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Further development of a spatial framework for mapping ecosystem services

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1 Background

1.1 Summary of Project

1.1.1 Summary of Phase one

Phase one of the 'Spatial Framework for Assessing Evidence Needs for Operational Ecosystem Approaches' project identified habitat attributes which are important for, and influence the role of the habitats in delivering ecosystem services (Medcalf *et al* 2012). The project used a series of case studies to map ecosystem services and analysed the quality of data available. Phase one tied thinking and evidence together in a way that illustrated and compared the process across different habitat types and began to explore and compare ecosystem delivery across different contextual settings and geographical variability.

Phase one demonstrated the process and outcomes of taking a pragmatic approach to assessment of ecosystem services, with emphasis placed on utilising the large body of data already available to inform policy decisions at national, regional and local levels. Using these datasets, an ecosystem service 'spatial framework' was developed to assist users and demonstrate what is currently possible when it comes to the mapping and modelling of ecosystem services. The project took the UK NEA descriptions and analysed these further in terms of current data and knowledge about each service, for a selection of habitat types. The previous phase also identified areas of the country where ecosystem service knowledge is good, with readily available data and complete spatial coverage.

The spatial framework approach should contribute to the objective of facilitating users:

- To describe the biophysical characteristics occurring within a landscape;
- To make links between the physical and biological characteristics of habitats and the major ecosystems services being provided;
- To identify practical and appropriate ways in which habitat (and other biodiversity) data can be used to identify and understand ecosystem service provision;
- To identify ways in which habitat data can be used to describe landscape characteristics and understand how this varies spatially; and,
- To understand the effect the condition of habitats and the way they are managed has on ecosystem service delivery in different landscapes.

As work in this area develops, the project highlighted that there is a need for more consistent and compatible data across wider areas of the terrestrial landscape to support decision making at a variety of spatial scales. Consideration of fitness-for-purpose for ecosystem service mapping is also important.

1.1.2 Summary of Phase two

JNCC sought to further develop the spatial framework approach developed in Phase one to quantify and value ecosystem services, focusing on simplifying the identification of services; drawing on available data in a clear, robust and structured way. The work carried out in Phase two built on the previous JNCC project 'Spatial Framework for Assessing Evidence Needs for Operational Ecosystem Approaches' completed for JNCC by Environment Systems in 2012. This phase has used ideas developed previously to create a more practical framework which can be used under different decision scenarios, applicable at local, landscape and country levels.

The work done had been designed to provide a practical understanding of the ways habitat and other aspects influence the output of ecosystem services, and the kinds of information that are required to design and monitor management strategies. The outputs from the study will support JNCC in its goal of embedding the ecosystem services framework in decision making.

This report covers the work completed by the end of October 2013.

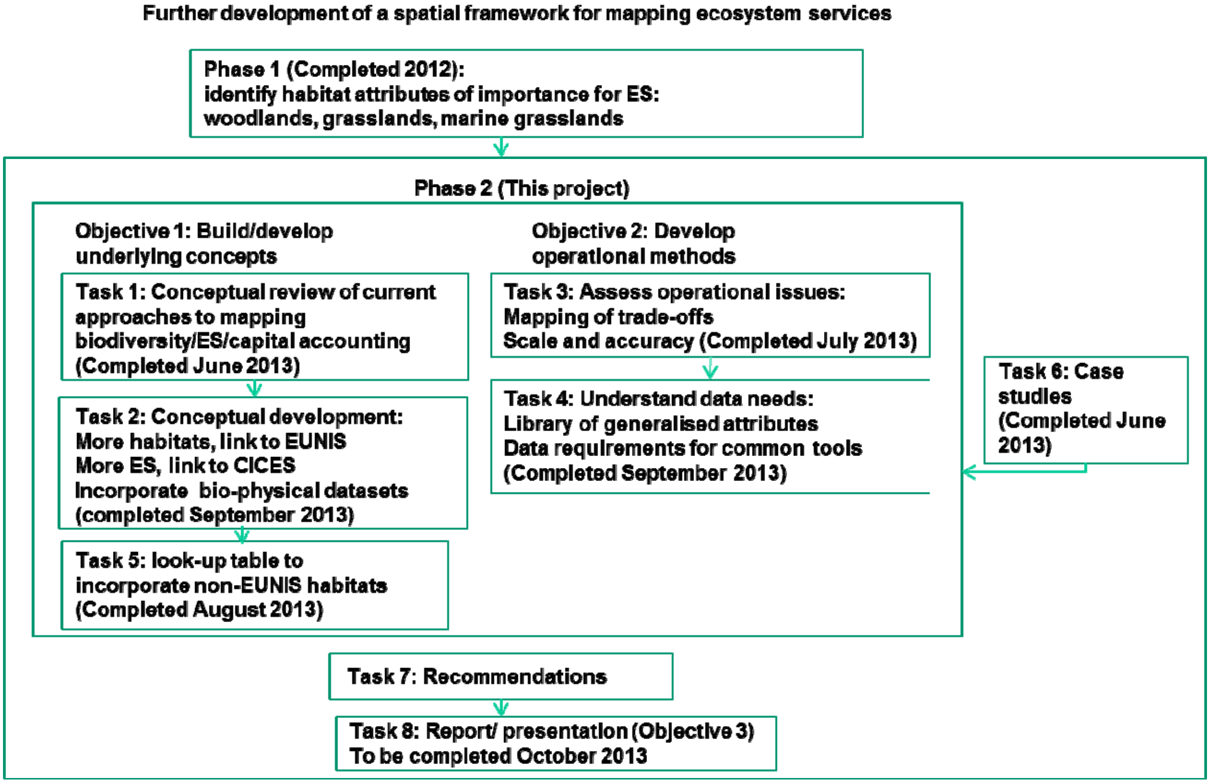


Figure 1. Overview of the project tasks and process for mapping ecosystem services.

An overview of the project and its tasks is shown in Figure 1. Phase 1 has been completed. Objectives 1 and 2 (in Phase 2) are complete. Objective 3 was met in October 2013.

1.1.3 Project objectives

The aim of this project was to unpack and operationalise that part of the evidence base relating to the spatial distribution of habitats and the delivery of ecosystem services.

The spatial framework approach has two main components and should contribute to the objective of facilitating users:

1. To make links between the physical and biological characteristics of habitats and the major ecosystem services being provided.
   - To identify practical and appropriate ways in which habitat (and other ancillary) data can be used to identify and understand ecosystem service provision.
   - To understand linkages between habitat classification systems and ecosystem services.
2. Provide a framework database which can show:
   - What is possible to map given a particular ecosystem service.
   - What the most appropriate options are for the use of data, under-pinned by the four key factors (habitat, soil/geology, landscape and management).

The project followed the approach agreed at project initiation in March 2013.

1.2 Ecosystem approach

The ecosystem approach provides a framework for looking at whole ecosystems (abiotic and biotic) within decision making processes. The concept emerged as a central principle in the implementation of the Convention on Biological Diversity (CBD, 2004) which focuses on the holistic and integrated management of land, water and living resources to promote conservation and sustainable use. Using the ecosystem approach helps to view the environment as a system, enabling decision makers to think about the spatial scale of their interactions with the natural environment. The application of the approach is dependent on the local, provincial, national or global conditions but includes two key but common aspects (Defra, 2010):

1. Looking for opportunities to work with natural systems to deliver policy objectives.

2. Includes a thorough impact assessment that considers both positive and negative impacts of the policy options on the services we get from nature.

It encourages an adaptive management strategy that can be employed to deal with the complex and dynamic nature of ecosystems and counteract the lack of knowledge or comprehension of their functioning.

1.3 Ecosystem services

Ecosystems provide various processes and benefits to society; collectively these benefits are known as ecosystem services and directly (or indirectly) contribute to human well-being and economic prosperity. The concept of ecosystem services has provided important insights to decision makers on the value of biodiversity to society; many challenges remain in terms of operationalising these ideas in policy and management (Daily *et al* 2009; Potschin and Haines-Young, 2011). As the UK National Ecosystem Assessment (2011) has shown, while the existing evidence base is fragmented, and many knowledge gaps exist, there is sufficient understanding to enable some immediate progress.

2 Conceptual review

The first task of this project was to review current approaches in mapping biodiversity, ecosystem services and capital accounting. Several projects are underway at the time of writing with the aim of pooling knowledge and summarising activity in terms of ecosystem goods and services case studies. The ‘Ecosystem Service Mapping Gateway’ developed by the NERC Biodiversity and Ecosystem Service Sustainability (BESS) Directorate has started bringing together information on the growing number of activities concerned with mapping ecosystem service delivery at the landscape level and has launched a service called the ‘Ecosystem Service Mapping Gateway’ (BESS, 2013). A number of these activities have already been listed on the Gateway, some of which have been included in the case studies considered in Table 1.

This project therefore did not set out to replicate this effort but instead examined these activities to inform the development of the framework by pulling out common themes (such as methodological approaches), identifying information needs and using them to assist with providing a basic understanding of how to model and map key ecosystem goods and services. This process is described in more detail in this section.

2.1 Role of modelling systems and tools to analyse ecosystem services

The mapping and modelling of ecosystem services has become a key approach to aid landscape management and is an important aspect within the practical application of the ecosystem approach. The aim of mapping is for operational users to be able to integrate knowledge of the spatial distribution of ecosystem services into planned or existing land use strategies or practices. This will inform decision making by enabling users to assess the spatial agreement between areas which support ecosystem functions, biodiversity and those that supply ecosystem services.

Maps are useful for spatially explicit prioritisation and problem identification (Maes *et al* 2013). Mapping helps to identify and visualise ecosystem services, providing an opportunity for a broad evaluation at a range of scales. In addition, it helps people to understand and communicate the full range of ways in which the natural environment contributes to wellbeing and can initiate discussions with stakeholders by visualising the locations where valuable ecosystem services are produced or used and explaining the relevance of ecosystem services to the public in their territory (MAES 2013). Without this better understanding, those responsible for managing our landscapes do so with a degree of uncertainty as they become aware of the value of an ecosystem approach but lack the necessary support to implement it. With this in mind, research and the development of mapping techniques for ecosystem services has been steadily increasing.

2.1.1 Scale

Scale is an important factor to consider when mapping ecosystem services. Natural systems have intrinsic scales of operation and do not have definitive boundaries. There is often a mismatch between production, consumption and management of ecosystem services. The scale at which spatial data can be integrated into an ecosystem mapping exercise is primarily related to the different requirements and uses of spatially explicit information, the spatial resolution of the data and the detail within the data attribution, most commonly, the classification. It is assumed that different scales have different requirements and uses of spatially explicit information.

Ecosystem services can be modelled at scales ranging from neighbourhood to catchment, to strategic national and European scales. The geographical information for modelling the spatial component of ecosystem services is also available at different spatial scales. For example, there are various ancillary datasets available within the UK which can be used to map ecosystem services, for example, geology, land cover and elevation. However, the scale of the area under examination and the detail of the habitat classification required need to agree during any mapping exercise, i.e., a project which focuses on national scale mapping would suit the detail of the broad habitat classification.

Therefore, it is important to understand the relationship between scale of modelling and suitability of the data available. We have started to address this within our framework approach. We propose the use of a matrix table (Figure 2) to determine and highlight suitable habitat classification systems, soil, geology, landform and management datasets for mapping ecosystem services at a range of scales from site scale to the European scale.

Factors: Habitats

Scale	Bespoke habitat data	NVC	I-H-S	Phase 1 (Levels 1 & 2)	Phase 1 (levels 3&4)	NFI	OS MM	Landcover map	Broad Habitats	Priority Habitats	NEF Broad Habitats	EUNIS (Levels 1&2)	EUNIS (Levels 3-8)	Corine	Bespoke ecological networks	Integrated Habitat Networks
Site	3	1	1	N	N	N	1	N	N	N	N	N	N	N	3	N
Neighbourhood	3	1	1	N	2	N	1	N	N	N	N	N	N	N	3	N
Town	3	2	1	N	2	1	1	N	N	N	N	N	1	N	3	N
Catchment	N	N	1	1	1	1	1	1	1	1	1	N	1	N	3	1
County	N	N	1	1	1	1	1	1	1	1	1	N	2	N	3	1
Region	N	N	1	1	1	1	1	1	1	1	1	1	2	N	3	1
National	N	N	N	1	1	1	1	1	1	1	1	1	2	N	N	N
EU	N	N	N	N	N	N	N	N	N	N	N	1	2	1	N	N

Factors: Soil

Scale	Bespoke soil data	NSIS Soils 1:25,000	NSIS Soils 1:250,000	NATMAP Vector	NATMAP 1000	NATMAP 5000	NATMAP Soilscapes	The European Soils Database
Site	3	N	N	N	N	N	N	N
Neighbourhood	3	N	N	N	N	N	N	N
Town	3	1	N	N	N	N	N	N
Catchment	N	2	1	1	N	N	1	N
County	N	N	1	1	N	N	1	N
Region	N	N	1	1	2	N	1	N
National	N	N	1	1	2	2	1	N
EU	N	N	N	N	N	N	N	1

Factors: Geology

Scale	DiGMapGB-10 (Bedrock)	DiGMapGB-10 (Superficial)	DiGMAPGB-10 (Mass Movement)	DiGMAPGB-10 (Artifical ground)	DiGMAPGB-10 (Linear Features)	DiGMapGB-25 (Bedrock)	DiGMapGB-25 (Mass Movement)	DiGMapGB-25 (Artifical ground)	DiGMapGB-25 (Linear Features)	DiGMapGB-50 (Bedrock)	DiGMapGB-50 (Superficial)	DiGMapGB-50 (Mass Movement)	DiGMapGB-50 (Artifical ground)	DiGMapGB-50 (Linear features)	DiGMapGB-250 (Bedrock)	DiGMapGB-250 (Linear Fault features)	DiGMapGB-625 (Bedrock)	DiGMapGB-625 (Superficial)	DiGMapGB-625 (Linear)
Site	1	1	1	1	1	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Neighbourhood	1	1	1	1	1	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Town	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	N	N	N
Catchment	N	N	N	N	N	N	N	N	N	1	1	1	1	1	1	1	N	N	N
County	N	N	N	N	N	N	N	N	N	1	1	1	1	1	1	1	N	N	N
Region	N	N	N	N	N	N	N	N	N	N	N	N	N	N	1	1	2	2	2
National	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	1	1	1
EU	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Factors: Landform

Scale	SRTM 25m	SRTM 50m	SRTM 90m	ASTER 30m	Ordnance Survey Landform Panorama	Ordnance Survey Landform Profile	NEXTMAP BRITAIN DTM 10m posting	NEXTMAP BRITAIN DTM 5m posting	GET MAPPING DTM 5m posting	GET MAPPING DSM 2m Posting	LiDAR 2m	LiDAR 1m
Site	N	N	N	N	N	2	2	1	1	1	1	1
Neighbourhood	N	N	N	N	N	2	2	1	1	1	1	1
Town	N	N	N	N	N	2	2	1	1	1	1	1
Catchment	1	N	N	1	N	1	1	N	N	N	N	N
County	1	1	N	1	2	1	N	N	N	N	N	N
Region	1	1	N	2	2	1	N	N	N	N	N	N
National	1	1	2	2	1	1	N	N	N	N	N	N
EU	2	2	1	2	N	N	N	N	N	N	N	N

Key	Description	Code
Suitable level of detail	Data is suitable for the scale of mapping	1
Use with discretion	Data may not be ideal for the scale of mapping and the user should use discretion	2
Bespoke data	Data the user has selected is bespoke and no assumption can be made by the spatial framework project team	3
Not recommended	Not recommended at particular scale	N

Figure 2. Suitability of habitat classification systems, soil, geology and landform for mapping ecosystem service provision.

2.2 Ecosystem service mapping and modelling tools

To aid the mapping of ecosystem services, a number of tools have been developed in the form of GIS platforms to present the spatial distribution of ecosystem services. In this context, an ecosystem service tool seeks to bring together evidence across both natural and social processes and aims to capture information on ecosystem services and associated benefits for policy and decision making.

Eleven exemplar projects were selected for review in Task 1; five were listed on the ESMG website[1] (four were sourced from the Ecosystem Knowledge Network (EKN)[2] and the remaining two were from other sources that members of the team were aware of. These eleven examples have highlighted several different tools currently being utilised and have evaluated ecosystem services at a variety of spatial scales which include site specific to strategic scale. They are listed in Table 1.

Table 1. Exemplar projects considered in the review.

Project	Scale	Source
Mapping Ecosystem Services	Strategic	ESMG
Valuing Ecosystem Services in the East of England	Regional	EKN
Bassenthwaite Pilot	Catchment	EKN
Cambrian Mountains	Farm and Landscape	Polyscape literature
Willamette Basin	Catchment	InVEST literature and InVEST workshop
National Wales Mapping	Strategic	ESMG
Durham Biodiversity Action Plan Area	County	EKN
Liverpool City	City	ESMG
Forest Ring	Local	ESMG
HS2 Buckinghamshire	Local	EKN
Tamar Catchment Pilot	Catchment	ESMG

The findings have been summarised in terms of the modelling systems used, the modelling / software tools used, their spatial scale of operation and the ecosystem services mapped and are summarised in Table 3.

2.2.1 Modelling systems used

The review (Table 2) showed that by far the most popular modelling system applied to the mapping of ecosystem goods and services was to use the functionality in GIS systems to add together layers of data to give each specific area on the ground a value. For example, when considering water regulation a data set on land cover would be ‘scored’, with sealed surfaces assigned a low value and woodland a high value. This was then overlaid by a slope dataset, which gave steep slopes a low value and gentle slopes (or floodplain) a high value. For any area of land, the value of water regulation is therefore a sum of the land cover, soil and the slope. Some of the systems combined the maps in a straightforward way by

[1] Ecosystem Service Mapping Gateway: http://www.nerc-bess.net/ne-ess/
[2] Ecosystems Knowledge Gateway http://ekn.defra.gov.uk/

identifying whether contribution towards the service was present or not, and other scoring systems used a ‘high – medium – low’ approach.

Often the existing GIS data sets used did not occur at the same scale of mapping or used exactly the same extent. In order to overcome this, a GIS technique known as overlay analysis is often utilised, where each layer is turned into a ‘grid’ data set called a ‘continuous raster dataset’ and each individual grid square within it is given a data value. These grid values are then summed together to produce an ‘overlying’ value layer (see Figure 3). It is the combinations of values which help determine the overall spatial variation of importance for the service being examined. Where features have a negative effect on the service, this area or raster grid square is reduced in value.

These methods are called additive raster models; many projects adopting the approach have designed written GIS interfaces which can be added to GIS software or act as a standalone piece of software to undertake this additive raster modelling process, assisting the user in the modelling. These are referred to as ‘tools’; the ones considered as case studies are outlined below.

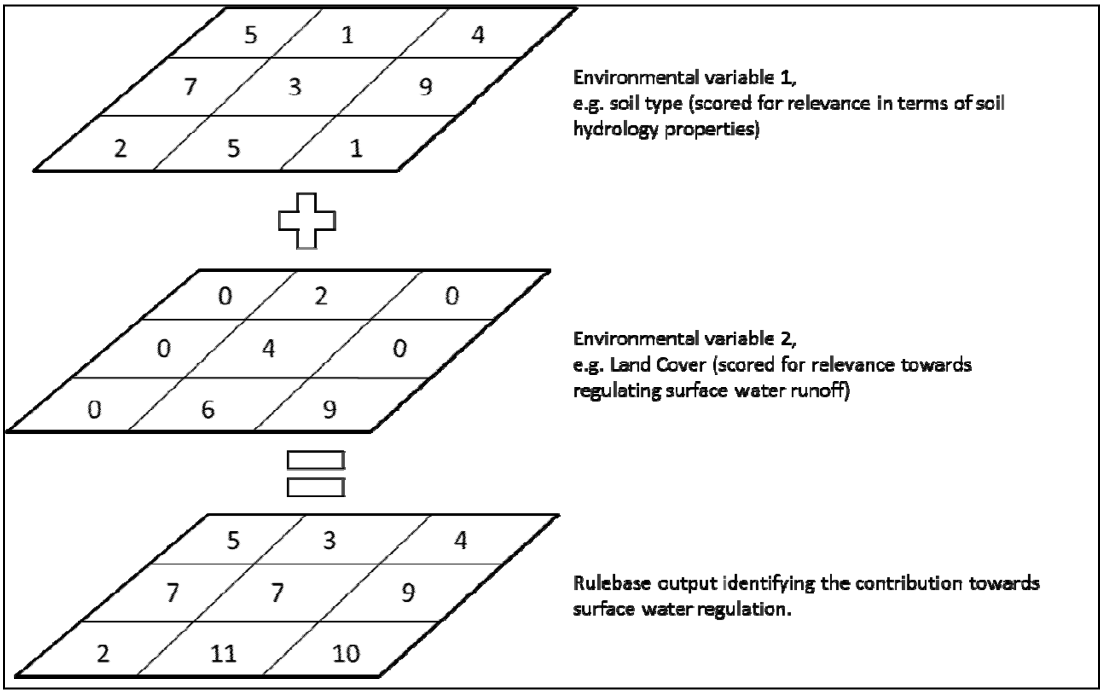


Figure 3. An example of the theory behind an additive raster model.

2.2.2 Ecosystem service mapping tools

A short overview of the tools utilised within the 11 reviewed projects is provided below and summarised in Table 2.

i Land utilisation capability indicator (Polyscape)

Land utilisation capability indicator (LUCI, the formerly known Polyscape) is a GIS toolbox which uses multiple criteria analysis to explore the impacts of decisions on land use or management changes (Jackson *et al* 2013). It has been designed as a negotiation tool to enable engagement with local land owners and stakeholders by incorporating local knowledge and validation into the model (Jackson *et al* 2013). There are six tools included in the suite which look at current and potential impacts of land management change and synergies and trade-offs. The Polyscape tool has been used frequently in Wales (Jackson *et al* 2013).

The modelling system uses basic algorithms combined with an additive raster function.

ii InVEST

InVEST[3] is an open source GIS-based ecosystem service mapping and valuation tool which was created by the Natural Capital Project. It focuses on integrated decision making and stakeholder engagement is a critical stage within the process. It uses land use/cover to estimate levels and economic values of multiple ecosystem services and the market value of the commodities provided by the landscape (Nelson *et al* 2009). The tool is mostly utilised in the USA and developing countries in relation to spatial planning at a strategic scale. InVEST is currently being utilised in the Wessex-BESS project[4]. The InVEST suite is now available as standalone software. The models produce spatially explicit (areas which are composed of differing features but are still continuous) mapped outputs and return results in either biophysical terms or economic terms.

The modelling system uses sophisticated algorithms and a variety of raster functions to create spatially explicit mapped outputs.

iii SCCAN

SCCAN (System Cynorthwyo Cynllunio Adnoddau Naturiol/Natural Resource Planning Support System), developed by Countryside Council for Wales and Environment Systems, is an ecosystem service mapping system that aims to assist people in taking an ecosystems approach in their decision making (Countryside Council for Wales, 2012). The approach has been applied at a strategic national level down to county level mapping (Countryside Council for Wales, 2012). The mapping system has subsequently been further developed to deliver a tool, which incorporates both a top down and bottom up approach to ecosystem services modelling and mapping. This approach is flexible as it works on a variety of scales and collates information on a wide range of ecosystem services. This allows users to set priorities and assess the competing demands that are placed on natural resources.

The modelling system uses an evidence based rule base and basic algorithms within an additive raster function environment to create spatially explicit mapped outputs.

iv EcoServ-GIS

EcoServ-GIS[5] is a GIS toolkit, which has been developed by Durham Wildlife Trust to map ecosystem services at a county scale. The tool utilises a modified version of the Common International Classification for Ecosystem Services (CICES)[6] ecosystem service classification. The toolkit includes tools to model provisioning, regulating and cultural services with an additional tool to grade green space according to the opportunities they provide for enjoying nature and wildlife (Durham Wildlife Trust,

[3] InVEST http://www.naturalcapitalproject.org/InVEST.html
[4] Integrated ES Modelling (Wessex-BESS)http://www.brc.ac.uk/wessexbess/Integrated_ES_modelling
[5] EcoServ-GIS http://www.durhamwt.co.uk/2013/02/version-1-of-the-ecosystem-services-mapping-toolbox-ecoserv-gis-is-now-ready-for-release/
[6] CICES http://cices.eu/

2013). Phase 1 of the tool development was completed in December 2012, while the next phase began in April 2013.

The modelling system uses basic algorithms within an additive raster function environment within ArcGIS Model Builder.

v Mersey Forest Approach

The Mersey Forest has developed a green infrastructure mapping method which can be applied at a county to site level scale. The modelling system utilises a typology and functionality mapping methodology which uses the OS MasterMap Topography layer as the baseline parcel system. The approach categorizes land as one of a range of green infrastructure types or as a non-green infrastructure type and assigns functionality to these types. This method has been applied to projects in Liverpool (Mersey Forest, 2011) and Northwest England.

vi Unknown/Bespoke

There were a few projects listed on the ESMG which had not provided information in relation to the GIS techniques used to map their ecosystem service assessment, which had stated they had used mapping techniques. They were included in the review, to highlight that there are users out there whom we assume could be using a ‘broad brush’ form of ecosystem service mapping.

Further information on data concepts can be found in the accompanying user manual (Small *et al* 2013).

Table 2. A summary of the characteristics of ecosystem services mapping approaches reviewed by the project.

				Scale									Ecosystem					Final regulating ecosystem services										Bespoke			Final provisioning					Bespoke			
Project	**Name of tool**	**Modelling System**	**Geographical locations in which tool applied**	**Farm**	**City/Town**	**Local**	**Catchment**	**Landscape**	**County**	**Regional**	**Strategic**	**European**	**CICES**	**UKNEA**	**MEA**	**TEEB**	**Other**	**Biodiversity**	**Climate regulation**	**Water regulation (inc.flood & Drought)**	**Disease and pest regulation**	**Pollination**	**Noise**	**Water quality**	**Soil quality**	**Air Quality**	**Erosion regulation**	**Nutrient retention**	**Soil organic content**	**Sediment retention**	**Crops**	**Livestock/Aquaculture**	**Fish**	**Trees, standing vegetation, peat**	**Water supply (clean water)**	**Food**	**Agriculture**	**Timber provision**	**Energy**
Cambrian Mountains (Wales)	LUCI	Additive raster models	Pontbren, New zealand, Ghana	Y			Y	Y									Y		Y	Y											Y							Y		
Willamette Basin	INVEST	Additive raster models	Williamette basin, Hawaii, Tanzania								Y						Y	Y	Y	Y		Y		Y				Y		Y								Y	Y
		Valuation																																					
National Wales Mapping	SCCAN	Additive raster models	Wales, South East Wales, Torfaen & Bridgend county borough councils						Y	Y	Y			Y	Y		Y	Y	Y	Y		Y		Y			Y								Y	Y		Y	Y
Durham Biodiversity Action Plan Area	Ecoserv-GIS	Additive raster models	County Durham, Darlington, Gateshead, South Tyneside, Sunderland					Y	Y				Y						Y	Y	Y	Y	Y	Y		Y	Y												Y
Liverpool City	Mersey Forest Approach	Typology/function mapping	Liverpool, North West England, Ayrshire, Europe		Y												Y		Y				Y		Y											Y		Y	
Forest Ring	Unknown	Mapping (?)	Forest of Dean			Y											Y		Y	Y				Y															
HS2 Buckinghamshire	Mersey Forest Approach	Typology/function mapping	Buckinghamshire			Y			Y								Y																						
Tamar Catchment Pilot	Unknown	Additive raster models	Tamar Catchment			Y	Y										Y	Y	Y	Y				Y															
Bassenthwaite Pilot	Unknown	Valuation	Bassenthwaite Catchment				Y										Y	Y	Y	Y				Y			Y								Y	Y			
		Land Management MatriY																																					
		Mapping																																					
Mapping Ecosystem Services	Unknown	Mapping/raster models (?)	England								Y			Y					Y	Y					Y	Y	Y					Y			Y	Y	Y			

2.2.3 Summary of ecosystem service classifications used

Out of the 11 exemplar projects chosen, the majority have adopted their own bespoke ecosystem service classification. This indicates that users are adapting their classifications to match their data availability and policy needs.

The projects, at least initially, follow the general typology of the Millennium Ecosystem Assessment (MEA, 2005), which has global scale applicability, but add or redefine categories according to the focus of the study. For example, the TEEB study (see DeGroot *et al* 2010), proposed a category of 'habitat services' to be used alongside the more familiar provisioning, regulating and cultural service groups. The UK National Ecosystem Assessment (UK NEA) used a slightly different range of services, mainly to reflect the differences when ecosystem services considerations are applied at the national rather than global scale.

Out of the projects reviewed, it became apparent that there were commonalities between ecosystem service categories and final ecosystem services being mapped by users. The short review highlighted that regulating services are often mapped more frequently than other service categories, with climate regulation, regulation of water flows, food provision, water quality and recreation being common services repeatedly mapped by users in different projects (Table 2). These initial findings complement some of the wider reviews which have summarised recent literature on mapping ecosystem services by Martinez-Harms and Balvanera (2012) and Egoh *et al* (2012).

In an attempt to overcome the problems of multiple classifications and understanding the correspondences between them, a Common International Classification of Ecosystem Services (CICES) has been developed as part of recent work concerned with the revision of the System of Environmental and Economic Accounts (SEEA) (Haines-Young and Potschin, 2013). CICES has now been adopted as part of the framework for 'experimental accounts' proposed by the United Nations Statistical Division (UNSD)[7], and as the basis of the mapping of ecosystem services at the European scale under the MAES initiative (MAES, 2013)[8]. The latter is of special relevance because JNCC represent the UK interest in the MAES advisor group, and the methods developed here could influence approaches that are taken up more widely.

This project has undertaken the conceptual development phase of the project using the CICES classification as the linking system because it has the following strengths:

- It is an internationally recognised method;
- It considers services at a reasonable level of detail;
- It has comprehensive documentation and presents examples to show best practice;
- It works at the level of provision of the service, rather than benefits of the service. It therefore provides a picture of existing services being delivered by the environment;
- It has been set up to prevent double counting of the underlying services (e.g. within the supporting and regulating ecosystem services);

2.2.4 Ecosystem service valuation

Ecosystems deliver a broad range of services, some of which have associated environmental, economic and social values placed upon them by human beings. The UK NEA regards ecosystem service 'goods' as those aspects which include all use and non-use, material and non-material outputs from ecosystems that have value for people. 'Benefits' are

[7] http://unstats.un.org/unsd/statcom/doc13/BG-SEEA-DraftingPro.pdf
[8] http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

the direct and indirect outputs from ecosystems that include perceived cultural and spiritual experiences. They also have value in terms of human well-being and encompass a wide spectrum of benefits, for instance, health benefits from clean air and social benefits from recreation. Goods and benefits, therefore, can be either explicitly or implicitly given a value by society (either in monetary or social terms); assigning a value allows them to be more readily integrated with other information to inform decision making.

Valuation gives decision makers a more complete understanding of the range of benefits and costs arising from policy action. This includes valuation of some types of ecosystem goods and services that may not be taken into account in conventional decision-making (e.g. cultural benefits). As a result, the 'true' value of natural assets can be better accounted for. Locations which are most likely to be of value in some way can be identified. Valuation also helps identify the extent to which stakeholders depend on and impact upon ecosystem services, and can be used to establish the stakeholders who could contribute actions to benefit ecosystem service outputs.

Valuation dominantly focuses on the final ecosystem services which can be directly consumed by humans rather than the underpinning ecological processes benefiting other services.

In principle it is possible to value ecosystems in qualitative, quantitative or monetary terms:

- **monetary valuation**: a monetary value is placed on the impact, to translate quantitative evaluation into a single common currency to enable aggregation and comparison;
- **quantitative assessment**: describes the nature of the value in terms of the relevant quantitative information (e.g. estimated 25% decline in catch, for 24 fishermen from three villages etc.);
- **qualitative valuation**: describes the value and ideally indicates the relative scale of value (for example, in terms of high, medium and low). The scaling needs to be relative in terms of all ecosystem services being assessed at a specific geographic level (e.g. site level, global etc.).

i Mapping techniques

Mapping ecosystem 'goods' in terms of describing their value relies on giving each area of land either an actual monetary value, an explicit quantitative value or an explicit qualitative value. The majority of ecosystem valuation studies use simple tailor-made spread sheet models. Mapping ecosystem valuations provides an indication of where ecosystem costs (e.g. risk of environmental degradation) and benefits are occurring and may reveal unexpected benefits and costs.

In order to represent the variations in the value spatially it is necessary first to undertake a 'benefit mapping' exercise using supporting techniques such as overlay mapping, multi-criteria analysis and participatory mapping. Benefit mapping aims to identify locations which are most likely to be of value in some way to people. A widely used ecosystem service mapping and valuation tool includes InVEST. The tool allows for simple economic valuation with a particular focus on direct and indirect market valuation and includes aspects like market price and avoided damages. Supplementary analysis, such as contingency valuations can be carried out to examine the InVEST output further.

Further information on the valuation of ecosystem services is discussed in briefing note 2 – mapping valuation of ecosystem services.

3 Conceptual development

3.1 Overview

Presentation and visualisation are key to the uptake and use of a spatial framework. In Phase 1 of this research (Medcalf *et al* 2012) a large spread sheet was produced. It set out the data and information about the relevant habitat that was important in helping to quantify and map its role in ecosystem service mapping, but it proved unwieldy to use. The team were aware from the outset that adding in more habitats, more ecosystem services and more data on biophysical processes would make such a spread sheet based approach even more complex and unwieldy to use. Therefore, in the concept development, two key needs were considered critical to delivering a fit for purpose spatial framework, these were:

1 The need for improved presentation of the interactions so the spatial framework can be further developed to meet the needs of advanced users.

In order to make clear the linkages between habitat mapping systems and ecosystem services a Bayesian Belief Network approach has been developed and tested. This is an excellent presentation tool allowing a graphical representation of the relationships and linkages between habitats and services. Bayesian Belief Network software (Netica) has been used to view and understand the different habitat typologies and their relationships to the different ecosystem service classifications. This can be a useful visualising tool, particularly for the more advanced user, but it does require installing the software viewer.

2 The need for a database to demonstrate how the different features of the environment, habitats, landform, soil / geology and cultural / management aspects influence the ecosystem services mapped.

The conceptual review and the development of the Bayesian Belief Networks has re-enforced the importance of understanding the bio-physical properties of each community. This together with the scale they are mapped at, as well as how they relate to the key factors of soil/geology, landscape and management need to be considered. Taking these into account the final framework from this phase of the project was developed in a user-friendly MS Access database. This gives a simplified yet robust interface and could link data through the concept of biophysical properties[9]. The concepts included within this database are described in section 3.3.

3.2 Implementation of conceptual development and understanding non-EUNIS habitat links with ecosystem services

The conceptual development described in section 3 shows how the relationships between EUNIS and other habitat types have been formulated in terms of the ecosystem services provided by that habitat. The initial set of habitat look up tables is supplied with this report as an Excel spread sheet.

[9] The database does not have the ability to calculate Bayesian Belief.

However, as well as the habitat type, the Spatial Framework developed in Phase 1 of this research (Medcalf *et al* 2012) demonstrates the importance of three other key factors:

- landform
- soil and geology
- management

For the Spatial Framework to be a useful working tool it needs to be as comprehensive as possible with each of the factors mentioned above incorporated. The certainty behind the rules, the accuracy and degree of knowledge of the data and the linkages between each of the different factors need to be clearly understandable so that the output is transparent and useful. We have developed a tool showing practitioners what can be achieved with the available datasets.

3.2.1 Biophysical Characteristics

Ecosystem services link the functions of the environment to all the goods obtained from the environment, both those that are immediately obvious in terms of their value (such as the provision of food crops) and the more hidden value (such as the mitigation of climate change by the binding up of carbon within soil and vegetation). These services are intrinsically linked to the habitats / land-cover present on any area of land. They are further influenced by the key factors of the landform, soil/geology and management of the area (Figure 4).

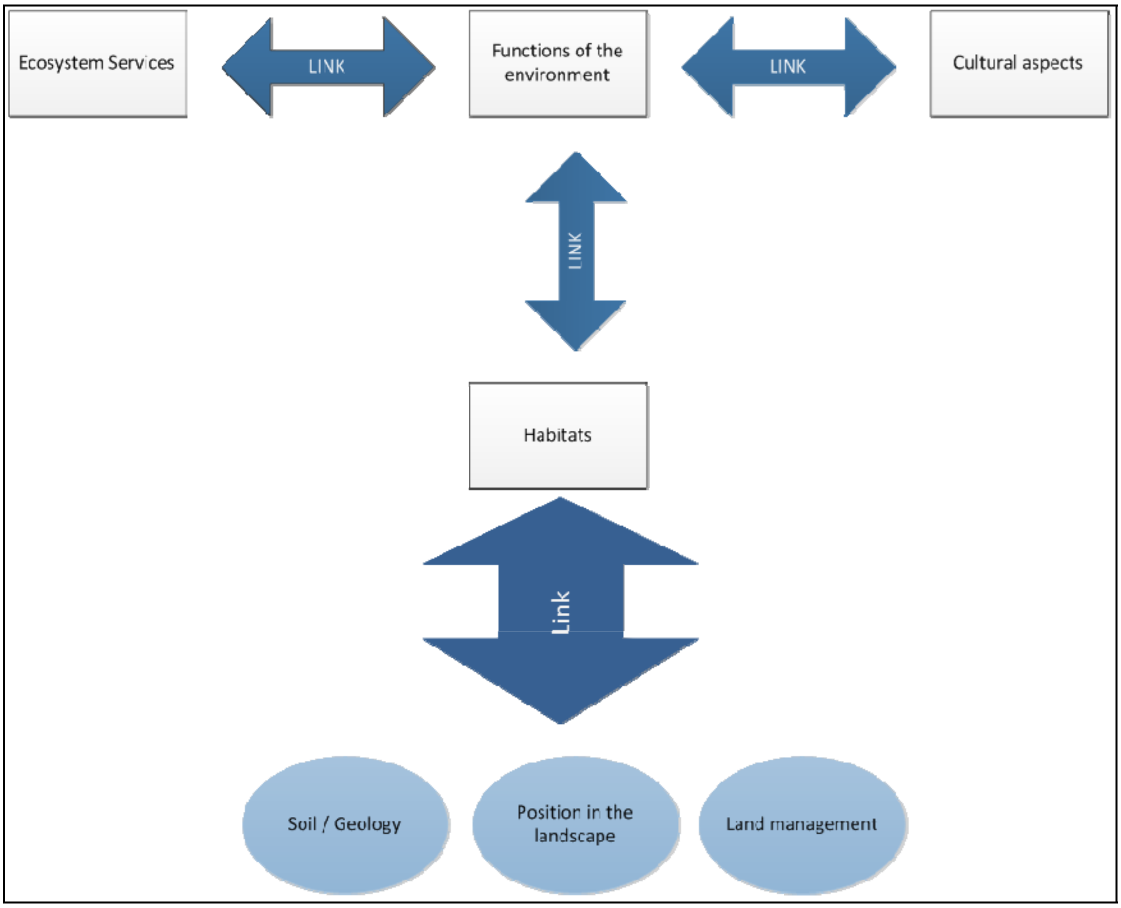


Figure 4. Relationship between ecosystem services, habitat and the environment.

When considering the link between habitat or land-cover type and the ecosystem services provided by the environment it is clear that the influence that habitats have on the functions of the environment is dependent on their biophysical characteristics. That is, habitats with long-lived wood growth or those that accrue large amounts of plant material over their lifetime will have a more profound role in storing carbon, than fine leaved grasslands where little dead material is accumulated. A habitat with deep rooted species which take up or utilise a large amount of water, will have a higher role in the regulating of rainfall events than a shallow rooted habitat with little evapotranspiration activity. Some of the biophysical characteristics are subtle and intricate, but it is possible to summarise the main features that impact on the contribution a habitat can make to the major ecosystem service considered in the NEA and CICES classifications.

Table 3 shows the summary groupings of biophysical characteristics which we consider will have the most influence on the ability of habitats to provide ecosystem services.

Table 3. Summary groupings of biophysical characteristics important for the regulating ecosystem services.

Primary biophysical characteristic of the habitats	Primary biophysical factor in habitats	Biophysical Characteristic of habitat (Primary features have the most profound effect, tertiary least)	Example characteristic feature influencing amount of contribution to service provision	Final regulating ecosystem services						
				Climate regulation	Hazard regulation (includes water regulation)	Pollination	Water regulation	Soil Quality	Air Quality	Noise regulation
1 - Below ground bio-physical features	Root depths	1^0	Deep rooted species (e.g. Trees, Bracken)	H	H	NA	H	H	H	NA
		2^0	Perennial plants (moderate root systems)	M	M	NA	M	M	M	NA
		3^0	Shallow rooted species (often annual plants)	L	L	NA	L	M	M	NA
2 - Below ground biological features	Species richness	1^0	Varied and abundant soil micro and macro fauna / flora	H	H	NA	H	H	M	NA
		2^0	Moderately abundant soil fauna/flora	M	M	NA	M	M	M	NA
		3^0	Limited soil fauna/ flora activity	L	L	NA	L	L	L	NA
3 - Above ground bio-physical features	Leaf Area Index	1^0	Large number of fleshy leaves	H	H	NA	H	NA	H	H
		2^0	Moderate amount of fleshy leaves	M	M	NA	M	NA	M	M
		3^0	Small spiny leaves	L	L	NA	L	NA	L	L
	Biomass / canopy height (surface roughness)	1^0	Woody / Trees (tall)	H	H	NA	H	H	H	H
		2^0	Shrubs/bracken - high standing matter	M	M	NA	M	M	M	H
		3^0	Small low growing grass	L	L	NA	L	L	L	L
4 - Above ground biological physical features	Species richness	1^0	More than 20 species associated with habitat	M	L	H	L	H	M	M
		2^0	11-20 species	M	L	M	L	M	M	M
		3^0	Less than 10 species	L	L	L	L	L	L	M
	Naturalness/ resilience	1^0	Native species well-established / ancient communities	H	L	H	H	H	H	H
		2^0	Mix of native and no-native species	H	L	M	L	L	M	M
		3^0	Non-native or Invasive species (recent)	H	L	L	L	L	M	M

Using these four key biophysical factors it is possible to categorise each of the habitat classifications and so provide a linkage between classifications based on their major ecosystem service functions. This linkage is helpful in evaluating how the different habitat classifications relate to one another in terms of their contribution to the hidden and noticed ecosystem services provided. It is also helpful in showing, which habitat classification systems allow for these major functions to be identified and which are not at a sufficiently detailed level to allow these to be distinguished. For example, all classification examined distinguish broad-leaved woodland from grassland. Thus it is possible to map the role of trees in accruing carbon using information derived from any habitat classification system. However, the rich biodiversity of the ancient semi-natural woodland can only be mapped given Phase 1 or HIS, whereas CORINE and OS MasterMap have no quality information associated with the woodland type and therefore cannot be used to allow the biodiversity aspects of woodland service provision to be mapped.

3.3 Ecosystem Services Spatial Database

3.3.1 Background to the spatial database

To encourage discussion and to progress the Framework approach, the project team produced a ‘structure’ for a decision framework, which is supported by a database.

It helps the user to understand what ecosystem services are mapable, at what scale, and using which data.

The ecosystems spatial framework database was built using a customised Microsoft Access 2010 database. This customised interface allows users, unfamiliar with MS Access, to easily interact with the information and generate reports (Figure 5). This customisation was achieved using ‘MS Access forms’, which limits the user’s interaction with the raw database to a few simple buttons and selection boxes. The forms are driven by several background tables that are used in conjunction with SQL queries and VBA scripts. These are used to create the selections and allow the user to navigate the database. For example, when the user clicks the report button for options 1 and 2 (Figure 5) MS Access reports are created then saved to a location selected by the user. For Option 3, the rule base considerations report relating to the selected service is copied to a location selected by the user.

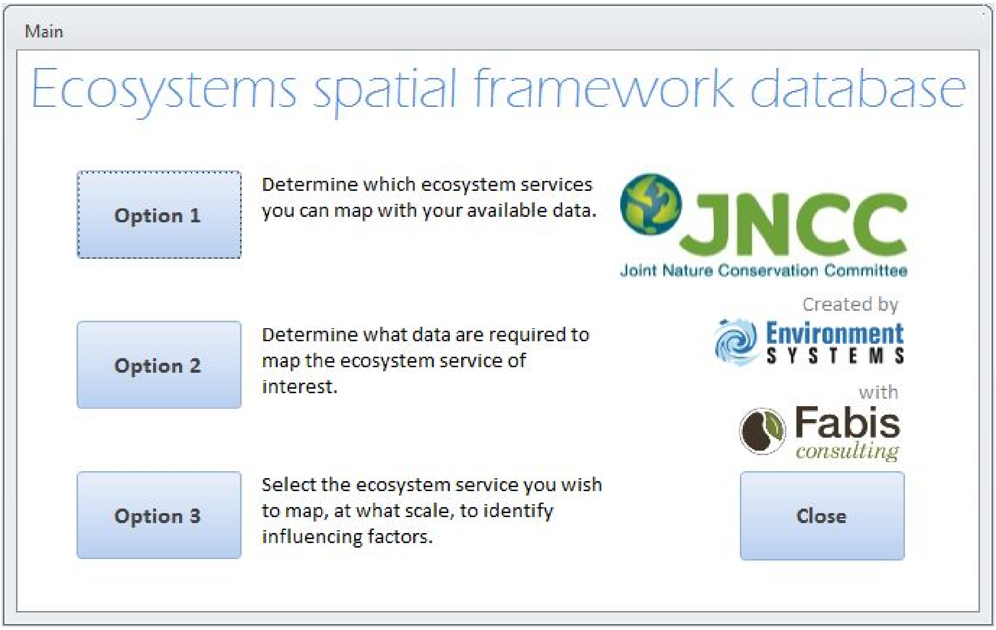


Figure 5. Database user interface.

3.3.2 Rationale

The rationale behind the development of a spatial framework database was to start bringing together the large body of data already available and demonstrate how these datasets could be used to inform the development of scientific rules to underpin an ecosystem services inventory and to facilitate the mapping process.

3.3.3 How to use the database

The database takes into account the main factors and the logical steps that need to be followed in a process that should facilitate and inform mapping of ecosystem services. Each of these factors is discussed in more detail in this section.

The database takes into account the scale of the project that the user is considering and the data available in terms of habitat, soil, geology, landform and management. The data lists included in the database are not by any means an exhaustive list. The data listed are those which are familiar to the project team, some of which the project team have experience in utilising in an ecosystem service mapping context.

There are four stages to follow when using the options within the database (mapped out in the conceptual diagram, Figure 6):

Stage 1: The user selects the ‘option’ they require from the main splash screen

Stage 2: The user fills in the requested form for their selected option.

Stage 3: The database processes the selection to create an output or inform the user that no output can be created from their selection.

Stage 4: The reports are saved.

Stage 5: Depending on whether option 1 or 2 has been selected, the user then can move onto option 3.

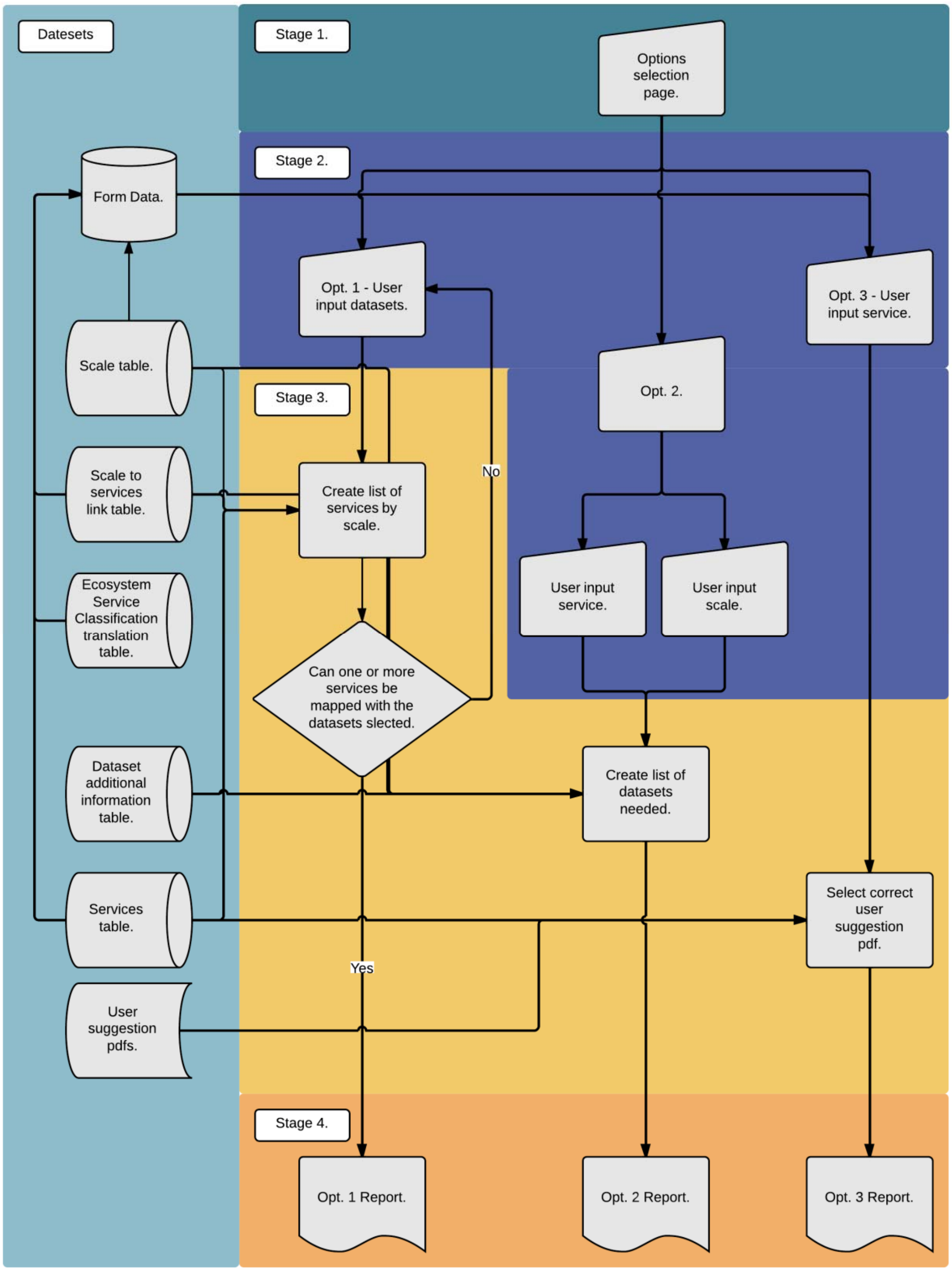


Figure 6. Conceptual flow diagram showing the database design.

There is an accompanying user guide, which discusses data concepts and the key stages in operating the JNCC spatial framework database (Small *et al* 2013).

3.4 Bayesian Belief Network

3.4.1 Background to Bayesian Belief Networks

Bayesian Belief Networks (BBNs) are multivariate statistical tools with a graphical output, designed to represent and analyse the uncertainty that often surrounds our understanding of complex systems. They are a way of representing the certainty (or the level of knowledge) about the links between different data as probabilities.

The Bayesian Belief Networks show these links and probabilities in a graphical way as the simplified example in Figure 7 illustrates.

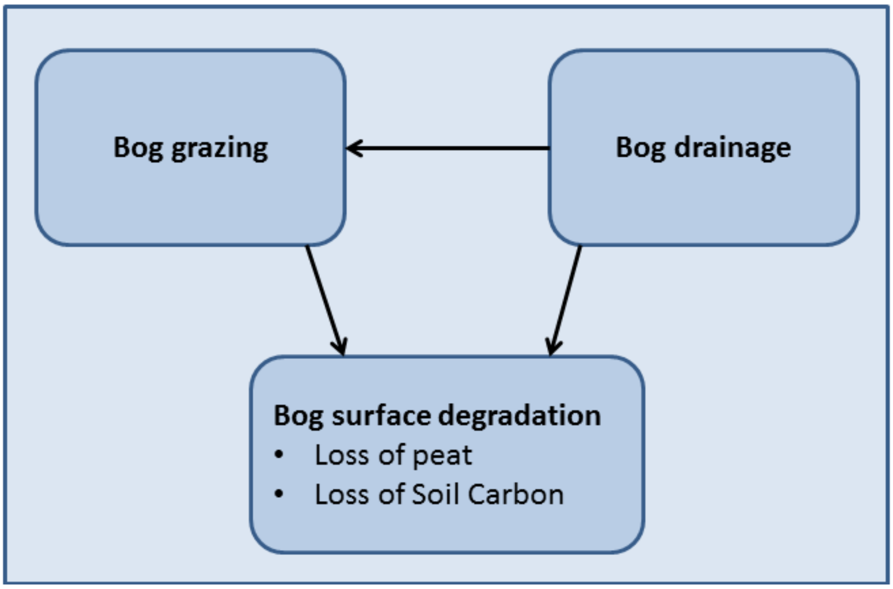


Figure 7. A simple Bayesian Belief Network. The drainage of a bog leads to an increase in grass species and therefore an increase in its value for grazing. Both drainage and grazing of the bog lead to degradation of the bog surface and subsequent loss of peat and soil.

They are very useful in ecosystem service modelling as they allow visual representation of the relationships between classification systems. In Phase two of this project we have been developing Bayesian Belief Networks to do two things:

- Show the correspondence between the different habitat mapping systems currently being used for ecosystem goods and services mapping and modelling;
- Evaluate the links between these habitat classifications and the ecosystem goods and services models;

For those unfamiliar with Bayesian Networks, a fuller introduction and overview on the development of the Bayesian Belief Network is provided in an associated report from this work (see briefing note 1).

3.4.2 Habitat classifications and ecosystem goods and services

In order to build the Bayesian Belief Networks and the database which will form the basis of the final operational framework it was necessary to understand the existing habitat classifications and their potential for providing information useful for mapping ecosystem goods and services. This framework considers all the commonly used habitat survey definitions available in the UK, (with the exception of the very detailed Annex I data, as maps for these are restricted to individual sites and are therefore not widely available for ecosystem service mapping at a larger scale).

To a certain extent, the more exacting the class descriptions of the habitats, the better the likelihood that the ecosystem services that they represent can be mapped and the greater the confidence in the link between the habitat and the ecosystem service. This is because, where a very exact description of the habitat is present, the structure and diversity of the community is more certain. For example, for the general class B1 coastal dunes and sandy shores, it is only possible to suggest broad ecosystem service values for carbon sequestration which would be low. However, with B1.8 moist and wet dune slacks, carbon is actively being incorporated into the soil and would be scored moderate. The most commonly used classification systems for habitat mapping at catchment to landscape level are:

- Phase 1 (level 4 e.g. A1.1.1 (Broad-leaved semi-natural woodland),
- Integrated Habitat System level 2 (e.g. WB3.1 upland oak woodland); and
- EUNIS level 3 (e.g. G18 *Quercus* dominated wood).

The NVC classification is used to map the protected sites at Annex I level and is a very detailed system for specific areas, it has therefore not been included in this tranche as it would only be available for discrete blocks of land.

In addition to the habitat classifications, broad habitat groupings are being commonly used to represent habitat type in ecosystem goods and services projects. These include Broad and BAP Priority habitat data, OS MasterMap TOID topographic identifiers, Welsh NEF Broad Habitats and Land Cover Map 2007.

The classification systems are an attempt to classify reality into recognisable groups that can be identified on the ground in a repeatable way. Each of the habitat classification systems has been designed with a different purpose; however, none of them have been designed specifically to map ecosystem goods and services. Phase 1 was designed to give a good general overview of British habitats, so that important sites for nature conservation could be identified (JNCC, 2007).

The EUNIS habitat classification was designed to give a comprehensive European classification that could be used to describe general trend and setting across the whole Union. Biodiversity Action Plan (BAP) Broad habitats and the former BAP priority habitats attempted to further segregate the specific habitats of importance in Britain. OS MasterMap TOIDs were designed to map landscape related features pertinent to navigation in the countryside; Land Cover Map 2007 describes broad groupings relating to CORINE. Because of the different reasons for the classification systems they all have strengths and weaknesses in terms of their use in ecosystem service mapping descriptions. When considering the relationship between the classes in the habitat systems these distinctions in terms of how well they can be used to describe ecosystem goods and services were identified. An example in Table 4 below shows some of the differences identified between EUNIS and Phase 1. The analysis notes how the difference may impact on the services it is possible to map from these habitats.

Table 4. Examples of summary information describing the main differences between EUNIS and Phase 1 and the implications for mapping ecosystem goods and services.

EUNIS Category	Phase 1 Category	Effect on Ecosystem service/ bio-physical score
A	Not present	The marine habitats describe deep ocean habitats not covered in Phase 1. In the intertidal zone the EUNIS classification works on the energy conditions of the water, whilst Phase 1 has a very simple textural description. It would therefore be possible to map more marine services with EUNIS than Phase 1.
B	H5	The EUNIS classification splits the above MHL coastal classes into more detailed grouping than Phase 1. For example shingle drift line is differentiated from the underdeveloped dune drift lines. Because of this it would be possible to map the ecosystem services of this coastal zone in more detail with the EUNIS classification. For example the sand line drift lines show where active sand-dune systems are present and this can indicate functioning coastal systems able to prevent erosion.
C1.1	E2.1 and E2.2	In contrast to the marine and coastal classes, within the wetland classes the EUNIS classifications are less detailed. Phase 1 splits flushes according to their nutrient status. Basic flushes have a much higher floristic diversity than acid ones and therefore have a different biodiversity score. This difference can be captured in the modelled output.
E1.2	B3.1 and 3.2	Semi-improved and old semi-improved grassland areas can be key sites for habitat restoration EUNIS does not make a distinction between species rich unimproved calcareous grasslands and semi-improved calcareous grassland. Phase 1 separates the grasslands into three levels (four in Wales) of agricultural improvement, making this a better system for describing and mapping ecosystem opportunities to enhance biodiversity.
E2 and E3	B2.1 and B2.2 B1.1. and B1.2.	Neutral and acid grasslands are split based on altitude in the EUNIS classification and not on species richness as is the case in Phase 1 classification. Altitude is perhaps less significant in a UK context and can be gleaned from other sources, it is unlikely that this difference leads to better descriptions of ecosystem services than that provided by Phase 1 in the UK using EUNIS.
F9	A2 / A1.1.1	Phase 1 lacks a class for wet woodland which is provided by EUNIS. Therefore, it is a stronger classification for these features as they play a significant role in many of the water and erosion control services.
FA.4	J2.1	EUNIS classifies hedges are part of a heathland category whereas in the UK they are either considered as a specific habitat or part of woodland as this was the origin of many of the thicker hedgerows present in the UK. It is conceptually difficult to consider hedges as heathland and this needs to be well understood if EUNIS is being used for rule development.

The links between the habitat classification systems and the ecosystem services are complex and multi-faceted. When analysing the linkages between the different classification systems and the ecosystem services it was possible to map, it became clear that it is the biophysical attributes of the habitats that allow either a detailed or general view of the services they provide to be made. This led to an attempt to describe the main biophysical attributes of the habitats and to classify the habitats according to these. Exploring how far we can take these biophysical properties of habitats and link them to ecosystem service provision was analysed by taking the Phase 1 Habitat survey classification and using Bayesian Belief Networks (discussed in section 3.4.4).

3.4.3 Key findings from earlier BBN work

i Linking habitat mapping systems using Bayesian Belief Networks

In order to develop the spatial framework, the relationship between the different habitat classifications (in relation to how they may affect ecosystem goods and services modelling) had to be described. These relationships are mapped out in an Excel workbook, which is available as an annex. The different habitat mapping systems and an example of how they link in terms of ecosystem service delivery are described in section 3.4.4.

In order to link the habitat classification systems together it was necessary to choose one of them as the linking classification so that there was a common reference point. This project has selected the EUNIS Level 2 and 3 classification system as the back-bone for the cross tabulation of habitat classifications.

Figure 8 shows some output from this cross-tabulation process. In this BBN the classifications have been linked through the degree of biological correspondence between categories.

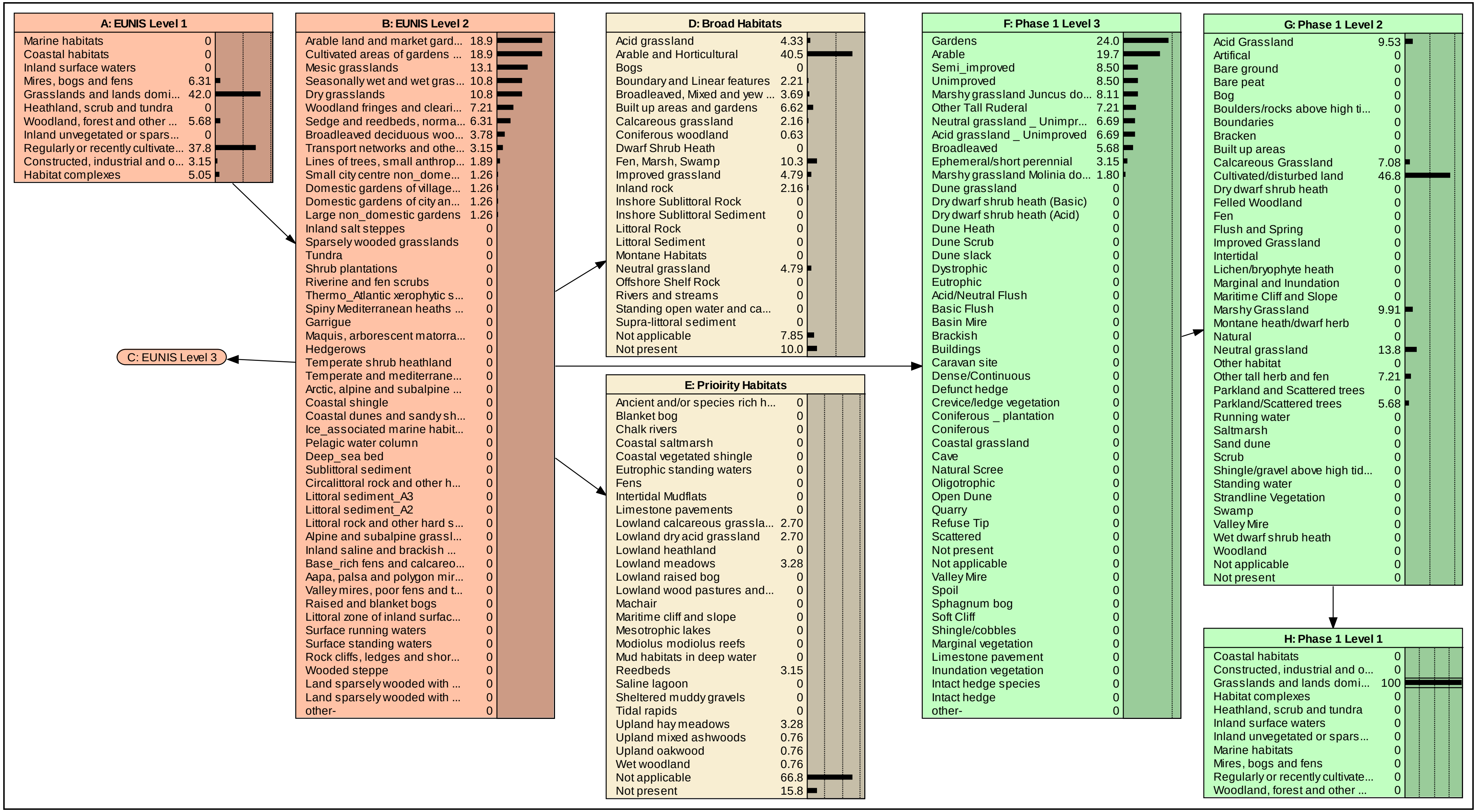


Figure 8. Phase 1 Grassland habitats Linked to EUNIS and Broad and Priority Habitats.

Figure illustrates how, by selecting the ‘Phase 1, Level 1’ habitat category ‘grasslands’ (see: green box at the lower right corner of the diagram), the EUNIS equivalents (in the pink boxes), together with the corresponding habitats in the Broad Habitats and Priority Habitats (yellow boxes) and Phase I (green boxes) classification systems can be displayed. The considered degree of correspondence is indicated by the black bars. The length of the bar is related to the number of relevant sub classes within the main class shown, that is the number of links between the main EUNIS class and the sub-classes for the habitat relationship diagrams.

The BBN consists of what is known as a ‘directed acyclic graph’ (DAG) which represents the system of interest as a set of variables, known as ‘nodes’ in the network (each node is depicted as a box) and the relationships between them (shown as arrows between the nodes).

The variables (nodes in the network) show the names of the categories in each of the habitat classifications and they are represented in the diagram as a list in a table. The bars adjacent to each of the class names show the degree of correlation. In this example EUNIS ‘grassland habitats’ at Level 1 relate to eight EUNIS level 2 habitats; twelve Broad Habitat classes (with the greatest level of correspondence being with the arable and horticultural land class), and encompass 11 Phase 1 level 3 habitat classes. The length of the bar is related to the number of relevant sub classes within the main class shown, that is the number of links between the main EUNIS class and the sub-classes.

ii Linking ecosystem service outputs using Bayesian Belief Networks

Work has already been undertaken to link up the different ecosystem service classification using BBN and the Netica software (Haines-Young, 2011). These types of analysis have also been run on the UK NEA to model land cover change under a range of different future scenarios (Haines-Young *et al* 2011), and in the pilot studies done as part of the Valuing Nature Network (VNN), where they were used as a framework for understanding valuation issues[10].

The structure of a BBN for the purposes of illustrating the links between components of two ecosystem services classifications and the UK NEA Broad Habitat classification is shown in Figure . This shows the links between the UK NEA habitats and the CICES ecosystem service classification. The ‘nodes’ include the four levels in the CICES hierarchy (nodes C to F); these are represented by the different service categories at the different levels in the CICES classification. Other nodes in the system represented by the network are the UK NEA ecosystem service categories (Node B) and the Broad Habitats that the NEA identified as important for the delivery of ecosystem services (Node A).

[10] http://www.valuing-nature.net/vnn-projects

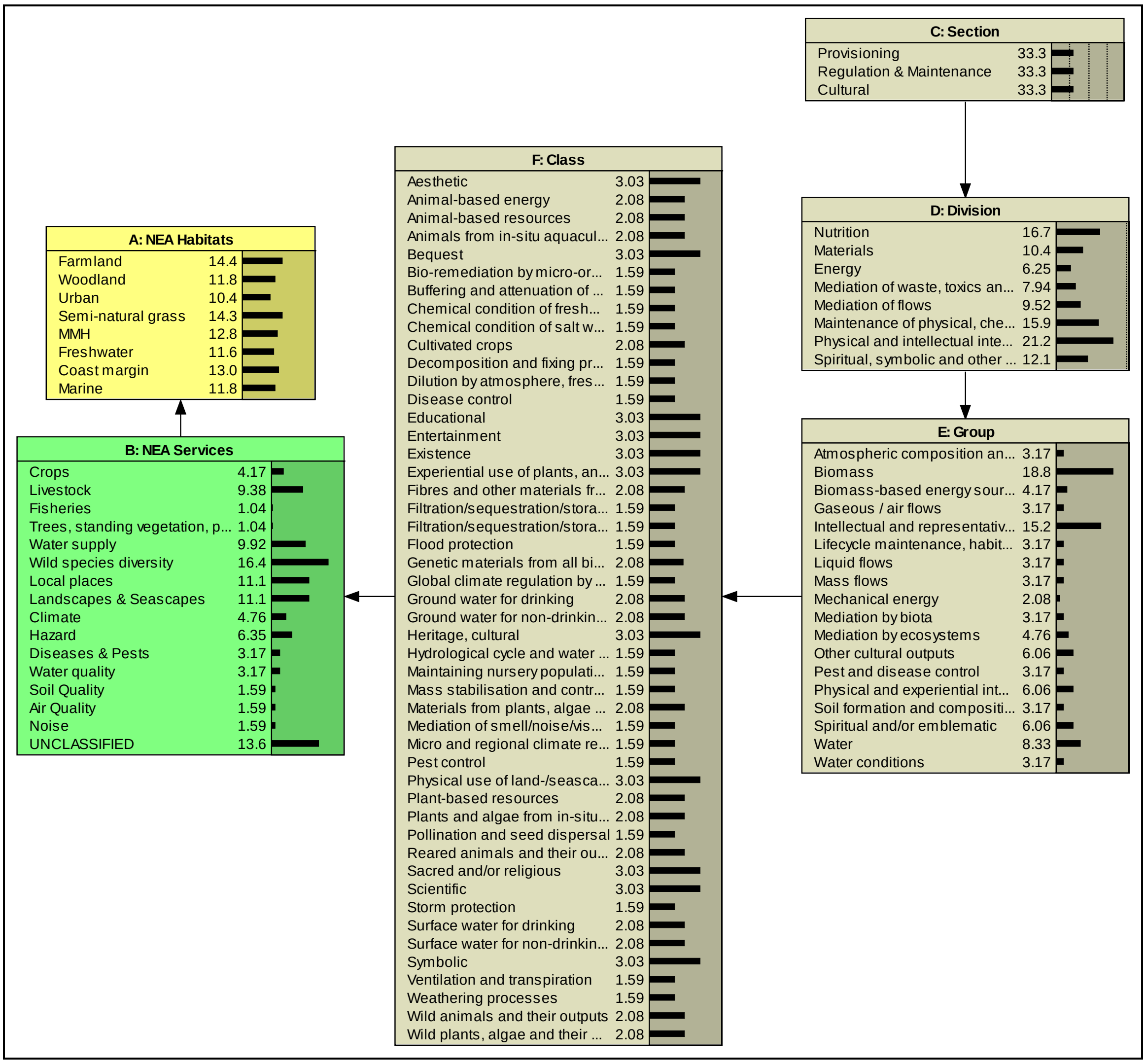


Figure 9. Using nodes in a BBN to illustrate the links between different elements of three classifications used in ecosystem services work.

3.4.4 Linking Bayesian Belief Networks to the rule base for ecosystem services via functions

The aim of this part of the project was to start identifying the opportunities and barriers to using Bayesian Belief Networks (BBNs) to display information about the potential output of ecosystem services from a given habitat, on the basis of its biophysical characteristics. The work mainly drew on the preliminary spread sheet that was constructed by the project team for a range of Phase 1 Habitats but also explores how the additional, more general context information from the Ecosystem Spatial Framework Database (ESFD) can be used.

The problem that lies at the heart of this work is that there is no simple relationship between the output of an ecosystem service and the biophysical characteristics of a habitat. Whether a given habitat type is capable of providing a particular service may depend on a number of factors, and the relationships between the inputs and outputs may be complex and non-linear. Moreover, since the characteristics of the habitat may vary over time and space, it may be very difficult to say what services are associated with a given habitat in a specific location without much additional local information. Given the state of current knowledge, assessments of the potential output of ecosystem services from different habitats are either model-based, or depend on the judgement of experts and/or stakeholders. As a result there is likely to be some uncertainty in any assessment. Moreover, as new knowledge becomes available, then the basis of the assessment may need to be modified. In this paper we consider how BBNs might be used as a decision support tool in this kind of situation.

In terms of identifying the potential opportunities and barriers of using these tools, the current paper should also be considered in the context of the examination made of the potential of these networks to display the relationship between different habitat classifications and different ecosystem service typologies. This other work showed that BBNs could be used to help people identify the relationships between different classification systems in an interactive way, using a simple graphical interface. In undertaking this work it was however, recognised that the classification problem was a relatively simple one, because the relationships between the different systems are relatively well defined. If these types of BBN could be extended to help the user identify what types of ecosystem service might also be associated with a given habitat or groups of habitats, then this type of approach may be more generally useful as a decision support tool. This paper therefore explores the question of whether on the basis of the information currently available, such an extended system for predicting the potential of a habitat to deliver different ecosystem services can be developed.

3.4.5 Comparing Database and the BBN Approaches

The reason for exploring BBNs as a decision support tool is that they potentially offer a more flexible approach to the problem of modelling the output of ecosystem services than a more conventional database. The difference between the database and BBN approaches can best be seen by considering the way the spread sheet linking biophysical characteristics and services might be used. Thus, while the information in the spreadsheet is useful, it is essentially a static tabulation of biophysical characteristics and service output potentials against different habitats. The user can select a habitat and review the biophysical characteristics assigned to it and the predicted importance for a given service. However, because the system does not contain any ‘coding’ for the relationship between the biophysical characteristics and service outputs, the assessment provided by the system cannot be modified if additional information about the particular site being considered is available. For example, in the case of soil carbon the spreadsheet records that the impact of greater rooting depths of conifers on soil carbon is ‘low’, except if it is found on deep peat soils, when it is rated as ‘negative’. In the present spread sheet exceptions like this are few in number, but a review of the additional, general descriptive information provided for each service in the Ecosystem Spatial Framework Database, suggests that the number of such qualifications could increase significantly, especially if management status is also considered a mediating factor.

Given the number of potential combinations of the biophysical characteristics and additional contextual information such as soil type, management and landform, the number of database entries required to cover all possibilities could become very large. An alternative approach, which is the one being considered by using a BBN, is to try to express the relationships between the various biophysical characteristics, factors and ecosystem service outputs using some kind of general set of rules or functional relationships, and then using these to generate the predicted service output in a dynamic way. An advantage of this approach would be that the user could modify the input data according to the knowledge they have of a site or how, for example, it might be changed by a management intervention. Using the Bayesian approach, a further advantage would be that the uncertainty surrounding the result could be expressed in probabilistic terms.

Despite the flexibility of a rule-based approach, the methods are by no means simple to implement because, as noted above, the relationships between the factors that control ecosystem services and outputs are complex and only partially understood. In the remaining parts of this paper we therefore explored the basis that the current project provides to take this kind of analysis forward, and identify what the potential next steps might be.

3.4.6 Modelling ecosystem services

Rather than using the spreadsheet describing the biophysical characteristics of different habitats and service output as a simple database, we could consider it as a body ‘expert knowledge’ on the subject, and use it to derive some of the initial rules that a Bayesian Network might need. Figure 10 has been constructed from the data on the seven ecosystem services considered in the study; in each case the average score assigned to each biophysical characteristic has been averaged across the 44 level 3 Phase 1 habitats. The coding follows the schema set out in Table 5 of the Interim Report: The biophysical characteristics were rated on a three point scale, 1 indicating that it was of primary importance in determining the level of service output, and 3 indicating that it was less influential. The significance of the habitat for a given service was then assessed as being ‘high’, ‘medium’ or ‘low’ in terms of the service being considered .

The data shown in Figure 10 suggests that the relationships implied by the expert assignments in the database are broadly linear. In all cases, except that of cultivated crops, as the rating for each biophysical characteristic changes from 1 through 3, the significance for each services declines (i.e. changes from high through to low); for cultivated crops there is a simple inverse relationship. The major difference between the service assessments is that for some (e.g. water quality and quantity, and vegetation and soil carbon) there is a finer distinction made in the output levels than for others (biodiversity, physical/experiential and cultivated crops). The extent to which the differences reflect a better understanding of some services than others, or if the differences can really be assessed in this finer resolution way, is unclear.

In detail, these bar charts also show the contribution of each biophysical characteristic to the overall score at each of the service output levels. These data do not suggest that there appears to be any difference between the services in terms of the strength of the contribution of the individual biophysical characteristics to overall output levels, nor does the strength of the contribution change across the range of outcome levels. As a result, using these data, the predicted services outputs are likely to be highly correlated with each other; e.g. those situations where the contribution of the habitat to mitigating water flows are high are also likely to contribute to higher water quality.

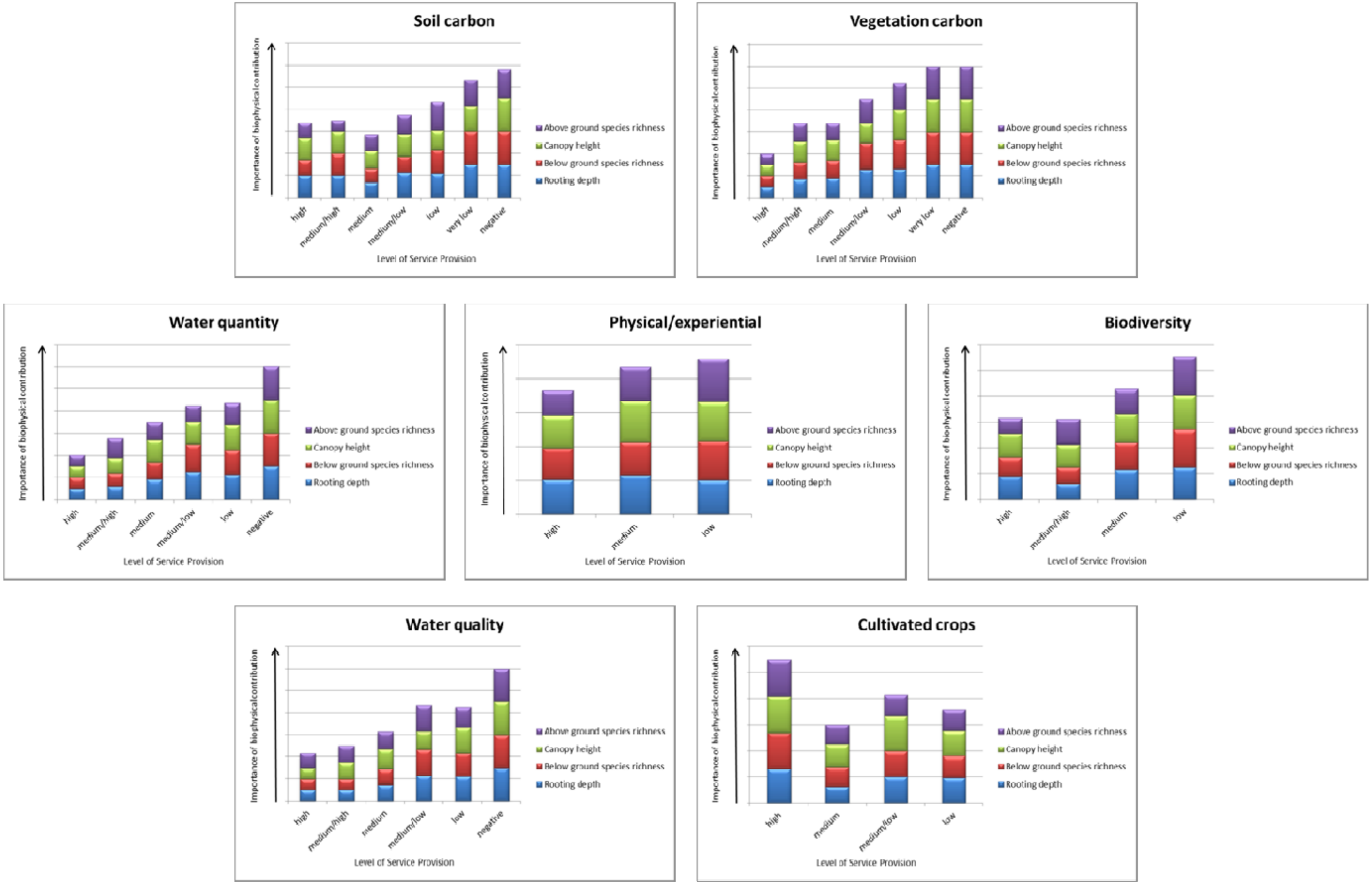


Figure 10. Average significance scores of each biophysical characteristic for the seven ecosystem services considered in the study.

Figure 11 shows a BBN that can be developed using these kinds of data. It was built using the 'training' tool provided as part of the Netica BBN software. In order to undertake the analysis those habitats (cases) where all of the biophysical characteristics were recorded as 'not applicable' were removed from the training data; where one or more were assigned N/A, these entries were treated as 'missing data' (i.e. unknown). In all 68 of the 76 records available were used.

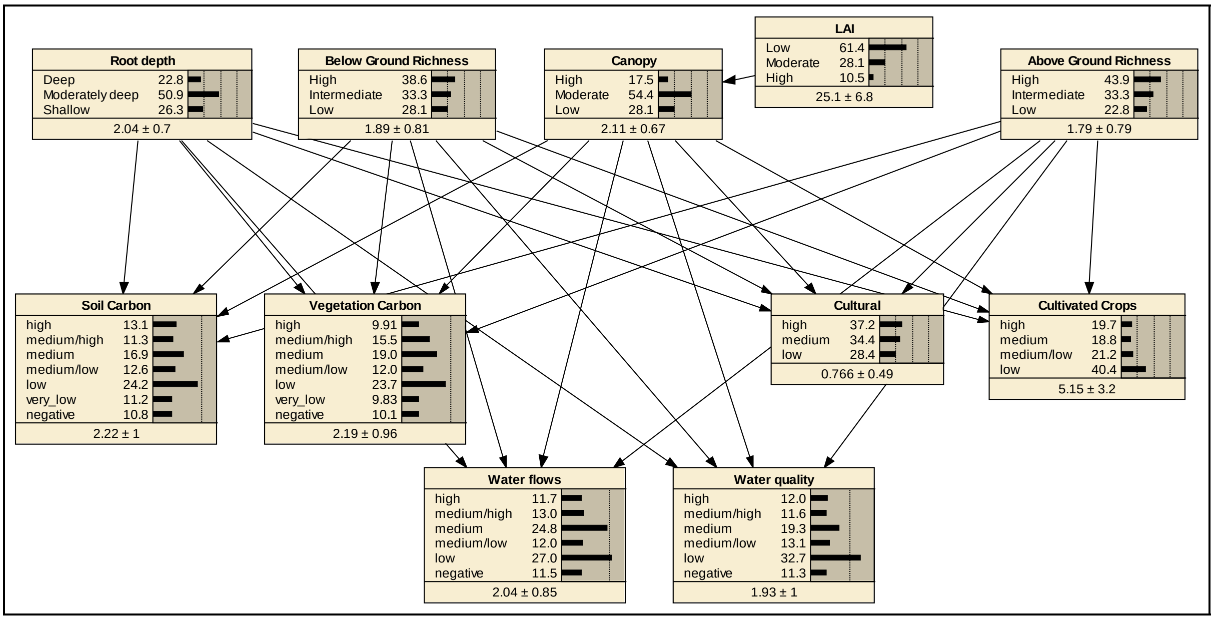


Figure 11. Initial BBN linking biophysical characteristics to ecosystem service outputs.

The use of the spread sheet data to train the BBN is straightforward and clearly evidence-based, but it suffers from the disadvantage that the number of cases used for the calibration is relatively small, and so not all possible combinations of the input biophysical characteristics are available. As a result the probability distributions for the service outputs do not always show a clear pattern; the distributions for soil and vegetation carbon, for example, as well as water quantity and quality are all multi-modal. This problem would potentially reduce, if more examples could be added to the database and used as additional training data. An alternative strategy would be to amalgamate some of the assessment categories. For example, the multi-modal characteristic of the four nodes discussed above could be reduced if some of the intermediate assessment levels were combined (e.g. medium/high, medium, and medium/low).

Given the unavailability of additional training data, the strategy of reducing the number of assessment categories has been used. The resulting BBN is shown in Figure 12. The simplification process seems to have eliminated the problem of multi-modal probability distributions for the service assessments. Most importantly, the behaviour of the network also seems to match expectations about the way the biophysical characteristics should influence service output. For example, as a comparison of Figures 13 and 14 shows, the training algorithm seems to have captured some of the expected relationships between below ground characteristics and their impacts on soil carbon and water flows, with deeper rooting depths and higher below ground biodiversity predicting higher soil carbon and a stronger influence on water quantity and quality. Deeper rooting depths and higher below ground biodiversity also seem to promote higher service levels for water quantity and quality.

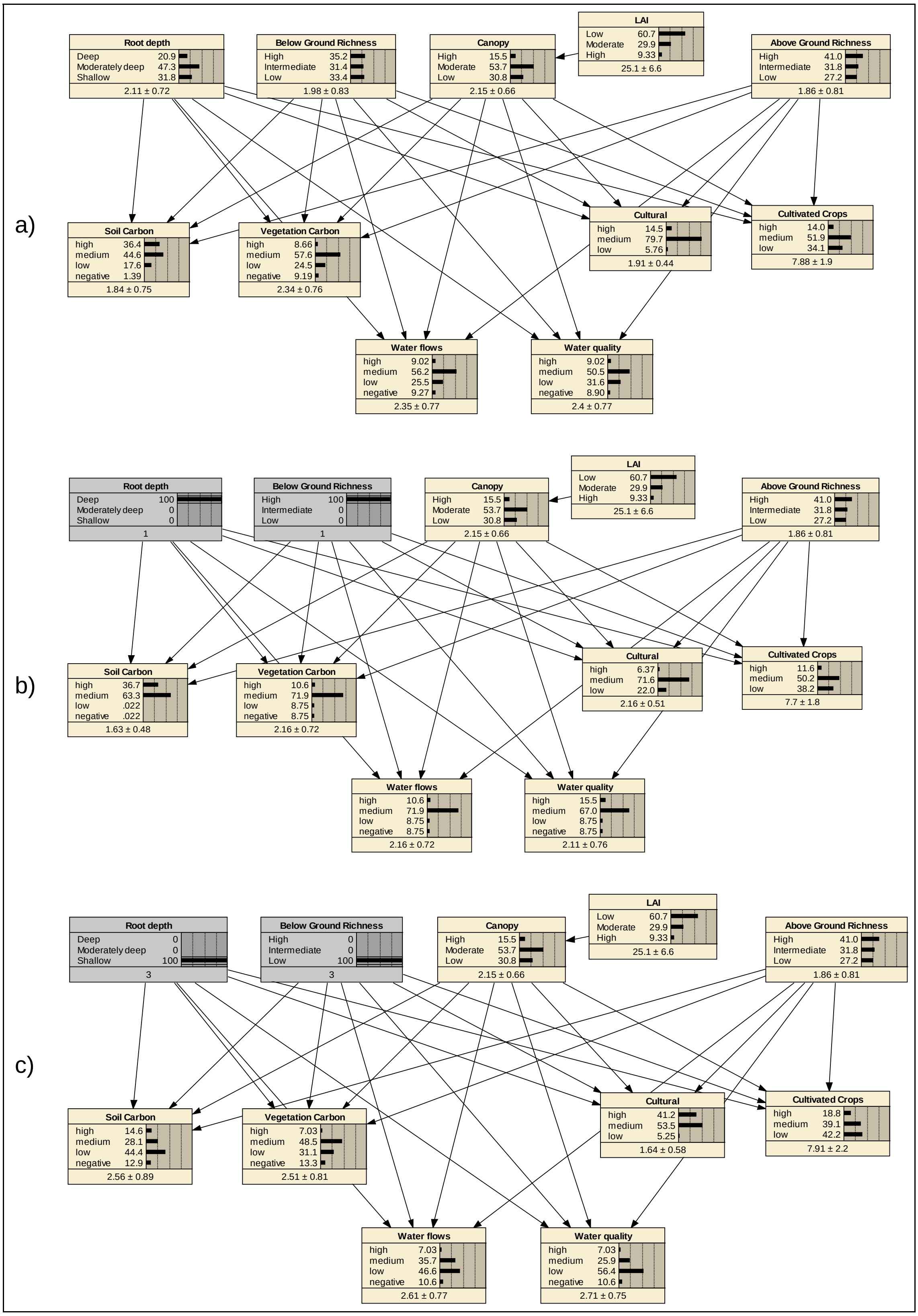


Figure 12. Simplified BBN linking biophysical characteristics of habitats to service output.

The network also seems to have captured some of the expected synergies and trade-offs between the services. One of the advantages of the BBN representation of the training data is that the user can select a given output level for a particular service and use the 'back-chaining' property of the network to review the assessments for the other services. For example, Figure 13 shows the effect of selecting either 'medium' or 'low' levels for water quantity (flows) on the other services. In the case of both soil and vegetation carbon the BBN predicts that we should find higher levels where water flow is assessed as ‘medium’ compared to when it is assessed as ‘low’.

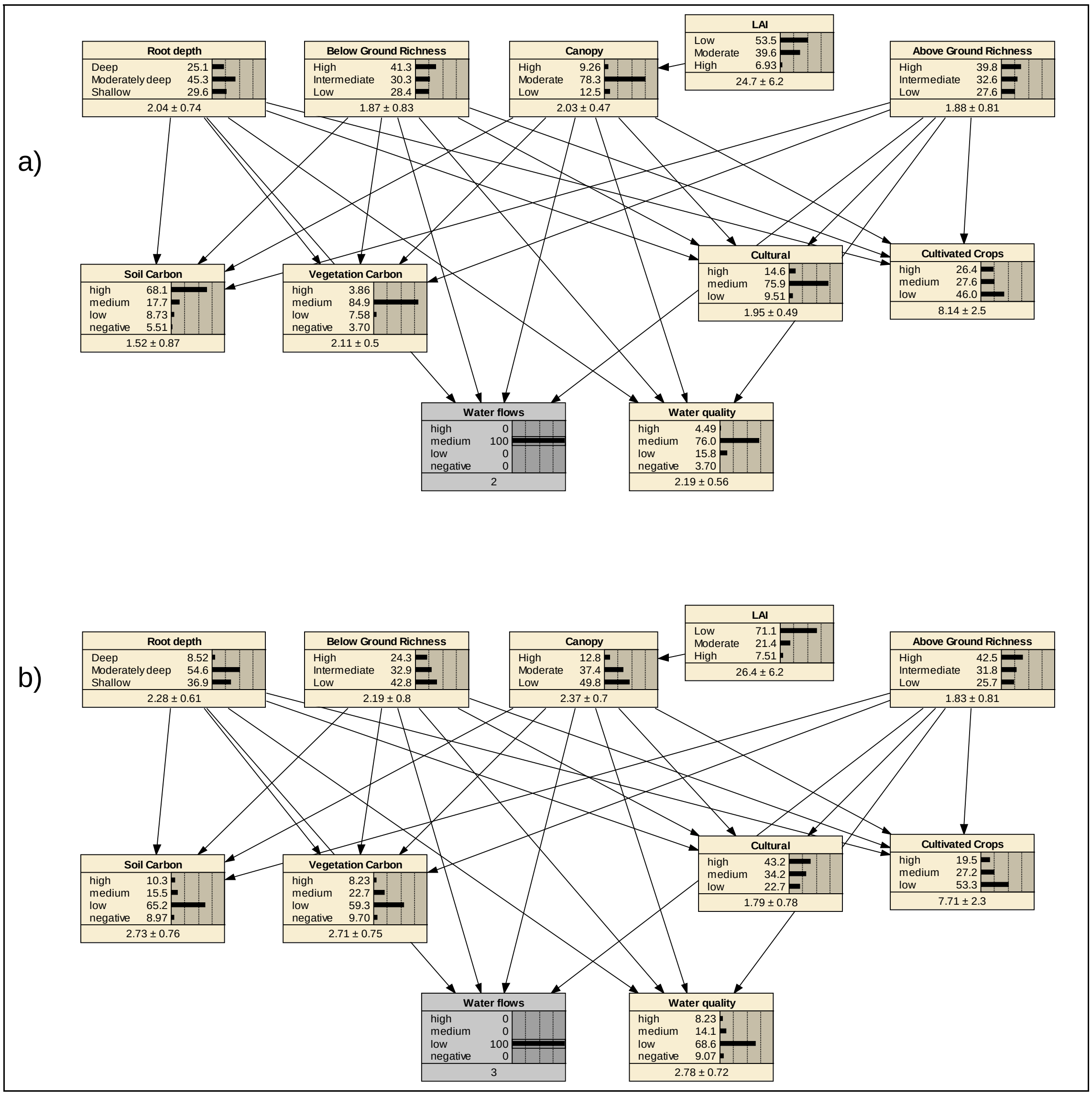


Figure 13. Use of the BBN to identify the trade-offs and synergies between services outputs.

Netica provides a tool for testing the accuracy of the predictions made using a network such as the one described above. The algorithm works by selecting a target node (in this case one of the ecosystem services) and comparing the predicted state for each case against that recorded in the training data. The system reports the outcome as a % error rate. Making this analysis for the seven services considered here shows that for soil and vegetation carbon, water quantity and quality, and cultural and cultivated crops, the error rates were 16%, 13%, 17%, 20%, 16%, and 16% respectively. Thus overall the network seems to be reproducing the initial training data with an accuracy of around 80%, which seems broadly acceptable at this stage.

Although some aspects of the behaviour of the BBN shown in Figures 12 and 13 are plausible, its preliminary nature is emphasised by a number of other features. For example, a sensitivity analysis suggests that for all the services the findings are most dependent on the node for canopy height. However, one would expect the nodes for rooting depth and soil biodiversity to be more influential for soil carbon than the above ground conditions. On the other hand, the node for cultural services seems to be most sensitive to findings for the nodes for rooting depth and below ground biodiversity, rather than canopy height. Thus, despite the low error rates reported above, there seems to be some scope for looking at the structure of the network and the training data more critically, to ensure that the scoring is as unambiguous as possible and that the model captures important theoretical relationships.

3.4.7 Developing and applying the BBN approach

Although the BBN described above is rudimentary, the initial results are promising and it may therefore be worthwhile to explore the approach more actively. The most important aspects that need to be considered are as follows:

i Refining the model structure

The approach used to develop the existing model was exploratory, in the sense that it has assumed that all the biophysical characteristics are relevant inputs for all the services being considered; thus in the network diagrams above, each of the biophysical nodes is linked to each of the services. The limitation of this approach is that the structure may not fully reflect our theoretical understanding. Moreover, this fully linked structure may introduce a number of redundancies into the network. There are a number of tools available when constructing BBNs to determine which links are most significant and in any future work these could be used to create as parsimonious a model as possible.

A further aspect that needs to be considered is that in the database some of the relationships were coded as ‘not applicable’, and at this initial stage the entries were treated as ‘missing data’. The result was that they had no influence on the calibration of the nodes. The consequence of this strategy needs to be explored further, and options for dealing with situations where the influence of certain nodes needs to be ‘switched off’ need to be identified and tested. The BBN allows users to look at the consequence of only setting certain nodes, and of setting all the states of other nodes as ‘equally likely’. This may be sufficient to reproduce what is being implied in the way the database was coded up – but the consequence needs to be tested further by comparing the outcomes predicted by the model against the empirical assessments for particular habitats.

The final area where some refinement of the model could be considered is in terms of defining more explicitly the way the nodes are related to each other. The approach used here is to some extent inductive, in the sense that the model structure (table definitions) simply follows the relationships defined when the database was created. The probability distributions could, however, be generated by using mathematical functions that more explicitly capture our theoretical understanding of the way the variables are linked. For example, the small experimental network shown in Figure 14 used the scores for the biophysical characteristics in a normal distribution function to estimate the probabilities of service outcomes. The advantage of this method is that the resulting distributions are better defined and this is especially useful where a greater range of output levels needs to be considered.

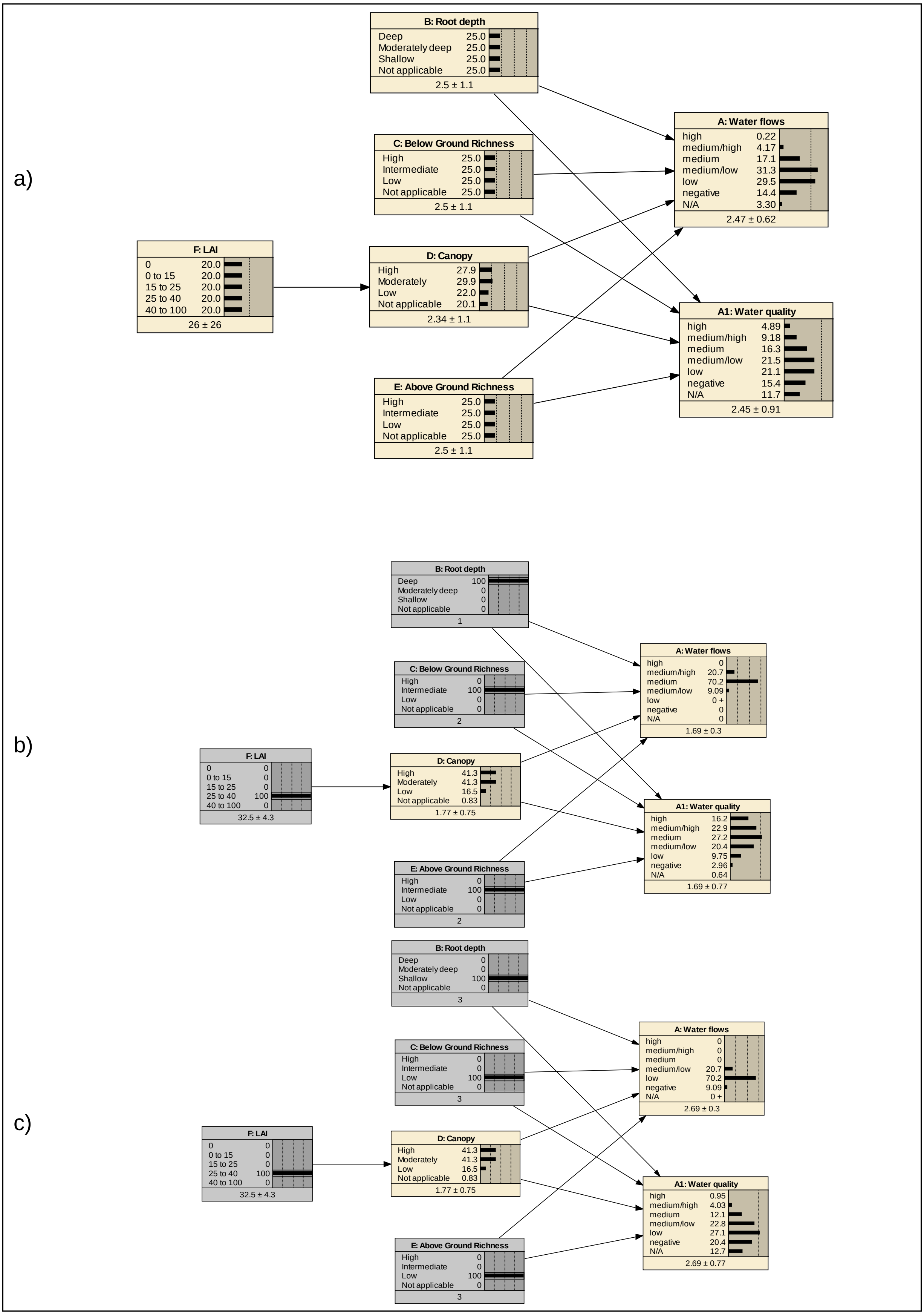


Figure 14. Use of normal distribution function to model service outcomes.

The disadvantage is that a greater number of assumptions have to be made about the way the inputs combine, which makes the approach conceptually more challenging. For example, the model in Figure 14 assumes that the influence of each biophysical characteristic is additive and all are equally weighted. Nevertheless, despite the greater challenge of this approach, as a comparison of Figures 14b and 14c suggests, such a network is capable of reproducing the same kinds of pattern for water quality and quantity as seen in Figure 12.

In any future study it would be useful to consider this kind of modelling approach further in order to overcome the problem of a limited amount of training data. One strategy would be to use the results of calibration using the training data as a starting point, and then refine the probability tables using expert judgement and/or mathematical functions like those shown here.

3.4.8 Linking the BBN model to the Ecosystem Spatial Framework Database and Habitat Classification Systems

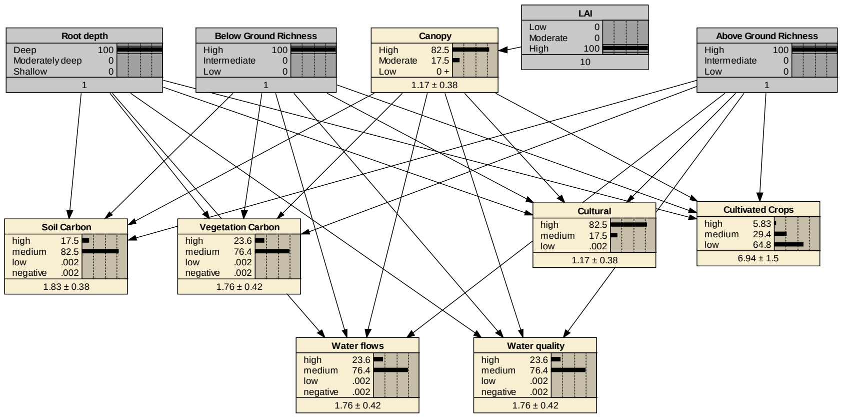
Although the database references biophysical characteristics and service outputs to specific habitats, the habitat itself was not used as an input to the network. Rather the approach was to use this body of data to derive some general relationships. As the analysis of error rates showed, the network performed reasonably well in terms of reproducing the outputs for each case. Thus in terms of using the network operationally, the database represented by the current spreadsheet only needs to be set up with the biophysical characteristics assigned to each habitat, and these can then be read into the network as cases and used to predict the service levels.

The approach is illustrated in Figure 15 (a), (b) and (c). Here the records for 'broadleaved woodland' (record 1), unimproved acid grassland (record 13) and improved calcareous grassland (record 17) have been read into the BBN in turn; the resulting predictions are shown and can be compared to the assignments contained in the database.

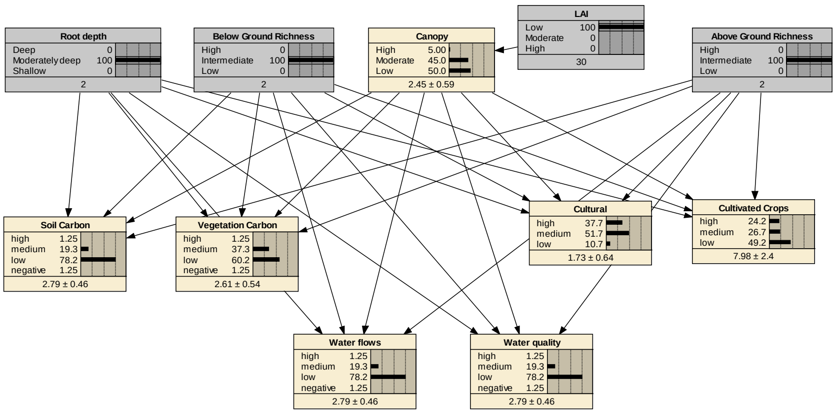
Thus operationally, the user could select a habitat, and on the basis of the biophysical characteristics pre-assigned to it, the system would predict what the service output levels would be. By not tying the prediction to a particular habitat type, however, the user can then modify the network configuration to reflect any local or specific characteristics that they may have knowledge of, say that the above ground species richness is especially high. This design strategy would allow the more flexible inclusion of a range of context variables, like soil type or management change. In the existing network the relationship between Leaf Area Index (LAI) and canopy height has been included and modelled using the database. The existing network allows this to be changed by the user to see what effect variations might have if all other things remain the same. A review of the descriptive text for each service to identify the other contextual information that would need to be included in the network is an important next step.

Phase 1 Level 3	Atmospheric composition and climate change (with focus on soil Carbon	Atmospheric composition and climate change (with focus on vegetation carbon	Liquid flows (Water Quantity Regulation)	Liquid Flows (Water Quality Regulation)	Biodiversity	Physical and experiential interactions Recreation	Cultivated crops/reare d animals and their outputs
A1.1	medium	high	high	high	high	high	low
B1.2	low	low	low	low	medium	medium	medium
B3.2	low	low	low	low	high	high	medium/low

A) Broadleaved woodland (A1.1)



B) Unimproved acid grassland (B1.2)



C) Improved calcareous grassland (B3.2)

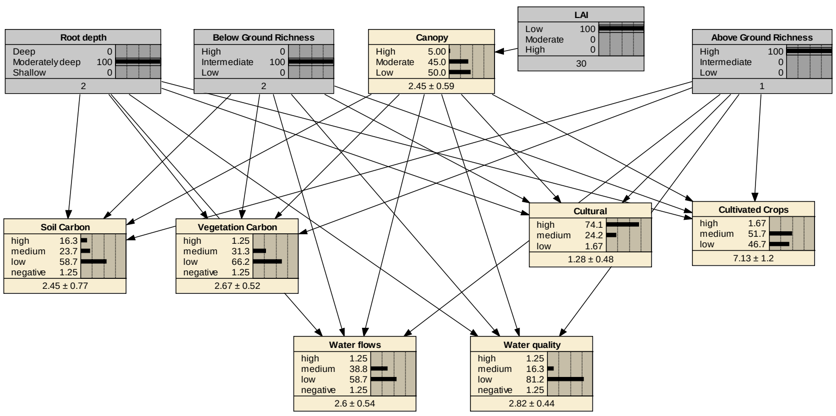


Figure 15. Example of BBN output for selected cases (table shows assignments in database, and networks show predictions for the relevant biophysical characteristics).

There would, however, be some merit in developing a network structure that did link the various habitat hierarchies through to the predictions for the ecosystem services, so that the user could examine, for example, the service characteristics for ‘all woodlands’, say rather than one specific type. Alternatively the user might want to identify the types of habitat where a service is likely to be important. Given these kinds of requirement it might well be that in developing an operational version of these networks, while they are based on the same sets of relationships, different versions of the networks would be presented to the user to meet particular needs. The approach is illustrated in Figure 16 (on the following page), in which the model shown above has been set up to link to the Phase 1 habitat classification. While the training data contains only one example of each of the Level 3 habitats, using the upper tiers into which they are nested, enables the user to see what assessments are made for more general habitat types, such as all ‘woodlands’ (Figure 16a) or all ‘grasslands and marsh’ (Figure 16b).

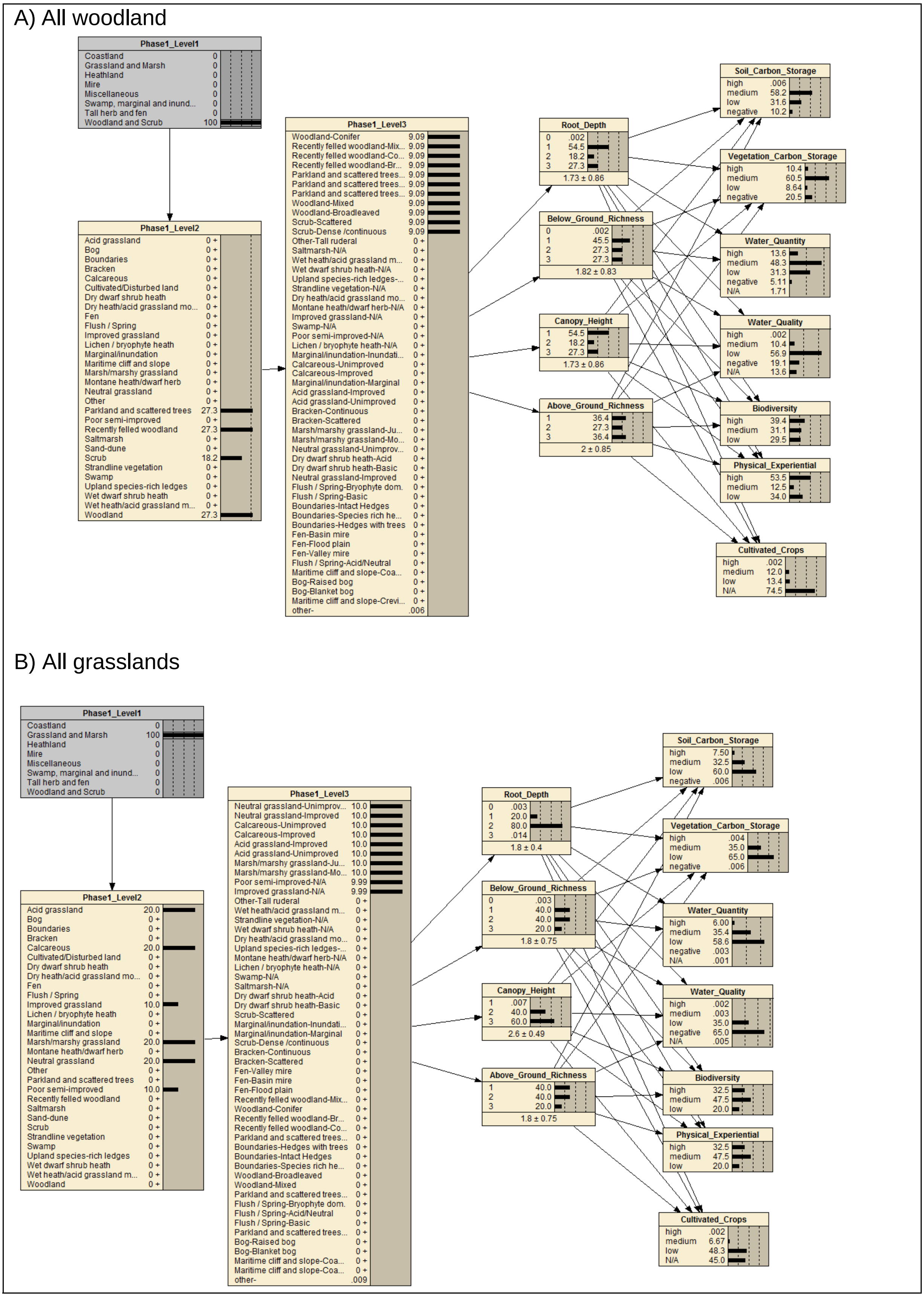


Figure 16. Refining the BBN to model the effect of habitat types.

4 Introduction to the decision types

Most ecosystems are capable of delivering more than one ecosystem service; that is they can be regarded as 'multi-functional'. Ecosystems interact in complex ways and can be affected both negatively and positively depending on the management interventions.

Some ecosystem services can co-vary positively, i.e., more of one means more of another. Other services occurring within the landscape may co-vary negatively, i.e., more of one service means less of another, for example, increasing food provision may reduce regulating services such as soil quality, climate regulation and water regulation (Elmqvist *et al* 2011). It is apparent that in some situations not all services can be optimised simultaneously. It is in this context that the notion of a trade-off occurs.

The value of applying an ecosystem services framework to land management lies in the fact that it is possible to establish and compare how different actions will lead to different ecosystem service deliverables. This part of the project has started to address how different forms of synergies and trade-offs can be mapped, and to consider the best ways to depict this and inform policy makers and land managers of potential changes in ecosystem services in situations by utilising other methods.

This project addressed four different situations in which the use of spatial inventory and ecosystem services mapping is likely to help in decision making at local and regional scales, namely in:

<u>INVENTORY PRODUCTION</u>: making an inventory of ecosystem services;

<u>BEST / WORST CASE SCENARIO MODELLING</u>: determining where the best and worst place for action might be;

<u>IDENTIFYING OUTPUT CHANGES</u>: identifying the changes in ecosystem service output arising from planned change; and,

<u>IMPROVING OUTCOMES</u>: determining the best strategy for improving the output of ecosystem services in an area.

The decision making needs that these situations give rise to can be addressed by a range of approaches. Three policy papers describe and explain the approaches that are being developed for application in these situations; these include trade-off analysis, ecosystem service opportunity mapping, multi-benefit mapping and monetary valuation of ecosystem services. All of these methods give a value to the land for the service under consideration, but only the last addresses the monetary value of the services.

Suitability of ecosystem services mapping approaches to addressing particular policy needs

Type of ecosystem services mapping approach	Ecosystem Services and Policy needs			
	Inventory Production	Best/Worst case scenario modelling	Identifying Output changes	Optimising outcomes
Ecosystem Services Trade- offs	Prerequisite	Suitable	Suitable	Suitable
Ecosystem Service Opportunities	Prerequisite	Suitable	Suitable	Suitable
Areas with Multiple Benefits from Ecosystem Services	Prerequisite	Not Suitable	Not Suitable	Suitable
Monetary valuation of ecosystem services	Prerequisite	Suitable	Suitable	Not Suitable

This section of work looked at:

- Addressing each situation
- At what scale the four situations could be addressed

Three information notes (Haines-Young *et al* 2013 b,c,d) and a research paper (Haines-Young and Potschin, 2013) support this section and accompany this report.

4.1 Opportunities and Benefit mapping

4.1.1 Opportunities mapping

In ecosystem services, the notion of ‘opportunity’ encompasses situations where ecosystem services output might be enhanced by modification of the current management regime. Mapping ecosystem services opportunities provides policy makers with a systematic method to identify and communicate where the output of particular services might be expected, based on a range of inputs, such as habitat type, substrate, management and geographic location. In common with other “suitability” mapping methods decision makers can explore ‘what-if’ questions in a decision support role and predict the varying level of service output under differing scenarios.

It is important to recognise the different types of application when deciding a mapping approach that will assist with decision making. Opportunity mapping is well-suited to those situations where the intention is to predict where a particular ecosystem service might be anticipated and looks at spatial variations in some ‘final ecosystem service’ derived from a set of underlying functional relationships. It is particularly valuable for testing “what if” scenarios in two of the situations addressed by this project:

- Determining where the best and worst place for action might be; and,

- Determining the best strategy for improving or 'optimising' the output of ecosystem services.

4.1.2 Benefit mapping

Ecosystems deliver a broad range of services, some of which have associated environmental, economic and social values placed upon them by human beings. How people value these services may differ between different groups of people, at different times and in different places (Haines-Young and Potschin, 2011).

In principle it is possible to value ecosystems in qualitative, quantitative or monetary terms (WBCSD, 2011).

- **monetary valuation**: a monetary value is placed on the impact, to translate quantitative evaluation into a single common currency to enable aggregation and comparison;
- **quantitative assessment**: describes the nature of the value in terms of the relevant quantitative information (e.g. estimated 25% decline in catch, for 24 fishermen from three villages etc.);
- **qualitative valuation**: describes the value and ideally indicates the relative scale of value (for example, in terms of high, medium and low). The scaling needs to be relative in terms of all ecosystem services being assessed at a specific geographic level (e.g. site level, global etc.).

Mapping ecosystem 'goods' in terms of describing their value relies on giving each area of land either an actual monetary value, an explicit quantitative value or an explicit qualitative value. Mapping ecosystem valuations provides an indication of where ecosystem costs (e.g. risk of environmental degradation) and benefits are occurring and may reveal unexpected benefits and costs. Creating an inventory of ecosystem services within the area under consideration is a starting point to understanding the current situation and starts the processes of understanding how to value the services present. From this baseline, any tradable goods or public benefits can be revealed and valuation of these can begin to be explored.

Benefit mapping identifies which locations are most likely to be of value in some way to people and in common with 'opportunity' mapping is well-suited to those situations where the intention is to:

- Identify the changes in ecosystem service output; and,
- Determine where the best and worst place for action might be.

In order to make use of the growing body of literature on valuation, the summarised benefit mapping approaches described here and in Haines-Young and Potschin (2013) should use a standard typology of ecosystem services so that experience and examples gained in one area can be transferred to other places. The use of CICES in the current project will be helpful in this respect but future work may be needed to understand better how it could be linked to the various valuation databases such as ENVI (Environment Canada, nd) that are now available.

4.2 Trade-offs

Identifying solutions when changes are proposed and examining alternative choices or outcomes, invariably involves identifying and assessing trade-offs. Ecosystem services are interconnected and taking a spatial approach will reveal what could happen if particular land management decisions are made on the ecosystem services being examined.

Recognition of the trade-offs and synergies that may arise in different ecological contexts is a key management task, providing the opportunity to identify different political, economic, environmental or social ends that may benefit or disadvantage different individuals or groups.

Trade-offs are location specific and spatial scale refers to whether the effects of the trade-offs are felt locally or at a distant location. Analysis of trade-offs is particularly valuable for testing "what if" scenarios and clearly has implications in three of the situations addressed by this project, which are in fact closely linked:

- determining where the best and worst place for action might be;
- identifying the changes in ecosystem service output; and,
- determining the best strategy for improving or 'optimising' the output of future supply of ecosystem services

Recognition of which situation provides the 'best' and 'worst' context for action requires some knowledge of what the consequences of ecosystem change are for those who benefit from the different services.

4.2.1 Practical application

In practical terms trade-offs can only be identified in the context of particular types of management action or policy measure. That is, they represent the marginal changes in service output that result for a particular type intervention. They cannot therefore be mapped in the abstract, but require some notion of a base-line against which any changes in a particular service can be judged. The need to take account of the 'before' and 'after' situations therefore makes the mapping task more complex than when dealing with a single service.

To account for the before and after situation, users can begin to understand and visualise such affects by assessing management action 'scenarios' through the use of GIS tools available. For instance, LUCI identifies areas where interventions provide multiple benefits and areas where intervention is not desirable due to existing socio-economic situation or where ecological value is high (Jackson *et al* 2013).

5 Future developments

5.1 Developing the Bayesian Belief Networks

5.1.1 Bayesian Belief Network - Next steps

Although this study has been of an exploratory nature, it has demonstrated that it is possible to use a BBN tool to model service outputs given a set of biophysical characteristics. As the discussion has shown, many challenges remain. Nevertheless, it is clear that such a tool might be a useful complement to the Spatial Ecosystem Services Database Framework also being developed by this project. By way of summary, Figure 16 outlines the possible relationship between the different ‘subsystems’ in a larger ‘operational version’. The existing work has shown that it is possible to move through the different habitat classification systems using a BBN structure. Thus, as Figure 17 shows, users could select a given habitat, using the classification system relevant to their application and the result could be passed to an underlying database where the relevant biophysical characteristics for this kind of habitat are held. As in the existing study this database can be generated using expert knowledge or empirical evidence.

Once the biophysical characteristics have been extracted from the database, the system would pass these data to the BBN that predicts the service profile, and the user would be able to modify the input to reflect any local knowledge they might have. Alternatively, they may modify the inputs to reflect some management or intervention scenario. As Figure 16 suggests, these inputs would then be used to make an assessment of the likely ecosystem service associated with the selected habitats and their relative importance.

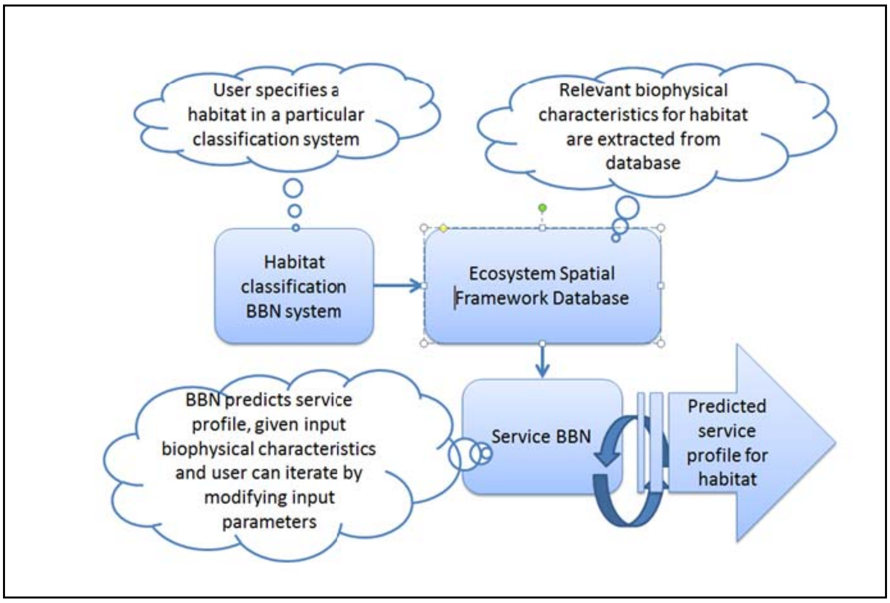


Figure 17. Linking habitat classification and service prediction BBNs through a habitats database.

The choice of platform on which to integrate the different modules shown in Figure 16 would need to be carefully considered. Recent exploratory work done as part of the UK National Ecosystem Assessment Follow-on and the EU-funded FP7 OpenNESS Project, has found that once developed, systems such as those used to provide translations between different classification systems and predicted service relationships could be made available via a set of web-based tools. This would eliminate the need for users to purchase the specialist BBN software or have extensive training in its use; instead these BBN tools and associated databases could be offered generally as an internet service. In order to take advantage of the latest web-based methods any future work might use the HUGIN system rather than Netica.

A further opportunity that this work opens up is the possibility of using these BBN tools to develop mapping applications for ecosystem services. In other work done within this project we have reviewed approaches to opportunity and benefit mapping, and showed that, given the complexity of most situations, the methods required are essentially model-based . The mapping methods generally take a series of input layers, and generate an assessment of potential service output by combining them in some way. Our review suggested that Bayesian methods were one way in which this could be done. The work done here demonstrates the feasibility of the approach. Thus, in Figure 15, the records shown could be referenced to habitat polygons, for example, and the outputs used to generate a new service layer that could be then be mapped. Given the capability of mapping a number of services simultaneously, the potential to identify trade-offs and service bundles would also be available.

5.1.2 Bayesian Belief Network - Software

i Netica

Netica is a software system used widely by the research community. While as a research tool it is powerful, its versatility in terms of designing an operational tool is more limited. It was selected for use in this project on the basis of the existing experience of Fabis, and the fact that it is freely available for applications involving networks that the user does not need to edit; networks larger than around 15 nodes can be loaded in the free version – but not modified and saved.

The Netica system provides tools for customisation, but the work required to develop the necessary algorithms is beyond the scope of this project. The aim of using such a system is to prove the concept, and identify the opportunities that exist for future development. The team are aware of other developments in the field and the possibilities that other BBN software systems have to generate more 'user friendly' output.

ii HUGIN

As part of other work team members are, for example, collaborating with HUGIN to develop web-based ecosystem service applications of BBN, as part of the UK NEA Follow-On Project and OpenNESS[11], that would meet many of the requirements of an operational tool, should JNCC wish to further develop this approach[12]. An experimental tool for modelling the level of ecosystem service outputs based on knowledge of selected habitat characteristics was developed during the JNCC project (as discussed in section 3 of this report), an example of this tool using the Phase 1 Habitat Survey classification is published on the HUGIN Openness website. The expert assessment was used to train the BBN network using the HUGIN software.

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[11] Operationalisation of natural capital and ecosystem services [online] available at: http://www.openness-project.eu/

[12] Modelling ecosystem service outputs using habitat characteristics [online] available at: http://openness.hugin.com/example/habitat

5.1.3 Further development of the framework- database

There are already some clear ways in which the database could be taken forward, for example:

- Incorporation of further ecosystem service classifications (e.g. Natural Resource Wales's ecosystem service classification).
- Incorporating a way of choosing which classification system you would like to base on rather than always starting with CICES.
- Inclusion of more CICES services.
- Incorporation of further information on dataset attributes e.g. habitat types, soil types.
- Link between habitat classifications (e.g. EUNIS) and probable provision of ecosystem services to accompany Bayesian Belief Networks (BBN).
- Making it a stand-alone system without the need for compatible versions of MS Access.
- Normalising the data base to lock down the background tables to enhance efficiency.

5.1.4 Further Development of the framework concepts

There are several further areas that would benefit from future work. These are:

- This project looked at the seven most commonly mapped ecosystem services, however, a large number of other services have been considered and it would be possible to build information about these into the spatial framework format.

- The different methods of classifying habitats each have their own characteristic in terms of how well they map on to the ecosystem services. Using a biophysical classification, it would be possible to link each of these to the services.

- It would also be possible to practically apply different mapping techniques to some pilot areas to further understand trade-offs, scenario building and opportunity mapping

- Adding monetary valuation in relationship to biophysical concepts would be a useful addition to the framework concepts.

This framework has brought together examples from many projects in terms of how different habitat classifications, ecosystem classification and methods can be considered in terms of their bio-physical processes and the ecosystem services that they provide, in conjunction with the other key factors of landform, soil/geology and management. There is a potential to use the framework to help standardise some of the methods and terminology involved in this young and growing science.

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7 Glossary

Term	Definition
Adaptive	The process by which management goals or policy objectives are changed on the basis of evidence and experience or stakeholder consultation.
Bayesian Belief Network	Multivariate statistical tools with a graphical output, designed to represent and analyse the uncertainty that often surrounds our understanding of complex systems.
Benefit mapping	The process of identifying and depicting variations in the levels of benefit derived from ecosystems over space and time.
Benefit transfer	A method or procedure to estimate economic values for ecosystem services at a location based on adjusted information derived studies done elsewhere.
Biophysical characteristic	A structural or functional attribute of an ecosystem or habitat.
Constraint mapping	The process of identifying and mapping the factors that control the output of an ecosystem service.
Contingent valuation	An economic valuation technique based on a survey of how much respondents would be willing to pay for specified benefits.
Decision support tool	Something that allows users to explore the consequences of policy or management choices so that they can review proposals or options critically.
Decision rules	An algorithm that selects an option from a set of alternatives on the basis of evidence available.
Ecosystem assessment	A social process through which the findings of science concerning the causes of ecosystem change, their consequences for human well-being, and management and policy options are brought to bear on the needs of decision-makers.
Ecosystem function	The subset of the interactions between biophysical structures, biodiversity and ecosystem processes that underpin the capacity of an ecosystem to provide ecosystem services.
Ecosystem structure	A static characteristic of an ecosystem that is measured as a stock or volume of material or energy, or the composition and distribution of biophysical elements. Examples include standing crop, leaf area, % ground cover, species composition (see ecosystem process).
Ecosystem processes	An dynamic ecosystem characteristic measured as a rate, that is essential for the ecosystem to operate and develop, such as decomposition, production, nutrient cycling, and fluxes of nutrients and energy (see also ecosystem structure and biophysical characteristic).
Ecosystem service	The contribution which the biotic and abiotic components of ecosystems jointly and directly make to human wellbeing and economic wealth.
Ecosystem service benefits	The direct and indirect outputs from ecosystems that have been turned into products or experiences that are no longer functionally connected to the systems from which they were derived. Benefits are things that can be valued either in monetary or social terms (see ecosystem goods).
Ecosystem service bundles	A set of associated ecosystem services that are delivered by an ecosystem or found associated with particular types of place or habitat.
Ecosystem goods	All use and non-use, material and non-material outputs from ecosystems that have value for people.

Ecosystem service opportunities	The potentialities of ecosystems in terms of possible service outputs (see opportunity mapping).
Ecosystem service output	A measured level of an ecosystem service.
Ecosystem service typology	A classification of ecosystem services defining the various types and subtypes of service (e.g. MA, TEEB, CICES).
Ecosystem service trade-offs	Management choices that intentionally or otherwise change the type, magnitude and relative mix of services, such that the output of some ecosystem services are enhanced and others are diminished (see also ecosystem service synergy).
Ecosystem service synergy	Management choices which enhance multiple ecosystem services. A set of ecosystem services whose output are correlated with each other because the factors that control or influence them all in the same way. (see ecosystem service trade-off).
Ecosystem service valuation	The process whereby people express the importance or preference they have for the service or benefits that ecosystems provides.
Environmental setting	Locations or places where humans interact with each other and nature that give rise to the cultural goods and benefits that people obtain from ecosystems.
Final ecosystem service	Are the outcomes from ecosystems that directly lead to good(s) that are valued by people (see ecosystem goods).
Functional relationship	An association between two or more properties or characteristics of an ecosystem such that the level of one can be predicted by reference to the other(s).
Multi-functional ecosystems	Ecosystems that are capable of delivering more than one ecosystem service.
Monetary valuation	The process whereby people express the importance or preference they have for the service or benefits that ecosystems provides in monetary terms.
Mitigating	The mediation of an impact or potential impact arising from a change in the conditions affecting an ecosystem.
Multi-modal	A frequency or probability distribution with more than one maximum.
Modelling system	A logical or mathematical algorithm that is based on some theoretical understanding that is used to represent the behaviour of an ecosystem so that its responses to changed inputs can be investigated. Such models are necessarily simplifications of reality.
Opportunity mapping	The process of identifying and mapping the potential output of ecosystem services from different ecosystems or habitats (see ecosystem service opportunities).
Operationalisation	The process by which concepts, data, and models are made usable by decision makers.
Physical datasets	A set of measurements of the biophysical characteristics of an ecosystem.
Production function	A method or algorithm that uses information about the structure and function of ecosystems to estimate the output of an ecosystem service (see also modelling system, decision support tool, and suitability mapping).
Suitability mapping	The process of identifying and mapping where the outputs of particular ecosystem service are to be anticipated given prevailing conditions or the biophysical characteristics of different locations (see also constraint mapping, opportunities mapping and benefit mapping).