradeoffs amongst services.

The scale at which each node is mapped is fundamental to the utility of the map produced. Mapped output produced at national, regional or operational scales will vary in their degree of accuracy and their potential utility to different stakeholder groups. For example, opportunity maps produced at resolutions appropriate for large landscape scales may indicate areas where changes are required; offering only limited utility for ecosystem managers, who require information about actual changes to be made on the ground – which may involve very local level tradeoffs not captured at regional scales. The requirements for mapping over different time periods may also vary. The 16 categories of mapped output and their interactions are discussed below referring to nodes by their alphanumeric coding in Figure 4.2.

4.3.1.1 Stocks of natural capital

At the point of ecosystem service provision the spatial arrangement, quantity and composition of *functional units* within a landscape will have a strong influence on both the nature and amount of services produced (node 1A). As all landscapes exhibit degrees of heterogeneity in their composition understanding spatial variation in the location of similar types of functional unit (particularly at landscape scales) is a key requirement for assessments of their capability to provide ecosystem services and for decision making associated with their management. By associating features with ecosystem services, in situ values (node 1B) can be assigned, using, for example, benefit transfer approaches, where values are assigned to objects with specific characteristics and later used to assign values for objects with similar properties in other systems (see Lautenbach, 2011; Troy and Wilson, 2006). Acknowledging the potential roles of keystone features (or landscapes) to provide multiple ecosystem services allows identification of hotspot or coldspot (1C) areas. Note that these valuations are *in situ* focussed solely on the point of provision and do not acknowledge variation in reception of ecosystem services.

4.3.1.2 Flows of ecosystem services

Ecosystem functions are recognised as 'ecosystem services' when humans benefit either directly or indirectly from them and hence there is a need to map some service flows (node 2A – see above) from the point of provision to reception. The area of effect associated with an ecosystem service ranges from *in situ* benefits (such as the provision of shelter) to benefits realised at a global scale (such as mitigation of global warming through increased carbon sequestration). As such, some ecosystem services have no flow component whilst others have diffuse or global benefits (e.g. global climate regulation). Where flow pathways exist the value of services may vary in relation to the location of recipients. Topography may modify value of some services along the flow pathway, the number of uses and users of a service and the scarcity or abundance of the benefits within receptor populations may also influence value (Morse-Jones *et al.*, 2011). Synergies and trade-offs can exist amongst ecosystem services at the point of provision (where a functional unit is associated with the provision of multiple services such as woodlands on marginal land providing a broad range of provisioning, regulating and cultural services), or a mixture of benefits and disadvantages (e.g. a wetland providing multiple benefits for water quality and regulation but limiting the agricultural productivity of an area). There may also be interactions amongst ecosystem services within the flow pathway and at the point of reception. Explicitly identifying service interactions in terms of synergies and tradeoffs amongst ecosystem services (node 2B – see above) is fundamental to managing them for broader societal benefits. Once stocks, flow pathways and synergies/trade-offs between ecosystem services have been identified it is then possible to identify opportunities for interventions to improve ecosystem service provision (node 2C – see above). These are areas where change will improve ecosystem services in relation to management objectives for a given landscape, taking into account impacts on those ecosystem services (and stakeholders) likely to be affected by the interventions. Whilst priorities for interventions can be informed by landscape and strategic scale analysis, the final decisions about what interventions to make where, in a particular landscape, requires mapping and implementing management decisions at local scales down to that of the farm and the field.

3.3.1.3 Impacts

To link ecosystem functions and benefits to human wellbeing requires explicit acknowledgement of the points of reception for ecosystem services at which impacts are manifest (node 3A – see above). Understanding the linkages between ecosystem provision and ecosystem receptor areas is important for policy development as decisions by 'upstream' stakeholders' to meet local requirements may lead to positive or negative consequences from the perspective of 'downstream' stakeholders at larger scales (Hein *et al.*, 2006a). Once receptor areas have been identified then stakeholders who benefit ('winners') and stakeholders who either do not receive services or who see a decrease in service supply ('losers') can be identified (node 3B – see above). This may be complicated as for any change in land use, individual stakeholders may be winners within the context of some ecosystem services and losers in relation to others, especially when temporal elements are taken into account (for example, where unsustainable land use strategies provide short term benefits but degrade the system over the long term). The spatially explicit identification of winners and losers allows identification of drivers for modification to existing ecosystem service provision or pressures (node 3C – see above). This can be fed back into opportunity mapping (node 2C - see above) to support an iterative decision making process. Finally, values (nodes 3D, 4C and 5D – see above) can be mapped for past, present and future or alternative scenarios of ecosystem provision. These values focus on the point of reception (to beneficiaries of those services) and are likely to be different from values which focus on the point of provision (i.e. the value of retaining keystone features within a landscape itself – node 1B)

4.3.1.4 Temporal components

Ecosystem service provision has strong temporal dimensions. Developing a spatially explicit understanding of trends in ecosystem service supply is vital for future management. Mapping the impacts of historic land use change helps to explain variation in current ecosystem service supply and provides valuable information on the nature of potential interventions to address shortfalls in delivery (by identifying historic land use). Mapping both historic land cover (node 4A) and historic transformations (node 4B) can provide valuable insight into both current and future ecosystem service delivery (see Reyers *et al.*, 2009 for an example) and feed into identification of opportunities for interventions (node 2C).In a similar way requirements to understand future drivers of land use change (e.g. the effects of climate change) or exploration of alternative scenarios for land use requires development of future/alternate land use maps (node 5A) that can be used to inform models of ecosystem flows. These can be used to then map potential impacts (node 5B – see above) and potential winners and losers (node 5C – see above)

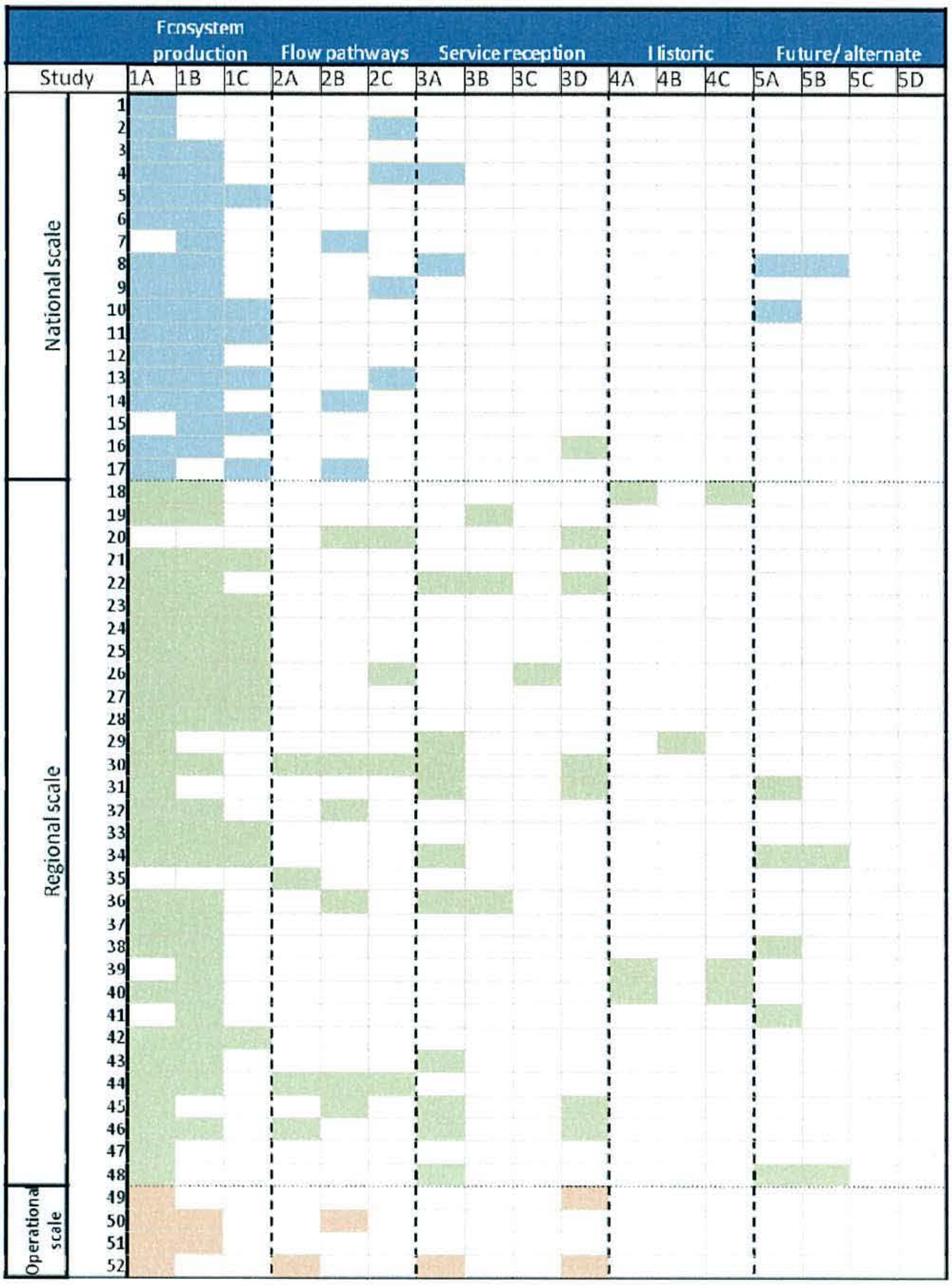
4.3.1.5 Uncertainty

Given the widely acknowledged gaps in data about ecosystem processes, the degree to which maps present uncertainty is an important consideration. There is an increasing move towards explicit acknowledgement and communication of uncertainty when negotiating land use management (Morss *et al.*, 2005).

4.3.2 The utility of spatially explicit methodologies

Table 4.1 provides an overview of the categories mapped in the 52 studies reviewed. This is based on the conceptual framework described in Figure 4.2. The maps presented in the studies seldom describe a single node in isolation and usually combine two or more of these nodes together.

Table 4.1: Summary of the relationships between ecosystem mapping approaches (n=52) and the conceptual framework presented in Figure 4.2. The studies are disaggregated by scale where blue = national scale, green = landscape scale and orange = local scale).



Analysis of Table 4.1 suggests that, as might be expected in the early stages of methodology development, the output focuses on the nodes related to mapping stocks of natural capital. Much of the existing research focuses on describing ecosystem service production (nodes 1A or 1B). Most of the studies focused on providing national or regional scale output for areas greater than 1000 km^2.

Only four studies mapped flows of ecosystem services (node 2a) (Kozak *et al.*, 2011; Beier *et al.*, 2008; He *et al.*, 2011; Nedkov and Burkhard; Simonit and Perrings, 2011). Tracking services from the point of provision through to the point of supply is critical for most ecosystem services – especially regulating services. It is dangerous to assume that any service arrives at the most 'logical' destination (based on proximity or topographical routing). For example, protein production in Wales is primarily aimed at the export market with 80% of livestock destined for overseas markets and significant amounts of water (equivalent to the daily requirements of the entire Welsh population) are abstracted from Welsh catchments through canal systems to provide water for Birmingham (Russell *et al.*, 2011).

Whilst many maps presented spatially distributed values these did not constitute flows (see Swetnam *et al.*, 2011; Troy and Wilson, 2006; Chen *et al.*, 2009; Tallis and Polasky, 2009). In some instances the nature of the ecosystem service being mapped meant that mapping flows were unnecessary (i.e. carbon benefits - see Swetnam *et al.* 2011). Where multiple ecosystem services are mapped representing flow pathways is complex. This is a significant gap in current mapping methodologies and makes mapping interactions between ecosystem services difficult unless synergies and tradeoffs are explored at the point of provision. 16 studies identified ecosystem service hotspots (as in Figure 4.3) - where functional units deliver multiple benefits ((Egoh *et al.*, 2009; Bai *et al.*, 2011; O'Farrell *et al.*, 2010; Crossman and Bryan , 2009; Gimona and van der Horst , 2007) but these were focussed on the point of provision and did not explicitly identify who benefits and where those benefits were manifest.

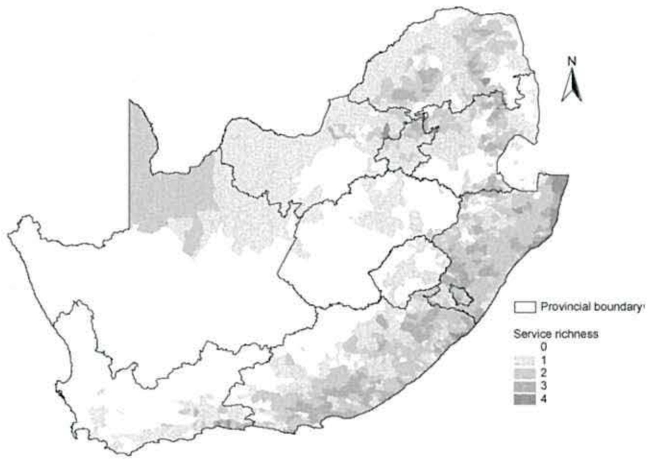


Figure 4.3 Map showing number of ecosystem service hotspots per catchment in South Africa, based on five ecosystem services: surface water supply, water flow regulation, soil accumulation, soil retention, and carbon storage (Egoh *et al.*, 2008).

Related to this there were 13 attempts to map receptor areas for ecosystem services (node 3a). Where geographical locations were identified there was no clear link to final recipients. Even in cases where recipients were clear such as for flood risk (Nedkov and Burkhard; Batker *et al.*, 2010) while it was relatively easy to document stakeholders who have been flooded there was no attempt to identify potential beneficiaries of floods – such as areas of farmland which have increased nutrient supply from seasonal flooding were included. The importance of developing appropriate methodologies directly linking services to recipients was demonstrated in Kozak *et al.*, 2011 where a comparative case study of two wetlands in Illinois demonstrated potential variation in value of the two wetlands between \$28,258 - \$2,548,793,956 and \$531,926 - \$216,284,749 respectively, dependent of the spatial discounting method used. This gap was acknowledged in a number of studies (Nelson *et al.*, 2009). The ARIES toolkit[8] should in principle be able to address this issue but the capability has not been demonstrated in published output.

Similarly, there was only limited identification of synergies and/or trade-offs amongst ecosystem services (see also section 4.3.4). Often these were implicit – through presentation of two maps – but some studies integrated output to produce ecosystem service hotspots (Egoh *et al.*, 2009; Bai *et al.*, 2011; O'Farrell *et al.*, 2010; Crossman and Bryan , 2009; Raymond *et al.*, 2009; Gimona and van der Horst , 2007). In almost all cases this was based attributes of key features at the point of

[8] http://esd.uvm.edu/uploads/media/ARIES.pdf

provision (1C) rather than a more holistic assessment over the range of the service. Valuing or bundling ecosystem services at the point of provision (Raudsepp-Hearne *et al.*, 2010) may be confusing as receptor areas for each ecosystem service may vary spatially.

4.3.3 Ecosystem services and scale

There was considerable variation in the scales used to map ecosystem service provision. As indicated in Table 4.1 most studies were at regional scales (>1000km^2 but sub-national). Four studies produced output at local scales below 1000 km^2, (Kozak *et al.*, 2011; Troy and Wilson, 2006; O'Higgins *et al.*, 2010b; Lavorel *et al.*, 2011). However, the resolution of these datasets varied (see also Figure 4.4) from detailed (10m^2 grids) to relatively coarse (30m^2 and above) potentially limiting their utility to ecosystem managers in terms of citing interventions to improve ecosystem service provision..

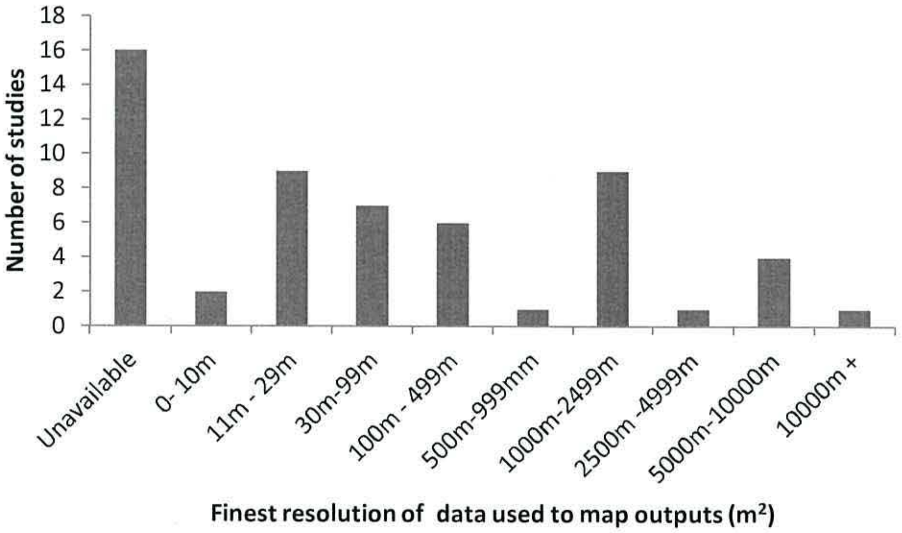


Figure 4.4 Resolution of data used to map outputs in reviewed studies.

There was a five fold order of magnitude range in the size of landscape mapped amongst studies (Figure 4.5), with a significant number of studies mapping areas over one million hectares. Only two studies used nested approaches, mapping ecosystem service provision at a range of scales (Troy and Wilson, 2006; O'Higgins *et al.*, 2010a).

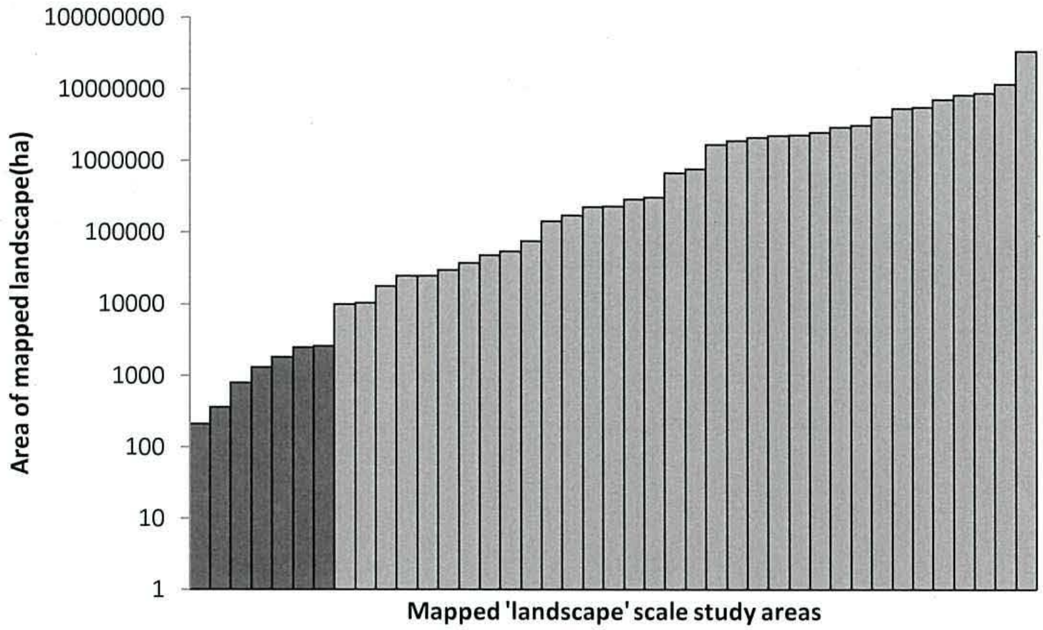


Figure 4.5 : Size of area of mapped at landscape scales (the bars in dark grey indicate output mapped at 'local scales' (<10 000ha)). National and international studies were not included.

Whist there is clear utility in mapping large scale changes in ecosystem service provision, there are clear limitations associated with using maps of this nature to inform on the ground decision making about lands use change. Moving between scales requires some degree of simplification (Seppelt *et al.*, 2011), which may ignore local level tradeoffs. Many of the maps of ecosystem services were composite views built by layering factors on top of each other. It was difficult to determine the resolution for most datasets presented as this was not explicitly expressed, also where multiple layers were mapped at different resolutions then interpretation of merged datasets becomes difficult (see, for example, Figure 4.5)

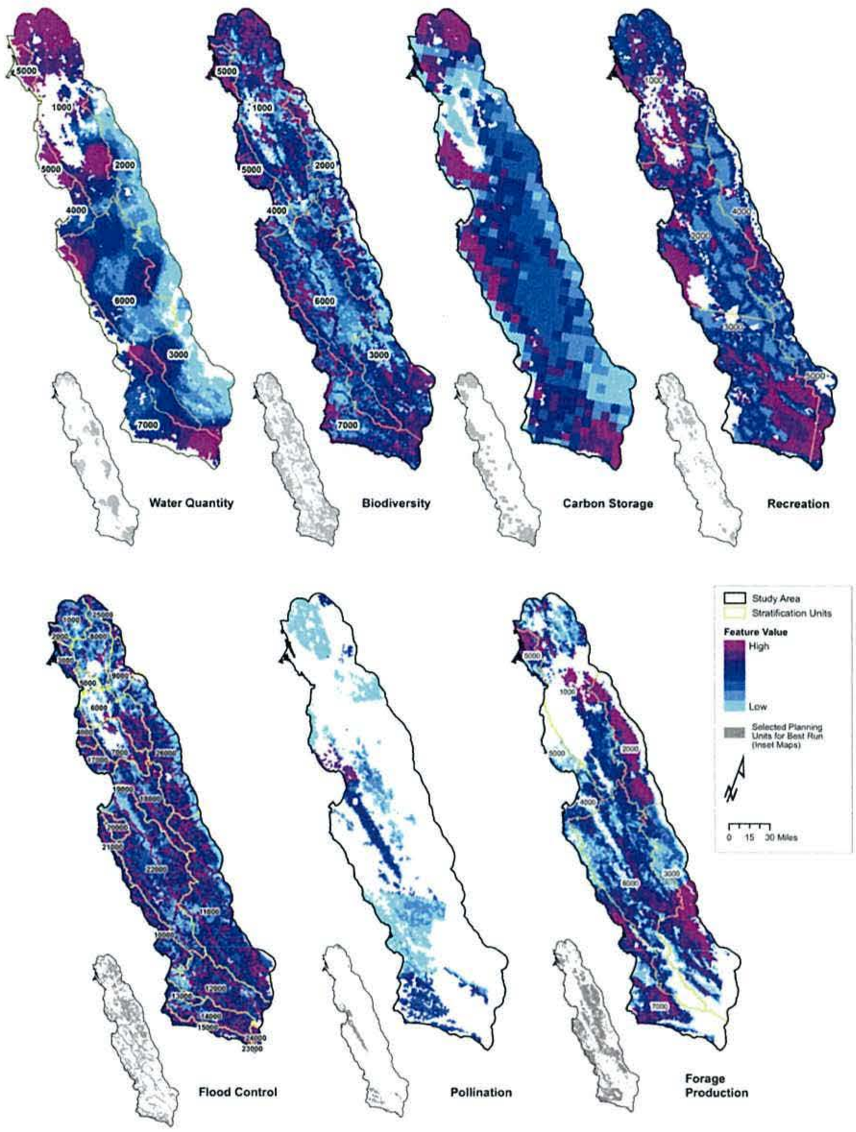


Figure 4.6: Output from Chan *et al.* 2007 showing clear differences in the resolution of spatial data being used, particularly for carbon storage(at 5 Sq. Mile resolution or 12.9 km^2) and the detailed datasets used for forage production.

A third of the studies focussed on national level ecosystem service provision (e.g., Egoh *et al.*, 2009; Eigenbrod *et al.*, 2010b; Wendland *et al.*, 2010) and a smaller number of international studies (Kienast *et al.*, 2009; Maes *et al.*, 2011; Luck *et al.*, 2009).

In all examples a single boundary was used to define the extent of ecosystem service delivery (see Figures 4.5 and 4.6 as examples) in almost all cases (with the exception of studies exploring flood risk and water regulation) the 'catchment areas' for individual ecosystem services were undefined (i.e. identification of a boundary associated with an individual service starting from point of provision through to point or reception). In most cases these were based on socio-political boundaries or catchment boundaries (despite some ecosystem services not being associated with water as in Figure 4.7). Whilst this was clearly pragmatic from a governance/management perspective there is clearly an issue with using a single boundary in this way to describe multiple ecosystem service delivery.

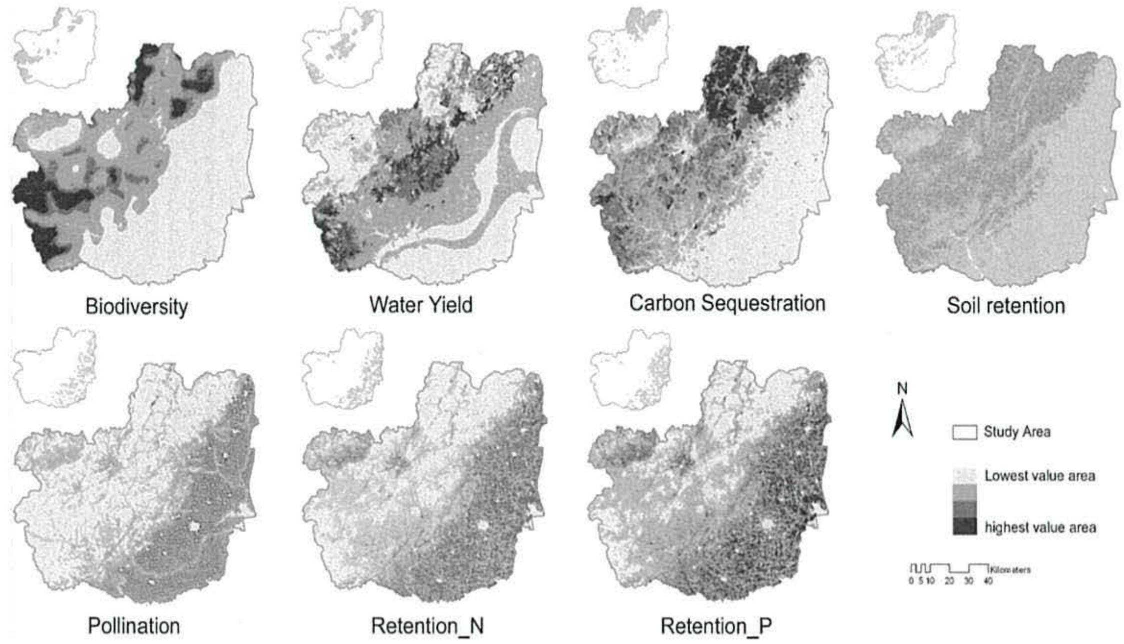


Figure 4.7 Spatial distributions of biodiversity and the six ecosystem services using the InVEST tool in Baiyangdian watershed (China)(Bai *et al.*, 2011). Only three of the ecosystem services illustrated (water yield, soil retention and P retention) manifest solely within the surface catchment area. The other services clearly leak outside (or would require mapping of the sub surface catchment (e.g. N retention) to map properly).

Whilst the rationale for ecosystem boundaries for the national tools was self explanatory (being based on political boundaries) there are clearly issues with using socio-political boundaries or even topographical boundaries for mapping ecosystem services where there is likely to be 'leakage' either into or out of the systems in question particularly where beneficiaries are not identified or potentially lie outside mapped areas. This is particularly important for transboundary water bodies and protected areas.

4.3.4 Characterisation of mapped outputs

There was significant variation in the number of ecosystem services mapped within the studies Figure 4.8) with 65% of studies mapping from 1 to5 services and only 13% mapping a single ecosystem service. Given the lack of mapping of recipients this suggests that many of the maps here are more realistically measuring ecosystem function and not ecosystem service provision. The studies that did map all ecosystem services were assessments based on interviews with local stakeholders (Raymond *et al.*, 2009; Bryan *et al.*, 2010; Bryan *et al.*, 2011; Maynard *et al.*, 2010). These were exclusive to Australia (and also included the largest regional scale studies).

i.

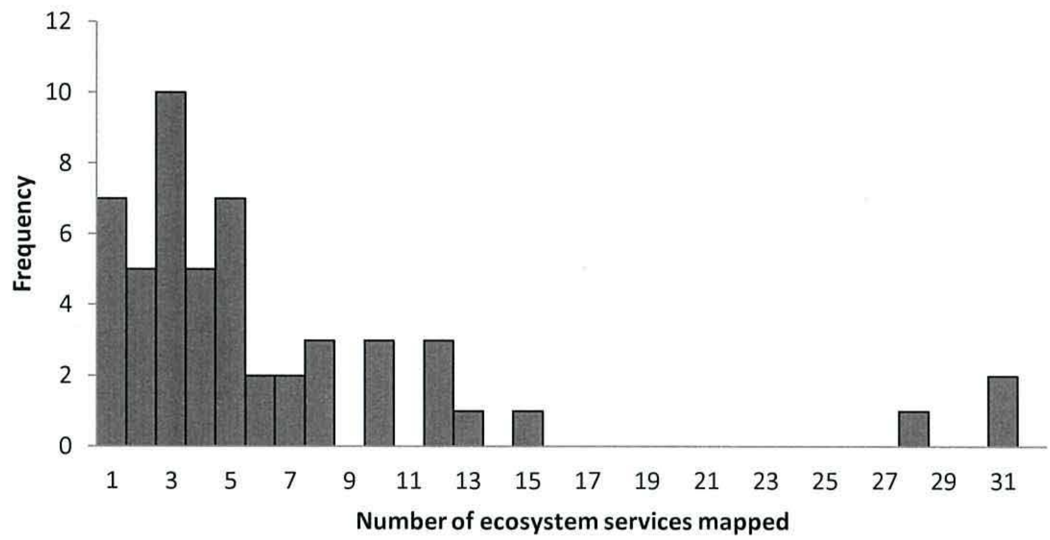


Figure 4.8: Distribution of number of ecosystem services mapped per study. Note: One study (He *et al.*, 2011) did not clearly indicate the number of ecosystem services mapped[9]

Of the services mapped the most common were regulating and provisioning services (Figure 4.9). Supporting services (where they were not part of the stakeholder focused studies mentioned above) were not mapped.

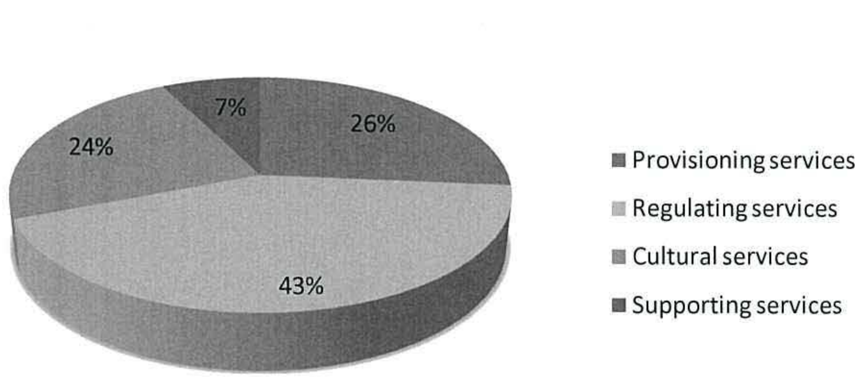


Figure 4.9: Proportion of different ecosystem categories mapped

[9] The proceeding study (in Chinese) suggests three, based on interpretation of presented graphs

There were considerable inconsistencies in how ecosystems were defined in the studies. Whilst many of the studies referenced the MA (2005), in a number of cases the typologies presented ignored, expanded or heavily modified the MA categorisation. A number of studies used composite services combining two or more services under one metric, for example, cultural value (Troy and Wilson, 2006; Liu *et al.*, 2010) or regulation services (Sherrouse *et al.*, 2011). Figure 4.10 gives an indication of the number of ecosystem services mapped but in many instances ecosystem services were presented which did not conform to the MA typology for example, farmer livelihood and energy production (Metzger *et al.*, 2006) or production of raw materials (Ruiz-Frau *et al.*, 2011). The MA used broad categories, such as climate regulation; but many of the maps showed carbon sequestration, which is a single component of climate regulation. As such, a degree of caution is required when interpreting the results presented in Figure 4.10 as there was an element of subjectivity to allocation of services.

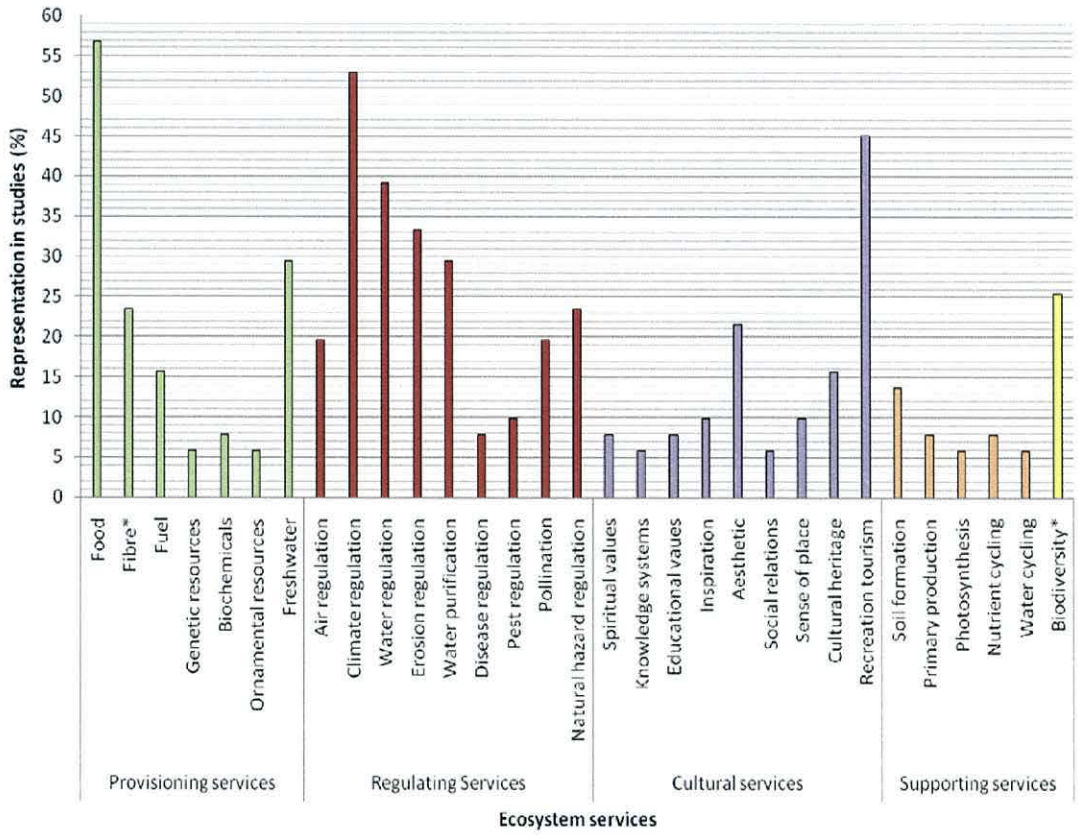


Figure 4.10: The types and frequency of ecosystem services mapped (based on the MA (2005) ecosystem service typology).

4.3.5 Temporal dynamics

Only four studies identified temporal variation in ecosystem service provision (He *et al.*, 2011; Bateman *et al.*, 2011; Zhang *et al.*, 2011; Burkhard *et al.*, 2010). One study (Reyers *et al.*, 2009) mapped historic land disturbance (see Figure 4.11) in relation to impacts on current service provision

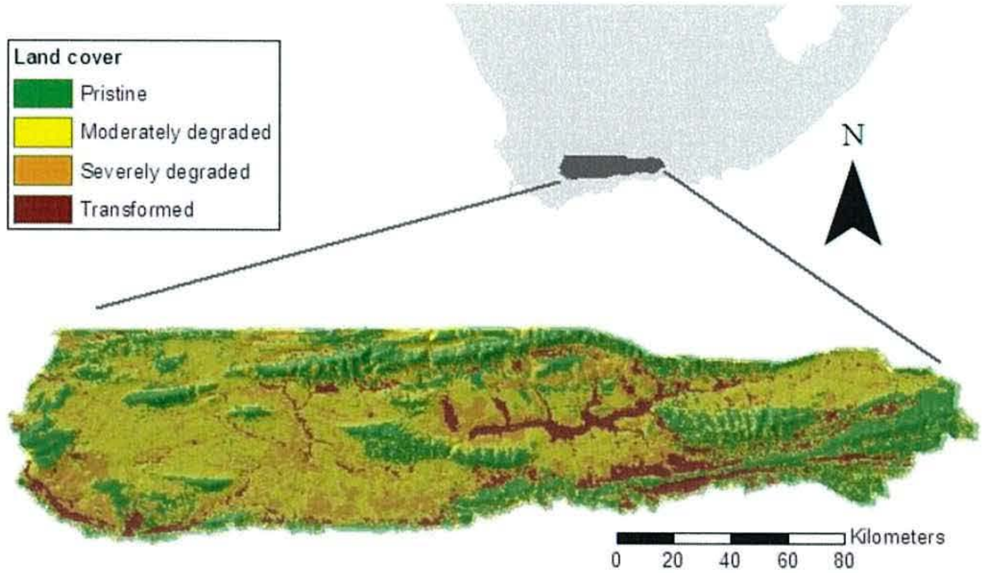


Figure 4.11: Transformed areas in the Little Karroo -South Africa (from Reyers *et al.*, 2009)

4.3.6 Uncertainty and validation

Uncertainty was handled in a variety of ways – in a limited number of studies it was the principal focus (Kozak *et al.*, 2011), but in most cases maps were presented with no acknowledgement of underlying uncertainty. In studies where alternate scenarios were presented the uncertainly is implicit (Bateman *et al.*, 2011; Wang *et al.*, 2009). While not addressed visually, uncertainty was explicitly discussed in relation to underlying data in three studies (Liu *et al.*, 2010; Metzger *et al.*, 2006; Willemen *et al.*, 2010) but largely ignored in other studies.

4.4 Conclusions

Despite the clear implications from the maps about changes to ecosystem supply there were very limited attempts at linking these results to target populations. Current approaches largely ignored direct interaction with stakeholders (with the exceptions of Swetnam *et al.*, 2011; Ruiz-Frau *et al.*, 2011; Raymond *et al.*, 2009; Maynard *et al.*, 2010; Bryan *et al.*, 2011). For example Gret-Regamey *et al.*, (2008) looked at impacts of urban expansion versus woodland expansion on probabilities of avalanches and mapped changes to areas of effect. This produced output that was clearly useful for town level decision making but it did not identify or link to all the stakeholders affected by the various options. This would have potentially been very useful for validation of output, and perhaps appropriate given the nature of the changes. There were no studies that drew explicitly on local knowledge held by people living in the area to ground proof output. A number of papers did look at stakeholder values associated with areas of ecosystem service provision (Pettit *et al.*, 2011; Raymond *et al.*, 2009; Sherrouse *et al.*, 2011). The methodologies employed to select stakeholders was unclear but did not explicitly include ecosystem managers living in areas associated with ecosystem service provision, nor stakeholders explicitly identified as recipients. The lack of information about stakeholder preferences and priorities constrains development of targeted management strategies.

All mapping methods presented appear to be in the early stages of development, despite many recent publications appearing, most are still in the development and testing phase. There was considerable variation in the methods used for ecosystem service evaluation, the selection of ecosystem services to be assessed, and the spatial scale to which they referred. This makes comparisons difficult and highlights a need for clearer. The main focus of almost all of the maps was on informing policy level decision making at regional or national scales. The methodologies presented were primarily aimed at informing science and intermediary groups (such as policy makers) rather than tools for operational decision making by local ecosystem managers (i.e. for use in agri-environment schemes for example). There is a clear need to develop tools that bridge this gap.

There was a large variation in the scales at which ecosystem services were mapped both in terms of the size of the landscape unit and the resolution of data. What constitutes a functional unit for the supply of ecosystem services is determined partially by the requirements of the observer and partially by the scale at which they are observed. This variation can have a strong influence on how landscape functions are perceived and measured. At a landscape scale an example of a functional unit could be a woodland, where collectively the assemblage of organisms (trees and associated biota) combines to provide a distinct set of services which differ from neighbouring land uses (such as an arable field). If the function is carbon sequestration then it is relatively straightforward to distinguish between these functional units in their ability to sequester carbon. Individual trees and hedgerows also sequester carbon, at varying degrees depending upon their age and location. These features are not frequently mapped and thus their collective impact is not taken into consideration. Where decisions are being made at scales which include these features then there is a clear requirement for higher resolution data.

Based on this assessment a number of clear requirements can be identified that would improve the utility of spatial tools for operational decision making at local scale:

1. Resolution

Policy makers (and other intermediaries) and land managers need to be able to see and prioritise opportunities for making and managing change across a range of scales. To do this first requires mapping natural capital at scales that are appropriate to the target audience. For local stakeholders this will require mapping at finer resolutions to capture land use features such as hedgerows and tree features that potentially provide ecosystem services. Developing operational approaches are likely to requires the ability to zoom down to field and farm scales. up to the immediate landscape. The resolution of output used in most studies does not support operational decision making at these local scales.

2. Flow pathways

A major gap identified in this review is the mapping of flow pathways. Fuller understanding of the interactions between ecosystem services requires that these pathways are identified. It also enables ecosystem service boundaries to be identified, and thus the final recipients of service. This may be critical where services flow over, for example, national boundaries. It is also reasonable to assume that the strength or quality of the service may not be equal everywhere – there may be degradation of the service as one moves away from the point of provision (especially for diffuse services such as pollination). Given the dynamic nature of flow pathways there is scope for utilisation of more dynamic visualisation tools that can capture the fluidity of the processes. All the studies reviewed offered static maps

3. Synergies and tradeoffs

Mapping the interrelationships between ecosystem services is essential in an ecosystem approach (as it identifies the manner in which changes deliver benefits or negative impacts). There is a need to develop holistic techniques for exploring multiple ecosystem services together, possibly through the use of ES bundles (Raudsepp-Hearne *et al.*, 2010). Integration would be facilitated by the use of consistent typologies of services. Identification of synergies at the point of provision does not necessarily produce the same results to all beneficiaries as the benefits may be realised at different locations – currently the ability to map these are very limited.

4. Uncertainty

Developing spatial output for decision making in data sparse environments is challenging. The general lack of data available for many ecosystem processes for most landscapes means that is a high likelihood that decision making will not be evidence based At operational scales where stakeholders may which to use mapped output to negotiate land use change, there is a requirement to communicate and discuss this uncertainty. This was a major gap in the output presented in this review.

5. Land use data

Issues have been raised about the use of land use datasets as a proxy for ecosystem services (Eigenbrod *et al.*, 2010a) but clearly the quality of the land use data will play a significant role in delivering useful output. At operational scales local stakeholders will need to be able to identify features for which they have management responsibility. There are also a number of features for which there are no central repositories of mapped data (such as sub surface drain systems in the UK). These gaps need to be acknowledged. Scaling up land use datasets is necessary for regional or national scale toolkits but care needs to be taken such that small scale features which may be critical for ecosystem service delivery are not overlooked.

6. Stakeholder engagement - Linking ecosystem services to recipients

In all but a minority of the studies presented recipients of services were ignored. Given the utilitarian nature of ecosystem services there needs to be clear identification of where beneficiaries are in relation to service provision (and also clearly where services are not reaching intended recipients). It is also reasonable to suggest that many stakeholders are unaware of the role their environment is playing in their well being. It is critical that spatial tools cater for non expert engagement in their output. The output produced needs to be understood by a range of different stakeholders. Ideally spatial tools should assist in the flow of information between the three broad stakeholder groups outlined in this study.

CHAPTER 5

REQUIREMENTS FOR SPATIALLY EXPLICIT NEGOTIATION OF ECOSYSTEM SERVICE SYNERGIES AND TRADE-OFFS

5.1 INTRODUCTION

Chapter Five describes the specification and application of a spatially explicit approach for negotiating ecosystem service provision in Wales. The first section details the development of specifications for the approach. Then findings from the initial application at Pontbren and the Elwy catchment are described. The final section explores the utility of the approach.

5.1.1 Background

The concept of 'ecosystem services' has been increasingly used to account for the broad suite of benefits people derive from nature (Daily, 1997; Costanza *et al.*, 1997; MA, 2005; de Groot *et al.*, 2002). The Millennium Ecosystem Assessment (MA) provided a powerful summary of the effects of ecosystem degradation occurring globally and the sobering implications for human well being. Its publication also produced a step change in the amount of attention paid to the concept by both scientists and policy makers (Fisher *et al.*, 2009; Defra, 2007; Defra, 2007). The MA identified a number of different anthropogenic drivers that had accelerated degradation of ecosystems over the last 50 years. These included land use change (primarily for the provision of food, fibre and fuel), climate change, invasive alien species, overexploitation, and pollution. Given the varied landscapes (and seascapes) in which humans operate there is unlikely to be generic solutions to these problems. Developing site specific holistic strategies will require collaboration between scientists, policy makers and land users at the scales at which changes are being made to ecosystems (which we define here as a 'local' scale - see also Chapter 4 Section 2.2). Achieving this goal will require integration of ecosystem service concepts into management strategies so that a broad range of services are explicitly considered in decision making (Daily *et al.*, 2009).

Much of the research on ecosystem services has focused on economic valuation (Costanza *et al.*, 1997; Cornell, 2011) which provides a rationale or evidence base for policy makers to value nature for human benefit. A number of recent studies have begun to look at requirements to integrate ecosystem service concepts in landscape planning and management (Fisher *et al.*, 2009; Cowling *et al.*, 2008; Helming and Perez-Soba, 2011; Balmford *et al.*, 2011; de Groot *et al.*, 2010). A key issue is how to engage local land use planners and managers with the complex interdisciplinary requirements required for more holistic ecosystem management. This presents a number of significant challenges.

All ecosystem services have spatial and temporal dimensions (Fisher and Turner, 2008; Boyd and Banzhaf, 2007). The areal extent and spatial configuration of landscape features (such as trees, ponds, or wetlands) will both produce services and interact with ecosystem service flow pathways as they move from a point of origin through to single or multiple points of reception. Land use planning also occurs at a range of scales. Within landscapes, farmers and other land owners make decisions to modify 'their' natural capital to meet their livelihood requirements. The net impact of these land use decisions on ecosystem service provision depends upon the nature of the decision, the location of the action and the extent to which these actions are replicated elsewhere within the landscape (Jackson *et al.*, 2007). These autonomous decisions can affect the delivery of services to other stakeholders at greater distances from the point of modification. An example of this would be changes to water quality downstream from where increased arable activity has occurred. Land use planning to address issues such as reduced water quality are made at regional scales, often by external stakeholders.

Policy solutions may involve farm scale interventions (such as PES schemes) but these are often spatially insensitive, offering generic rather than locally tailored solutions. To enable land owners to make more informed decisions land use planning needs to be spatially explicit and enable farmers to see potential impacts on multiple interacting services within a landscape context (de Groot *et al.*, 2010). This is particularly important where collective action is required to address issues (Pretty and Smith, 2004). Understanding and mapping this spatial dimension of ES delivery is now recognized as a fundamental requirement for to make the ecosystem service approach operational (Morse-Jones *et al.*, 2011).

5.1.2 Requirements for Negotiation

Interactions at operational scales are largely concerned with management decisions made at the point of ecosystem service provision. Typically at these scales local needs and values will have a strong influence on planning and will be influenced by socio-economic drivers and the socio-cultural context prevalent within the landscape (Turner and Daily, 2008). Accordingly different stakeholders (and sectors) may have conflicting visions of desired outputs from 'their' landscape. To address this intermediary stakeholders (i.e. those who directly or indirectly shape interactions among ecosystem managers, environmental service beneficiaries, and the ecosystem itself (Swallow *et al.*, 2007) need to consider the balance between the livelihood requirements of local stakeholders with the wider needs of society who will be affected by their management decisions (by acknowledging potential trade-offs and synergies amongst ecosystem services arising from landscapes). Under an ecosystem service approach there is a clear requirement for negotiation between the various stakeholder groups.

Implementation of new management approaches that consider multiple ecosystem services will require interdisciplinary methodologies (Anton *et al.*, 2010; Bolliger *et al.*, 2011). Individual stakeholders (be they individuals or institutions) will have varying capacities to negotiate outcomes based, in part, on their degree of understanding of ecosystem dynamics. To address this there is a need for greater knowledge exchange and shared learning between stakeholders (Cowling *et al.*, 2008). This needs to occur both between sectors (for example in Wales this would include organisations such as the Forestry Commission (with responsibility for woodlands) the Environment Agency (with responsibility for water), The Countryside Council for Wales (responsible for biodiversity) and various NGOs such as the Woodland Trust) and between these groups and the farming community and other local land owners. Given the current gaps in scientific understanding about ecosystem processes (Kremen and Ostfeld, 2005) there is a strong likelihood that there will only be limited scientific data available to inform decision making, although these shortcomings can be partially addressed through use of other qualitative evidence, such as local knowledge (Sinclair and Joshi , 2000) (see Chapter 3).

Visual representations of landscape functions are increasingly recognised as important tools for communicating complex issues between scientists and non-experts (Appleton and Lovett, 2003). There has been increased interest in using Geographical Information Systems (GIS) to represent ecosystem service provision (Egoh *et al.*, 2008; Gimona and van der Horst, 2007; Naidoo and Ricketts, 2006; Chen *et al.*, 2009). Two high profile approaches have been developed, the InVEST approach (Tallis and Polasky, 2009; Nelson *et al.*, 2009) and ARIES (Villa , 2009) both offer the ability to visualise changes to ecosystem service provision but are concerned with broad scale analysis at relatively low resolutions. Little attention has been paid to exploring opportunities (including the mapping of synergies and tradeoffs) at local scales. We define 'local' here as the scale between field and immediate landscape scales. The term 'landscape' itself is used frequently in the ecosystem service literature but is often poorly defined (Hein *et al.*, 2006; Zhang *et al.*, 2007). It exists largely as a conceptual tool rather than a definable scale.

There is a need for a clearer definition of landscape in order to develop operational frameworks. For the purposes of this study we recognise that a definition of a landscape is based on the functional scale required for decision making and management of individual ecosystem processes; ideally this would include both the point of provision and the point of reception for each ecosystem service. The boundary will vary between ecosystem functions. Water regulation, for example, will require management at catchment or sub-catchment scales. The use of a topographic catchments would be inappropriate for services such as food production which may instead be based on a series of nested physical and social factors such as slope, topography, soil type and distance to market or infrastructure such as roads. These boundaries become harder still to define for services such as pollination. The key point is that ecosystem service boundaries will overlap but will seldom be the same (this is not represented in current approaches – see chapter 4). In management terms they will often be larger than an individual holding but as a rule of thumb no larger than 1000 km^2. None of the existing tools explicitly acknowledge local stakeholder requirements or use participatory approaches for engaging local stakeholders in alternate management at these scales (Sherrouse *et al.*, 2011; Troy and Wilson, 2007).

5.1.3 Objectives

What are the requirements for supporting negotiations about land use change in relation to managing ecosystem service provision?

a. What are requirements for appropriate engagement of local stakeholders in ecosystem management?

b. What resolution of spatially disaggregated data are required for developing representations to inform management decisions and are these data available?

5.2 METHODS

5.2.1 Study sites

Output described in this paper is from two sub catchments in Wales (see Figure 5.1).

The initial research was conducted in the Pontbren sub catchment, a tributary of the River Severn in mid Wales. The initial implementation of the tool was at Pontbren, was where a group of farms had implemented a substantial shelter belt and hedgerow scheme (described in Chapter 2). Scientists had been invited in to monitor changes in the catchment focussing primarily on impacts of tree features on flood risk (see Carroll *et al.*, 2004; Jackson *et al.*, 2008; Wheater and Evans, 2009) and the impacts of the initiative on biodiversity (McHugh , 2003; Moro and Gadal, 2007; Eycott *et al.* , 2007). Pontbren is a relatively small (approximately 1000 ha) upland sub catchment. The second study site selected was the Elwy sub-catchment, a tributary of the River Clwyd in north Wales. This catchment was chosen as it was a mainly upland catchment, similar in terms of land use but significantly larger in area (approximately 27000 ha). The primary farming activity in both areas is livestock production, mainly sheep or mixed herds, with a small amount of dairy production towards the eastern edge of the Elwy catchment. Pontbren and most of the Elwy lie within Less Favoured Areas (LFA) and, as such, the farmers are eligible for *Tir Mynydd*, an area based payment for eligible forage land.

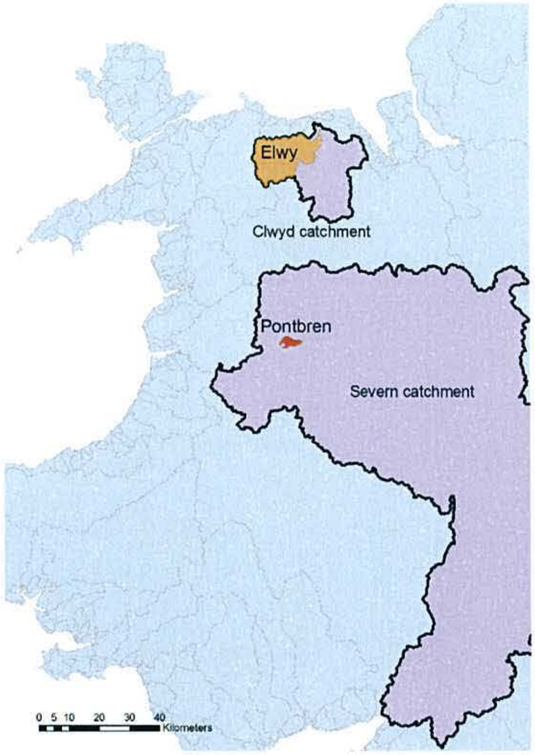


Figure 5.1: Location of the Pontbren (in red) and Elwy (in orange) study sites. The main catchments are in purple.

5.2.2 Methods

As the primary function of the output was for negotiation purposes the process was designed to be both iterative and participatory. Figure 5.2 outlines the methodological steps taken to generate output.

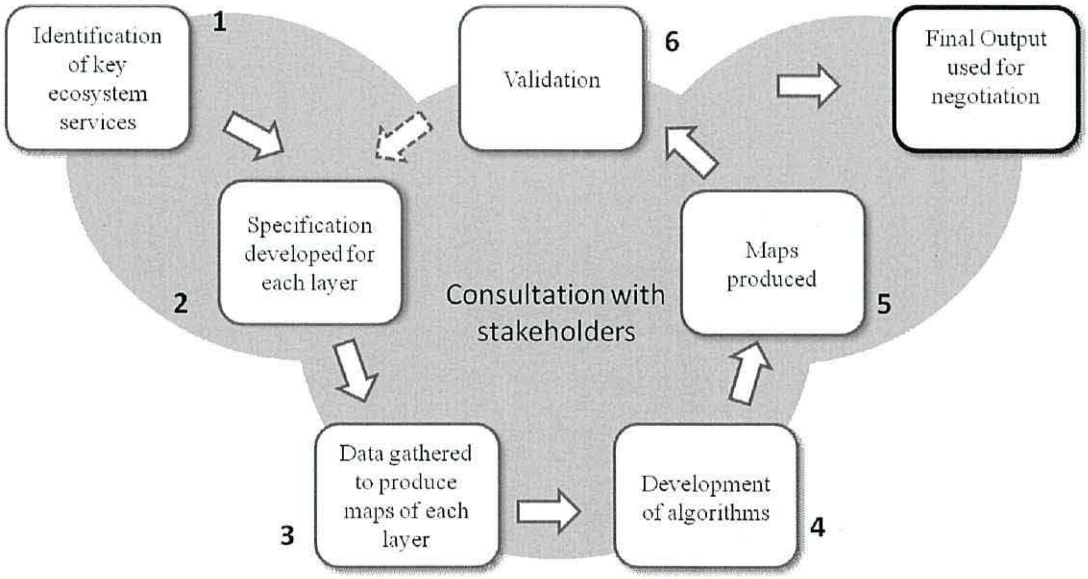


Figure 5.2: The key steps in the methodology used for developing the approach (white nodes). Stakeholders interaction is central to the process and informs all activity (represented by the gray area)

Step 1 represents a scoping phase where strategic priorities for ecosystem service provision within a specified landscape were identified. We recognise that priorities will vary between landscapes with, for example, water regulation a higher priority in landscapes with populations living in areas prone to flood risk. Priorities may also be influenced by socio-cultural, economic and policy drivers. It was also acknowledged that where stakeholders inhabit or derive a living from the landscape then this should be explicitly recognised as potential interventions could potentially interfere with their livelihood strategies.

The specifications for mapping were then generated collectively with both local stakeholders and experts (Step 2). This included identifying features within the landscape that were important for the provision of specified service and potential flow pathways where appropriate. These specifications were then used to identify data requirements to produce maps (Step 3). Given scientific uncertainties about ecosystem function and the likelihood of data limitations the rules used to generate mapped output drew on both available quantitative or qualitative data. This allowed the incorporation of local knowledge where appropriate to address gaps.

These rules were then used to develop algorithms that could be implemented in the GIS (Step 4 - documented in Jackson *et al* 2010) with each ecosystem service assigned to a layer within the GIS. Given the need to map synergies and tradeoffs algorithms were also developed that enabled layers to be traded off against each other. This resulted in a series of initial mapped output (Step 5). In the final step (6) the results were presented back to stakeholders for validation and where issues were identified a second iteration was started, with new specifications or data being incorporated or existing algorithms were modified. The final output then provides a validated spatially explicit environment for wider negotiation which explicitly identifies areas of opportunity and tension in ecosystem service provision.

5.3 RESULTS AND DISCUSSION

The role of trees in the provision of various ecosystem services was a central component of much of the research at Pontbren (see section 5.2.1) and served as an initial focus for negotiation. Initial discussions were held with a range of stakeholders at Pontbren about priorities for tree placement within the landscape. Different actors identified different locations for tree placement to meet their objectives. Figure 5.3 (below) illustrates this using three simplified prescriptions for tree placement in a Welsh farmland landscape. Figure 5.3a shows now tree configurations could meet livelihood objectives of Welsh hill farmers. Farmers identified the primary value of trees was *in situ* for providing shelter for livestock against the prevailing wind. Trees also provided timber and fuel that farmers could utilise. Figure 5.3b shows a hypothetical arrangement of trees for reducing water regulation where interception of surface water and sediment was the priority. This resulted in tree features arranged to intercept flows both in the uplands and in riparian areas. Figure 5.3c shows potential tree configurations for a biodiversity agenda driven landscape – where habitat connectivity and habitat conservation were the prime objectives. In this scenario the wetland habitat was fenced out to limit grazing and regenerate the habitat. Woodland habitat connectivity was improved by connecting woodland patches.

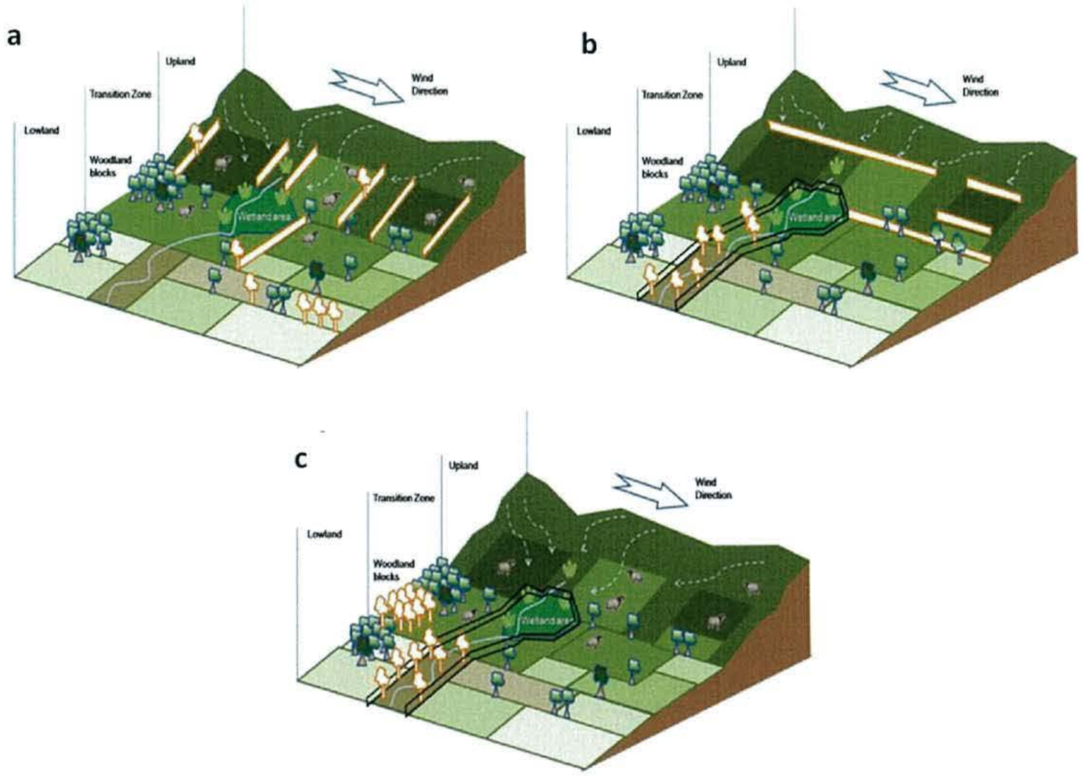


Figure 5.3 Illustration a shows typical interventions favoured by hill farmers. Illustrations b and c show hypothetical tree arrangements for scenarios to improve water regulation and biodiversity respectively

The figures illustrate potential tensions in land use – where, for example, the wetland area is not protected in the farming scenario (and may even be drained to improve productivity) whilst it was conserved in the other two scenarios (but for different reasons, in the first instance to regulate flows and in the second to provide habitat).

5.3.1 Development of an initial specification

An initial specification was drawn up that outlined five requirements for output. These are described below:

1. The output needed to integrate across scales from field to landscape. Maps needed to be at fine enough resolutions to enable identification of landscape features that the local stakeholder(s) have management responsibility for (i.e. moving from field through to the whole farm or woodland scale). Opportunities also needed to be mapped at landscape scale – to provide the wider context and inform prioritisation for interventions.
2. The output needed to be spatially explicit as the location and extent of features within the landscape have a strong impact on ecosystem service

provision. This includes explicit identification of areas currently providing ecosystem services and areas of opportunities for increasing the supply.

3. As changes in land use affect multiple ecosystem services simultaneously it was important to map more than one service. The need to carry out holistic assessments is a central tenet of ecosystem services thinking (MA, 2005). By representing multiple ecosystem services together it is possible to identify potential synergies and tradeoffs between ecosystem services.
4. To be useful in any landscape the tool must be able to utilise generally available data in the first instance.
5. The output should support the implementation of policy at landscape scales. By trading layers off against each other win-win locations can be identified. It also explicitly recognizes ecological assets that deliver of multiple ecosystem services and where compensation may be required to secure the provision of public goods

5.3.2 Mapped output

Given the nature of research in Pontbren the initial requirement was to provide maps that showed opportunities for enhancing tree cover (and other soft engineering solutions) in relation to three ecosystem services: food production (representing the farmers livelihood needs), habitat connectivity (a supporting service) and water regulation (primarily for reducing downstream flood risk).

Local stakeholders (including the scientists conducting research on the site) were consulted throughout map development – to provide local knowledge (about the condition and composition of land use features – see section 5.2.2.1 below) and validate available datasets (see section 5.3.2.5). The farmers were also able to efficiently improve the quality of the land use data – particularly where tree and hedgerow data was absent by identifying older hedgerow systems and also by providing details about species composition

5.3.2.1 Agricultural layer

The agricultural layer represents the current land use priorities in the catchments – The aim was to develop a spatial rule set that identified land that was of marginal value to the farmers' livelihoods as these areas would have low opportunity costs for placing interventions that benefit other ecosystem services. An initial rule set was created through discussions with the farmers that identified two main factors: soil drainage and slope. Land that was too steep or where there was heavy water logging of the soil was identified as low value. The data requirements for mapping this could be met using a digital terrain model (DTM) and soil data (the Ordinance Survey 10m and the National Soil Research Institutes (NSRI) Soilscapes datasets respectively – both of which are nationally available). Two slope thresholds were identified; farmers suggested that land below 5° was high value, and land above 15° was considered marginal (identified by agricultural salespeople as the point at which operating farm equipment was considered unsafe). The farmers initially challenged this figure suggesting it was too low but observations of slopes where farmers had already implemented changes suggested that the reverse was true and that farmers were actually taking land out of production at lower slope thresholds.

To allow for these discrepancies the algorithms were modified to allow adjustable slope thresholds. Figure 4 shows the initial output for the agricultural layer. The output presented in the subset shows where the farmers made interventions

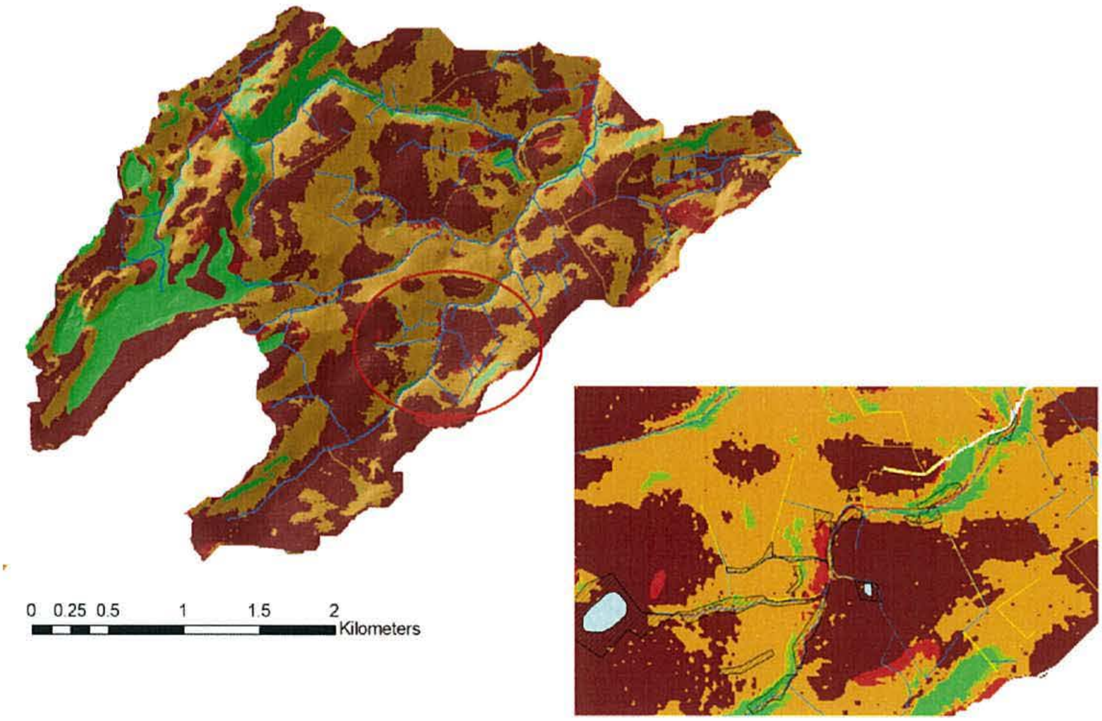


Figure 5.4: Output for the showing the agricultural layer for the Pontbren catchment. Maps use a five colour 'traffic light' system. For the individual service layers areas of the map in red indicate high existing value for the ecosystem service is question. Areas in maroon have some existing value and orange indicates neutral or marginal value. Green indicates high opportunity for change (as the land is low value for agriculture) with lighter green indicating the highest level of opportunity. The red circle shows where the subset figure is derived from. This figure uses the same scheme with the hatched areas representing tree planting, the blue circles are new ponds and the yellow lines indicate new hedgerows

The plantings all avoid red areas, with most within or close to green areas of the map or adjacent to streams. Due to the coarseness of the DTM the steep land adjacent to streams were not picked up in the mapping output. There was also areas where the soil data was incorrect (for example the output would suggest that the new pond to the left of subset figure had been created on valuable farmland (coloured maroon). At the time of the survey this area would have been drained and in agricultural production, but was a very wet area where the farmer had lost sheep and was responsible for higher incidence of foot rot amongst his flock (from infection by the anaerobe bacteria *Dichelobacter nodosus).* Data constraints such as this require adaptive iterative approaches to mapping ecosystem services. Incorporating local knowledge was valuable for improving these datasets. In addition the farmers also identified a number of idiosyncratic factors that would affect where trees were planted on their farms. An example of this was farm security (where trees might either reduce vision within the farm, and thus were a problem or where they provided benefits by providing a screen). These elements were excluded from the generic rule set but editing facilities were incorporated within tool to enable these elements to be added at the individual farm level.

5.3.2.2 Woodland habitat connectivity

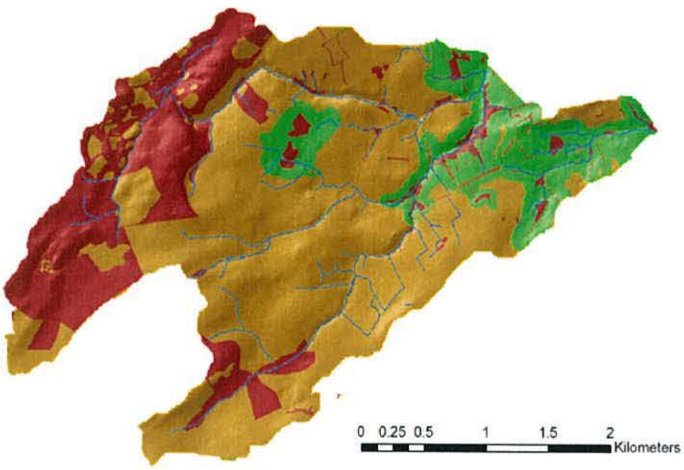


Figure 5.5: Map of tree habitat connectivity for Pontbren (A) and a trade off map generated between map 2B and 3A. All maps use the same scheme as identified in Figure 5.4 above

A map was generated to show opportunities for enhancing woodland habitat connectivity at Pontbren (see Figure 5.5). This was based on initial research exploring habitat connectivity on the farm (Eycott *et al.*, 2007). The algorithms follow the calculation procedures and parameterisations of Forest Research's woodland habitat connectivity tool (Watts *et al.* 2008). The output was based on nationally available land use data (in this case the Countryside Council for Wales's (CCW) Phase 1 dataset). The output shows areas of core high value habitat in red (where red indicates that a reduction of these areas is undesirable) and the greens areas indicate the areas of opportunity for expanding the existing habitat network. The farmers to the west of the catchment were less happy with these maps as they suggested that only tree planting to the east of the catchment provided biodiversity benefits. This was at odds with their observations that the tree planting had provided clear improvements in biodiversity. They were also aware that core woodland areas in the east included significant areas of non-native woodland (*Quercus rubra* a non-native oak species) which were low in biodiversity value therefore of limited value to woodland species. The Forest Research methodology uses generic species which the farmers could not relate to and they considered it problematic. The habitat connectivity maps generated more negative comments than other layers.

5.3.2.3 Water regulation

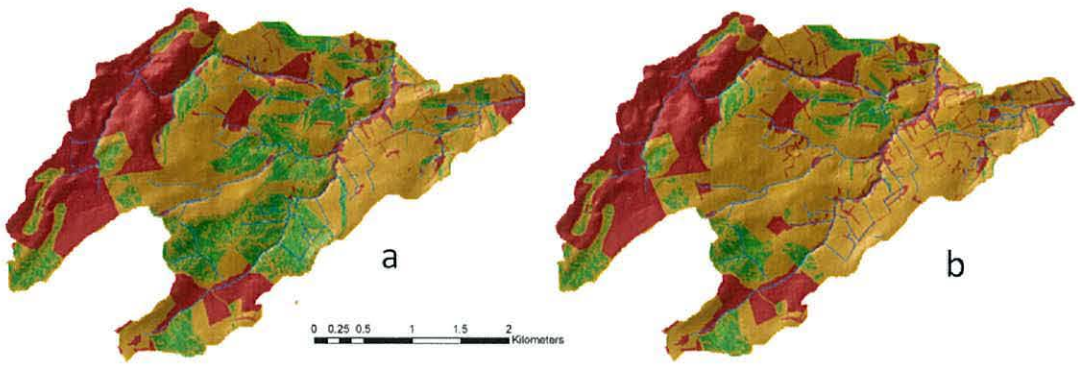


Figure 5.6 Mapped output of flow accumulation for the Pontbren catchment. Figure 5.6a shows flow accumulation based on the land use data for the catchment; Figure 5.6b uses a corrected land use dataset that incorporates changes in tree cover and wetland creation established by the Pontbren farmers.

The evidence for the effectiveness of soft engineering solutions for mitigating flood risk in the UK are currently complex and uncertain (Foresight, 2011). In naturally drained soils water moves vertically, but in areas where drainage is impeded then there is a tendency for lateral flows to increase (resulting in high surface runoff). Trees can intercept these flows and by increasing infiltration slow the movement of water into the river channels (Carroll *et al.*, 2004). The flow accumulation maps draw on the modelling work conducted at Pontbren (Jackson *et al.*, 2008) and used corrected flow accumulation as a proxy for surface run-off. The algorithm removed any flow that accumulated on "sink" areas (i.e. areas that potentially stored water or increased infiltration. Areas where a large amount of unmitigated flow could accumulate were treated as priority areas for change[10] (see figure 5.6a). The maps clearly differentiate areas of opportunity within the catchment and identify the head water areas to the west of the catchment as being priority areas for change.

Figure 5.6b uses the same flow accumulation algorithm but with a modified land use dataset that incorporates the changes in tree cover made by the farmers. It clearly shows that there was a strong likelihood of increased interception of surface flows by the new plantings, particularly towards the southern edge of the catchments.

5.3.2.4 Trade off layers

Synergies and tradeoffs in ecosystem service provision can be visualised by combining the output from two or more layers. For trade off layers, green areas indicate synergies in opportunities to enhance services, red areas indicate synergies in current ecosystem provision, orange indicates trade-offs or negligible synergies in either opportunities or current provision. Potentially, there are an almost infinite number of options for numerical evaluation of trade-offs. These have some impact on which parts of the landscape are assigned as "green" or "red/maroon". The output demonstrated in this study uses the "additive" option. With this option, light green indicates opportunities to enhance all services under consideration, dark green opportunity to enhance some services with no degradation of any, red indicates existing provision by the landscape to all services, maroon existing provision from some services and no opportunity to significantly enhance others.
An example of this is given in Figure 5.7; the bright green areas identify areas where the woodland connectivity could be improved with low impact upon farm productivity. The larger areas of dark green identify where changes could be made that will have a positive impact on one service without negatively affecting the other function (although not enhancing it either).

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[10] Initial output identified grassland with > 500 m^2 contribution as high priority (shown in light green); Areas with moderate flow (100 – 500 m^2) shown as dark green; areas with negligible flow, with (<100 m^2 contribution) are shown as orange and areas already with trees or other flow sinks are shown as red.

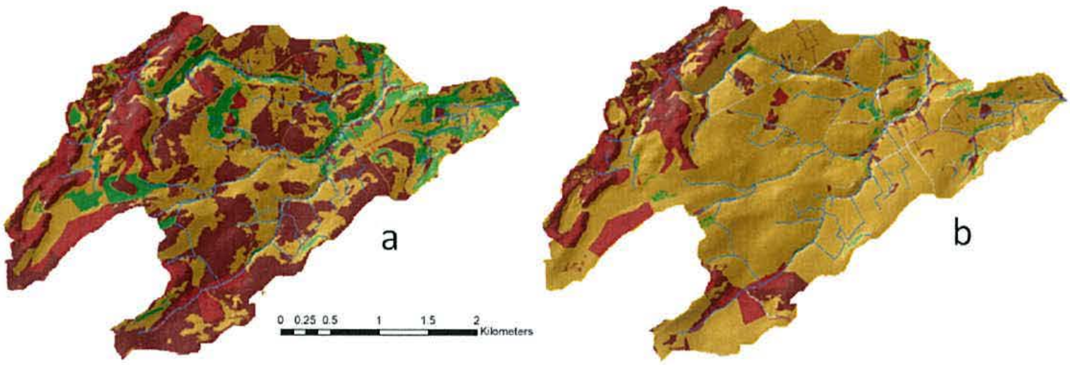

Figure 5.7: Two examples of trade off layers. Green areas identify synergies between ecosystem services (light green areas are positive for both services, and dark green are positive for one and neutral for the other) similarly red areas indicate trade offs. 5.7a shows a trade off between the agricultural and the habitat layers and 5.7b shows all three services traded off against each other. Light green areas are locations where changes provide benefits to flood risk and habitat connectivity at no cost to agricultural productivity.

By bringing in more layers it is possible to identify areas where interventions provide multiple benefits (see Figure 5.7b) and also those areas that are clearly undesirable for planting or other interventions due to their agricultural or ecological value. As the output for Figure 5.7b suggests adding more than three layers, whilst possible, tends to result in very limited areas that provide multiple benefits. Initially the tradeoffs considered each ecosystem service equally. In catchments where there is a clear political agenda for prioritisation of an ecosystem service it may be useful to modify the trade off maps to favour a key service. The trade off algorithms were expanded from the additive option demonstrated above (which treats all services equally) to include a weighted additive (which allows the addition of weightings for individual services), a conservative option (which only identifies areas where synergies exist –hence less opportunities are visible but these are all positive for all services mapped) and finally the Boolean tradeoffs (which enables users to select a combination of additive and conservative option for each service).

5.3.2.5 Validation

In common with many other spatial tools land use data, in particular, plays an important role. The requirement to use national scale datasets meant that resolution and the accuracy of the data were relatively low. Three separate maps of tree cover were available for Pontbren and all were different. These inaccuracies were discussed with stakeholders throughout the process allowing us to be transparent about uncertainties. Features such as hedgerows are absent from all the current suite of widely available land use datasets. Where land use data is accurate it does not have data associated with it about the condition, age, composition or management associated with the feature – all of which could significantly affect the delivery of service. We found that farmers were able to provide that level of detail very quickly in discussions over the maps although there were significant transaction costs associated with organizing meetings. A focus group discussion held with the farmers was used to validate the mapped output. The farmers were shown the maps alongside aerial photography (as with Figure 5.9 below).

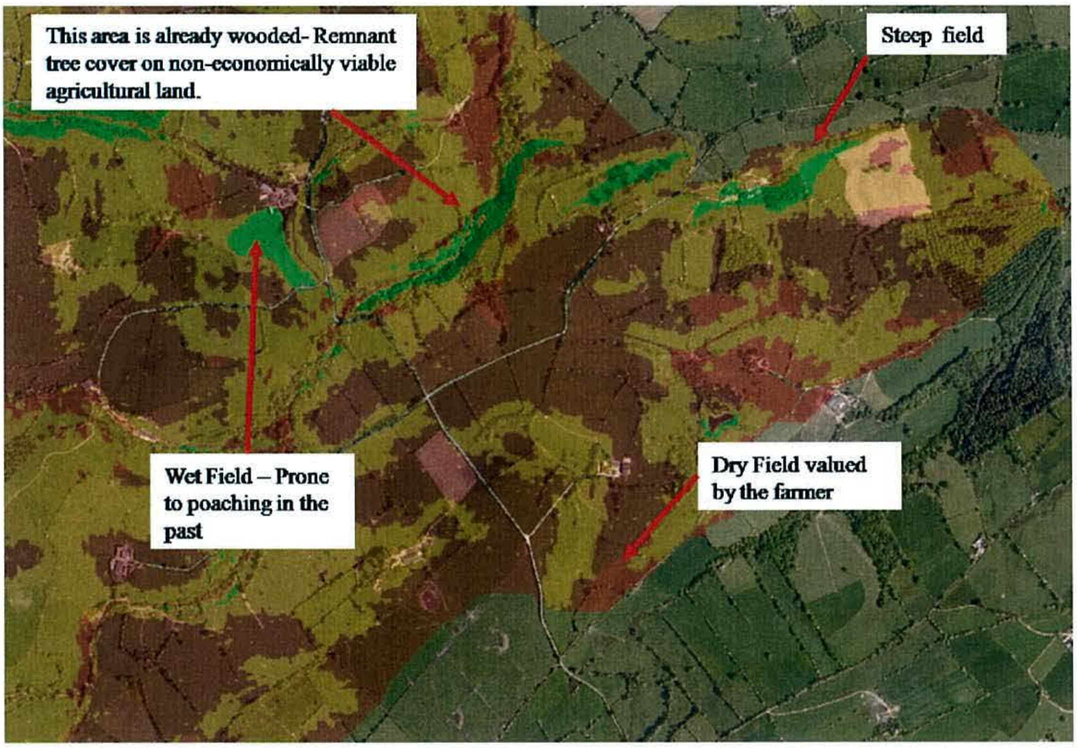

Figure 5.8: Farm impact layer overlaid with 2006 aerial photography. Subset comments are derived from ground truthing with farmers

The process of developing maps collaboratively with stakeholders allowed issues such as data gaps and areas of uncertainty to be explicitly identified and, where possible, addressed. Participation was recognised as vital both for increasing knowledge exchange between stakeholders and for validation of output. Both processes increase ownership of the maps and their final utility for negotiation.

5.3.3 Scale

Given the relatively small area occupied by the Pontbren farms it was important to explore the mapped output at broader catchment scales. The ability to move between field scale decisions through to wider landscape scale considerations was identified in the initial specification. At these broader scales farmers and intermediary groups can see the context for management decisions (be it a field, farm or woodland block) for services that manifest at these scales – such as water regulation. Figure 5.10 shows the agricultural and the water regulation layer for the Elwy catchment. At these broader scales the spatial variability of the soil fertility was more marked than at Pontbren. The initial implementation in the Elwy used the same rule set developed for Pontbren. Two sub catchments were selected for initial testing of the output (Figure 5.10); an upland sub catchment very similar to Pontbren (the Gallen) and a more fertile lowland sub-catchment (the Meirchion). Interviews with farmers revealed that, at broader scales, the aspect of fields was as an important additional factor to consider within the agricultural layer; in particular fields with south facings aspects were more highly valued then fields with northerly aspects as they received more light and the grass growth was generally better (and the fields tended to be drier).

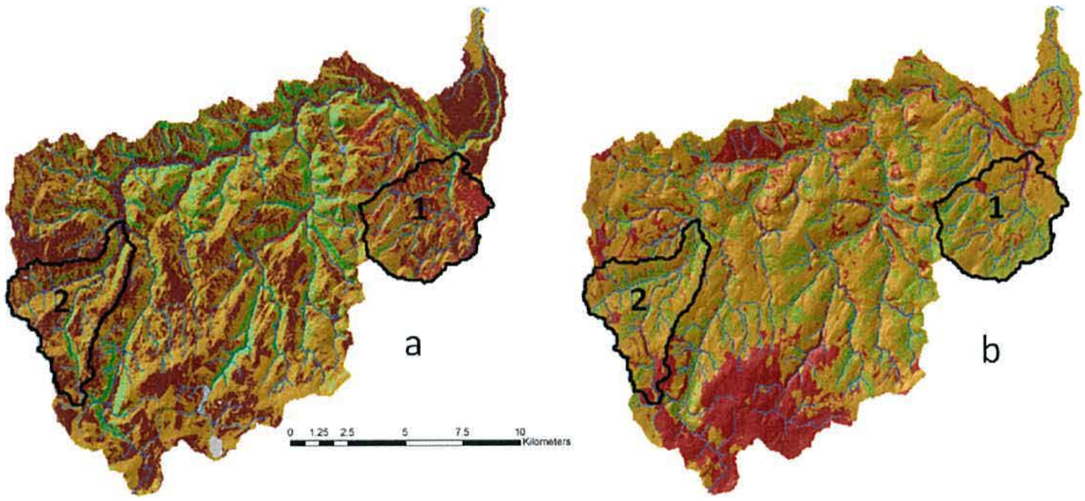

Figure5.9 The farm impact (a) and the flow accumulation (b) maps for the Elwy catchment (27000 ha) identifying opportunity for interventions along the steeper river valleys. The agricultural map is based on algorithms modified to place a higher value on southerly aspects. Two sub catchments are highlighted: (1) represents the Meirchion sub catchment and (2) represents the Gallen sub catchment.

Exploring the underlying land use in the catchments revealed another significant difference. In areas identified as marginal within the Meirchion the land use had considerable areas of tree cover whereas in the Gallen significantly more of the marginal land was being utilised for agricultural production and there was less tree cover (Figure 5.11). This was confirmed by the local Coed Cymru officer who acknowledged that he had no clients in the Meirchion (because marginal land was already wooded) most of his clients being in the upland areas.

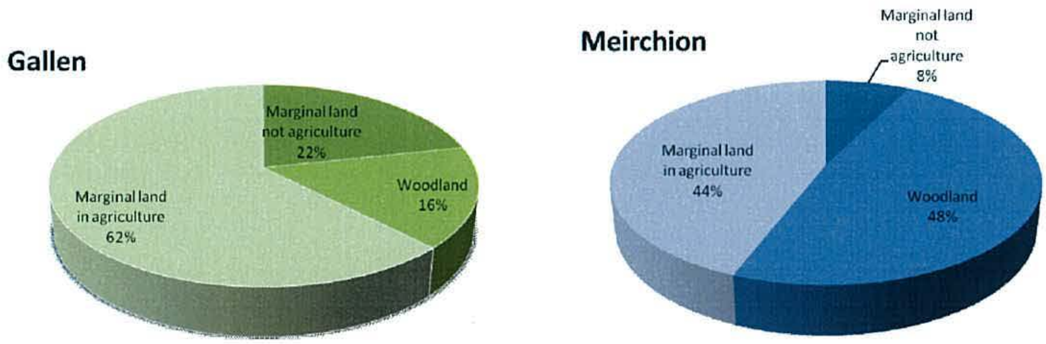

Figure 5.10: Variations in agricultural and non agricultural land use in marginal area in the Elwy valley. The woodland component is highlighted.

This has important implications for agri-environment schemes as this would suggest that the opportunity costs were higher in the Meirchion as it was in an equilibrium state where as in the Gallen the land that should have been low value for agriculture was being improved to provide fuel. These areas were potentially worth targeting in agri-environment schemes. Interestingly almost the entire Meirchion catchment was eligible for *Tir Mynedd* despite having considerably better soils then elsewhere within the catchment. The *Tir Mynedd* payments only take into account the ALC soil classifications which are coarse and do not consider factors such as slope, drainage and aspect.

As in Pontbren validation interviews were conducted with local farmers and other stakeholders working in the Meirchion and Gallen sub catchments (n=10) to check the plausibility of the output. Whilst the farmers in the Elwy catchment reacted positively to the mapped output they recognised greater inaccuracies with the underlying data, particularly associated with the land use datasets. The NSRI Soilscapes data used in UK maps were at a 1km^2 resolution and did not accurately capture all the local variation in the soil at farm scales. The land cover data had better resolution (10m^2) but also contained many inaccuracies at farm and field scales largely due to the age of the data collection (see Cherrill & McClean, 2000). Farmers were able to ground proof these elements quickly (both for their own farms and within the wider catchment, enabling the maps to be updated. None of the farmers visited had ever seen their farms in this context before. Farmers readily understood the farm impact and flood risk maps and were able to suggest changes (such as the incorporation of aspect). As in Pontbren the farmers identified missing features that they recognised as important; particularly the lack of hedgerow data and other small woodland features (see Figure 5.12). The farmers associated these features with having a strong influence on water and habitat. For example the farmers drove their vehicles along hedgerows rather than across the middle of fields as they know the soil is drier there. There was a clear recognition of the drying function of hedgerows.

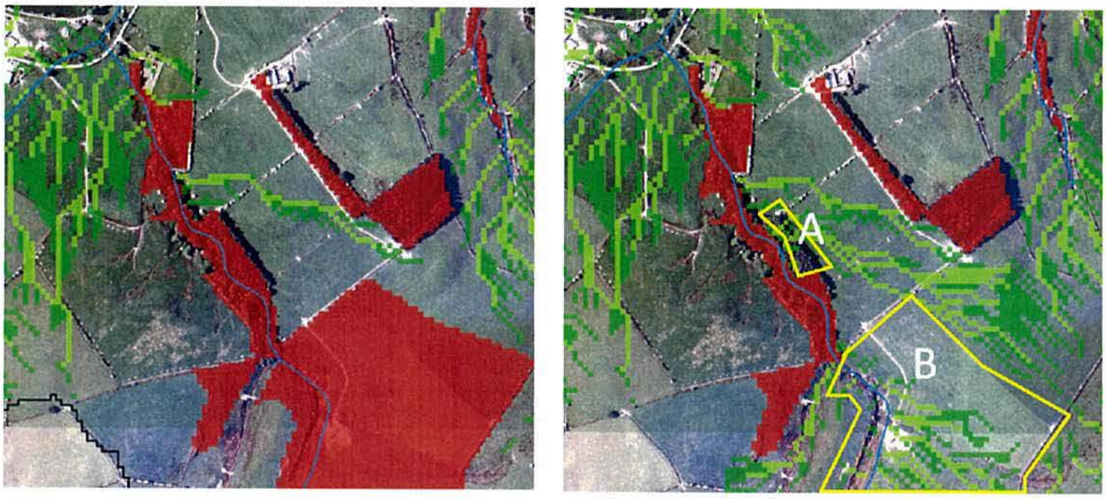

Figure 5.11: Ground truthing land use data in the Elwy catchment. The two plates shows the effect of incorporating local knowledge within the flow accumulation maps before (first plate) and after discussions with the farmer. The maps are standard Polyscape output as shown in Figure 5.6 but with orange (neutral) areas removed for clarity. These layers are overlaid over aerial photography (from 2004). The farmer identified the conifer block at point A as being low value for intervention as the land under it was very steep with no understory and evidence of substantial soil erosion. The wetland in area B had been recently drained and converted into improved grassland. The impact of modifying the land use data to reflect this is illustrated in the second plate.

Given that issues with resolution and quality of datasets arose throughout the process it was important that stakeholders understood that the output was a starting point for negotiation rather than a finished product – which differs from how most people intuitively understand maps. In presentations of this data many local stakeholders were surprised at the poor quality of the underlying datasets.

5.4 DISCUSSION

By taking a spatially explicit approach and developing rules collectively the maps produced showed clear priority areas within both the Pontbren and Elwy sub catchment that could be targeted for the delivery of regulating services. This suggests that offering farmers generic prescriptions, as is the case in existing Welsh argi-environment schemes is unlikely to address these issues. Farmers engaged with the tool as their livelihood objectives were explicitly taken into consideration and by using their local knowledge they had ownership and engagement with the data being mapped. This may also highlight tensions between where farmers may want to make interventions and where they are likely to be effective – which could have implications for compensation. The final trade off maps highlights relatively small areas where there are synergies across all other ecosystem services (see Figure 5.7b) suggesting these areas should be priority areas for interventions.

The final specifications were used to develop algorithms that make up the Polyscape tool. The Polyscape output provides a base line for policy level decision making at field and landscape scales (providing computationally efficient output from 10 km^2 to 1000km^2) and clearly differentiates areas of opportunity within the catchments for each ecosystem service.

The approach taken in generating output for Polyscape was designed to increase participation of all stakeholders in the process of collective landscape decision making. Different stakeholders had different levels of understanding about the services studied and the output provides an intuitive platform for knowledge exchange. The interdisciplinary nature of ecosystem service provision requires better interaction between stakeholder groups. By explicitly acknowledging the constraints of using national datasets and through incorporation of local knowledge the tool provided a basis for negotiation without being overly prescriptive.

5.5 Conclusions

Achieving environmental outcomes that meet the demands of both land owners and land use planners requires tools that enable negotiation between these stakeholder groups. Within the context of ecosystem services this requires the ability to communicate opportunities for change in a manner that explicitly acknowledges the interactions between ecosystem services and the potential effects across a range of scales. The structure of the approach enables critical conflicts of interest to be recognised (and potentially compensated) and also allows identification of areas where there are clear synergies for delivering ecosystem services. The approach described here (Polyscape) was designed to bring stakeholder groups together at the scale required to enact change. The collaborative process of map generation creates an environment that encourages positive environmental outcomes by building in the criteria outlined above. Initial findings suggest that the approach offers a means to increase trust and learning between stakeholders which in turn fosters more participatory approaches to land management.

The process outlined described here, that led to the creation of the tool, was developed to address these issues and facilitate spatially explicit negotiation of ecosystem service provision in agricultural landscapes. We feel that visualising ecosystem service interactions at landscape scale helps to explain the need for landscape scale management to farmers. This is an important step for the generation of the social capital required for coordinated management. The final specifications recognised 6 steps:

1. The mapped output should integrate across scales from field to landscape.
2. The output should be spatially explicit
3. Multiple services need to be mapped together
4. To be useful in any landscape the tool must be able to utilise generally available data in the first instance.
5. Integrate scientific evidence with local knowledge. Data constraints require adaptive iterative approaches to mapping ecosystem services, using all relevant sources of knowledge, including local knowledge generated by local stakeholders through their interactions with the environment.
6. The output should support the implementation of policy at landscape scales.

CHAPTER 6

APPLICATION OF THE POLYSCAPE APPROACH IN THE CAMBRIAN MOUNTAINS

6.1 INTRODUCTION

The research presented in this chapter involved application of the Polyscape approach developed in previous chapters to a case study in the Cambrian Mountains, an area that has been used by the Welsh Government for testing and evaluating agri-environmental approaches. The approach was embedded in an Adaptive Landscape Project funded by the Department of Food and Rural Affairs (Defra) which explored resilience of priority habitat to climate change. The first part of this chapter describes the background, development and application of Polyscape output for the project, while the latter part reports on feedback from key stakeholders (local farmers, ecologists, policy makers and members of the local community) on the credibility, saliency and legitimacy of the Polyscape outputs and approach.

6.1.1 Background

Climate change is now widely recognised as one of the major drivers of global biodiversity change and loss (Thomas *et al.*, 2004). In 2007 the UK Biodiversity Partnership produced revised national priorities for biodiversity conservation (Defra, 2007). This document provided guidance on practical steps to reduce the impacts of climate change on biodiversity and how to adapt existing habitat management plans in light of current climate change projections. Central to this were six principles to promote positive adaptation of biodiversity (Defra, 2007). These were:

1. Conserve existing biodiversity.
2. Reduce sources of harm not linked to climate.
3. Develop ecologically resilient and varied landscapes.
4. Establish ecological networks through habitat; protection, restoration and creation.
5. Make sound decisions based on analysis.

6. Integrate adaptation and mitigation measures into conservation management, planning and practice.

The Cambrian Mountains Initiative (CMI) is a wide-ranging project that aims to help promote rural enterprise, protect the environment and add value to products and services in Mid Wales. The Welsh government in partnership with the CMI were interested in looking at the implications of building this guidance into local scale adaption strategies at the level of land use options adopted by farmers. Changing land use will likely impact a broad range of ecosystem services. A central aim of the research was to make potential synergies and tradeoffs between steps to conserve habitat and the provision of other important ecosystem services in the landscape explicit. This was in line with emergent Welsh environmental policy objectives for agri-environment management which seek to build climate change resilience into, and secure sustainable delivery of ecosystem services from, implementation of existing biodiversity objectives (Welsh Assembly Government, 2008). Given that much of the valued priority habitat found within Wales exists as a complex mosaic either within or adjacent to agricultural land, requirements to engage local stakeholders (principally farmers) in habitat conservation have been recognised. Given this context, the participatory and spatially explicit approaches embraced in Polyscape, were thought likely to be useful for identifying and exploring areas of opportunity with local stakeholders, for safeguarding (and potentially expanding) habitat, both within and outside, formal conservation areas.

It is not only habitat that is threatened under changing climatic conditions. There are also likely to be changes to the provisioning requirements and regulating capacities of the landscape. Using predicted climate change scenarios Sutherland *et al.*, (2008) suggest that there will be a step change in demand for food within the UK, increasing pressure for conversion of land to agriculture. Strategic requirements for increased food security remain a significant driver behind existing UK land use strategies (Defra, 2010). Climate change is likely to both increase the frequency of extreme weather events and change flows of freshwater (Sutherland *et al.*, 2008). Currently, the responsibility for addressing these issues at local scales lies with different sets of actors (primarily farmers, whose actions are influenced through agricultural policy, and then the Environment Agency and CCW in the second – although other groups may also be involved). Attempts to mitigate and adapt to climate change are likely to involve land use changes superimposed on top of changes driven by needs for food and water. A 2010 policy directive by the Welsh Government put in place policy requiring expansion of woodland area in Wales by 100 000 ha (implemented over a twenty year period) to increase carbon sequestration (Welsh Assembly Government, 2010a; Welsh Assembly Government, 2010b). This policy is currently administered by the Forestry Commission. Suggested land use changes to meet any of these objectives could create tensions with existing land use at local scales. Developing co-ordinated management strategies that identify potential conflicts as well as win-win scenarios and that bridge sectors (e.g. agriculture, forestry, biodiversity conservation and water regulation) are likely to provide the most cost effective solutions. There is also a requirement to look at how policy objectives can be translated to action on the ground. Part of this process is likely to require identification of synergies and tradeoffs amongst ecosystem services at local scales.

6.1.2 Agri-environment schemes in Wales

State funded land management schemes were introduced in the EU in the early 1990s. The schemes in Wales provide grants for public goods (i.e. environmental goods and services) provided by farmers through land management schemes. Land management schemes funded through Axis 2 can therefore be viewed as the State (in this case the Welsh Assembly Government) buying environmental goods and services ('public goods') from farmers who would otherwise not supply them.

In 2008 the EU conducted a 'Health check of the Common Agricultural policy. As part of this exercise the Welsh Government reviewed it agri-environmental schemes. The results showed that the schemes had limited objectives that only partially addressed the *Wales Environment Strategy*. In addition the level of monitoring did not provide clear baseline with which to measure progress towards meeting objectives. Both *Tir Gofal* and *Tir Cynnal* (the extant agri-environment schemes in Wales) were primarily concerned with biodiversity objectives (Wales Audit Office, 2007). These are set to be replaced by a new scheme, *Glastir*, in 2013. Under *Glastir* the agri-environmental objectives have been broadened to include climate change (through carbon capture) and water management measures alongside biodiversity objectives (National Assembly for Wales, 2011). Under the new scheme there is recognition by policy makers that meeting these objectives requires making changes at landscape scales (Welsh Assembly Government, 2008). Existing agri-environment schemes are voluntary and currently largely limited to farm level schemes. This currently does not allow ecosystem services that manifest at landscape or catchment scales (such as water regulation) to be addressed. The proposals for *Glastir* scheme incorporates both an entry level scheme, which targets intervention to secure biodiversity, carbon capture and water quality targets (available to all farmers). A higher level element is also planned to encourage collective action on specific ecosystem services from groups of stakeholders within targeted landscapes. The higher tier scheme incorporates the three priority foci and also includes water regulation, access to the countryside and the preservation of the historic environment. Given that Polyscape has, as a central focus, stakeholder engagement in negotiation relating to the provision of ecosystem services, there was policy interest from the Welsh Government in applying and testing the approach in a Welsh landscape.

6.1.3 Objectives

The principal aim of this study was to produce and evaluate the utility of applying the Polyscape approach outlined in Chapter 5, in relation to policy objectives in the Cambrian Mountains. The Polyscape approach was applied in the study site and the resulting maps were evaluated by a range of different stakeholders groups, including local community members. The main research questions were:

To what extent is the mapped output produced from adopting the Polyscape approach to visualising impacts of land use change on ecosystem service provision legitimate to stakeholders?

1. How plausible is the output to local stakeholders?
2. To what extent does it address local stakeholder needs?

6.2 METHODS

6.2.1 Study site description

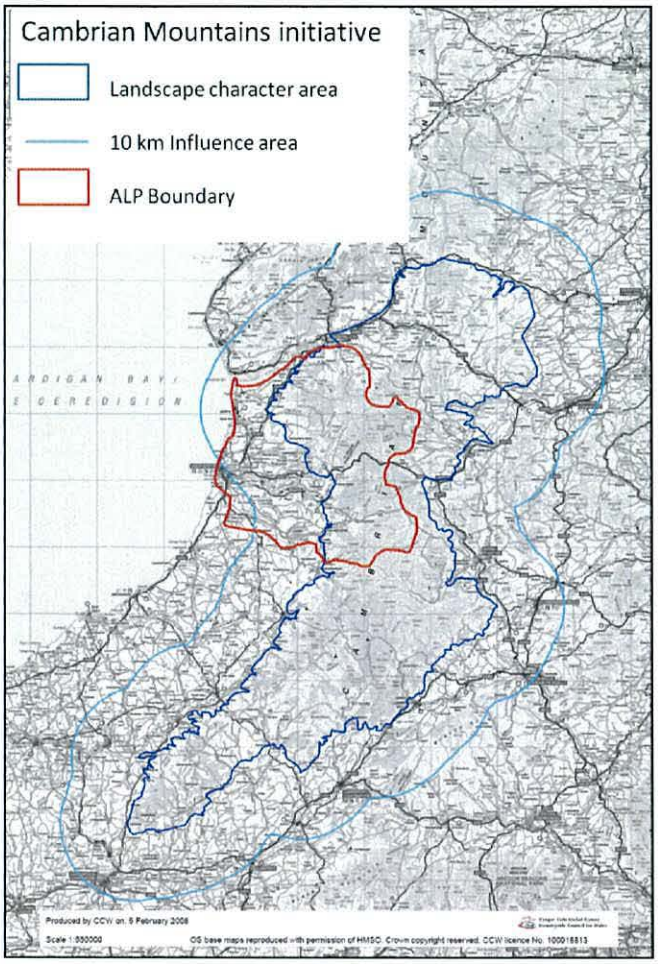

Figure 6.1: Map of the Cambrian Mountains Initiative area (outlined in blue) with the study area outlined in red

The broad remit of the CMI is focused on development activities to encourage rural enterprise in Wales. This includes a strong emphasis on encouraging environmentally sensitive approaches to farming. The Cambrian Mountains (see Figure 6.1) has a long association with agri-environmental research in Wales, being the first designated Environmentally Sensitive Area (ESA) in 1987 (Boatman *et al.* , 2008). The Ecosystem Services Working Group, one of four working groups in the Initiative, is involved with testing the practical implications of agri-environmental policy with the farming community. The Ecosystem Service group is headed by the Welsh Government and the Countryside Council for Wales (CCW)[11]. Much of the

[11] http://www.cambrianmountains.co.uk/the-region/ecosystems/applying-the-ecosystems-services-concept

recent work of this work group has focussed on the development of options for the putative higher tier '*Glastir*' agri-environment scheme. The study area encompassed five catchments to the north western edge of the CMI area (see Figure 6.1). These consisted of the Leri, Ceullan, Clararch, Clettwr and Rheidol catchments (see Figure 6.2 below). In total this amounted to an area 38 000 ha, encompassing 10% of the Cambrian Mountains Initiative area

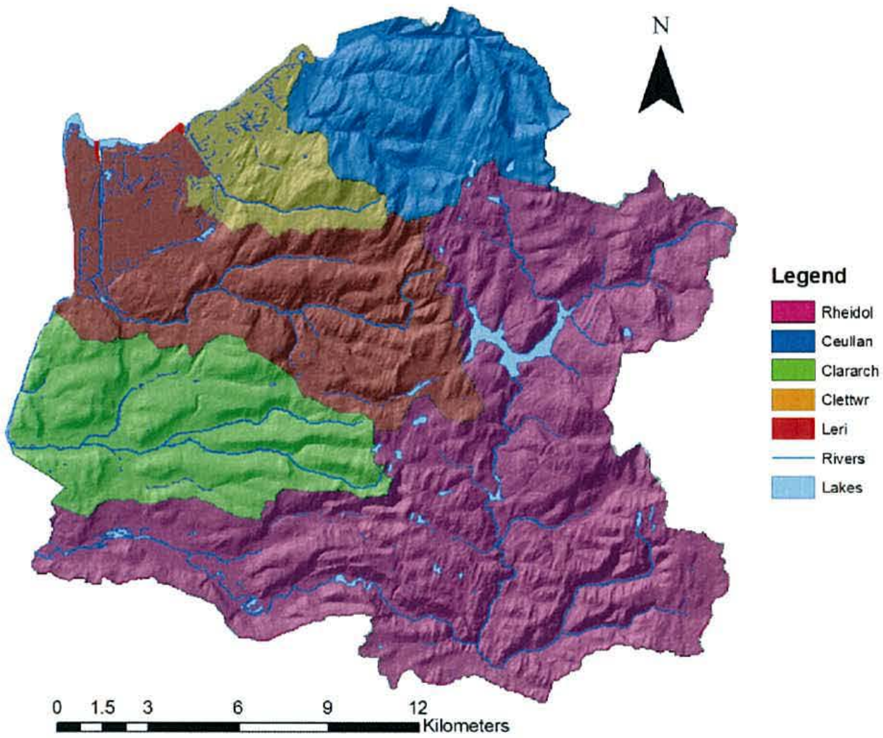

Figure 6.2: The five catchments that make up the study site (catchment boundaries derived from the Environment Agency Water Framework Directive Maps)

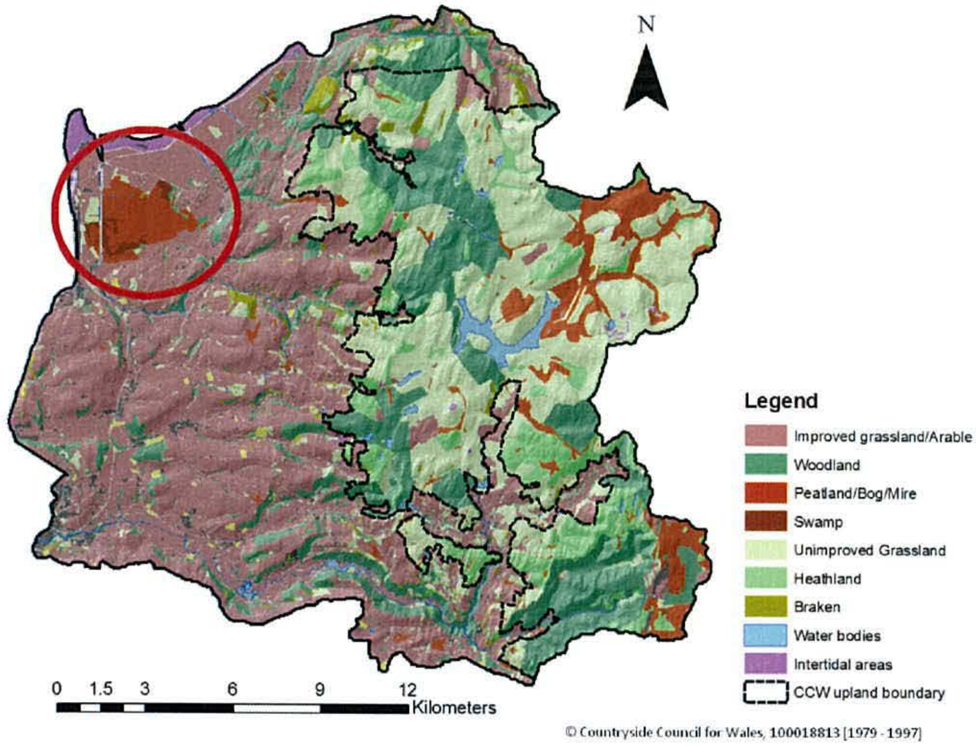

Figure 6.3: Simplified land use map of the study site – based on CCW Phase 1 dataset (produced in the 1980s). Cors Fochno is the area of raised bog circled in red.

As with much of Wales, the study area has a strong upland/lowland dynamic. The basic land use types are illustrated in Figure 6.3. Farming activities are based on livestock production on the areas of improved grassland in the lowland western edge of the study area. There are substantial areas of coniferous woodland that bridge the area between the uplands and lowlands. The upland areas are less fertile and provide very little agriculturally productive land. Much of the uplands consist of areas of unenclosed upland heathland which provides rough grazing for livestock. The lowland soils consist mainly of free draining acid loams, whereas in the upland area the soils were more acidic loams with a peaty surface layer. The study area contained areas with substantial stores of soil carbon (peat and organo-mineral soils) both in the uplands and in the Cors Fochno complex within the lowland coastal zone.

Approximately 13.5% of land within the study area was covered by statutory nature conservation designations. This included 29 Sites of Special Scientific Interest (SSSIs); A number of SSSIs were also internationally designated (including five Special Areas of Conservation (Cors Fochno, The Sarnau and Rheidol woods and gorge) and two Special Protection Areas (the Dyfi estuary and Elinydd). The Cors Fochno complex was also designated as a UNESCO Biosphere Reserve and as a

Ramsar site. A number of the SSSIs within the catchment were present as a result of Wales's post industrial legacy (including the Rheidol Shingles and Backwaters and Afon Rheidol Ger Capel Bangor SSSIs) which support distinctive species rich communities that have developed on the metal-rich substrates produced as a result of mining activities in the area.

Localised climate change predictions for the area based on the UK Climate Impacts Programme (Jenkins *et al.*, 2009) suggested that, under the medium emissions scenario winter mean temperatures were likely to increase by 2.0ºC and summer mean temperatures by 2.5ºC. Seasonal patterns of precipitation were likely to change with rainfall likely to increase by 14% during winter and to fall by 17% during the summer – although the mean annual rainfall was predicted to remain roughly the same. There was also likely to be greater intensity associated with weather events, with greater extremes in precipitation and temperature. The mapped projections from the UKCP09 had a resolution of $25km^2$ (Jenkins *et al.*, 2009) which does not enable fine-grained spatial differentiation.

6.2.2 Specification for mapped layers in Polyscape

The first principle set out in the UK Biodiversity Partnership seeks to (a) conserve protected areas and other high quality habitats; and (b) conserve the general range and ecological variability of habitats and species (Defra, 2007). The study was given access to unreleased remote sensed high resolution ($5m^2$) Phase 1 land use dataset (Lucas *et al.*, 2011). This land use data was used to provisionally identify potential priority habitat within the catchment. Once the priority habitat was identified, surrounding land use types were categorised in terms of levels of risk or opportunity in relation to meeting biodiversity objectives. The two main reasons to change land use were either because the current land use type was more valuable as habitat from an ecological perspective: for example, the reversions of stands of coniferous woodland back to broad-leaved where they overlie what was originally planted ancient woodland (PAWS) sites (Goldberg *et al.*, 2007), or where an adjacent land use type presented a threat, such as along river corridors suggesting that some form of buffer (riparian planting, for example) could be introduced. The rules used to generate the maps were developed through iterative consultations with ecologists from CCW (and converted into Polyscape output). The output represented a simplified interpretation of CCWs' priorities, identifying areas of high existing biodiversity value and areas with potential for change.

To explore the implications for managing the land for biodiversity purposes three further layers were created that represented a) priority areas for the provision of a set of selected ecosystem services and b) areas of opportunity associated with improving the delivery of service. Ideally an ecosystem service assessment should include mapping interactions between a holistic set of services (Everard, 2009). an initial suite of three ecosystem services were selected on the basis of their perceived importance by policy makers in Wales, for the area concerned: agricultural productivity, water regulation and carbon sequestration. The rationale for their selection was that a) they were central components of the planned agri-environmental objectives under *Glastir* (National Assembly for Wales, 2011) and b) represented ecosystem services likely to be significantly affected, directly or indirectly, through climate change (as outlined in the introduction).

6.2.2.1 Agricultural productivity

The agricultural productivity layer was designed to reflect the primary livelihood concern of the land owners within the catchments by identifying both prime and marginal land for agriculture from a farmer' perspective. The initial output was generated using specifications developed for Pontbren and the Elwy (see Section 5.3.2.1) and then modified through scoping interviews with farmers as described in Section 6.4.2.

6.2.2.2 Water regulation

The water regulation layer was based on algorithms developed for Polyscape at Pontbren (see Section 5.3.2.3). Information on storage and permeability regions was derived from soil and land use data. Land units were grouped within the landscape according to the similarity of their hydraulic properties and spatially explicit topographical routing.

In keeping with the methodology initial output for both the agricultural and water regulation layers were presented to a small set of farmers (n=4) within the study areas for validation and, where appropriate, initial output was modified to meet local requirements. All interviewees had parcels of land in both uplands and lowland areas of the study area.

6.2.2.3 Carbon sequestration

A third layer mapped carbon sequestration within the catchment. The carbon layer was adapted from work done on mapping carbon sequestration using Polyscape in New Zealand (reported in O'Leary, 2010). The specification for that study and it's adaptation for use here was developed by Bethanna Jackson at Victoria University of Wellington, New Zealand. Carbon opportunity calculations were based on the IPCC Tier 1 protocols (IPCC, 2006); which separated carbon into above ground biomass, below ground biomass, deadwood, litter, and soil carbon. The methodology set out under the PAS 2050 protocol (British Standards Institute, 2008), using the IPCC first tier data, was adopted. This used standard rates of carbon accumulation and loss which were applied to soils and land use data for the study area. The algorithms calculated levels at pseudo-steady state; assuming carbon levels when the land use/management regime has been in place long enough for the system to come into equilibrium. The thresholds used in Polyscape were set as follows:

- high existing value of carbon held >500 kg/ha (red areas on the Polyscape maps);
- high opportunity for change <80kg/ha (light green areas on the Polyscape maps)

Welsh or UK specific data were available for many quantifications of carbon and were used where possible. Additional data for the carbon sequestration layers were derived from Adger *et al.*, 1992; Adger and Subak, 1996; Forest Resource Assessment, 2010; Patenaude *et al.*, 2004; Patenaude *et al.*, 2003; Smart *et al.*, 2009 and Smith *et al.*, 2000.

6.2.3 Data sources

The basic map layers were produced using nationally available datasets, in line with the principles outlined in Chapter 5. Polyscape mapping requires land use data, soil data, and a digital terrain model (DTM) to run the default algorithms. The datasets used in this study are described in Table 6.1 below. The major difference in this study from previous applications at Pontbren and Elwy, was the availability of higher resolution land use data. The initial implementation of Polyscape at Pontbren (see Chapter 5) used CCW's Phase 1 dataset. This data was generated during the 1980s and was increasingly considered out of date and was in the process of being updated for CCW using data derived from remote sensing. Given the requirements for high quality land use data and at the request of CCW an early iteration of the Phase 1 data (generated in 2009 with a resolution of $5m^2$) was the main land use dataset used in this study.

Table 6.6: Spatial datasets used in the study

Data set	Type	Resolution	Notes
CCW 1980s Phase 1	Land use	$10m^2$	Data drawn from field survey 1980s
CCW 2009 Phase 1	Land use	$5m^2$	Remote sensed data 2009.
NSRI Soilscapes	Soil	$1\ km^2$	Farewell *et al.*, 2011
OS Land PROFILE	DTM	$10m^2$	
EA Flood risk	Flood risk	Im^2-$10m^2$	Uses DTM and LIDAR
Core and Focal Habitat Network	Habitat network	$20m^2$	Watts *et al.*, 2008

6.2.4 Evaluation of Polyscape output

This study identified four main stakeholder groups involved in decision making about changes to ecosystem service delivery:

- Local landowners responsible either explicitly or implicitly for delivering ecosystem services in the landscape. Primarily private farmers, but also public bodies, notably the Forestry Commission, responsible for the publically owned forest estate.
- Intermediary groups with responsibility for securing the delivery of ecosystem services.
- Ecosystem service beneficiaries (including both local land owners and residents in local towns).
- Policy makers (mainly the Welsh government, Environment Agency, Countryside Council for Wales and the Forestry Commission)

The initial aim of the evaluation was to seek the views of representatives from the key stakeholder groups that the project sought to engage, about the credibility of the mapped output. That is, did they think that the mapped output was broadly representative of local landscape conditions? This combined aspects of credibility (how accurate the outputs are) and legitimacy (how acceptable the outputs are to stakeholders), we also sought to address saliency (how relevant the approach is to present needs) by reviewing the Polyscape approach in relation to other approaches in terms of meeting present needs for agri-environment policy implementation in Wales (Lusiana *et al.*, 2011).

Evaluation of the output in terms of combined credibility and legitimacy were conducted through interviews with 15 individual local land owners and one focus group discussion with five intermediary stakeholders. In interviews and focus group discussion the stakeholders were presented with Polyscape output for the four layers described above. These included presentations of alternate versions of the agricultural layer (where slope thresholds, fertility and aspect were modified in response to suggestions from the four farmers initially consulted about the agricultural layer, see Section 6.4.2) and two sets of water regulation (one based on the 2009 Phase 1 land use data, the other on the 1980s Phase 1 data). The saliency of the approach was also discussed with the stakeholders in relation to two other spatially explicit approaches in use by the Welsh Government (habitat network maps and woodland opportunity maps). Finally, a stakeholder meeting was held in the Welsh Government building in Aberystwyth where the mapped output was presented to members of the local community (drawn from the study area) and intermediary stakeholders (representative from Welsh government, Defra, Environment Agency, Countryside Council for Wales and the Forestry Commission), where the saliency and legitimacy of the approach and outputs were discussed.

6.3 RESULTS

The results are presented in two main sections on development of the mapped output and then its evaluation by stakeholders.

6.3.1 Priority habitat layer

Ten priority habitat types were identified in the catchment area using the most-recent list of UK BAP priority species (Biodiversity Reporting and Information Group, 2007). These were: Bog (raised and blanket), hedgerows, lowland mixed deciduous woodland, upland oak wood, upland mixed ash woodland, wet woodland, lowland heath, upland heath, coastal salt marsh, lowland unimproved grassland and riparian habitat. Transferring these habitat categories to Polyscape output was achieved by using the closest comparable Phase 1 land use category. This was an iterative process and where issues occurred, CCW specialists were consulted to develop a consensus on the relevant 'rules' to be applied. Examples of this iteration are discussed below for particular habitats.

6.3.1.1 Bog and peat

Bog was identified by CCW ecologists as of particular importance as habitat within the study area. There were discrepancies between the two land use datasets (1980s Phase 1 and the 2009 Phase 1). Although the area of bog was higher in the 2009 dataset (1,412 ha compared with 987 ha) there were areas, particularly in the south east of the study area, where CCW specialists believed that significant areas of bog were omitted from the 2009 data. The recommendation of the CCW ecologists was to utilise the 1980s Phase 1 datasets as this had been extensively ground truthed in the local area. All bog identified by the 1980s Phase 1 data was identified as a key habitat. The ecologists were also keen to identify where inappropriate land use (such as commercial forestry or improved grassland) overlaid other heavy peat soils (not identified as bogs). In these instances the Phase 1 land use data was interrogated using the NSRI Soilscapes data to identify areas having high opportunity for change.

6.3.1.2 Woodland

There were four woodland priority habitats: lowland mixed deciduous woodland, upland oak wood, upland mixed ash woodland and wet woodland. The categories used in Phase 1 datasets (both 1980s and 2009) only identify broadleaf woodland (A1.1). As no further disaggregation was possible all broadleaf woodland was considered as priority habitat. Wet woodland was a subset of both the deciduous woodland (A1.1 in 1980s Phase 1 dataset) and scrub (A1.2). There were no existing maps detailing where wet woodlands were within the study area (or, for that matter, in the whole of Wales). A provisional wet woodland layer was developed by selecting all broadleaf woodland or scrub that overlaid poorly drained or wet soils (using the NSRI Soilscapes data). Given the resolution of the Soilscapes data (1 km^2) and lack of species composition for the scrub/woodland, this wet woodland identification needs to be treated with a degree of caution. During the consultation CCW ecologists were unsure how to categorise conifer woodland. For the initial iteration conifer woodland was treated as neutral unless the plantations were either sited on an ancient woodland site described as Planted on Ancient Woodland (PAWS) sites or on deep peat soils, where in both cases they were then classified as high priority for change. Forestry Commission Wales (FCW) staff were not involved in discussions because habitat classification and priorities for conservation are the remit of CCW but this means that the rules developed for woodland classification did not take account of FCW views or expertise.

6.3.1.3 River habitat

River habitats are ecologically complex and requirements for riparian management remain unclear. Current prescriptions for *Glastir* advocate a 3m buffer but the rationale for this was not explicit, although it seems to implicitly acknowledge the farming value of land adjacent to rivers since a wider buffer, width depending on surrounding habitat, might be expected to be necessary to ensure water quality. A buffer of 10m either side of the main rivers was mapped to recognise the general biodiversity value of this area. Historically, many of the rivers to the west of the study area were polluted from lead mining. The farmers were able to quickly identify where these lead mines were and locations where disturbance of the riverbed could release lead sediments. These rivers were described as 'dead' by farmers, meaning that they did not support fish and, if they were aware of streambed disturbance that would mobilise lead so they removed stock to stop them drinking lead polluted water. This highlights a local tension amongst stakeholders about values of biodiversity as some SSSIs were there primarily because of factors considered by others to be contaminants. As a consequence, for the project, all watercourses were identified as important habitat, irrespective of their current water quality. The final rules used are summarised in Table 6.2 below

Table 6.7: Phase 1 categories and rules used to determine Priority habitat layer

Priority Habitat	CCW Phase 1	Summary of final rules used for mapping priority habitat
Bog (raised and blanket)	E1.6.1 (blanket bog) and E1.6.2 (raised bog)	Identified as a key priority habitat within the catchments. CCW ecologists unhappy with 2009 remote sensed data for peat so used original 1980s Phase1 data to identify habitat areas
Other heavy peat soils	Not applicable	NSRI Soilscapes data was used to identify heavy peat soils (classifications: 1013a, 1013b, 1024a). Any land use identified as unsuitable by CCW ecologists overlying heavy peat soils were treated as high priority for change.
Hedgerows	J2.1 (hedgerows)	Hedgerow data was available in the 2009 remote sensed dataset only. This was treated as priority habitat.
Lowland mixed deciduous woodland, upland oakwood, upland mixed ash	A1.1 (broad leaved woodland)	There was no means for disaggregating the broadleaved woodlands down into the three BAP categories. All A.1.1 woodland was treated as priority habitat
Wet woodland	Not classified	No maps were available for wet woodland – The areas of wet woodland were derived using A1.1 and A2.1 (scrub) categories in 2009 Phase 1dataset. Woodland and scrub overlying waterlogged soils (derived from NSRI Soilscapes) were treated as wet woodland.
Lowland heath	D1.1 (wet heath), D6 (dry heath)	Areas of heathland were derived from the 2009 Phase 1 datasets. Lowland and upland heaths were distinguished by interrogating the dataset using CCW's upland boundary
Upland heath	D1.1 (wet heath), D6 (dry heath)	
Coastal saltmarsh	H2.6 (saltmarsh)	Derived from 2009 remote sensed CCW Phase 1 datasets
Lowland unimproved grassland	B1.1 (unimproved acid grassland)	Detailed Phase 2 mapping of lowland grassland was available for the catchment. This dataset was used to identify lowland grassland areas (as opposed to 2009 remote sensed dataset)
River systems	G.1 (standing water) G.2 (running water)	All standing and running water was identified as Priority habitat based on 2009 remote sensed dataset. A10m buffer either side of running water was identified as priority habitat

Areas with high opportunity for change (shown as bright green in the Figure 6.4) are the areas of peat soils not currently vegetated with blanket bog, the conifer woodland and scrub on ancient woodland sites, and acid grassland next to heathland (all these occurring mostly in the upland zone) and areas of improved grassland that lie next to priority habitats (mostly in the lowland zone particularly around Cors Fochno to the north west of the study area).

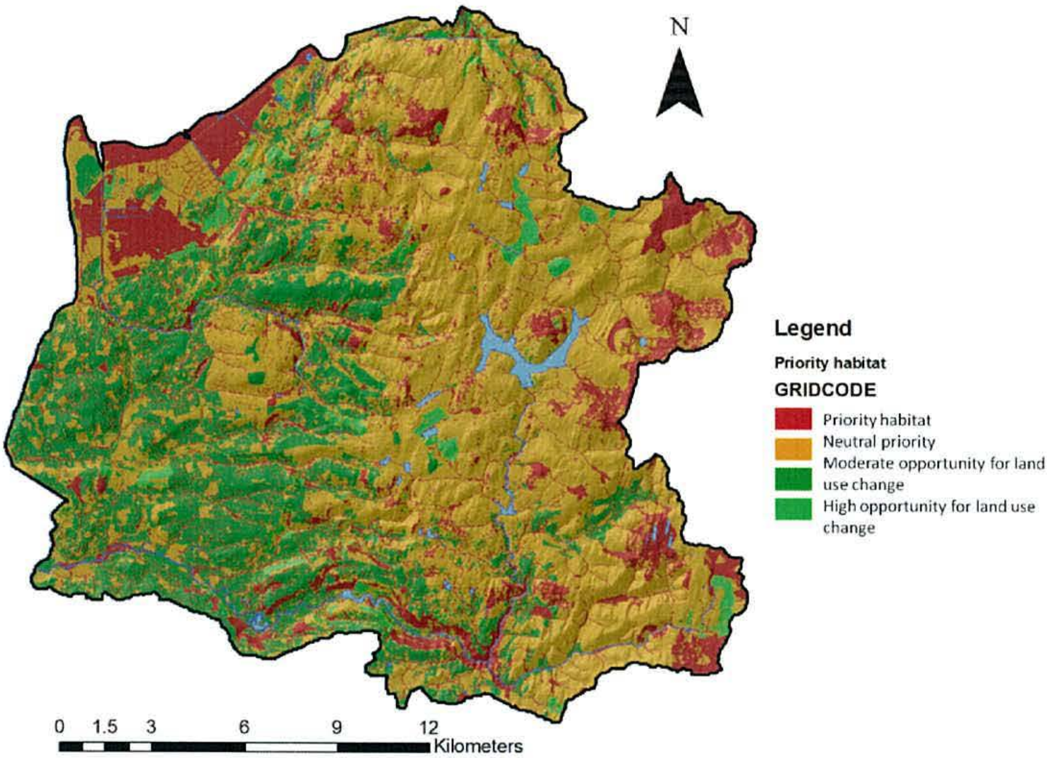

Figure 6.4: Map of priority habitat in the study area. Maps in Polyscape use a five colour 'traffic light' system. For the individual service layers areas of the map in red indicate high existing value for the ecosystem service is question. Areas in maroon have some existing value and orange indicates neutral or marginal value. Green indicates high opportunity for change (as the land is low value for agriculture) with lighter green indicating the highest level of opportunity.

The total area identified as high opportunity for change with respect to priority habitat conservation was approximately 1054 ha (2.7% of the study area) and was made up primarily of coniferous woodland and improved grassland (681 ha and 345 ha respectively).

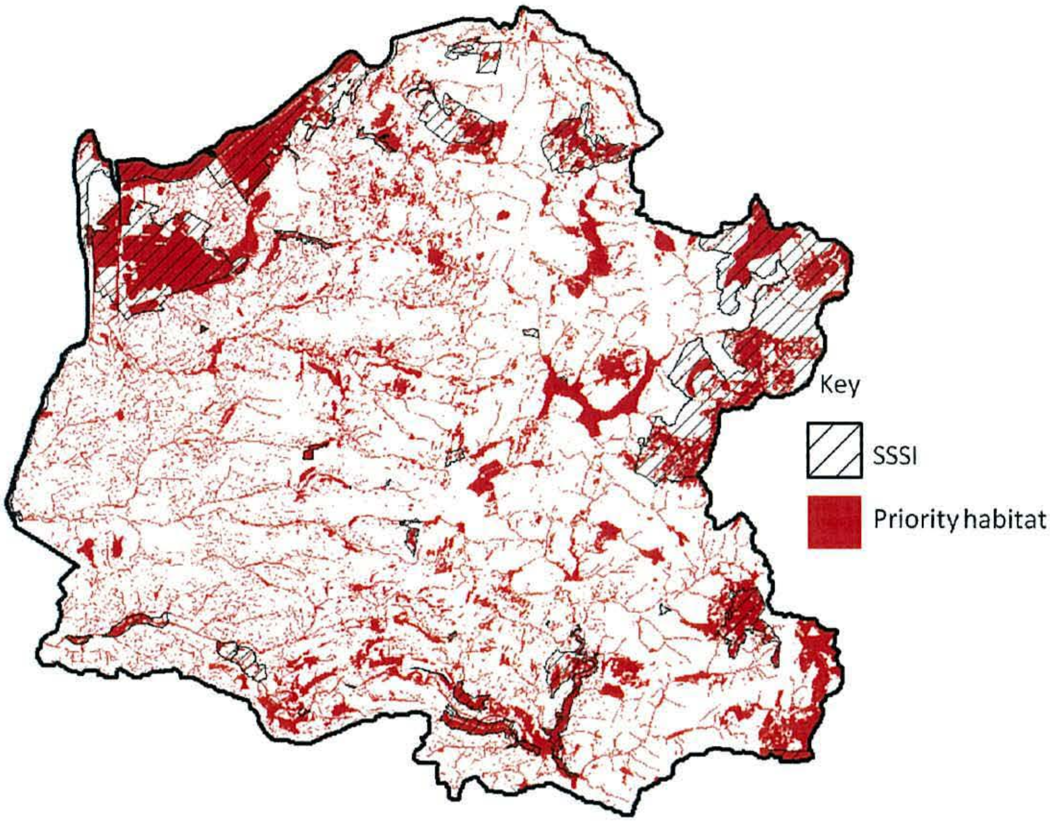

Figure 6.5: Location of priority habitat in relation to conservation areas

Once the priority habitat was mapped then the designated nature conservation sites within the study area were overlaid, consistent with Principle 1(a) (Section 6.3.2). Priority habitat accounted for 8019 ha of the study area, approximately 21% of the total area, although the riparian buffer accounts for a significant proportion of this (Figure 6.5). SSSI's accounted for an area of 5112 ha, but only had 2818 ha of priority habitat meaning that approximately 70% of the priority habitat lay outside areas of formal protection. This has clear implications for broader stakeholder engagement in the management of habitat.

Habitat connectivity was also identified as important within this study but metrics for this were not used in mapped output (see Section 6.5.2). The main issue was in terms of prioritisation of networks and related issues to condition of habitat.

6.3.2 Agricultural production

The initial output was developed using slope and drainage thresholds developed at Pontbren (Figure 6.6a), with the soil fertility option disabled. Initial feedback from farmers suggested that this captured the lowland areas well but was inaccurate for upland areas, which had considerably lower soil fertility. However when national scale soil fertility data was incorporated the output became much more homogenised in terms of its agricultural opportunity (Figure 6.6b), because the underlying soil data identified most of the catchments as having low fertility soil (categorised as Grade 4 or 5 using agricultural land classifications (MAFF,1988).

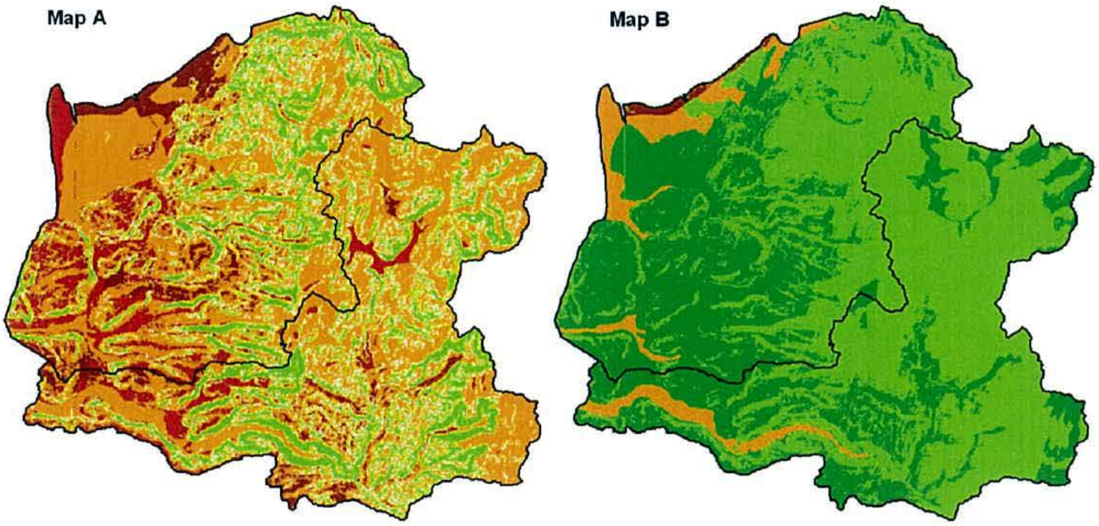

Figure 6.6: Initial agricultural productivity maps (a) with just slope and water logging and (b) inclusion of soil fertility

The agricultural layer was then modified to allow the fertility scores to be adjusted to consider soil fertility present within the catchment rather than comparing the soils in the catchment with the highest grade soils in the country. In effect the range of soils grades considered was condensed and the fertility values were distributed amongst a narrower range of soil types. The farmers stated the importance of fields with southerly aspects (similarly to farmers in Elwy see Section 5.3.4) and this option was included in the final output. Figure 6.7 shows one of the farm parcels used in the scoping study. Significant portions of the land on that parcel were identified as having marginal agricultural value and the farmer owning it agreed but identified inaccuracies in the Polyscape output relating to the soil quality on his neighbour's land (Figure 6.7) which was confirmed when the soil data was re-assessed - demonstrates the value of local knowledge for ground truthing datasets.

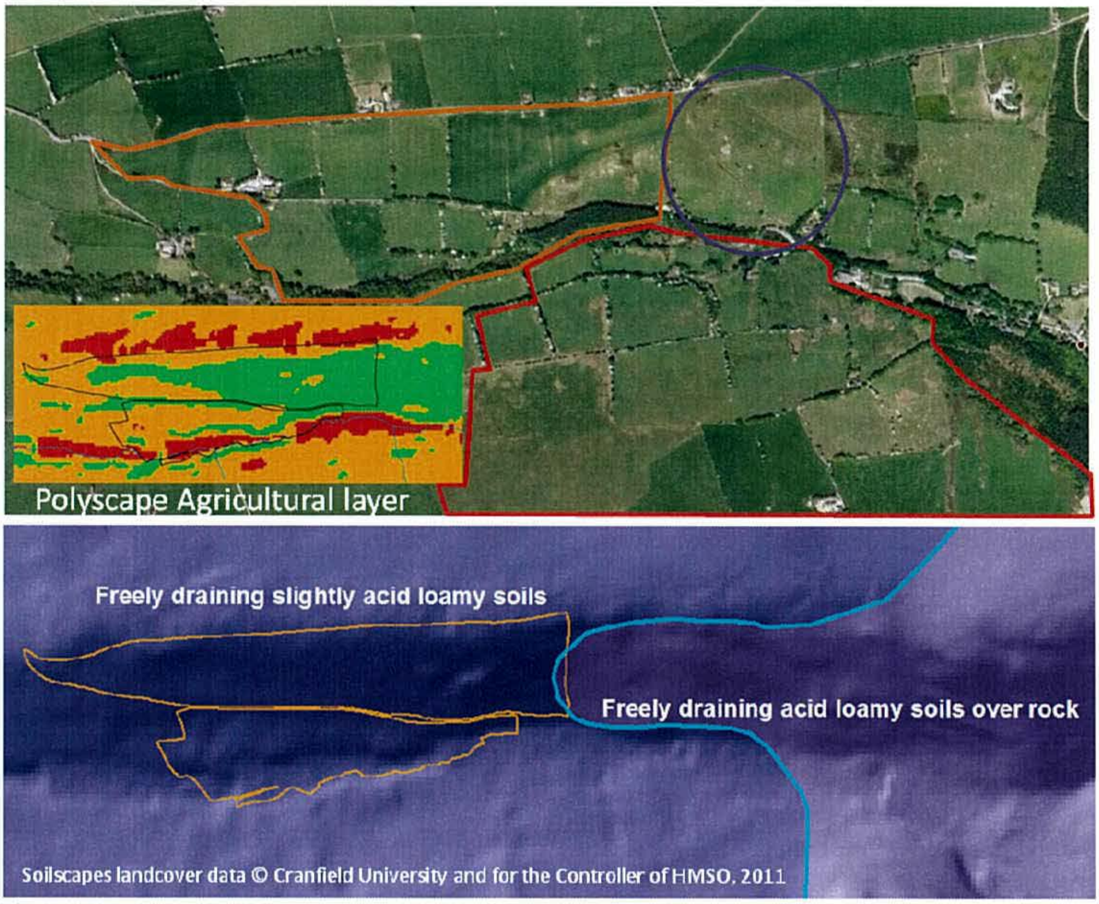

Figure 6.7: One of the farm parcels used for the scoping exercise (outlined in orange) from the scoping interviews with corresponding agricultural output from Polyscape shown in the inset. In response being shown the Polyscape data the farmer was happy for the representation of his farm but felt that the tool had misrepresented the soil quality of his neighbour (the area circled in purple). The underlying Soilscapes soil data confirmed this difference (presented in the second figure below), the initial iteration of Polyscape output did not distinguish between the two soil types.

The final agricultural value output is presented in Figure 6.8. Given that agriculture is the predominant land use in the study area, the map identifies land of high value to agriculture using red (suggesting that changing land use in these areas will disadvantage farm productivity and meet resistance from farmers). Areas identified as green are areas that potentially are of lower value to farmers – and thus offer opportunities for interventions. The map identifies areas of high value for farming (in maroon) towards the western side of the study area and identifies areas for potential change along the steep valley sides and in the upland parts of the study area. The only area of high value for agriculture (red) is at the edge of the Cors Fochno peninsula because it was both flat and free draining. The initial scoping studies revealed that this area was not farmed because the soils were too sandy. This suggested that a further modification was required to the algorithm to mask coastal soils which require different interpretation than those in the rest of the catchment.

This was not implemented within the existing study since the specific issue was corrected for the study area in the participatory ground truthing but would improve future initial outputs.

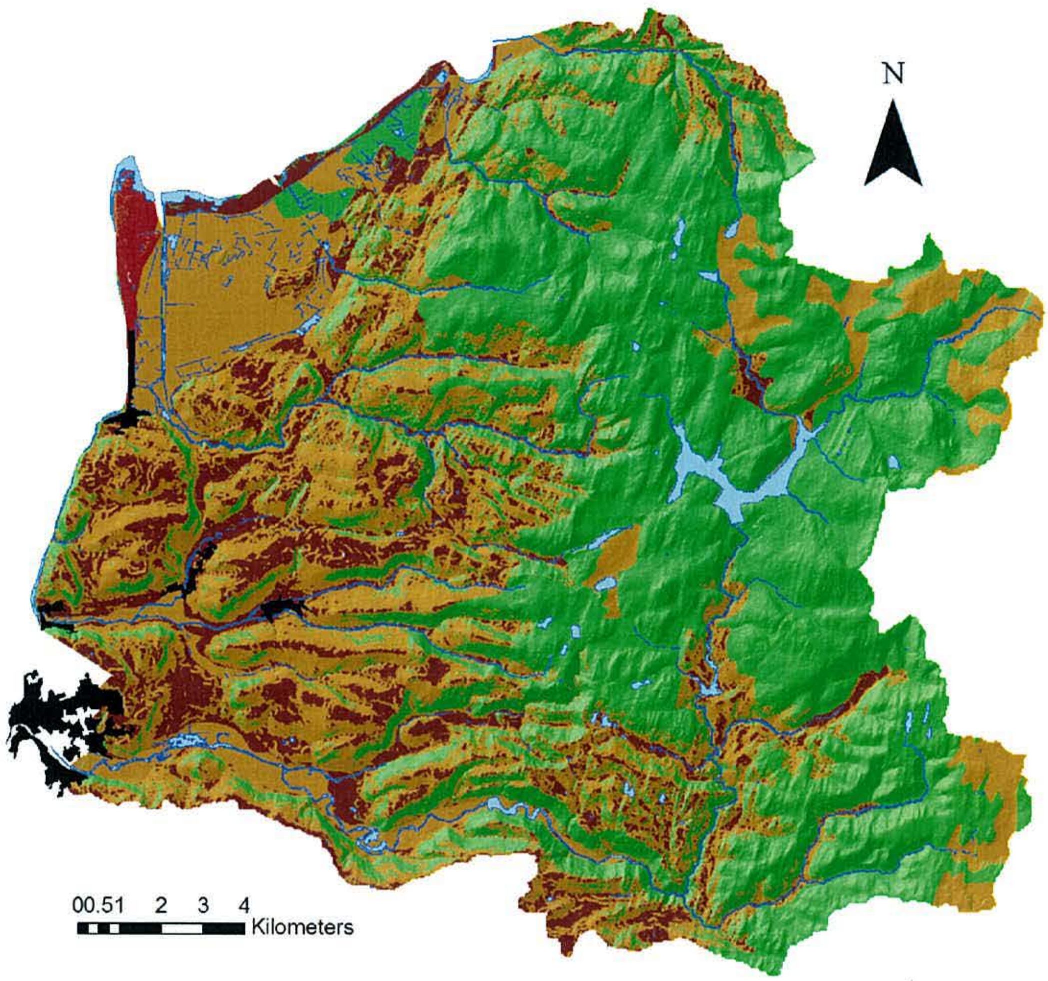

Figure 6.8: The agricultural productivity layer for the study area (which incorporates a modified soil fertility algorithm and values southerly aspects)

When asked about opportunities to increase food security in the catchments during the scoping interviews the farmers stated that the lowland and upland areas were currently operating at 'sensible' limits. The lowland soils, whilst productive, were not perceived to be as fertile as soils in other parts of Wales. The farmers noted that the productivity of farm parcels was strongly influenced by management. At an individual farm level there were opportunities for intensifying certain farm parcels as not all farmers were working the land to capacity (during the field visits the farmers identified examples of neighbouring land being very extensively farmed in relation to their own). The farmers also identified urban expansion onto good agricultural soil as a significant threat to some of the most productive farmland in the study area. A new algorithm was developed for Polyscape to enable identification of areas that could be used as farmland in that they were flat and fertile but that were not currently being used for that purpose.

Upland parts of the catchment were recognised as marginal value for agriculture, especially over the dense peats. These areas had been farmed more intensively in the 1980s but were now retained primarily for income generated through agri-environment schemes (*Tir Gofal*). The change in management associated with that had allowed the land to become unproductive. Increasing productivity in these areas would be difficult although farmers said that stocking levels could increase twofold (as had been done in the past) if lamb prices rose significantly.

6.3.3 Water regulation

The water regulation output shows much of the upland area as being valuable for water regulation (Figure 6.9). The use of high definition land use data allowed hedgerows to be represented in contrast to the output presented for Pontbren and Elwy in Chapter 5 that did not capture woody features at this resolution. When compared to the water regulation layers based on the 1980s Phase 1 datasets (which excluded hedgerows) the inclusion of hedgerows resulted in more of the flows of water being intercepted.

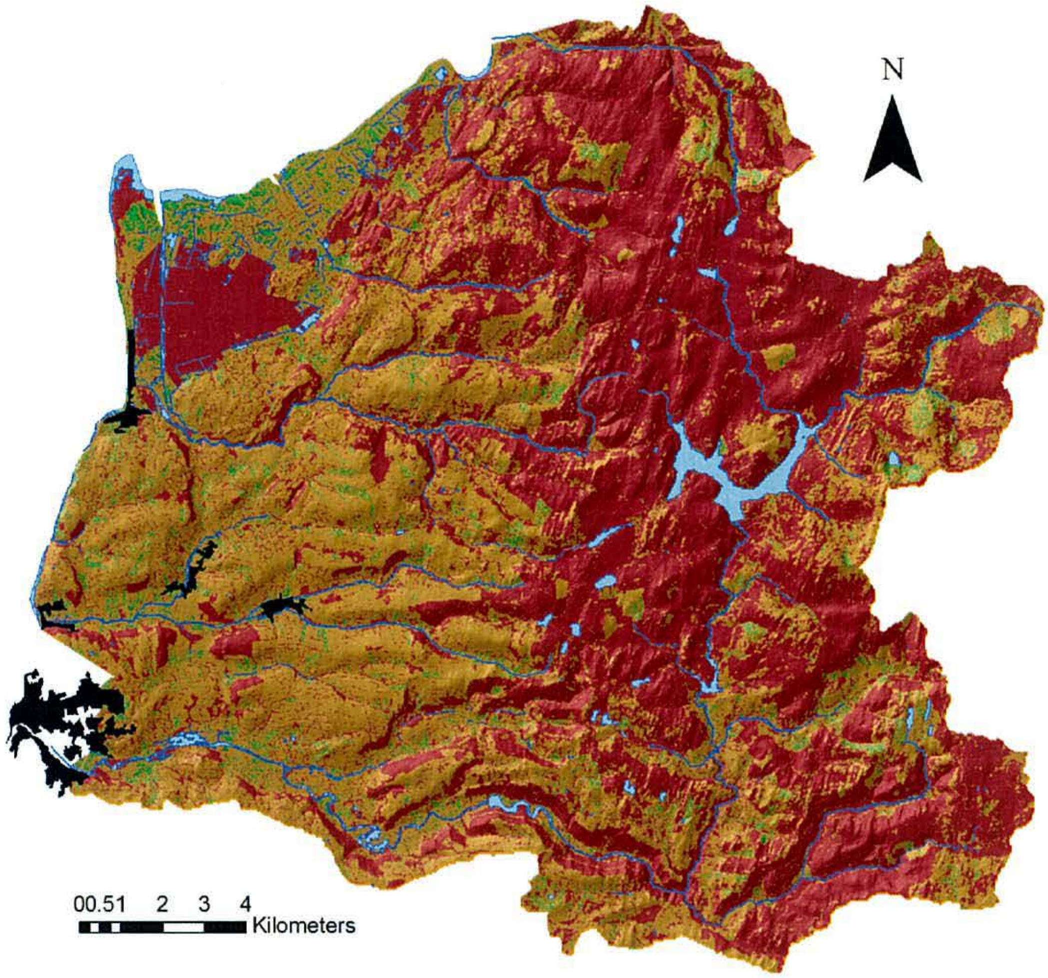

Figure 6.9: The water regulation layer for the study area. Areas of the map in red indicate high existing value water regulation. Orange areas indicates neutral or marginal value. Green indicates high opportunity for change (as the land potentially generates significant surface run-off) with lighter green indicating the highest level of opportunity.

As would be expected the presence of hedgerows served to decrease the area of opportunity for intervention to intercept flows (illustrated at a subcatchment level by comparison of Figures 6.10a and b). At present the Polyscape algorithm assumes that a hedgerow intercepts any amount of accumulated flow, and this may overstate their effectiveness where accumulated flows are large (Viaud *et al.*, 2005).

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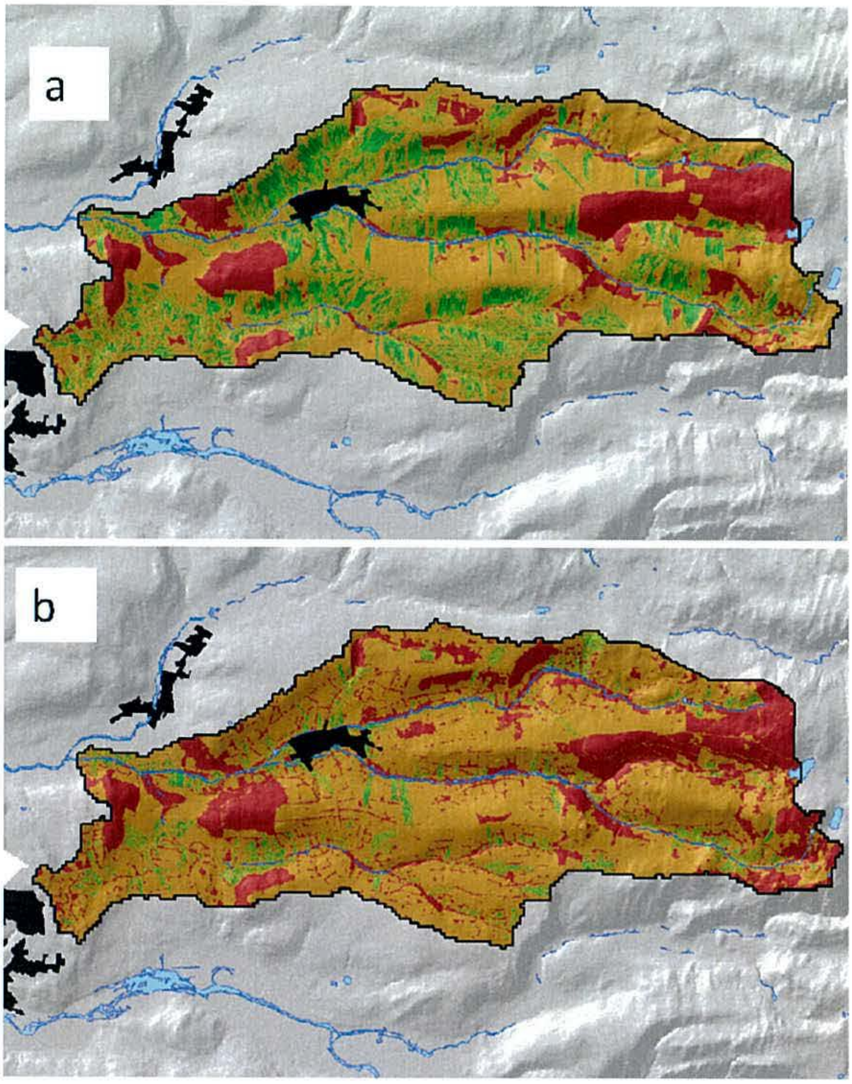

Figure 6.10 Comparison between Polyscape water regulation output for the Clararch sub catchment with the 1980s Phase 1 data (a) and the 2009 Phase 1 data (b) that includes hedgerows. Areas in black are towns. Colour scheme follows Figure 6.9

During the scoping studies farmers said that the water regulation layer using 2009 Phase 1 data was accurate. Areas identified as having high flow accumulation generally corresponded to wet areas on their farms.

6.3.3.1Mapping drainage

During the interviews farmers identified a significant gap in the water regulation layer, noting that field drains were not included. The significance of the relation between drains and water regulation at landscape scales are unclear in the literature, although the indications are that they play a significant role (Wheater *et al.*, 2009; McIntyre and Marshall, 2010).There are no spatial datasets available mapping drain networks in the UK. Farmers often have drainage maps for more recently installed drainage networks on farm but, in many instances, this is an incomplete record (i.e.

older drains systems are not mapped). As drainage systems were usually used in heavier soils a preliminary map was produced that suggested where land could have been drained by combining the areas identified as having water logged soils (from the NSRI Soilscapes data) with areas of improved grassland from the date Phase 1 datasets. The results are presented in Figure 6.11.

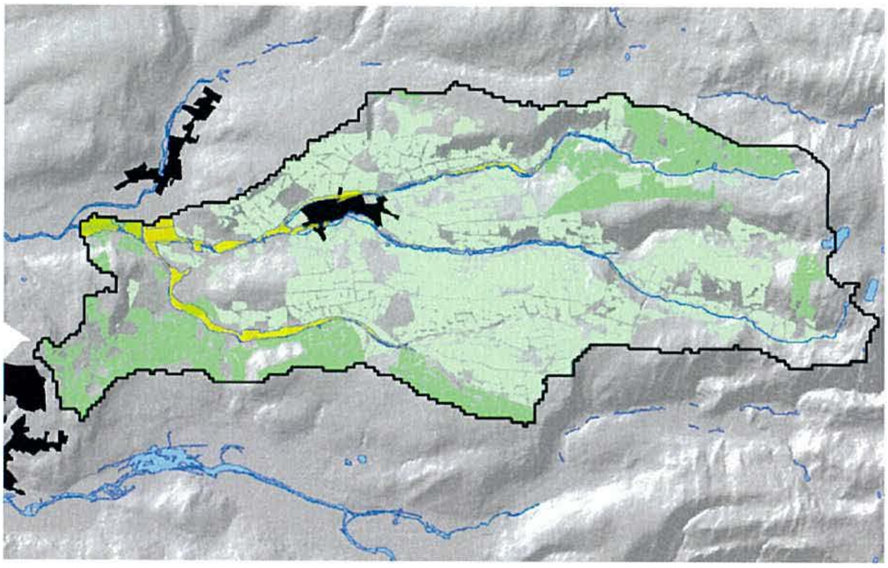

Figure 6.11 Map showing improved grassland (light green). Where improved grass land overlies heavy soils it was coloured dark green, to represent the likely presence of drains. Local flood maps were overlaid (highlighted in yellow)

The potential field drain area output was then overlaid on the Polyscape water regulation output (Figure 6.12) to identify areas that may be contributing to flood risk from drains as well as from surface runoff.

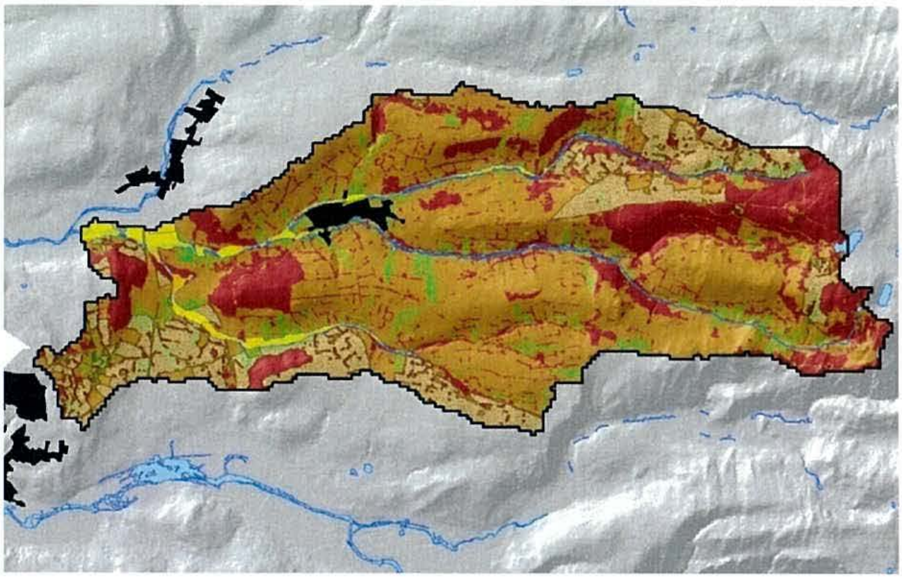

Figure 6.12 – Suggested drain locations (identified as khaki areas here) overlaid over Polyscape output. Areas of the map in red indicate high existing value water regulation. Orange areas indicates neutral or marginal value. Green indicates high opportunity for change (as the land potentially generates significant surface run-off) with lighter green indicating the highest level of opportunity.

6.3.4 Carbon storage and sequestration

The initial output for carbon was based on reasonable but crude approximations of soil carbon stocks in the catchment (Figure 6.13a). This provides an indicative snapshot of wher carbon storage is currently high and where there are opportunities for greater carbon storage. The initial output confirmed *a priori* expectations of areas of high carbon in the catchment (e.g. peat was identified as a priority for conservation, and woodland areas and much of the uplands were also valued for their current carbon storage). The underlying lack of data for certain land use types resulted in a degree of uncertainty, for example, in relation to the salt marsh areas. This uncertainty was not communicated in the final maps, but intermediate maps were produced for each of the data components as part of the output (i.e. above and below ground biomass, litter, soil carbon and deadwood). This enabled stakeholders to view the impact of data gaps when desired.

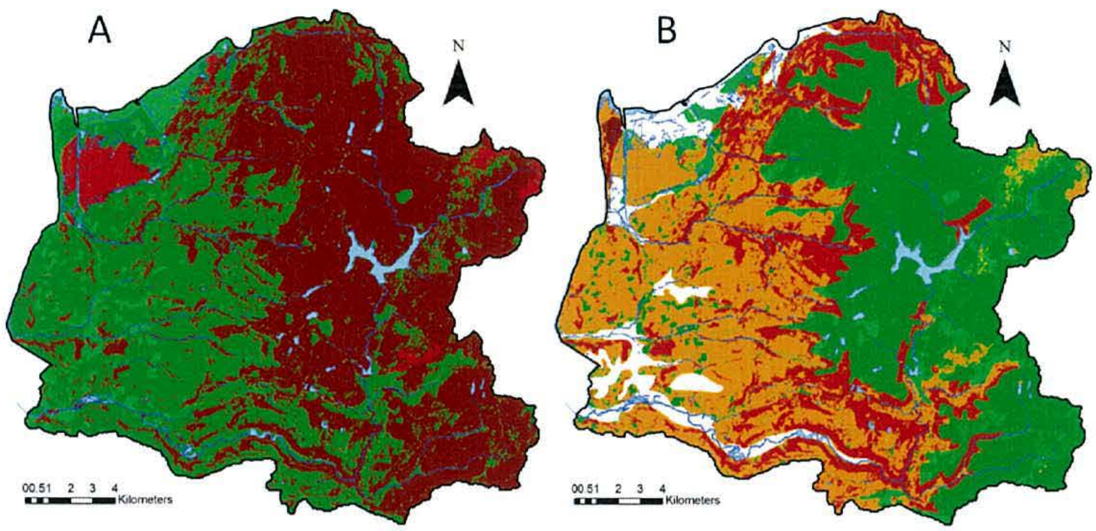

Figure 6.13: Polyscape output for carbon storage and sequestration (a) shows the initial output for the carbon storage scenario where areas of the map in red indicate high carbon storage. Areas maroon indicates moderate value and green areas have low carbon storage. In (b) the maps show areas where carbon is in a steady state in the catchment (orange) and areas that are actively storing (red) or potentially losing carbon (green)

Having implemented the layer (a) an option was included to allow the default thresholds to be adjusted to reflect local conditions in much the same way as the agricultural layer (see Section 6.4.2). This local estimate of thresholds was calculated by looking at the means and standard deviations of carbon stock. This allowed either an absolute calculation based on national or international standards to be made, or a relative calculation based on the mean and ranges of carbon sequestration in the area of interest.

A second option was also implemented which identified where the current regime was likely to be significantly reducing or augmenting levels of carbon resulting from previous regimes (Figure 6.13b). For example, many woodland areas or rough grazing areas would be considered as of moderate to high value according to the initial "pseudo-steady-state" calculation, indicating preservation was desirable. If these areas are overlaying particularly organic soil such as peat, a reduction of stored carbon (and associated net CO_2 emission) would be calculated in the second carbon map, and there could be interventions that may be appropriate to prevent this. Stakeholders had limited capacity to evaluate the carbon layer, perhaps unsurprisingly, given the large degree of scientific uncertainty. However the real

6.3.5 Trade offs

A series of trade off maps were generated using the additive option in Polyscape (Figure 6.14) where all services were considered equal (see Section 5.3.2.4). A final layer, where all services were traded off against one another, is presented in Figure 6.14. In the maps red areas, such as the Cors Fochno, complex identify areas of high existing value (the bog area has low value for farming so is not contested and has high value for carbon sequestration, water regulation and as habitat). The reason Cors Fochno changes from red to maroon in the habitat-agriculture trade off (Figure 6.14c) is because of the way that the agriculture layer represents opportunity (i.e. the bog is low value for agriculture and so has high opportunity to be used for other purposes).

Interestingly, when the synergies between the agricultural layer and the habitat layer were analysed (Figure 6.14c) 2051 ha of land was identified as of low value to farming but as high value as priority habitat. Approximately half of this area (488 ha) falls within the high priority for change category of the first habitat map (Figure 6.4). This suggests that these areas could be modified relatively easily

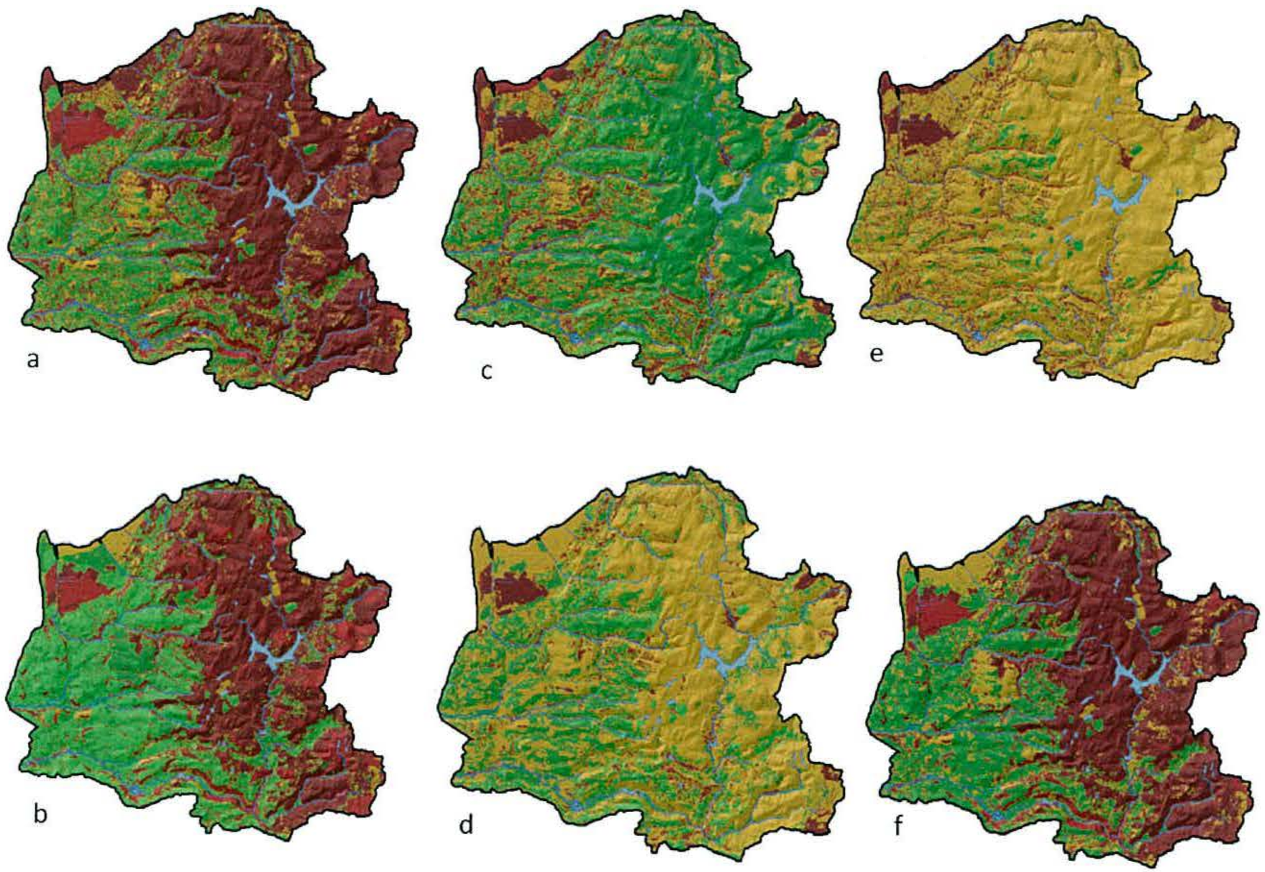

Figure 6.14 Trade off maps showing (a) habitat vs. water regulation; (b) habitat vs. carbon sequestration; (c) habitat vs. agriculture ; (d) habitat vs. agriculture vs. carbon sequestration (e) habitat vs. agriculture vs. water regulation and (f) habitat vs. water regulation vs. carbon. Green areas identify synergies amongst ecosystem services (light green areas are positive for both services, and dark green are positive for one and neutral for the other) while red areas indicate tradeoffs.

Figure 6.15: Map showing synergies and trade offs amongst all four layers: biodiversity, agriculture, water regulation and carbon storage for the Cambrian Mountain case study. Green areas identify synergies between ecosystem services (light green areas are positive for both services, and dark green are positive for one and neural for the other) showing and similarly red areas indicate trade offs

The four-way synergy and trade-off map suggests a strong synergy between the conservation of existing biodiversity in key areas such as Cors Fochno, and large parcels of upland heath, particularly on the eastern edge of the study area (Figure 6.15). There are also significant ribbons of high combined priority for maintaining existing service delivery along several of the river valleys (predominantly the valley floors), particularly the middle reaches of the Rheidol and the Leri.

Table 6.3 summarises the areas of synergy, where there were win-wins amongst ecosystem services (with a win for agriculture being that the land was of low value and hence relatively easily available for other uses). The table suggests, for example, that there were substantial areas where changes could improve both habitat and carbon (approximately 24% of the total area although this would be strongly dependent upon the nature of the intervention). When agriculture was also considered (see Figure 6.14d) the area dropped significantly (to 4.6% of the total area).

Table 6.8: Areas (ha) of synergy amongst ecosystem services identified from the trade off maps for the Cambrian Mountains case study.

Area (ha)	Ecosystem Services						
	H & A	**H & WR**	**H & CS**	**H, A & CS**	**H, A & WR**	**H, WR & CS**	**Trade all**
Total win-win area	2096	759.2	9191.2	1779	108.8	758.8	102.5
Win-win area inside SSSI	44.8	13.2	124.9	33.6	2.5	13.1	2.3
Win-win outside protected areas	2051.2	746	9066.3	1745.4	106.3	745.7	100.2

Key: H = Habitat; A = Agriculture; WR = Water Regulation; CS= Carbon sequestration

6.3.6 Transition zone

The initial mapped output suggests that many of the opportunities lay at the transition between the lowland and upland areas suggesting an edge effect. These transition areas were also important for interventions targeted at water regulation (Figure 6.9) as this was where many headwaters were situated. A basic and tentative agricultural transition zone was identified and mapped (see Figure 6.14 below), based on altitude. This was a simplification, as the zone is only partially defined by topography; socio-economic factors (such as land rent) also play a role.

The transition zone depicted in Figure 6.16 was exploratory, rather than definitive, but farmers identified and discussed this transition during scoping interviews (when discussing the intensity of farming). From these discussions, a suggestion arose that the transition was potentially more malleable in terms of modifying farming practice, because farmers in this area were less likely to be able to take full advantage of extant agri-environment schemes (e.g. there were few Tir Gofal agreements in this area) as the habitat was not of high enough value but nor was the land of the highest agricultural productivity. In addition the farmers suggested that farm sizes were generally smaller, limiting the ability to convert land (eg add tree cover) from agricultural production without financial compensation. Land in this area was often rented to younger farmers, and was also potentially more intensively run, suggesting reduced opportunities for agri-environmental interventions.

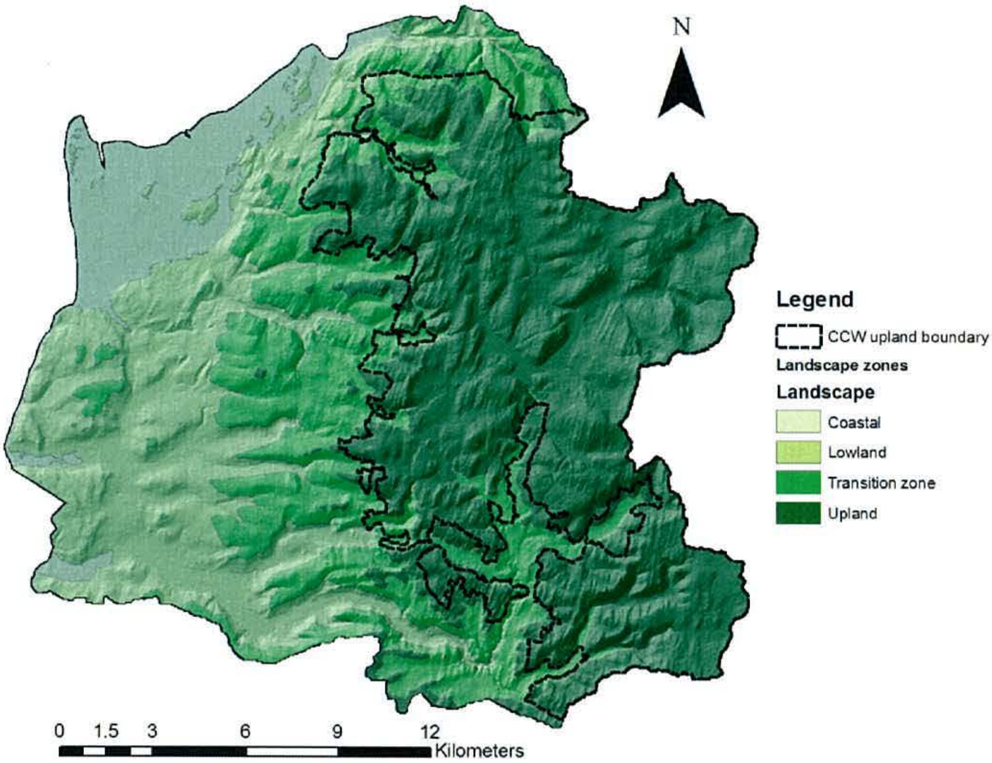

Figure 6.16: Map identifying the possible extent of a transition zone between upland and lowland with a particularly high level opportunity of land use change to improve ecosystem service delivery.

6.4. STAKEHOLDER EVALUATION OF MAPS

6.4. 1 Credibility and legitimacy of output

The farmers clearly understood the concepts behind the Polyscape output and generally found the output intuitive. The maps were presented without farm boundaries (as they were not available) and farmers' found initial orientation problematic. While the farmers understood the concepts behind the agricultural and water regulation layers, they generally struggled to understand the trade-off layers with over 60% stating that they were difficult to interpret (Table 6.12). This is consistent with the individual ecosystem service layers corresponding to features on the ground that farmers might be expected to recognise where as the trade off layers do not.

Table 6.9 Farmers' evaluation (n=15) of Polyscape output for the Cambrian Mountains case study.

	Polyscape output	High	Moderate	Low
Understanding of the conceptual frameworks behind Polyscape output		11	4	
Understanding of the rules used to develop Polyscape output	Agriculture	13	2	
	Flood risk	14	1	
	Priority habitat	13	2	
	Carbon	10	5	
	Tradeoffs	5	6	4
Credibility of output	Agriculture	10	5	
	Flood risk	14		1
	Priority habitat	12	2	1
	Carbon	11	3	1
	Tradeoffs	5	8	1
Overall confidence in Polyscape output		9	6	

The main reasons for the disparity between farmers' conceptual understanding of the rules and the credibility of the output was in relation to farmer perceptions of soil quality; the five farmers who were less happy with the agricultural output were also unhappy with the underlying soil data – suggesting that it was significantly more variable then represented in Polyscape output. As the output represented a single iteration this could possibly be improved with further incorporation of local knowledge. The farmers suggested the following improvements.

- Inclusion of farm boundaries for orientation purposes.
- Further iterations (with farmers) on soil quality used in the agricultural layer.
- The water regulation layer needed to include the farm drain systems. This is discussed briefly in section 4.3..

The final output from applying Polyscape to the Cambrian Mountains case study was presented internally to the CCW ecologists involved with development of the priority habitat layer (R. McCall, pers. comm., 2011). Their key comments in relation to the credibility of the output were that the land use data used to inform the priority habitat layer in Polyscape identified variation in land cover but did not identify the condition of habitat within land use types. Identifying habitat as high priority was no guarantee that it was in good condition. They stated that there was a need for explicit identification of management requirements to improve poor quality SSSIs and identify opportunities for areas outside those designated for conservation. Rather than being a problem with the approach, this reflects a more general problem with lack of data on habitat condition and would apply for all land use decisions. This does identify an issue in relation to how uncertainty is represented visually in Polyscape and in ES maps more generally (see Section 4.3.6)

The ecologists were also confused by the terms 'priority' and 'opportunity', and this was compounded by the focus on biodiversity. Specialists stated that, at first glance, the agricultural map was advocating 'ploughing up' the uplands – as the large areas of green were identified as opportunity for change. The agricultural layer differs from other layers as it identifies land that is of low value for agriculture so in effect represented 'opportunity for land use change to benefit other ecosystem services' which was misunderstood. Three further issues were identified by the ecologists:

1. The model implements a rule where heath land next to acid grassland was identified as higher priority for conservation than heath land not next to acid grassland, due to its extra value as a potential colonisation source for neighbouring acid grassland. Conversely, areas of improved grassland next to existing heath land were identified as areas that offer high opportunity for land use change – managed for reversion to heath land. It was suggested that acid grassland next to heath land should also be identified as a high opportunity for land use change.
2. The CCW specialists stated that heath land vegetation had a larger effect on water flow in the uplands than acid grassland but it was not differentiated in

the hydrology layer. The assumption was that the water regulation layer only considered trees.

3. The CCW specialists suggested that more layers (about other key ecosystem services) were required to develop a more integrated vision.

Whilst these two issues would be easily addressed in a second iteration, they highlight sensitivities associated with using the traffic light system adopted in Polyscape – in that there are subtle variations in meaning amongst colours in the different layers. The red areas in Polyscape do not mean that no change should be made, rather, they suggest caution in making changes in these areas because alteration of land use is likely to diminish the supply of one, or more, ecosystem services in question. Changes to enhance ecosystem service provision in these areas may still be possible. Stakeholders are used to maps being normative 'final products' rather than tools to assist a process of negotiation. The Polyscape output represents a component of a negotiation process with uncertainties involved, and forms part of a process rather than an ultimate product.

The second point the ecologists raised about hydrology represents a good example of the need for interdisciplinary engagement in land use planning and would be best addressed by involving specialists from the EA (who were not involved in the iterative development described here).

6.5.2 Saliency of the approach

All current land use decisions under the higher lever (Tir Gofal) agri-environmental schemes are made through direct consultations between farmers and intermediaries. Under this approach a biodiversity vision is taken to stakeholders for comment and amended according to their individual concerns - but without the use of maps showing distinct ecosystem services. In terms of saliency the key difference from the perspective of the local stakeholders was the inclusion of layers that addressed their livelihood (the agricultural layer). The farmers also valued the use of local knowledge to inform layers and felt this was significantly different from approaches that had gone before. The farmers acknowledged the value of having different perspectives shown on a range of maps.

In contrast, during their focus group discussion, the ecologists questioned the need for the maps, with the suggestion that addressing trade-offs was better done through discursive stakeholder consultation. In discussion, it emerged that discursive consultation did not support systematic consideration of multiple impacts and often results in consultation fatigue in relation to single-issue visions.

6.4.2 Legitimacy of the approach

Whilst a third of the farmers interviewed felt that the approach was biased towards government 'environmental' objectives (specifically the need for more trees), all farmers felt that these were legitimate areas to explore and that Polyscape offered a sensible methodology for doing this with stakeholders in the farming community. Five of the farmers stated that the approach was not needed, largely because they considered any external interference in their decision taking about land use as undesirable. Farmers were asked whether the output would influence their decision making. A number of the farmers with small land areas had no intention of planting more trees but over half the farmers were interested in planting trees and found the information on the wet areas of the farm, provided by the Polyscape output most useful – with over half the interviewees saying that they would plant trees in these areas if grants were available to assist them.

A workshop attended by 45 stakeholders including Welsh government officials, EA, FC and CCW policy officers and participants from the local community. During the workshop the utility and legitimacy of the approach were discussed (The findings from the stakeholder workshop are reported in Resources for Change, 2011; Smith and Bovey, 2011). The component of the workshop that focused on Polyscape output included a twenty minute presentation of the output and a 40 minute plenary discussion of the utility of the approach. This included having the output mapped on to GoogleEarth (Figure 6.17).

During the discussion the participants were generally enthusiastic about the Polyscape approach, particularly the visualisation of ecosystem services for discussions with stakeholders (which they considered was novel). The stakeholders recognised the value of taking a spatially explicit, and integrated approach (particularly the inclusion of the agricultural productivity layer as well as more usual environmental factors) but stated that other layers should also be included, particularly in relation to recreation and tourism which were both important to the local economy. They stated than inclusion of such layers would increase the legitimacy of the approach and enhance negotiation. The attendees recognised the value of an iterative negotiation process with stakeholders to arrive at outcomes. There was concern raised that the tool should only be used in negotiation rather than prescriptively, for example: "*... Polymapping could be an excellent discussion tool, haven't seen anything better and it should be used again and in a wider context. If what comes out of the events is 'we like the polymap' there's a danger that it will be used to create decisions rather than create discussions that will lead to decisions*" and

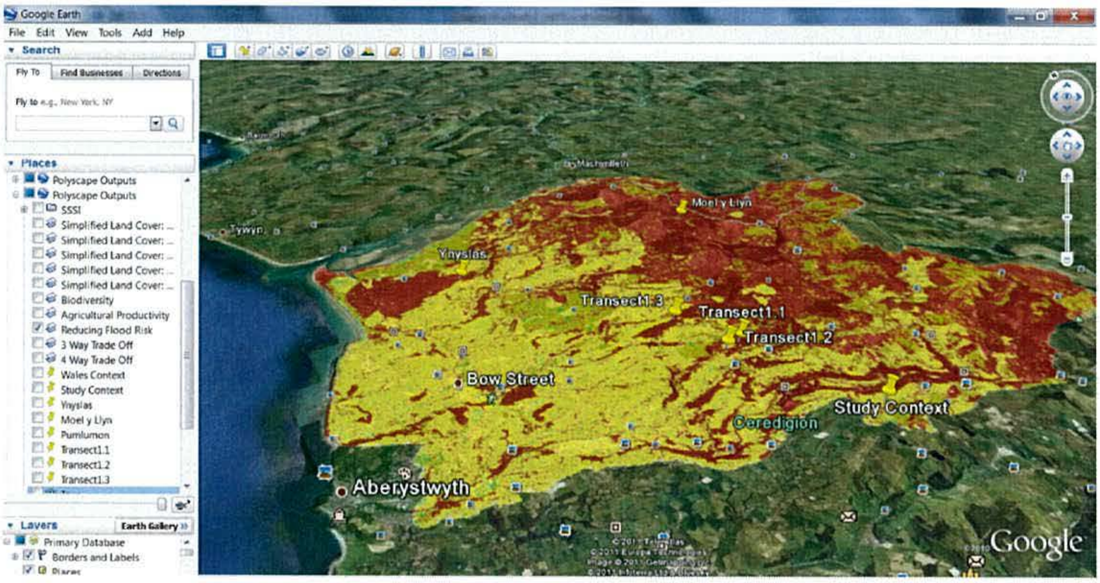

Figure 6.17: Polyscape output translated into .kmz files and presented in Google Earth during the stakeholder workshop

"*the [Polyscape] tool must not be used to arrive at decisions, but needs to be used at the point at which discussions start; its function is to make these discussions better informed, more focussed and meaningful*". Both participant observations reported in Smith and Bovey (2011).

6.5 Discussion and conclusions

Overall the results suggest that Polyscape is a valuable tool for engaging local and regional level stakeholders in decision making about ecosystem service provision. The inclusion of local knowledge in mapped outputs was recognised by both local and regional stakeholder as valuable for fostering participatory approaches to landscape management. The spatially explicit approach offered by Polyscape outputs was recognised as useful for both policy level and local level decision making in the Cambrian Mountains.

The real value of the approach documented here (and noted by all stakeholders) was the process of map development rather than the 'final' output produced. The iterative cycle of discussion and collective analysis associated with creating Polyscape layers allows stakeholders a platform to debate issues on relatively equal footing. Given the uncertainties the output from Polyscape should not be used for proscriptive decision making in isolation (although it should inform that process and clearly has a role for identifying key knowledge gaps)
The farmers who participated in the evaluation were satisfied that the maps provided a representative version of 'their' landscape that could be used as the basis for further negotiation (with a major caveat that soil data needed improvement). Farmers were able to understand the output and suggested improvements. The approach offered here was considered novel by local stakeholders.

Issues surrounding the quality of underlying data were particularly important. The use of the remote sensed 2009 land use data was a double edged sword. On the positive side it allowed significant refinements to land use datasets, including the representation of hedgerows, which were identified as keystone features in the lowland systems for biodiversity, carbon sequestration and water regulation. Having this resolution was important for farmers as they are key components within their system (a finding supported by the Polyscape output). If these features are not mapped then it is difficult to see how they are integrated into decision making. On the negative side, there were issues with the quality of the 2009 land use data, particularly in relation to areas designated as peat. Despite having a larger overall area of peat than the 1980s data, the maps missed major areas of peat that stakeholders identified as being present. The ecologists at CCW were unhappy about this and the resulting priority habitat layer (described in Section 6.4.1 above) drew on data from the 2009 Phase 1 survey, the 1980s Phase 1 data (which had been ground proofed), Soilscapes data (for identification of areas with high peat content) and CCW's lowland grassland habitat networks. This resulted in a difference in land use between the layers as the other Polyscape layers only used the 2009 Phase 1 data. The effect of this was that polygons did not match up evenly in the trade off layers – making interpretation difficult where the underlying land use data were used to interpret the results of the Polyscape analysis. With hindsight, it would have been better to develop one land use dataset and not attempt to incorporate elements of other maps into the biodiversity layer. As a result there are some inconsistencies with the output presented from the Polyscape trade-off layers

Many stakeholders were unused to a spatially explicit approach and the level of understanding about the quality of underlying data was low. The farmers were surprised that the soil data was not at a high enough resolution to make sense to them at a field level, and that drains were not mapped. There was an expectation that better datasets were available elsewhere, which was not the case in reality. There is an issue of how to present uncertainty to stakeholders. Where the underlying data were quite crude (e.g. the carbon layer) stakeholders could visualise the steps used to create the maps by exploring the individual layers. This process makes deficiencies in data explicit and can assist with defining local knowledge needs. Once the farmers were aware of deficiencies then they could begin the process of ground proofing data (although this would incur increased transaction costs). The iterative nature of the approach was a source of confusion (evident in the responses during validation) as stakeholders viewed the output as final – not as part of a process – despite this being made clear throughout the interactions with them.

A number of issues that merit further research were identified in relation to potential land planning in the study area: in particular, the importance of a transition zone between uplands and lowland, the importance of mapping field drains and habitat connectivity.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

In this chapter, conclusions are drawn from synthesis of the research presented in the preceding chapters and recommendations for immediate action and further research are then set out.

7.1 General Conclusions

The main driver for the research presented in this thesis was the need to develop effective approaches for using land use change to manage ecosystem service provision in agricultural landscapes, where land use change embraces changes in management of existing land cover as well as conversion from one form of land use to another. It was immediately evident from initial appraisal of case study ecosystem service provision at Pontbren (Chapter 2) that to be effective, approaches would need to engage land owners from the outset, incorporate their livelihood needs and local knowledge (Chapter 3) and be spatially explicit at local scales embracing the field, farm and immediate landscape (Chapter 4). Review of existing approaches (Chapter 4) revealed a major gap in provision of tools that operate for multiple ecosystem services including agricultural productivity, at local scales, and incorporate stakeholder engagement, facilitating inclusion of both scientific and local knowledge. These needs were addressed in the iterative development of tools and approaches with stakeholders in two case study landscapes in Wales (Pontbren and Elwy) to facilitate negotiation of land use change amongst stakeholders, at the local scales at which land use changes are made, and immediate impacts upon landscape scale processes can be assessed (Chapter 5). The resulting approaches and tools, brought together in a methodology and GIS toolkit referred to as Polyscape, were applied to improve adaptability of landscapes to conserve biodiversity in the face of climate change in the Cambrian Mountains (Chapter 6). Evaluation of the Polyscape approach and outputs by stakeholders in the Cambrian Mountains (Chapter 6) confirmed the importance of bringing scientific and local knowledge to bear in influencing negotiation amongst stakeholders in an iterative decision taking process, as opposed to production of prescriptive output. Overall, these findings have identified the need for land use policy to be implemented in a participatory and spatially explicit way, at local scales, if ecosystem service provision from agricultural landscapes is to be effectively managed across a complex network of stakeholder requirements that involves multiple actors and institutions. Maps that visualise at local scale, both opportunities for change, and the value of existing features for delivery of one or more ecosystem services, were found to be an effective basis for discussion of land use change to manage ecosystem service provision and, therefore, useful tools to implement policy at the scale at which land use decisions are taken. The Polyscape approach is now embedded in the Welsh Government's strategic forward planning for implementing agri-environment management.

The research presented here initially focused on identifying key considerations that should be taken into account to enable greater local stakeholder engagement in decision taking to manage impacts of land use change at the point of ecosystem service provision. The imperative here was to involve farmers, traditionally focussed on their livelihood goals, more effectively in ecosystem service management across a broad range of services, and to assist environmental managers and policy makers to understand and take impacts on agricultural production into account when implementing environmental policy. In Chapter 2, a case study assessment of changes to ecosystem services arising from modifications to land use in the Pontbren catchment was presented. Changes made to the spatial configuration of landscape features such as trees, ponds and wetlands affected their potential to deliver many regulating ecosystem services that are spatially sensitive. As many of these regulating ecosystem services were manifest at broader 'landscape' scales larger than individual farms, collective strategies and decision taking were needed to manage them. For stakeholders to engage in informed decision making that takes into consideration landscape scale processes they needed to be able to see and understand implications of policy at both field and 'landscape' scales. The key implication was that for policy relating to ecosystem service provision to be effective, there were requirements to target implementation at scales fine enough to capture the spatial sensitivities of interventions on service provision. The research identified the need for spatially explicit approaches capable of considering field, farm and landscape level decision making for a broad range of ecosystem services. This would enable farmers to see their farm in its landscape context and facilitate collective action where appropriate for the management of public goods (such as water regulation).

Mapping the interrelationships amongst ecosystem services is essential in an ecosystem approach as it identifies the manner in which changes deliver benefits or negative impacts (Naidoo and Ricketts 2006; Morse-Jones *et al.*, 2011). There are needs to identify areas where change will bring about multiple benefits but also that take into consideration local land use priorities. Policy makers and implementers need to be able to see and prioritise these opportunities for making and managing change and to be able to make policy spatially explicit at the local scales required to act upon them.

Ecosystem dynamics are complex and occur across many scales (Kremen and Ostfeld, 2005). The present research has shown that at local scales change in land use or management affects multiple ecosystem services simultaneously. Knowledge associated with understanding these dynamics as well as management responsibility is often split amongst a broad range of stakeholders. These include those living and working within the systems, those with responsibility for the management of ecosystem functions (ecosystem managers) and those stakeholders engaged in research (scientists, often from a broad range of disciplines). Given that the holistic management of ecosystems is likely to require interdisciplinary (rather that multidisciplinary) approaches to secure benefits (Daily and Ehrlich,1999; Fry, 2001), there is also a need for greater dialogue between sectors and actors associated with the landscapes being managed. Despite acknowledgement of the importance of local knowledge this resources is often underutilised (MA, 2005). Local scale ecosystem management generally occurs in data sparse environments. Informed decision making at these scales, is likely to require knowledge exchange amongst stakeholders. Both scientists and policy makers will generally lack knowledge relating to local practices and processes which may affect ecosystem function. One method to address this is the greater use of stakeholders' local knowledge of ecosystem function derived from observation and experience. Research into the Pontbren farmers' knowledge of water regulation and soil regulation in Chapter 3 demonstrated that the farmers' local knowledge of ecosystem function was comparable to scientific understanding but also complementary in key respects such the roles of drainage systems and the impacts of trees. The process of knowledge exchange amongst stakeholders also facilitated local stakeholder engagement which is vital for realising appropriate action since it is farmers in the end who decide on land use.

The extent to which existing tools designed to map ecosystem services were capable of meeting the criteria for ecosystem management derived from Chapters 2 and 3 were reviewed in Chapter 4. This involved a critical review of 52 studies. The findings make several contributions to the current literature. A major gap was identified in the mapping of flow pathways. Fuller understanding of the interactions amongst ecosystem services requires that these pathways are identified. It also enables ecosystem service boundaries to be identified, and thus the final recipients of service. These components are important prerequisites for effective management of ecosystem services aimed at overall improvements in human well being. Identification of synergies at the point of provision does not necessarily produce the same results to all beneficiaries as the benefits that may be realised at different locations – currently the ability to map these are very limited. The review revealed that most approaches were targeted at broader landscape scales (>1000 km^2) and lacked the fine resolution required for stakeholder negotiation. Another significant gap was associated with stakeholder engagement in the development of mapped output. Local knowledge was not used in any studies either to inform or to validate output.

The research findings in Chapters 2, 3 and 4 were used to develop specifications for mapping ecosystem service opportunities at local scales in Chapter 5. The specifications were developed iteratively with local stakeholders and experts and tested at two scales initially within the Pontbren catchment (10 km^2) and then more broadly in the Elwy catchment (270 km^2). A layered approach was developed, where maps of ecosystem services were overlaid on top of another in a GIS environment. The components of each map were based on local specifications combined with expert knowledge. Acknowledging the limited availability of data to inform more complex models the approach used nationally available data as a starting point. This provided the basic framework which was then modified to suit local conditions through an iterative, participatory process. By explicitly acknowledging the constraints of using coarse spatial data and through incorporation of local knowledge the tool provided a basis for negotiation without being overly prescriptive. The structure of the approach enabled critical conflicts of interest to be recognised (and potentially compensated) and also allowed identification of areas where there were clear synergies for delivering ecosystem services.

The approach enabled stakeholders to view opportunities for each mapped ecosystem service from a farm to an immediate (1000 km^2) landscape scale. Combining layers together allowed spatially explicit identification of synergies and trade-offs associated with implementing new interventions. The initial iteration mapped opportunities and constraints associated with regulating surface water flow, sustaining farm productivity, controlling sediment transport, increasing carbon storage and maintaining biodiversity (woodland habitat connectivity).

In the final section of the thesis the Polyscape methodology was applied in the Cambrian Mountains. This application focused on spatially explicit identification of areas of priority habitat within five catchments and identifying the potential synergies and tradeoffs amongst ecosystem services in relation to land use change and climate change. The approach taken was to identify areas of opportunity to make habitats more robust and then examine those opportunities in relation to other ecosystem services likely to be affected by climate change (water regulation, agricultural productivity and carbon sequestration). The approach taken and the mapped output were tested by a range of stakeholders including farmers, ecologists, and members of the local community and policy makers. The initial findings were that the outputs were credible and that stakeholders were willing to use the output as a basis for negotiating land use strategies. The approach incorporated multiple perspectives. Local farmers stated that the use of local knowledge for constructing the layers increased both the legitimacy and credibility of the output for them.

Feedback from both local stakeholders and intermediary groups identified Polyscape as a legitimate and salient approach for providing the basis for negotiation of ecosystem services in the Cambrian Mountains.

This research contributes to an emerging literature on the development of operational approaches to securing the supply of ecosystem services from local landscapes. The focus on stakeholder engagement offered here differs from existing spatial approaches and identified the need for locally relevant output to negotiate and implement changes to ecosystem services on the ground. Many of the existing tools focus on mapping opportunities at broad scales but there are often local constraints to implementation on the grounds that are not acknowledged. By starting with local stakeholders and bringing in a range of experts the mapped output using the Polyscape methodology, creates an environment for knowledge transfer and shared learning (Prahbu *et al.*, 2009). It is suggested that these elements are likely to lead to increase local uptake and engagement to what might be perceived as 'externally generated' approaches and better targeting for compensation in contested areas.

Finally, a number of important limitations to the locally focussed output were identified. First there was no quantification of changes to ecosystem services incorporated within the approach. Ecosystem service delivery is dynamic and will vary in relation to temporal conditions. Polyscape presents a simplified picture of opportunities; however the output looks complex and believable. Care must be taken in communicating these uncertainties clearly to stakeholders. A change in any part of the landscape will change the static image, with a time course dependent on the nature of the intervention. While it is possible to look at a series of static images that play out scenarios of land use change through time, the dynamics are not incorporated in the visualisation and impacts of slow growing features (such as trees) are captured in a binary rather than a progressive way.

In an ideal world the management of ecosystem services would involve understanding the effects of management across all ecosystem services. In practice this is unachievable and stakeholders have to decide which services to prioritise in any landscape and focus on their management. This study focused on focused on key provisioning and regulating services that were important with a Welsh context. For more holistic assessments a wider variety of ecosystem services could be mapped including cultural (and potentially supporting) services. In considering these elements the cost of implementation should be taken into account as well as the need for parsimony – only makes things as complex as necessary for the purpose – adding more complexity has potential disadvantages for comprehension and should be balanced against possible advantages of inclusiveness. Trading off multiple ecosystem services simultaneously is likely to be complex and potentially counterproductive, and would require substantially more sophisticated methods to explore synergies and tradeoffs than presented here. Polyscape is likely to work best where requirements for ecosystem services can be prioritised at broader landscape scales to limit the requirement to map everything. This is beyond the ability of the existing tool and other mapped approaches (see Chapter 4).

The tool works relatively well in a Welsh context where the agricultural landscape is relatively simple in that there are relatively few farmers with largish holdings. More biophysically complex landscapes would require adjustment in the way that land uses were zoned and interact with each other. For example in Wales the main provisioning service were sheep production and water; in more diverse systems there may be complex interactions and prioritisation between provision services (for example conflicts between fuel and food production) that may need to be considered before exploring trade-offs with regulating services. This may require additional factors to be mapped (such as distances walked for fuel wood), requiring quite complex specifications for interactions between provisioning services. This could potentially lead to requirements to do staged trade offs and synergy maps before other services were considered.

Another issue is that Polyscape maps ecosystem opportunities equally across the catchment. The reality is that at larger scales the size of effects varies significantly across a landscape. For example water regulation output is presented equally across the catchment – whereas the real gains are likely to be in the headwater areas. Zoning maps at landscape scales may communicate opportunities more realistically but it also requires subjective judgements on where the boundaries are defined.

The Polyscape methodology focuses at the point of provision. It is necessary to understand synergies and tradeoffs not only at this point but throughout the ecosystem service cycle (Rodriguez *et al.*, 2006). Many ecosystem services involve tipping points, for example once a degree of loss to water quality is reached it is almost immaterial how much more pollution occurs. Management to control water quality across 90% of a catchment can be undone by pollution occurring within 10 % of the catchment, particularly if this 10% is in the wrong place (Kay *et al.*, 2008). It is important to map not only the source of ecosystem services but throughout the ecosystem service cycle.

The focus of the Polyscape methodology was on the links between the spatial and social dynamics of ecosystem service provision at local scales. A number of other factors such as the conditions of features (such as woodlands) relating to their age, composition and associated management are also important for understanding ecosystem service delivery (Kremen and Ostfeld, 2005). In most instances these remain significant knowledge gaps at local scales. Incorporating local knowledge potentially offers a means to address these issues but incurs has high transaction costs (although we feel that the reverse is also true). A lack of awareness of local knowledge and limited experience of using participatory approaches (Edwards-Jones, 2001) mean that, certainly in a UK context, there are real limitations to using these approaches and training in the use of participatory methods is likely to be as important as provision of spatially explicit mapping tools.

7.2 Recommendations

The next logical step in developing the Polyscape approach would be to use and test it in an operational context, with resources available to enable targeted changes. As Polyscape identifies the need for targeting interventions in specific areas to achieve results it would be useful to explore what impacts such an approach would have, both in terms of altering biophysical dynamics and in terms of equitable stakeholder engagements: for example, who wins and loses if the management of ecosystem services are targeted rather than applied generally?

The review of spatial tools identified the need to map flows of ecosystem services. Because Polyscape focuses at the point of provision it only identifies services and dis-services to local stakeholders that might affect management decisions. However, clear links need to be made between biophysical provision from landscape features and their ultimate use by recipients – enabling identification of winners and losers. This is beyond the ability of all tools presently described in the literature.

Different features are associated with a broad range of services. Burkhard *et al.*, 2010 presented a framework showing values of ecosystem services associated with key features. The findings from this research suggest that the values on this matrix would change in relation to where the matrix was applied. Combining this approach with the approach developed for Polyscape could provide interesting results for policymakers.

This research suggests that there is a strong need to implement policy at local scales for effective ecosystem management. Achieving this would require methodologies and tools that produce mapped output as a basis for collective decision taking (and assessment of impacts of taking decisions and making change) but also decentralised and integrated governance structures amongst agencies and training in participatory methodology. Polyscape provides a tangible framework for doing this and if it was applied and continually developed in an iterative fashion with an appropriate range of stakeholders could be central plank in shifting implementation of land use policy towards locally relevant and integrated ecosystem service provision.

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Appendix 1

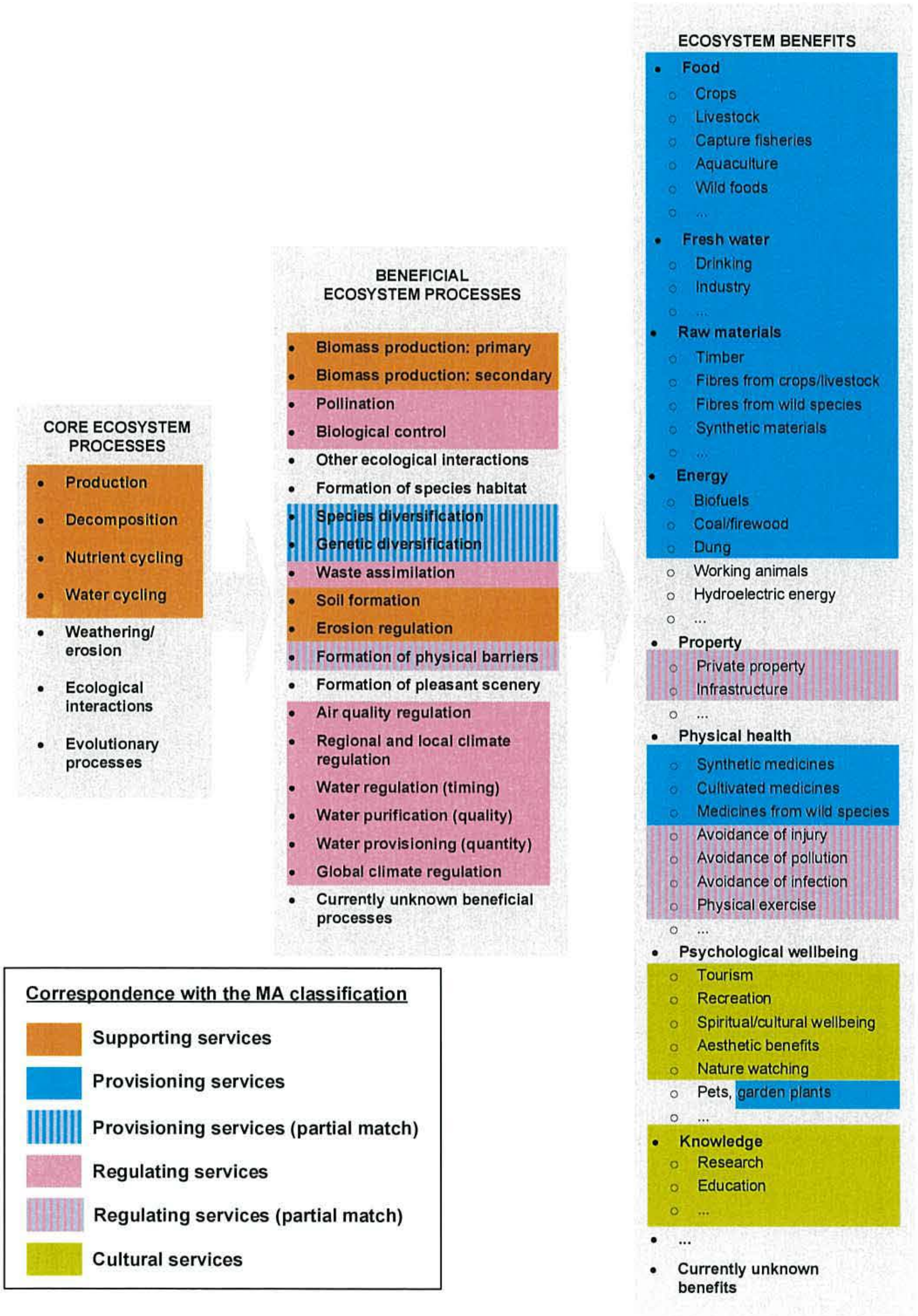

Figure A.1: Illustration of the relationship between core ecosystem processes, beneficial ecosystem processes, and ecosystem benefits used in Chapter 2. The lists are not exhaustive. Correspondence between this classification and the Millennium Ecosystem Assessment is given in the subset (From Balmford *et al.,* 2011)

APPENDIX 2

List of studies used in the critical review of spatial tools:

First Author	Date published	First Author	Date published
ARMSWORTH	2007	POLLARD	2010
BATEMAN	2011	RAYMOND	2009
BIRCH	2010	REYERS	2009
BURKHARD	2009	RUIZ FRAU	2011
BEIER	2008	SIMIONT	2011
BRYAN	2010	SWETNAM	2011
CCW	2010	VAN WIJNEN	2011
CHAN	2006	WANG, C	2009
CHEN	2009	WANG, E	2009
COSTANZA	2008	WILLEMEN	2010
DITT	2010	BAI	2011
EGOH	2011	NELSON	2009
EGOH	2008	BATKER	2010
EIGENBROD	2010	WENDLAND	2010
GIMONA	2007	SHERROUSE	2011
GRET-REGAMEY	2008	LAVOREL	2011
KIENAST	2009	METZGER	2006
KLUG	2010	LIU	2010
KRISHNASWAMY	2009	TROY	2009
LOCATELLI	2011	TROY	2007
LORZ	2010	HE	2011
LUCK	2009	KOZAK	2010
MAES	2011	ZHANG	2011
MAYNARD	2010		
MEHAFFEY	2011		
NAIDOO	2006		
NEDKOV	2011		
O'FARRELL	2010		
O'HIGGINS	2010		