Natural England Commissioned Report NECR073

Monitoring and modelling ecosystem services

A scoping study for the ecosystem services pilots

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NATURAL ENGLAND

Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Natural England commissioned this study to identify and comment upon existing data sources that might be suitable for monitoring change in ecosystem service delivery as a result of land and water management changes in the three ecosystem services pilot areas:

- Bassenthwaite Lake catchment (Lake District);
- South Pennines National Character Area (NCA); and
- the South West uplands (Exmoor and Dartmoor).

A secondary objective was to review and suggest modelling approaches to predict future ecosystem service provision.

The study findings have already been used to help identify data to inform baseline assessments of current ecosystem service provision within each of the pilot areas. It is envisaged that the tables of data sources will be used as a checklist for future projects of this nature as major national datasets are identified and linked to ecosystem services.

The report highlights the difficulty associated with using existing monitoring data and networks, which were largely designed to monitor environmental impacts, to monitor changes in the flow of ecosystem services. Some data are potentially good surrogates for ecosystem services or measure services directly (for example, measures of food production, or river flows) but for many services there are currently no appropriate existing datasets.

This review of modelling approaches and subsequent recommendations will be used to influence the development of tools to support implementation of the ecosystem approach. Natural England will seek to develop this modelling work through a collaboration with other government agencies and the wider research community.

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Further information
This report can be downloaded from the Natural England website: **www.naturalengland.org.uk**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

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Executive summary

As a means of demonstrating how ecosystem services can form the basis of integrated land management Natural England and a series of partners have established three pilot projects In each of these pilot areas the aim is to: determine the current ecosystem services being provided; agree a future land management vision to maximise service provision; and begin to change land management to secure these services. The three pilot areas are Bassenthwaite Lake catchment, the Southern Pennines national character area (NCA) and the south west uplands (Dartmoor and Exmoor NCAs).

An important part of the demonstration will be to establish how current and future land management affects certain ecosystem services. To determine the success or otherwise of land and water management changes implemented on the ground, the pilot projects will need to put a programme of monitoring in place. In many cases it will be possible to use or build on existing data to establish baselines and monitor change. In some situations there will be little or no data and in others, changes in management may take longer to affect ecosystem services than the duration of this project. In these cases we may need to consider modelling to predict the direction and magnitude of change. This desk exercise is the first stage in establishing how land use and land management change affect ecosystem services within the Natural England pilot areas

The aims of this project were to:

a) identify and recommend a suite of existing data and monitoring initiatives in each pilot which tell us about current and future ecosystem service provision;
b) identify and recommend modelling approaches which may help us predict the impact of particular land use and management changes;
c) identify gaps in data or understanding that might help us monitor ecosystem service provision

This project will not address the datasets or monitoring associated with biodiversity as this has already been addressed by Natural England.

This report briefly describes ecosystem services and the functions that define them; this provides a framework within which the data and models relevant to the pilot areas will be set. Indicators that allow these functions to be quantified are identified and then datasets that could populate these indicators, recording also which of these datasets are being routinely monitored. It then describes the models that could be used to predict these functions and how they change with land use/land management change. For a number of land use/land management changes relevant to the pilot project, the ecosystem services affected are identified and recommendations made as to which datasets could be used to quantify these ecosystem services. We then discuss how ecosystem services could be monitored, putting forward a framework that can be applied to the pilot areas. The final part of the report discusses the gaps in the data, modelling and monitoring and makes recommendations as to the way forward.

This project has identified that some of the fundamental datasets that are required to estimate the state and change of the ecosystems service delivery are not available at the scale of the pilot areas. This is also true of the datasets that would be required to try to

model the ecosystem services delivery. We have also identified that the monitoring currently being undertaken within the pilot areas would not be sufficient to determine changes in the ecosystem services delivery.

The most important ecosystem services delivered by the pilot areas were identified as:- Erosion regulation, Flood mitigation and water regulation, Recreation, Aesthetic, Climate regulation (carbon storage) and Food production. To be able to quantify these services a number of datasets are critical and to be able to monitor change in these services there are a number of critical parameters that need to be monitored or modelled.

The outcomes of this project suggest

- A detailed soil map should be produced for each of the pilot areas using a combination of soil survey and digital soil mapping.
- The Environment Agency data from the gauging stations and water quality sampling should be statistically analysed to investigate whether changes could be detected within the pilot areas. Continuation of the river monitoring network should be encouraged collecting data at shorter time intervals than at present.
- A model based on a Bayesian Belief Networks approach within a GIS framework to model the effects of land use /land management changes on ecosystem services should be built which can be applied across the pilot areas using a spatial scale relevant to the land use/land management changes to be instigated. This would be based on a series of biophysical drivers including:
    - Land cover – use the satellite derived land cover mapping from CEH
    - Topography – use the 10m resolution DTM (Ordinance survey)
    - Soil – use the most detailed soil maps available possibly enhanced by digital soil mapping
    - Climate – modelled output on 1km grid
    - Other datasets specific to different ecosystem services.
- A monitoring network should be set up to address some of the gaps in the data and process understanding. The network should consist of a number of sampling sites within each pilot area where a wide range of samples would be taken measuring land use, species richness, soil biology as well as other soil properties This network could be stratified by land use or by topography or based on a rectangular grid depending on the objectives. The network should be able to be adapted as areas of uncertainty are identified by the modelling and the monitoring.
- The home omnibus survey should be extended and spatially referenced so that visits and attitudes that specifically refer to the pilot areas can be measured.

Once the above are in place trial land use/land management change interventions should to be made to gauge their effects

1. Introduction

There is an increasing awareness of the importance of the natural environment in providing human society with a range of goods and services (MEA, 2005; Defra, 2007; Natural England 2009). Although the ecosystem approach and the concept of 'ecosystem services' has been around for some time there is now a move to incorporate the maintenance and enhancement of ecosystem services into policy and decision making (Defra, 2007). As a means of demonstrating how ecosystem services can form the basis of integrated land management Natural England and a series of partners have established three pilot projects In each of these pilot areas the aim is to: determine the current ecosystem services being provided; agree a future land management vision to maximise service provision; and begin to change land management to secure these services. The three pilot areas are Bassenthwaite Lake catchment, the Southern Pennines national character area (NCA) and the south west uplands (Dartmoor and Exmoor NCAs); see Figure .

An important part of the demonstration will be to establish how current and future land management affects certain ecosystem services. To determine the success or otherwise of land and water management changes implemented on the ground, the pilot projects will need to put a programme of monitoring in place. In many cases it will be possible to use or build on existing data to establish baselines and monitor change. In some situations there will be little or no data and in others, changes in management may take longer to affect ecosystem services than the duration of this project. In these cases we may need to consider modelling to predict the direction and magnitude of change. This report describes the first stage in establishing how land use and land management change affect ecosystem services within the Natural England pilot areas.

To do this we have

a) identified and recommended a suite of existing data and monitoring initiatives in each of the three Natural England upland pilot areas which tell us about current and future ecosystem service provision;
b) identified and recommended modelling approaches which may help to predict the impact of particular land use and management changes;
c) identified gaps in data or understanding that might help to monitor ecosystem service provision.

This project will not address the data or monitoring associated with biodiversity as this has already been addressed by Natural England.

Figure 1 Location of the three ecosystem service pilot areas
(note the map includes all three upland areas in south west England but the pilot will focus upon Dartmoor and Exmoor initially)

This report describes the approach taken by briefly describing ecosystem services and the functions that define them; this provides a framework within which the data and models relevant to the pilot areas will be set. Indicators that allow these functions to be quantified are identified and then datasets that could populate these indicators, recording also which of these datasets are being routinely monitored. It then describes the models that could be used to predict these functions and how they change with land use/land management change. For a number of land use/land management changes relevant to the pilot project, the ecosystem services affected are identified and recommendations made as to which datasets could be used to quantify these ecosystem services. We then discuss how ecosystem services could be monitored, putting forward a framework that can be applied to the pilot areas.
The final part of the report discusses the gaps in the data, modelling and monitoring and makes recommendations as to the way forward.

2. Methodological Approach

a) Cascade approach

The ecosystem services to be addressed were identified in the project specification (see Appendix 1). This initial list has been modified with reference to recent publications including de Groot (2009) and the developing CQuEL (Character and Quality of England's Landscapes) work (Land Use Consultants, 2010) and is given in the first column of Table 1. It is not possible in most ecosystems to quantify ecosystem goods and services directly because they are not directly related to particular measurements but are generated via the functioning of that ecosystem. To monitor changes in ecosystem goods and services it is important to monitor changes in the functioning of the ecosystem service in relation to some asset or intrinsic delivery. For example, to determine the change in “production service” of a livestock system as a result of reducing stock density, will not only require the change in the number animals per hectare to be monitored but some understanding of how the “production” or number of lambs per ewe would change under the change in management. In this project in order to identify the data and models appropriate to monitor each of the ecosystem services a cascade approach was taken in which ecosystem services are determined by ecosystem functions (sometimes for specific ecosystems). These functions can be measured using indicators which are then quantified using environmental data and models. This approach is similar to the *ecosystems services flows* approach adopted by CQuEL (http://cquel.org.uk/) but allows the same dataset to be linked to a number of different indicators and therefore different ecosystem services, demonstrating the importance of some of these datasets. The individual steps of this cascade (Figure) and the important properties of each are discussed below:

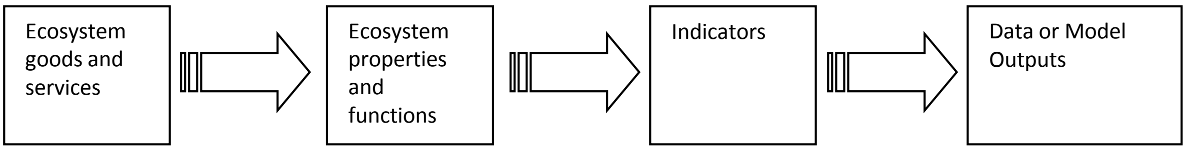

Figure 2 Cascade approach

i. Ecosystem goods and services -> Ecosystem properties and functions

To quantify ecosystem goods and services it is important to identify the ecosystem properties and functions or processes which are delivering these services. These functions are built from the fundamental properties and processes of the environment under consideration and can be quantified by monitoring or modelling that biophysical environment. As the ecosystem functions can depend on the ecosystem delivering them, the link between services and functions has to be considered within the context of the ecosystem (or resource). For example it is only appropriate to look at the provisioning service (food) within grassland ecosystems in the uplands since the other ecosystems do not produce food. The characterization of the function has to be scale specific and will depend on the spatial resolution of the existing data on the ecological properties and processes sustaining these ecosystem functions. These may or may not coincide with the scale at which ecosystem services delivery needs to be quantified. In this project these ecosystem functions need to be quantified at a scale fine enough to address ecosystem service questions at the land management scale (10’s of hectares) given existing information on soils, land use, etc. Ecosystem functions will also exhibit temporal variation within space and are not mutually exclusive: any given ecosystem will, at a given point in time and at any given location in space, supply numerous ecosystem functions and their interactions will be complex. The trade offs and synergies between the ecosystem functions, both in terms of the spatial and temporal "inputs" of environmental properties and processes and also the "outcomes" for ecosystem service delivery will be of particular significance to understanding the effect of land use/land management change on the ecosystem services in the pilot areas.

ii. Ecosystem functions -> Indicators

A robust assessment of the delivery of ecosystem services and how this changes under different management, depends upon a coherent and accurate measure of the ecosystem functions provided at a given spatial definition and scale. Therefore, it is important that these functions are estimated with some degree of confidence. To estimate or predict the result of these functions we need to identify **indicators** which quantify the magnitude or rate of change of the outcome of these functions. An indicator needs to be quantifiable and reflect changes in land use or management. For example the carbon content of the soil and how this changes with changes in land management gives an indication of the carbon sequestration of an area and allows the "climate regulation" service to be estimated

The use and interpretation of any proposed indicator requires baseline and threshold/limits or target values to be set. A **baseline** is a minimum or starting point of an indicator value (e.g. measurement which serves as a basis to which all following measurements are compared; a characteristic value - such as the 'background' value - for an element content in soil) and a **threshold** or **limit** is an indicator value at which a critical status is reached, which limits or threatens sustainable functioning of the ecosystem (e.g. guideline values for levels of contaminants in drinking water). Haines-Young (2009) defines the environmental limit as the point or range of conditions beyond which the benefits derived from a natural resource system are judged unacceptable or insufficient. In contrast a **target value** is the required value of the indicator that can be achieved under ideal conditions within a specified time scale – so a target should be quantified and time-bound (e.g. the amount of carbon that could be stored in the soil after ten years of management to increase carbon storage).

In this project the indicators were identified for each of the ecosystems and ecosystem functions based on Linstead *et al*. (2008), Huber *et al* (2007) and expert knowledge of the project team. Many of these indicators do not yet have baselines, thresholds or targets defined but are included to show the range and types of indicators. The indicators quantify the ecosystem function in one of two ways: either by measuring the outcome of the function or measuring the capacity of the ecosystem to carry out that function. For example, for the water purification and waste treatment service and the associated function "Amelioration & capture of chemicals & nutrients before they enter ground & surface water", the water quality can be measured as it leaves the ecosystem or the properties of the ecosystem that govern the ability to remove pollutants can be measured within the ecosystem. The indicators identified are also either primary or secondary indicators (called headline and sub-indicators in Linstead *et al*., 2008). Primary indicators are those which directly measure the ecosystem function and are shown in bold in the table- for example, the production of meat in kg/pilot area /yr measures the biomass production and hence quantifies the food ecosystem service of grassland directly. Whereas the secondary indicator "density of breeding ewes" needs to be combined with another indicator "number of lambs per ewe" in order to quantify the ecosystem function.

iii. Indicators -> Data

To quantify the ecosystem functions the indicators need to be populated with data. All data are subject to error so it is important if we want to identify the state and change in an indicator that the error or variability in the data is not so large that it masks the effects we are trying to detect. In many cases there will not be data available that can be used to directly quantify the indicators – in that case we need to consider modelling using data that are available or could be collected (see Section 5. Modelling).

b) Land use / land management change

In terms of defining the data which may be indicative of changes in ecosystem service delivery it was deemed helpful to consider indicators of the ecosystem service in question with respect to the land use or management changes the pilot projects might instigate. The land use/land management changes used to help identify suitable datasets and models were:-

1. Management of soils and hydrology

Changes include:

i) Blocking drains (or grips) on peat soils
ii) Re-vegetating bare peat
iii) Avoid soil compaction by livestock

2. Management of grazing

Changes include:

i) Avoid overgrazing/undergrazing of vegetation by livestock
ii) Introduce and encourage sustainable grazing regimes
iii) Changes to burning practice

3. Management of woody vegetation

Changes include

i) Increase woodland/scrubland
ii) Introduce and encourage sustainable woodland management for timber and fuel

4. Habitat restoration and rehabilitation

Changes include

i) Restore habitat connectivity – creating habitat, connecting habitats and restoring habitats
ii) Restore damage to habitats from pressure of walkers, horse riders and bicyclists

These management (and land use) changes were developed from the NE report "Mapping values: the vital nature of our uplands" (Natural England, 2010) which gave an overview of some of the critical managements that could be instigated within the pilot areas.

For each of these land use /land management changes the ecosystem services that they could affect were identified based on Reed *et al* (2009) and the judgment of the project team. The relevant indicators – for the appropriate ecosystems- were identified and an indication given of the direction of change in these indicators that might be expected (LUC 2009). This enabled the project team to summarize the main ecosystem services which would be affected most by the land use /land management changes that could be instigated.

3. Datasets

Table 1 shows the ecosystem services and ecosystems relevant to the upland pilot areas that have been considered in this project with the ecosystem functions delivered by those ecosystems for each ecosystem service. This table was populated using expert judgement and information from a range of relevant reports and papers, in particular Reed *et al* (2009) (see references for other sources). In some cases, where the ecosystem service is actually provided directly from a natural resource asset rather than through a subsequent process, there is no associated function as this is an intrinsic service. For example, freshwater supply as a provisioning service is intrinsic to the water courses and water bodies. Indicators and datasets that could be used to populate them are also included in this table following the methodology described in section 2. Haines Young *et al* (2010) recognised how difficult it is to define exactly what constitutes each ecosystem function in terms of some measurable parameter, since so many factors potentially influence each function; hence the indicators given in Table 1 are not exhaustive. In Table 1 each dataset is identified only by a number and name – more detail regarding each dataset is given in Table 2.

Table 1 Linking ecosystem services to datasets

Ecosystem services	Ecosystems/Natural assets	Ecosystem function	Primary and secondary state indicators	Datasets
PROVISIONING				
Food	Grassland	Growth of biomass	**Production of meat (lamb/beef) kg/pilot areas/yr**	10. Agriculture Regions
				7. Density ewes
				8. Number lambs
				9. Density cattle
				11. Farming Dartmoor
			Area of land currently under grassland (m2) being managed for meat production	2. Land cover
			Potential area of land under grassland (m2)	1. NATMAP/2. Land cover/ 3. Climate data/ 4. DTM:
				12. Grassland Dartmoor
Fresh Water	Water courses and water bodies		**Total annual surface water amount currently available (m3/pilot area/yr)**	3. Climate data (rainfall)/ 90. Climate 5km/91.Cliamte 1km
				90. Climate 5km
				91. Climate 1km
				13. Water abstractions
				14. River network
				5. Topographical data (water features)
			Groundwater reservoirs (m3/pilot area/yr)	Ground water abstraction volumes
				100. Aquifers
Fibre - Timber	Woodland	Growth of biomass	**Total biomass produced (kg/yr/pilot area) - Timber**	15. Woodland over >10ha
				16. Timber production
Fibre - Arable fibre crops	Arable land		**Total biomass produced (kg/yr/pilot area) - Fibre crops**	89. ACensus

<u>**Ecosystem services**</u>	<u>**Ecosystems/Natural assets**</u>	<u>**Ecosystem function**</u>	<u>**Primary and secondary state indicators**</u>	<u>**Datasets**</u>
Fibre - wool	Grassland		**Total biomass produced (kg/yr/pilot area) - wool**	17. Wool
Fuel	Peat bogs		**Peat removed kg/yr**	
			Area of peat being used for production (m2)	19. Peat status (*Peat cutting* and *extraction classes*)
Other raw materials	Minerals and rock		Mineral exploitations (number and location)	99. Mineral
				2. Land cover
Renewable energy	Suitability for wind farms		wind speed/ altitude/openness	20. Wind speed
			Current status of wind farms	21. Wind farms
	Coppiced natural/semi-natural woodland	Growth of biomass	Area of coppiced woodland	22. Area coppiced
			Area suitable for coppicing	
	Thinnings and waste from forestry plantations		Area of forestry plantations already using thinnings for renewable energy	
			Potential area of forestry that could use thinnings for renewable energy	
			yield of thinnings kg/ha	
	SRC/ Miscanthus		Area under SRC / Miscanthus and **biomass yield/year**	101. SRC/Miscanthus
			Potential area to grow bioenergy crops and **yearly biomass production potential**	101. SRC/Miscanthus
	Bracken, Gorse, Reeds etc cut and bailed for fuel		Areas and **yield** of these plants currently cut and used for fuel	

Ecosystem services	Ecosystems/Natural assets	Ecosystem function	Primary and secondary state indicators	Datasets
REGULATING				
Air quality regulation	Intensive farming systems	Ammonium production	**levels of Ammonium in the air**	92. AirQuality
			Area of land under intensive agriculture	2. Land cover
Climate regulation	All ecosystems	GHG emissions	**Methane and other emissions (amount of emissions)**	23. Methane emissions
			GHG emissions from Land use and land use change	24. Carbon dioxide emissions
				25. GHG emissions
	Forest		**GHG emissions from forestry**	27. GHG emissions2
	All ecosystems	Carbon sequestration	**Carbon in soils**	96. Soil carbon
				28. CS (Soil carbon)
				29. NSI (Organic carbon)
				1. NATMAP (Organic Carbon)
				18. Peats
				19. Peat status
			Carbon in vegetation	36. Vegetation carbon
			Change in landuse leading to change in carbon in soils and vegetation	2. Land cover
				37. CQC
				38. LCA
				39. Landscape change
	Woodland		**Carbon in forests**	30. Woodland > 2ha
				31. Woodland < 2ha
				32. FCS
				33. CFN
				34. Forestry type
				35. WGS

Ecosystem services	**Ecosystems/Natural assets**	**Ecosystem function**	**Primary and secondary state indicators**	**Datasets**
Flood mitigation and water regulation	All ecosystems	Water storage	**Water-storage (buffer) capacity in m3 (flood risk)**	40. Flood
				41. SFRA
			Water retention capacity in soils, etc. or at the surface	42. LandISclimate
		Water infiltration, impeding cross-land flows and aquifer recharge	Soil compaction	28. CS (Soil bulk density)
				29. NSI (Porosity and soil texture)
				1. NATMAP (Clay content (%))
			Run-off measurements	1. NATMAP (soils susceptibility to runoff based on soil series classification)
				43. HDTM
				4. DTM and SLOPE derived from DTM
	Woodland/Forest	Water infiltration, impeding cross-land flows and aquifer recharge	Frequency of low and high river flows	95. BIBER
			Catchment water yield, peak/flood flows, summer low flows	95. BIBER
	Wetland habitats	Water storage	Proportion of wetland in good condition	18. Peats
				19. Peat status
				2. Land cover
Water purification and Waste treatment	All ecosystems	Filtering of sediments and particles	**Quality of water**	102. DOC
				45. WFD
				93. Rivpacs
				94. BIOSYS
			Sediment flux in streams	46. WIMS - sediment load
			Properties of soil to measure ability to remove particulates	1. NATMAP

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&
Water infiltration</td><td rowspan="2">Sediments load</td><td>49. BGSsmall</td></tr>
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<tr><td>Pollination</td><td>Habitat mosaics managed for structural diversity and allowing flowering plants to flower</td><td>Maintenance of viable populations of pollinating insects</td><td>Number and impact of pollinating species</td><td></td></tr>
<tr><td>Biological Regulation (disease and pest control)</td><td>Habitat mosaics managed for structural diversity and allowing flowering plants to flower</td><td>Maintenance of viable populations of pest controlling insects</td><td>Number and impact of pest-control species</td><td></td></tr>
</table>

Ecosystem services	**Ecosystems/Natural assets**	**Ecosystem function**	**Primary and secondary state indicators**	**Datasets**
SUPPORTING				
Nursery habitat	Grasslands/peat bogs/open water		Number of transient species and individuals (esp. with commercial value)	55. RSPB
Genepool	Semi-natural habitats and those supporting rare/scarce species managed in favourable conditions		Natural biodiversity (esp. endemic species); Habitat integrity (irt min. critical size)	56. NVC
				57. Ramsar
				58. SAC
				59. SPA
				60. NP
				61. CWS
				62. Ancient Woodland
			Changes in the state of habitats supporting rare/scarce species	64. SSSIs trends
				65. Priorityspecies
	Semi-natural Grasslands		Numbers of native breeds currently used for conservation grazing	66. ESP
Nutrient cycling	All ecosystems	Nutrient cycling capacity	Soil quality	
			Soil biology as indicators	
			Quality: pollutants in soils/ Quality for agricultural use radioactive caesium in grasslands	67. ALC
				68. HLCA
				69. Iodine
Soil formation and regeneration	All ecosystems	Support for soil formation processes	bio-turbation	
			Soil depth	1. NATMAP (soil depth)
			Soil biology as indicators	
Biodiversity	All ecosystems			Biodiversity
				70. BRC

Ecosystem services	Ecosystems/Natural assets	Ecosystem function	Primary and secondary state indicators	Datasets
CULTURAL AND AMENITY				
Aesthetic: appreciation of natural scenery (other than through deliberate recreational activities):- Wildlife-rich environment	All ecosystems	Landscapes that offer: Sense of peace & quiet Sense of calm	Number/area of landscape features with stated appreciation	71. AONB
				72. Noise
				73. Tranquillity
				37. CQC (for broad habitats)
				97. Survey2001
Recreational: opportunities for tourism and recreational activities	Challenging environments (cliffs, hills, mountains, moorland)		Number/ area of landscape and wildlife features with stated recreational value	5. Topographic layer (roads, tracks and paths)
				74. National Trails & Open Access Land
			Number of visits	75. VAS
				76. S1994
				77. LS2005
				78. Grouse
				79. Pdensity
				80. ACORN
	Open access land		Countryside visit expenditure: expenditure on visits with overnight stays; Day trip expenditure	81. CLB
				82. Woodland Trust
				83. FCW
				84. National Trust
				85. PRoW
				86. MENE

Ecosystem services	Ecosystems/Natural assets	Ecosystem function	Primary and secondary state indicators	Datasets
Inspiration for culture, art and design	All ecosystems		Number of books/paintings/films inspired by areas	
			Number/area of landscape features of species with inspirational value	71. AONB
			Ancient trees and woodland	62. Ancient Woodland
			Height (mountains, hills, moorland) long view	4. DTM (Maps of viewshed)
				38. LCA
Cultural heritage and identity: sense of place and belonging	Semi-natural habitats	Landscapes: with a strong sense of identity, providing a perspective on locality	Number/area of culturally important landscape features or species	86. MENE
	Historic villages, field patterns and designed landscapes			5. Topographic layer
	Above ground archaeology			87. SAM
				104. HER
Spiritual & religious inspiration	All ecosystems	Landscapes that inspire through the emotions they conjure Connecting with nature or another/higher presence Closeness to the sky (Strongly influenced by changes in mood stimulated by changes in weather & season)	Presence of landscape features or species with spiritual value	71. AONB
				87. SAM
Education and science			Features with special educational and scientific value/interest	63. SSSIs
			Number of scientific papers published referring to different ecosystem types	98. Scientific papers

Table 2 List of datasets

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
1. NATMAP	LandIS	NATMAP- Soil properties of Soil series linked to NATMAP (Clay content (%), soils susceptibility to runoff based on soil series classification, soil depth, organic carbon...)	Vector: 1:250000/ Grid: 1 km2	National coverage. Mapped at Soil associations level. Within each Soil association, there may be more than one soil series.	NATMAP available: only Soil Association level	NATMAP available. More detailed map (Soil series level) in some areas (apr. 1/4)	NATMAP available. More detailed map (Soil series level) only in apr. 1/10 of the pilot area	NATMAP available: only Soil Association level	Level of detail could be improved to improve the precision of modelling	No
2. Land cover	CEH	LCM2000/**LCM2007**	Vector: differing levels of detail/ Raster: 25 m	About to be published (2010) based on CS and aerial photography	Available	Available	Available	Available	Crucial dataset for all quantification of ecosystem services - good quality	Yes approximately every 10 years but not possible to estimate change as methodology changes
3. Climate data	Met Office	Historic stations	37 historic stations in the whole of England. Monthly	Mean maximum temperature (tmax) Mean minimum temperature (tmin) Days of air frost (af) Total rainfall (rain) Total sunshine	Close station: Newton Rigg (From 1959-Current)	Chivenor station	No historic stations	Close station: Bradford		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
				duration (sun)						
	Met Office	Synoptic and climate stations	variable	Monthly & annual climatological averages,calculated by NCIC/ Elements from Metform 3208 - Monthly Return of Daily Obs	Keswick (From 1-1-83/current) Blencathra (From 1-1-92/current)	Saunton sands (From 1-1-89/current) Chivenor (1-1-1943/current) Liscombe (From 1-1-1993/current) Nettlecombe (From 1-1-1968/current)	Holne Priddons Farm (From 1-7-1998/Current)	Bradford (From 1-1-1908/current) Bingley n2 (From 1-1-1972/current) Rochdale (From 1-1-1914/current)	-	Yes
4. DTM	Ordnance survey (Digimap Collection	Digital Terrain Model (and derived: Slope, maps of viewshed...)	Grid: 10 m	Available	Available	Available	Available	Available		No
5. Topographic layer	Ordnance Survey	MasterMap Topographic layer	Large scale detailed mapping surveyed	High degree of accuracy. Offers very detailed referencing and includes roads, tracks and paths, land, buildings, water, rail, height, heritage structures, boundaries and addresses	Available	Available	Available	Available		Yes rolling program but not at specific intervals

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
6. Aerial photograpy	various sources including Cranfield University	Aerial photography	1970-1980	National parks	Available	Available	Available	Not available		
7. Density ewes	Defra (2007)	Density of breeding ewes	1km2	Overall coverage of England, but some suppressed data	Available	Available	Some Missing data	Available		
9. Density cattle	Defra (2007)	Density of beef cattle	1km2	Overall coverage of England, but some suppressed data	Available	Available	Some Missing data	Available		
10. Agriculture production	Defra (2008). National Statistics	Agriculture in the English Regions -at a regional level-production figures	Regional	Statistics on agriculture at regional level in England. It contains information for NUTS 1 regions,	Available	Available	Available	Available	Not relevant not at required scale	Annual statistics
11. Farming Dartmoor	University of Exeter/ Dartmoor National Park Authority	The state of farming on Dartmoor 2002 (Based on Defra and MAFF statistics)	Dartmoor area	Identify the trend shaping Dartmoor farming (changes in size structure and livestock numbers, …- period 1972-2000)	No	No	Available	No	Could be useful to give more confidence in livestock numbers than national figures	One off project
12. Grassland Dartmoor	Dartmoor National Park	Dry, Unimproved Grassland		What did they measure	No	No	Available	No		One off project

Dataset	**Owner**	**Data**	**Scale (Spatial and temporal)**	**Description**	**Bassenthwaite**	**Exmoor**	**Dartmoor**	**South Pennines**	**Confidence and relevance to pilot areas**	**Monitoring**
	Authority (2005)	Survey - Final Report 2003/2004								
13. Water abstraction	Environment Agency	Surface Water abstractions volume	point sources		Available	Available	Available	Available		Annual
14. River Network	Centre of Ecology and Hydrology/ Environment Agency	Detailed River Network (DRN)	1:1250 (urban), 1:2500 (rural) and 1:10000 (mountain/moorland areas)	Information available for the whole of UK	Available	Available	Available	Available		No
15. Woodland >10ha	Forestry Commission 2008	Map of woodland over 10 ha	National		Available	Available	Available	Available		How often re-estimated?
16. Timber production	National Statistics	Annual production of timber /ha	UK National estimates only							
17. Wool	Wool marketing board	Annual production of wool kg/yr	England, Wales, Scotland, NI - National estimates only							Annual update
18. Peats	Natural England (From BGS, BAP and NSI)	Map of peat soils	1:50000	Classified into: deep, shallow, other	Available	Available	Available	Available		
19. Peat status	Natural England (From BGS, BAP and NSI)	Map of peat status (Peat cutting and extraction classes identify extraction of	1:50000	Classified into: Deep peat, bare peat, hagged peat, gripped peat, burnt and others	Available	Available	Available	Available		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
		fuel)								
20. Wind speed	Dept for Business, Innovation and Skills	Map of annual mean wind speed (m/s)	1 km2 every year	10m, 25m or 45m above ground level	Available	Available	Available	Available		Yes
21. Wind farms	Dept for Business, Innovation and Skills (BIS)	Map of wind farms.	National		Available	Available	Available	Available		
22. Area coppiced	Defra	Maps with information about area under Woodland Grant Scheme	National		Available	Available	Available	Available		
23. Methane emissions	National Atmospheric Emissions Inventory (NAEI)Defra	Mapped methane emissions 2007	Grid: 1km2	Grid produced from points sources. A spatial disaggregated 1x1 km inventory is produced each year.	Available	Available	Available	Available		Annual
24. Carbon emissions	Defra (NAEI)	Map of carbon emissions 2007	Grid: 1 km2	Grid produced from points sources. A spatial disaggregated 1x1 km inventory is produced each year.	Available	Available	Available	Available		Annual
25. GHG emissions	Energy and Climate change	UK greenhouse Gas emissions	National statistics (No spatial data)	Range of estimates: 1990-2008						

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
	(National Statistics publications)									
26. Sulphur deposition	CEH Edinburgh (Dore *et al*)	Wet and Dry deposition of sulphur and nitrogen compounds and total acidity (NETCEN)	5km grid and every 10years from 1970	Model output	Available	Available	Available	Available		Every 10 years
27. GHG emissions2		Reporting of GHG emissions to the EU due to Landuse, landuse change and forestry kgmCO2/km2/ yr	NUTS4 areas (Local authority)	Model output based on disaggregating national figures	Available	Available	Available	Available		Every 5-10years - nationally but not necessarily spatially
28. CS	Countryside survey 2007, 1998, 1990, 1984 and 1978	Countryside survey (Soil carbon, soil bulk density estimated for the first time in CS2007, pH…)	300 samples in England	Allow to identify changes in the landscape	Available	Available	Available	Available	Data is not intended for disaggregation to pilot area scale - not enough points to identify change in soil carbon content	Every 10 years (unknown if continuing)
29. NSI	National Soil Inventory (NSI) (1980-2000)	Data of Organic Carbon in soils, porosity, Soil texture (Calculated particle size class)…	5 km2	5671 sites in England and Wales. Some resamples about 2000	10 samples/ 5 resamples	50 samples/ 28 resamples	34 samples/ 20 resamples	46 samples/ 23 resamples	Data is not intended for disaggregation to pilot area scale - not enough points to identify change in soil	No

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
									carbon content	
30. Woodland > 2ha	Forestry Commission	National inventory of woodland and trees (NIWT)	40 897 sample squares	Carried out every 10-15 years. Most recent survey (2003) is based on a combination of analysis of the 1:25000 OS map and, primarily, interpretation of aerial photography. Considered woods of more than 2 ha area	how many samples?	how many samples?	how many samples?	how many samples?		every 10 to 15 years
31. Woodland < 2ha	Forestry Commission	Survey of Small Woodland and Trees (SSWT)	1:25 000 aerial photographs were used to identify features, with field data collected for two out of the 16 (250 x 250 m) squares in each 1 km2 grid square.	Assess the extent of woodland of less than 2 ha in area and linear features	how many samples?	how many samples?	how many samples?	how many samples?		carried out as part of NIWT (every 10-15 years)

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
32. FCS	Forestry Commission	UK Forest Condition Survey (FCS)	National	8 species are assessed, based on a stratified random sample. Enable the calculation of annual carbon stocks in biomass at least at the individual tree level	how many samples?	how many samples?	how many samples?	how many samples?		
33. CFN	Forestry Commission	Carbon flux network (CFN)		Represent 2 species (Sitka and Oak).Limited geographical coverage. Most valuable contribution is in providing data for the parameterisation and validation of stand level process models of carbon and water exchange	how many samples?	how many samples?	how many samples?	how many samples?		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
34. Forestry type	Forest Research	Interpreted Forestry Type (National Inventory of Woodland and Trees with IFT)	National	Interpreted Forest Type Woodland Polygon > 2 ha. Woodland includes areas of tree cover with a crown density of, or likely to achieve, at least 20 %, a minimum width of 50 metres and a minimum area of 2 ha. Within woodlands, internal polygons identified with a minimum area of 1 ha. Carried out with the NIWT						Carried out as part of NIWT (every 10-15 years)
35. WGS	Forestry Commissio n	Woodland Grant Scheme (WGS)	National	WGS provided incentives for people to create and manage woodland. Individual Woodland Grant Scheme boundaries with the site name and reference.	Available	Available	Available	Available	Would give some indication of increase in woodland on an annual basis but not really appropriate at pilot area scale	

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
36. Vegetation carbon	CEH	Vegetation carbon in Great Britain	1 km2	Based on ITE LCM published 1995	Available	Available	Available	Available	Would need reestimating based on up-to-date LCM to give reasonable predictions	No
37. CQC	Dartmoor National Park Authority	Change in Countryside Quality Counts data (for broad habitats amongst others)		Contributes to the monitoring of landscape change (2003). Has not been updated recently	No	No	Available	No		No
38. LCA	Natural England/Scottish Natural Heritage	Landscape Character Assessment (LCA)	Variable (1:25000-1:50000)	LCA database identifies and assesses landscapes, allow understanding landscape change, and creating framework for developing landscape quality objectives in partnership with stakeholders	Available	Available	Available	Available		Database Updated. From February 2010: review of the existing guidance document and supporting papers.
39. Landscape change	Cranfield University	Landscape change 70-80	1:10000	Not updated. There are 50 types of landscape features identified using aerial	Available	Available	Available	Available		No

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
				photographic interpretation.						
40. Flood	Environment Agency	Map of Flood zones	National coverage	The map shows the area that could be affected by flooding, either from rivers (1 per cent or greater chance of happening each year) or the sea (0.5 per cent or greater chance of happening each year), if there were no flood defences, and the existing flood defences. It shows an assessment of likelihood of flooding (Significant, Moderate or Low)	Available	Available	Available	Available		Quarterly updated. Updates take place in January, April, July and October
41. SFRA	Dartmoor National Park Authority	Strategic Flood Risk Assessment (SFRA)	Dartmoor based on GIS	Give information about number of existing buildings within flood risk zone 3			Available			

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
42. LandIS climate	LandIS	Soil related climate data: *moisture deficit* and '*droughtiness*'	1 km2	Time period: 1961-75	Available	Available	Available	Available	Based on climate data up to 1975 so would need updating to current climate to give useful results for pilot areas although this would require considerable effort	No
43. HDTM	CEH	Hydrological Digital Terrain Model	1 km2	Contains data of Cumulative Catchment Area, Ground Elevation, Inflow Pattern, Outflow Pattern and Surface type	Available	Available	Available	Available	based on digital terrain model with functions suitable to derive hydrological variables	No
44. Chemical river	Environmental Agency	Map of trends in chemical river water quality (improving, static, declining, uplands)	Based on River Network	Only qualitative assessment (different colours)derived from WIMS data	Available	Available	Available	Available		Unknown
45. WFD	Environmental Agency (Water Framework Directive)	Water quality	for each river reach defined by EA	Classifies waters as High, Good, Moderate, Poor or Bad on the basis of the worst indicators of ecosystem	North West	SW River Basin Plan	SW River Basin Plan	Humber/ NW River Basin Plan	available in river basin plans	in line with EU directive

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
				health. Only qualitative assessment, no quantitative-derived						
46. WIMS	Environmental Agency	WIMS database :surface water quality data (ammonia, nitrites, oxygen...)/consented discharge/ turbidity and solid suspended		137216 points covering England and Wales. Some points with a lot of data available, some with a few data	290 points (87 closed)	820 points (443 closed)	433 points (285 closed)	1748 points (681 closed)		Yes at some of the sites
47. NVZ	Defra (ADAS)	Nitrate Vulnerable Zones 2002 (NVZ)	National	Have been established in areas where nitrate from agricultural land is causing pollution of the water environment	No NVZ within Bassenthwaite catchment	NVZ covering approx half of the Exmoor character area	NVZ covering approx 1/10 part of the area	Part covered by NVZ, Part covered by NVZ deferred slurry storage and part not covered by NVZ		
48. Nitrogen deposition	CEH/Defra 2008	Map of levels of nitrogen deposition exceeding critical loads for different soil types	1 km2		Available	Available	Available	Available	Based on national soil maps so not at a useful scale for pilot areas	

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
49. BGSsmall	BGS (British Geological Survey)	Drift Geology	1:625000	Small scale vector data of sediments (alluvial/glacial deposits). Covers England and Wales	Available	Available	Available	Available		No
50.BGSlarge	BGS (British Geological Survey)	Solid and Drift Geology	1:50000	Larger scale vector data for solid geology and sediments. Covers England	Available	Available	Available	Available	This should be useful for modelling	No
51. HLS	Environment Agency	HLS Targeting - High Risk Soil Erosion Areas	Grid: 1 km2	Estimated sediment delivery to watercourses expected to occur annually in England and Wales (1 in 10 year events). More metadata required to establish geographical spread/basis.	?	?	?	?		
52. Sediment sources	Hatfield and Maher, 2009. Earth Surf. Process. Landforms 34, 1359–1373	Fingerprinting upland sediment sources: particle size-specific magnetic linkages between soils,	Varied between < 1 km2 up to 9 km2	64 sites were measured and sampled	64 sites measured in Bassenthwaite catchment	No	No	No	Useful large scale data but not covering whole pilot area	

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
		lake sediments and suspended sediments. High-resolution soil magnetic susceptibility survey using a field susceptometer (ZH Instruments, SM400 probe)								
	Hatfield and Maher. 2008. Bassenthwaite Lake, Cumbria, UK	Suspended sediment characterization and tracing using a magnetic fingerprinting technique: Identification of catchment suspended sediment sources		19 suspended sediment samplers	19 samples within Bassenthwaite catchment	No	No	No		
53. Impact of grazing	Meyles *et al*., 2006. The influence of grazing on vegetation, soil properties and stream discharge	Impacts of grazing animals on hillslope hydrology and stream discharge		Measurements of: rainfall and runoff (between December 1998 and June 2000)/Stream discharge (15 minute basis)/Soil moisture (151 samples)	No	No	Holne Moor, a small catchment on east Dartmoor	No		No

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
	in a small Dartmoor catchment, southwest England, UK									
54. Moorland monitoring	Defra/ADAS	Moorland Vegetation Monitoring in Dartmoor	1994 survey: 50 sample points/ 1997: 30 re-sampled and 14 added/2003: 9 resampled and 50 added	Estimates changes occurring between 1994, 1997 and 2003 in Dartmoor moorland vegetation	No	No	Available	No		Resampled this summer?
55. RSPB	RSPB	Important Bird Areas (RSPB)	National level	Identified for the 2000 review	Available	Available	Available	Available	This could be useful depending on the data that was used	
56. NVC	JNCC	NVC survey		about 35,000 samples of vegetation. It is a detailed phytosociological classification, which assesses the full suite of vascular plant, bryophyte and macro-lichen species within a certain vegetation type	How many samples?	How many samples?	NVC maps available for Dartmoor (one old and one more recent)	How many samples?		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
57. Ramsar	NE	Ramsar Areas	100 km2		Available	Available	Available	Available		
58. SAC	NE	Special Areas of Conservation	100 km2		Available	Available	Available	Available		
59. SPA	NE	Special Protection Areas	100 km2		Available	Available	Available	Available		
60. NP	NE	National Parks	100 km2		Available	Available	Available	Available		
61. CWS	NE	County Wildlife sites (CWS)								
62.Ancient Woodland	Natural England	Ancient Woodland Inventory for England	1:63 360	Woods that were less than 2ha on the base maps are not included even though some of these are ancient	Available	Available	Available	Available	Will be of use to check CEH LCM 2007	?
63. SSSIs	Natural England	SSSI (Sites of Special Scientific Interest)			Available	Available	Available	Available		
64. SSSIs trends	Natural England	Monitoring of percentage of Sites of Special Scientific Interest (SSSIs) in favourable or unfavourable recovering condition			Available	Available	Available	Available		Approximately every 5 years
65. Priority species	Dartmoor National Park Authority	Monitoring of changes in priority species by type	scale?	Allow to identify changes as the monitoring has been			Available			Yes?

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
				carried out in 2009, 2008, 2007, 2005, 2000…)						
66. ESP	Natural England (2009)	Map of Environmental Stewardship payments	1:1250 - 1:10000	Accuracy is that of OS landline where boundary has been cloned i.e. relative accuracy is +- 1.2m at 1:2500 scale over a length of 200m. Precision: data captured with co-ordinate precision of sub 1 metre	Available	Available	Available	Available		Annually
67. ALC	ADAS	ALC Provisional Agricultural Land Classification	National?	Agricultural land classified into five grades (1: best quality, 5: poorest quality). Criteria used for assessment: climate, site and soil						No
68. HLCA	Defra	Overgrazing Investigations (HLCA)	Farm scale	Overgrazing and Unsuitable Supplementary Feeding cases investigated by Defra						No

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
69. Iodine	Lidiard, University of Bradford. 1994. Iodine in the reclaimed upland soils of a farm in the Exmoor National Park, Devon, UK and its impact on livestock health	identification of the local sources of iodine, the distribution of iodine between reclaimed and unreclaimed moorland soils and the differing capacities of reclaimed and unreclaimed soils to retain iodine			No	Study carried out in a farm within Exmoor	No	No		No
70. BRC	Biological Record Centres (Local)	Record of sites, habitats and species	County level		Tulli House/ The vital fauna of lakeland	Somerset Environmental Record Centre/ Devon Biodiversity Records Centre	Devon Biodiversity Records Centre	West Yorkshire Ecology/ Great Manchester Ecology Unit/ Lancashire Record Centre/ North and East Yorkshire Ecological data centre		
71. AONB	Natural England	Areas of Outstanding Natural Beauty			Available	Available	Available	Available		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
72. Noise	Defra / AEQ3	Noise Mapping Topography		Only available a shapefile detailing the source DTM datasets used for the Noise mapping project. More metadata required to establish geographical spread/basis.						
73. Tranquillity	CPRE	Tranquillity maps	National, regional and county scale (Grid: 0,5 km2)	In terms of "Most peaceful, least peaceful"	Available	Available	Available	Available		?
74. National Trails & Open Access Land	Natural England	National Trails	National	Line datasets and mapped areas. Note Natural England has a suite of Integrated Access Maps which combine the main data into one layer.						
75. VAS	MFF-Moors for the future	Visitor Attitude Survey	Exmoor			Available				
76. S1994	Centre for leisure Research	Visitors survey 1994	All the English and Welsh National Parks	Estimates of the number and nature of recreational visits and the characteristics and attitudes	Available	Available	Available			

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
				of visitors across the National Parks						
77. LS2005	Natural England (2002/3 and 2005)	England Leisure visits survey 2005	8 National Parks in England	the data from 2005 could be compared with the data from 2002/3	Available	Available	Available			
78. Grouse	Natural England	Grouse shooting activity in the English uplands (2001 and 2009)		Change in number of shooting days per year for each area and in number of game keepers employed	Available	Available	Available	Available		
79. Pdensity	ONS	Population Density 2001	National	Population density by Census Output Area (persons per hectare)	Available	Available	Available	Available		
81. CLB	Defra	Common Land boundaries and data	National	Provide input to mapping accessible land	Available	Available	Available	Available		
82. Woodland Trust	Woodland Trust	Woodland Trust Sites	National	Woodland Trust woodland is mainly open for access						
83. FCW	Forestry Commission	Forestry Commission Woodland	National	Map showing FC woodland, that is mainly open for access						

Dataset	**Owner**	**Data**	**Scale (Spatial and temporal)**	**Description**	**Bassenthwaite**	**Exmoor**	**Dartmoor**	**South Pennines**	**Confidence and relevance to pilot areas**	**Monitoring**
84. National Trust	National Trust	National Trust Boundaries	National	National Trust boundaries of land owned by the National Trust and land leased to the National Trust, they do not definitively indicate land managed by the Trust. Good input to a recreation supply model						
85. PRoW	Local authorities/ Geo Data	PRoW (Public Rights of Way)	National	Linear dataset						
86. MENE	Natural England	Monitor of Engagement with the Natural Environment (MENE)	regional and national level	Sample survey of the adult population. Undertaken as part of a weekly in home omnibus survey and fieldwork started in March 2009						
87. SAM	Natural England /English Heritage	Map of Distribution of Scheduled Ancient Monuments Sam at risk	National	Shown risk level (high, medium or low)	Available	Available	Available	Available		
88. Water colour	Local water authorities	Water colour trend	Points sources		United Utilities	South West Water	South West Water	Yorkshire Water		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
89.Acensus	Defra	Agricultural census	Cover England, Wales, Scotland and Northern Ireland (Available at county level)	The Agricultural census is carried out in June each year. It covers land use, crop areas and livestock numbers, types and sizes of agricultural holdings and the size of the agricultural labour force.40 thousand holdings in England are surveyed. Holdings are sampled using a stratified random sample.	Available	Available	Available	Available		Every year
90.Climate 5km	Met Office	Average monthly rainfall amount 1914-2000 (also Maximum and Minimum temperature, sunshine duration…)	5 km2	Large period of time, but coarse scale	Available	Available	Available	Available		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
91.Climate 1km	Met Office	Average monthly rainfall amount 1971-2000 (also Maximum and Minimum temperature, sunshine duration…)	1 km2	Finer scale, but short period of time	Available	Available	Available	Available		
92.Air Quality	Defra(UKAQA)	Air quality	123 AURN stations in the UK		No stations within the area	No stations within the area	1 station within the catchment: Yarner Wood	No stations within the area		
	UK Air Quality Archive	Maps of annual UK background concentrations	Grid: 1 km2	Maps of annual UK background concentrations for NOx, NO2, PM10 and PM2.5 and projections for other years-2020-	Available	Available	Available	Available		
93. Rivpacs	CEH	River Invertebrate Prediction and Classification System database	National (835 sample points throughout the UK)	Predicts the probability of occurrence of species/families/customised combination of taxa, family abundance, EQI...Uses BIOSYS database	3 samples sites	11 sample sites	4 sample sites	2 sample sites		

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
94. BIOSYS	Environment Agency	BIOSYS database	Full coverage of England and Wales (39646 records)	Macroinvertebrates identified at least at "family" level. Macroinvertebrates abundance (category and quantification). Can be linked to RIVPACS	180 points	258 points	167 points	591 points		The frequency of sampling depends on the budget available. The database should be consistent in terms of when the monitoring is implemented but not so much on how many times it has been implemented
95. BIBER	EA	River flow data	Points sources. 7796 points with ADCP measurements in England and Wales/ The monitoring frequency depend on the project		4 gauging stations	11 gauging stations	7 gauging stations	7 gauging stations		
96.Soil carbon	CEH	Soil carbon stocks across GB	1km2	Based on national soil maps						
97. Survey2001	Defra	Survey of public attitudes to quality of life and to the	National	Not spatial information. Only statistics at national	Available	Available	Available	Available	Not spatial information, only statistics at national	

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
		environment-2001		level					level	
98. Scientific papers	Web of science	Published Journal databases	International	Number of scientific papers published referring to different ecosystem types						
99.Mineral	BGS/CLG	Mineral resource maps in England and parts of south Wales	1:100000	The information presented on the maps are (amongst others) the geological distribution of all onshore mineral resources and location of mineral extraction sites, the extent of mineral planning permissions and licences for coal extraction	Available	Available	Available	Available		
100.Aquifers	Environment Agency	New aquifer designation maps	National coverage	The maps are split into two different type of aquifer designation (Superficial	Available	Available	Available	Available		It will be updated regularly to reflect the BGS ongoing

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
				(Drift) and Bedrock), The maps display "Principal Aquifers", "Secondary Aquifers", and "Unproductive strata"						programme of improvements to these maps
101. SRC/Miscanthus	Defra	Optimum sitings for energy crops and existing energy crops	National coverage (5 km2)	The maps show the opportunities and optimum sitings for energy crops within the different regions (High, Medium, Low) and also identify areas of existing energy crops, planted under the 2000 – 2006 Energy Crops Scheme.	Available	Available	Available	Available		
102. DOC	Environment agency	Concentration and flux of dissolved organic carbon (DOC)	100000 Locations with longest data records in England and Wales		No sample points	No sample points	No sample points	No sample points		
103. ADS40	British National Space Centre & Natural	ADS40 four-band digital aerial imagery,	resampled 2m resolution for specific projects	used to identify areas of burning	No data	image coverage was gathered on 5 days	imagery gathered on 4 days over 2 years	No data		no plans for reimaging

Dataset	Owner	Data	Scale (Spatial and temporal)	Description	Bassenthwaite	Exmoor	Dartmoor	South Pennines	Confidence and relevance to pilot areas	Monitoring
	England					over 2 years 2006/2007	2006/2007			
104. HER	Heritage Gateway	Historic Environment Records	County or National Park (Dartmoor, Exmoor, Lake District) level	Computerised details include site type, period, description of known history and condition, and sources of further information. It is linked to a Geographical Information System (GIS)	7000 sites recorded in Lake District HER(less in Bassenthwaite Catchment)	Exmoor National Park HER	Dartmoor National Park HER	Only HER available for North Yorkshire (around 5% of the character area)		

Table 2 is a list of all the datasets identified in this project and their availability within the pilot areas. The search for datasets was guided by the indicators identified in Table 1, Natural England datasets, web based searches and utilising the knowledge within the project team. For each dataset, there are comments as to its usefulness at the scale of the pilot areas and if possible the confidence that could be placed in it. It was difficult in most cases to determine the confidence in each dataset however this is assessed for a number of datasets in the discussion of specific land use/land management changes (Section 6). Many of the maps mentioned in Table 2 were derived from other datasets using various techniques such as interpolation and modelling which could introduce more error into the maps than was in the underlying datasets - see the discussion in Section 4. Modelling. For each dataset the frequency of recording was identified showing which datasets were inventories/ one off projects and which are being monitored over time.

One of the most important datasets needed to quantify current ecosystem service delivery is a map of the ecosystems or land use within the area of interest. The major source for this information within the UK is the Land Cover map produced by CEH. A number of maps have been produced since 1994 and the latest available map is LCM2000. A more up-to-date map is currently being developed (LCM2007) and is due to be released in 2010. These LCM's are used as the basis of the UK data within the European CORINE landuse database.

4. Modelling

In many cases (as shown in Table 1) quantifying an indicator of an ecosystem function is not straight forward – there is no direct link between measured data and the indicator. In such cases it may be appropriate to undertake some form of modelling to estimate the current ecosystem service delivery. This is even more true in the case of determining change in ecosystem services – changes in indicators cannot usually be monitored directly and need to be modelled. Models can also be used to *predict* changes in service delivery into the future. A modelling approach may be most appropriate where: the data required to show changes in ecosystem services do not exist or are too costly to collect; land management changes are expected to take a long time to affect ecosystem service delivery (e.g. it may take 20 years or more for new woodland planting to begin delivering the range of services associated with woodland); different landuse/land management scenarios are to be tested. Thus, a model can replace the collection of monitoring data in some situations (e.g. stream flows may be modelled for river reaches where there is no gauging station) and can also be used in a predictive way to determine what will be the result of doing X rather than Y.

Models range from complex process models which capture physical processes in a system to simpler functional models derived from statistical estimation using measured data. Selection of the appropriate model will depend on the available data, the extent and scale at which they are available, the types of models or estimation methods, but also the output requirements, which in this case are at the local to regional scale. We will take each of these considerations, and discuss how they may drive the choice of model and modelling approach for determining ecosystem service delivery (provision) at any given location.

a) Models types, formats and styles

Modelling ecosystem processes or functions is not a novel exercise and there are countless models of functions in the scientific literature (see Table 3 for a number of examples)

Table 3 Examples of models used to estimate ecosystem function

Model	Reference†	Type	Ecosystem Service
SWAT	http://swatmodel.tamu.edu/	Hydrological	Flood mitigation and water regulation, Erosion control
TOPMODEL	http://www.epa.gov/nrmrl/pubs/600r05149/600r05149topmodel.pdf	Hydrological	Flood mitigation and water regulation
INCA	http://www.reading.ac.uk/INCA/papers.htm	Hydrological	Flood mitigation and water and nutrient regulation
MIKE SHE	http://www.crwr.utexas.edu/gis/gishyd98/dhi/mikeshe/Mshemain.htm	Hydrological	Flood mitigation and water regulation
CENTURY	http://daac.ornl.gov/MODELS/guides/century_vemap.html	Soil biogeochemical cycling	Climate regulation (carbon storage)
RothC	http://www.rothamsted.bbsrc.ac.uk/aen/carbon/rothc.htm	Soil biogeochemical cycling	Climate regulation (carbon storage)
Escosse	http://www.scotland.gov.uk/Publications/2007/03/16170508/0	Soil biogeochemical cycling	Climate regulation (carbon storage)
TRIFFID	http://www.metoffice.gov.uk/publications/HCTN/HCTN_24.pdf	Terrestrial Vegetation	Flood mitigation and water regulation, Climate regulation (carbon storage), etc
YieldSafe	http://dx.doi.org/10.1016/j.ecoleng.2006.09.017	Terrestrial Vegetation	Flood mitigation and water regulation, Climate regulation (carbon storage), etc

† All web references checked in April 2010

Each model is parameterized in a particular way, operates at a particular scale and generates a particular output. A comprehensive review of all physically based models that cover natural processes that in turn deliver one or more of the ecosystem services is therefore neither practical nor useful. It is more useful and practical to present an organizational framework in which to assess existing models and future models as they are developed.

In broad terms, there are two types of modelling approach, a generalist approach in which many of the underlying processes are modelled implicitly or aggregated in ‘lumped’ parameters and a more specialist approach to modelling; in which processes are modelled explicitly. The first set of models (usually called **stochastic**) tend to contain a set of stochastic or functional relationships that are derived from model fitting to data; the second set of models (**mechanistic** models) attempt to explicitly describe the mechanisms and processes that occur in natural systems based on physical, chemical and biological process understanding. In most cases, all operational models will contain some generalization and some basis in process understanding, therefore. lie somewhere on the scale between purely stochastic models (e.g. regression) and purely mechanistic models. There are scientific and operational criteria that underpin and present a case of support for either of the modelling approaches.

In the case of **mechanistic** models, these represent the scientific understanding of how processes operate in a landscape and therefore are viewed as a more rigorous representation of reality. Their value, in terms of quantifying ecosystem service delivery, is in that they could be considered by the scientific community as more transparent and therefore credible. They are also useful in hypothesis building and furthering scientific endeavour, for where they fail to perform in the landscape, this clearly indicates that our understanding of processes at that location is imperfect. An example, in hydrological sciences, of such a mechanistic process based model is the MIKE SHE model (a watershed (catchment) modelling tool, Graham *et al.,* 2005) This model is an advanced, flexible framework for hydrological modelling. It includes a full suite of pre- and post-processing tools, plus a flexible mix of advanced and simple solution techniques for each of the hydrological processes. MIKE SHE covers the major processes in the hydrological cycle and includes process models for evapotranspiration, overland flow, unsaturated flow, groundwater flow, and channel flow and their interactions. Each of these processes can be represented at different levels of spatial distribution and complexity, according to the goals of the modelling study, the availability of field data and the modeller's choices. There are some significant disadvantages to these types of models;

1) As environmental systems and processes are complex, so are these models and the data requirements for parameterization and operation can be extremely high.

2) Computationally these models can also be extremely demanding and hence expensive to run.

3) The development of a framework that assesses multiple ecosystem services ,is capable of forecasting ecosystem service delivery dynamically, and is underpinned by a diverse set of models that are process based, will generate a set of unique challenges in terms of complexity and computational intensity. A particular concern in this case is where each process model is developed under different scientific paradigms. The movement of water through soil, for example, can be described in different forms by different models depending on whether the model was developed within the disciplines of soil science or hydrological science. Resolving these fundamental differences within the suite of models required to generate such a framework for quantifying ecosystem services will be extremely challenging.

In summary mechanistic models are:

- Transparent and therefore considered credible by stake-holders
- Complex
- Have high data requirements
- Computationally demanding

Stochastic, or functional models tend to be more operationally defined. They are simpler models derived to obtain a process outcome as simply and as efficiently as possible, in which the process and mechanisms that generate that process outcome are either ‘lumped’ in a simple functional relationship or accounted for implicitly by fitting some parameter to observed data. In its simplest form, these sets of models can viewed as simple linear statistical relationships between a set of variables that are easily available and the desired process outcome; for example, pedotransfer functions in soil science or discharge-stage relationships in hydrology. There are clear operational advantages to this approach, in that these models tend to require less data, can be tailored to the available data and can be computationally less intensive. If developed correctly, they can also contain within them an alternative scientific paradigm based on statistical (stochastic) theory. The assumption is that no process can ever be described perfectly in space and time over a landscape. If this is the case, then it is far more effective to treat process outcomes as the outcomes of a random process, for which statistical models can be generated from probability theory and confidence constructed around the prediction of the process outcome. As all models share a common theoretical underpinning it is far more straightforward to combine these models into a framework to model all ecosystem service delivery. There are, however, concerns with using this type of approach to modelling natural processes for ecosystem services delivery;

1. It is considerably harder to determine and allocate causality within a stochastic modelling framework. This can generate problems when troubleshooting existing models or in further development of these models.

2. Probability theory is complex and counter-intuitive and therefore often experienced as incomprehensible (and often suspect) by stake-holders.

3. Many of these models are derived from data and therefore cannot be easily extrapolated beyond the data envelope for which they were developed. In a similar vein, the quality of these models is dependent on the quality of the data on which they are developed.

4. The application of probability theory is based on a set of assumptions about the random process and where these assumptions are not met, there may be problems with the stochastic models and their outcomes. Probability theory is complex, and not all practitioners will be aware of these conditions on the application of stochastic techniques, nor can all conditions/assumptions be tested.

In summary stochastic models are:

- Not transparent and can be considered incomprehensible by stakeholders
- Relatively simple
- Unable to be extrapolated outside the range of data on which they were built
- Not computationally intensive

In reality, most models of natural processes that underpin ecosystem services delivery tend to be a compromise between the two extremes, containing mechanistic relationships where it is feasible and desirable and functional relationships where they are more efficient or the information is scarce. However, the degree to which they tend more to one or the other will determine their credibility, data and computational requirements, and types of outcomes that can be expected and therefore their suitability for quantifying ecosystem service delivery.

b) Data availability, quality and support

A key consideration, and one described elsewhere in this report, is the level and quality of data available. This also has considerable implications for the modelling. Data are required as inputs to any model of ecosystem functions, to parameterize the model and to obtain a measure of success of the model performance (validation). Ideally these data are available of sufficient quality at the spatial and temporal resolution required for the suite of models to be used to quantify ecosystem service deliver; in practice this is rarely the case. There are a number of considerations in terms of data quality and availability in terms of the modelling.

1) The different models will require data in different formats and will treat data differently. For example, mechanistic models may require two types of information; i) process parameterization, e.g. estimating rates of nutrient cycling or water movement and ii) model inputs, e.g. the nutrient concentrations in the soil, species composition etc. Stochastic models will approach data differently, often requiring an understanding of the underlying statistical distributions from which the data are a sample.

2) Data will be available in different formats and will be of varying quality, which will introduce uncertainty into the estimates of the state and change of the ecosystem services delivery. Data can be of poor quality due to a number of factors such as; poor analytical or sampling documentation, uncertain geographical location, sampling or analysis protocols that are not appropriate for what they are used at some later date. Generally, mechanistic models are less flexible when incorporating ‘fuzzy’ data, or data containing uncertainty. However it is possible, but the process is complex and computer intensive. Stochastic models are generally more flexible and their theoretical basis assumes uncertainty around much of the information on which they are constructed.

A final note must be made on support. **Support**, in the sense used for geographical samples, is the physical unit or mass upon which the observation is made. This could be a soil core, water aliquot, gas chamber, etc. The observation (data value) obtained by this sampling method is conditioned by the size of its support, so, for example, a soil carbon value from a single core with diameter 20 cm will have that as its support, and can only be related to forest biomass, measured on a hectare basis, with difficulty.

c) Problems and issues related to scale; ‘up-scaling and down scaling’

Models of environmental processes are often developed through research aimed at elucidating patterns and relationships between the environmental properties of interest. As described earlier, the modelling may be mechanistic or derived from a stochastic approach to the research problem. These relationships are commonly reported in the scientific literature from experimental work or monitoring and are then often used in different environmental models to supply input information that is sparse or to describe processes for which our understanding is incomplete. However, process understanding obtained (semi-) experimentally may not immediately be suitable for these different environmental models due to issues of spatial scale. There is usually a discrepancy between the spatial scale at which the process is studied and formulated (e.g. laboratory, core, plot or river reach), the scale at which information is available (e.g. a generalized value for land use or land cover unit) and the scale at which policymakers or managers need to make decisions (catchments, regions or nationally).

There are two major problems that may occur when scales are different. The first is when there is nonlinearity in the model then the average model output at a coarser scale is not the same as the aggregate average of the model outputs at a finer scale. This can introduce bias in the outcome as reported in Corstanje and Lark (2008). The second problem is the phenomenon of scale-dependence, where the factors determining the variation in a process depend on spatial scale and models of ecosystem processes developed at one scale are not necessarily applicable at another. For example a relationship between crop yield and soil carbon content may be linear when considered in a pot experiment but if this is scaled up to a field the relationship may become exponential, the yield being limited by other properties of the soil or climate.

The obvious effect of scale-dependence in ecosystem function models is that these models may consequently not be of use at other scales. There are, however, a number of other significant consequences to this phenomenon:

1) *Scale-dependence will obfuscate experimental results, particularly if these are carried out under semi-natural conditions.* This has been explored in various studies (e.g. Lark *et al*., 2004; Corstanje *et al*., 2007, 2008) and, for instance, has shown that strong relationships can be observed at some scales even though poor correlations were obtained in the overall experiment.

2) *Scale-dependence will determine the interpretation of monitoring results.* Several monitoring networks exist in the UK (e.g. Countryside Survey, Environmental Change Network) from which information is obtained and interpreted. Establishing likely causes of observed variation from these schemes will depend on understanding at what spatial scale these processes operate.

3) *Where the presence of scale-dependence is known, this should impact future sampling and experimental design strategies*. If scale dependencies have been

previously determined and quantified, these can subsequently be incorporated into the experimental or environmental sampling design.

d) Current modelling solutions

In general terms, there are two approaches to quantifying ecosystem services in the literature which broadly map onto the earlier discussion on modelling approaches. There are a series of models developed for other purposes, such as those given in Table 4 and many others that are used in the literature to describe typically one or more of the ecosystem services. For example, Leibowitz *et al*, 2000 developed a sediment transport model from which they derived a set of ecosystem services (provisioning, regulating), but the primary aim of the model was to determine erosion and sediment transport. Throughout the literature, there are numerous studies that propose and implement specific process models and couple to these outcomes of a specific ecosystem service. However, as described in the methodology (section 2), in order to quantify ecosystem services we need to model the outcomes of particular ecosystem functions – not going directly to ecosystem services. This introduces a qualitative layer (determining the ecosystem service directly from the model output) on a quantitative, predictive outcome from the model. Robust methods for doing so have not yet been developed.

A second approach is where the delivery of ecosystem services is assessed via the ecosystem functions that drive them, and the underlying models are developed specifically for this purpose. A recent novel development has been the introduction of the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) Model (Nelson *et al*., 2009). InVEST, which is being developed under the Natural Capital Project at the National Center for Ecological Analysis and Synthesis at California University, is a GIS based ecosystem services assessment framework and currently contains models for a number of services such as carbon sequestration and biodiversity. InVEST is open source, designed to run as a script in ArcGIS ArcToolBox and could be adapted to UK conditions and services provisions. However InVEST is at a very early stage of development including only very simple models and does not allow any estimation of error in the outputs. It is a static model combining GIS layers which are snapshots in time and estimate change in carbon sequestration, for example, under a changed land cover scenario as the difference between the carbon stored under one land use and that stored under a different land use where this has changed for a particular grid cell. The level of carbon storage being defined solely by the landuse class. To apply the InVEST model, as it is, in the three pilot areas would be possible but the results would be of limited use as, for example, the variation in soil type across the pilot areas would have no effect on the estimation of the effect of land use change on carbon sequestration. Also the InVEST model appears to take no account of possible scale dependence in the models being used – the grid size at which the models are run being driven by the input data and computation time availability.

Taking all these considerations in to account we believe that a stochastic, or statistical modelling environment is in all likelihood, the most effective way to determine the supply of ecosystem goods and services within the pilot areas. Within this realm, a Bayesian maximum entropy approach (BME) expressed as Bayesian Belief Networks (BBNs) is probably the most effective modelling approach. A BBN is a *graphical probabilistic* model; *graphical* in the sense that it presents the variables that affect the response of interest in the form of a network, *probabilistic* in the sense that the relationships between the drivers and response are conditioned by a probability. A classical example of a BBN is where the probability of a disease occurring is determined by a set of factors, each of which impact this outcome based on a set of conditional probabilities; i.e. the chance that a patient has lung disease is conditional on that patient smoking, and this condition is expressed as a probability.

The advantage of using a BBN, for quantifying ecosystem service delivery, is two fold; i) we can express, based on the literature, or from expert knowledge, what we think the relationships are between a certain biophysical ecosystem functioning (e.g. amount of water flowing per second in the river) to an actual service (provisioning of water) and ii) we can formally express and model variables that cannot be measured outright (such as aesthetic measures), these variables are formally known as *latent* variables. These networks can be updated and improved as new information becomes available, either through monitoring or from surveys, so they are a flexible, natural way of expressing ecosystem goods and services delivery.

The use of BBN in quantifying ecosystem services is recent and there only a few examples in the literature. Koellner *et al*. (2008) developed a BBN to assess the ecosystem goods and services in Switzerland, particularly emphasizing the advantages it delivers to planners. Haines-Young *et al* (2010) have successfully used BBN to support ecosystem service assessments for a number of ecosystem services relevant to the UK uplands – for example, BBNs have been developed for carbon storage and sequestration, water provisioning and flood regulation, and recreation; The Haines-Young report set out a conceptual framework for applying the BNN across the whole of the UK uplands but noted that the uplands are diverse and put forward suggestions as to how the BNN could be adapted to more specific areas of interest to improve the spatial representation of the ecosystem service delivery. Each of the ecosystem services quantified in this study were considered individually –no attempt to represent the feedbacks or synergies was made.

e) Recommendations

For the three pilot areas considered in this report we recommend that a series of BBNs, within an InVEST type GIS environment is a potentially effective and efficient framework that could be used to interrogate existing environmental data such as the land cover, topology, soil and climate spatial datasets (included in Table 2). This will allow for the identification of which ecosystem functions are possible, and at what level, at a given location in space. InVEST can handle multiple ecosystem functions and is, therefore, an ideal framework in which to determine the effect of multiple functions on service provision, for instance, determining the effect of multi-functionality in space. Some of the datasets identified in Table 2 also contain some information on the temporal variability of the biophysical environment. This type of temporal data is ideally suited to simulate continual change in the environment conditions and determine their effect on the provision of ecosystem services. However the InVEST framework would need to be developed to handle dynamic models and more detailed information on some aspects of temporal change are needed within the pilot areas. This dynamic framework would set the stage for subsequent scenario testing, including climate change.

5. Identification of the ecosystem services affected by land use/land management changes and assessing the applicability of currently available data

As stated in the methodology (Section 2) this project is focusing on a number of land use/ land management changes within the pilot areas and their effect on ecosystem services. For each of those changes Table 4 identifies the main ecosystem services that they will affect. Using the information in Table 2, the relevant indicators – for the appropriate ecosystems- were identified and an indication given of the direction of change in these indicators that might be expected under the specified changes in management (LUC 2009).

Table 4 Ecosystem services affected by land use/land management changes

Land use/Land management changes	Aim	Ecosystem services affected	Indicators of change	Direction of change
1.Management of soils and hydrology				
1i. Blocking drains (or grips) on peat soils	Restore water tables, reduce soil erosion	Fuel provision	kg/pilot/areas/yr	Decrease
		Fresh water provision		Limited, since direct use of fresh water from ecosystems is limited in England (Defra, 2010)
		Climate regulation		Increase (> carbon storage)
		Flood mitigation and water regulation	Condition of wetlands	Increase (enhances storage of water)?? Conflicting evidence
		Erosion regulation	Sediments in streams and soil depth	Increase (< eroding gullies)
		Nursery habitats	Inventories of number of transient species	Increase (improve peat bogs habitats)
		Aesthetic	Visitors surveys (appreciation of peat bogs landscape)	Increase
		Education and science	Number of papers addressing blocking drains influence	Increase
1ii. Re-vegetating bare peat	Avoid peat losses, improve water regulation	Fuel provision	kg/pilot/areas/yr	Decrease
		Climate regulation		Increase (> carbon storage)
		Flood mitigation and water regulation	Condition of wetlands	Increase (> water storage)
		Erosion regulation	Sediments in streams and soil depth	Increase (< eroding gullies)
		Nursery habitats	Inventories of number of transient species	Increase (> peat bogs vegetation)
		Soil formation and		Increase (> vegetation cover)

Land use/Land management changes	Aim	Ecosystem services affected	Indicators of change	Direction of change
		regeneration		
		Aesthetic	Visitors surveys (appreciation of peat bogs landscape)	Increase
		Education and science	Number of papers addressing effects of vegetating bare peat	Increase
1iii. Avoid soil compaction by livestock	Improve water and erosion regulation	Food supply	kg meat/pilot areas/yr	Decrease (< livestock)
		Fibre (wool) provision	kg/pilot areas/yr	Decrease (< livestock)
		Flood mitigation and water regulation	Run-off measurements	Increase (> water infiltration)
		Water purification and waste treatment	Water quality indicators	Increase (but intensity of impact very low)
		Erosion regulation	sediment flux in streams and soil depth	Increase (> soil losses)
		Aesthetic	Visitor surveys (appreciation of grasslands)	Increase
2. Management of grazing				
2i and 2ii. Introduce and encourage **sustainable grazing** regimes (Avoid **overgrazing** and **under grazing** of vegetation by livestock)	Less erosion, more biodiversity. Improve cultural services such as cultural heritage	Food supply	kg meat/pilot areas/yr	Increase (when avoid overgrazing)/ Decrease (when avoid undergrazing)
		Fibre (wool) provision	kg/pilot areas/yr	Increase (when avoid overgrazing)/ Decrease (when avoid undergrazing)
		Air quality regulation	Levels of ammonium in the air	Increase (when avoid intensive farming systems)
		Climate regulation	Methane emissions	Increase (< methane emissions) when avoid overgrazing/Decrease when avoid undergrazing
		Water purification and waste treatment	Water quality indicators	Increase when avoid overgrazing (< inputs of slurries)/Decrease when avoid undergrazing (but intensity of impact very low)
		Erosion regulation	Grazing pressure	decrease (when avoid overgrazing)/ increase (when avoid undergrazing)

Land use/Land management changes	Aim	Ecosystem services affected	Indicators of change	Direction of change
			Sediment flux in streams and soil depth	Increase (when avoid overgrazing)/ Decrease (when avoid undergrazing)
		Soil formation and regeneration		Increase (when avoid overgrazing)/ Decrease (when avoid undergrazing)
		Gene pool		Increase when using native breeds
		Biodiversity	Biodiversity indicators	Increase with sustainable grazing regimes
		Aesthetic	Visitor surveys (appreciation of grasslands)	Increase when avoid overgrazing
		Cultural Heritage	Visitor survey	Increase with sustainable grazing regimes
2iii. Changes to burning practice	Avoid losses of carbon	Water purification and waste treatment	Water quality indicators	Increase (< inputs of pollutants)
		Climate regulation		Increase(< losses of carbon)
		Flood mitigation and water regulation	Run-off measurements	Increase (> flood mitigation)
		Nursery habitats	Inventories of number of transient species	Increase
		Aesthetic	Visitor surveys (appreciation of landscape)	Increase
		Air quality regulation		increase (< particulates)
		Gene pool		Increase (when burnt habitats support rare/scarce species)
3.Management of woody vegetation				
3i Increase woodland/scrubland	Reduce flood risks, increase carbon sequestration	Food supply		Decrease (< ewes and cattle)/ but may increase provision of edible berries, fruits, fungi (taken from Defra-LUC project)
		Fibre provision		Increase (if timber is harvested)
		Climate regulation	Inventories of carbon in forest	Increase (> carbon storage)
		Water purification and waste treatment	Water quality indicators	Increase (but intensity of impact very low)
		Flood mitigation and water regulation	Catchment water yield, peak/flood flows, summer low	Increase (> vegetation cover)

Land use/Land management changes	Aim	Ecosystem services affected	Indicators of change	Direction of change
			flows	
		Erosion regulation	Sediment flux in streams and soil depth	Increase (> root matrix that fix soil)
		Soil formation and regeneration		Increase (>soil depth)
		Nursery habitat	Inventories of number of transient species	Increase/Decrease (depends on the previous habitat)
		Aesthetic	Visitor surveys (appreciation of forest and scrubland landscape)	Increase/Decrease (depends on previous habitat)
		Recreational	Number of visits	Increase
		Inspiration		Increase
		Cultural heritage	Visitor survey	Increase/Decrease (if remove typical grazing areas)
3ii. Introduce and encourage sustainable woodland management for timber and fuel	Reducing flood risk, increase biodiversity	Food provision	kg meat/pilot areas/yr	Increase (can increase provision of edible fruits and fungi)
		Fibre provision	kg/pilot areas/yr	Decrease
		Climate regulation		Increase (> carbon storage)
		Water purification and waste treatment	Water quality indicators	Increase (but intensity of impact very low)
		Flood mitigation and water regulation	Run-off measurements	Increase (< flood risk)
		Erosion regulation	Sediment flux in streams and soil depth	Increase (> vegetation cover)
		Biodiversity		Increase
		Aesthetic	Visitor surveys (appreciation of peat bogs landscape)	Increase
		Recreational	Number of visits	Increase
4. Habitat restoration and rehabilitation				
4i Restore habitat connectivity	Increase biodiversity	Food supply	kg/pilot areas/ yr	Decrease (if previous land use was grazing)
		Nursery habitats	Inventories of number of transient species	Increase (
		Gene pool		Increase (> area of habitats supporting rare/scarce species
		Biodiversity	Biodiversity indicators	Increase

Land use/Land management changes	Aim	Ecosystem services affected	Indicators of change	Direction of change
		Aesthetic	Visitor surveys (appreciation of habitats with high conservation value landscape)	Increase
		Education and science	Number of papers addressing join up fragmented habitat influence	Increase
4ii Restore footpath damage	Improve recreation service, control erosion	Flood mitigation and water regulation	Run-off measurements	Increase
		Erosion regulation	Sediment flux in streams and soil depth	Increase (< soil losses)
		Aesthetic	Visitor surveys	Increase
		Recreational	Number of visits	Increase
		Inspiration		Increase
		Cultural Heritage	Visitor surveys	Increase

A summary of the main ecosystem services which would be affected most by the land use /land management changes are shown in Table 5.

Table 5 A summary of the main ecosystem services affected by the landuse/land management changes in the pilot areas

Ecosystem Service	**Ecosystem**	**Ecosystem function**	**Indicator**	**Datasets**
Erosion regulation	All ecosystems	Soil stabilisation & Water infiltration	Sediment flux in streams	46. WIMS sediment loads
	Upland peat		Colour in water (DOC)	88. Water colour
Flood mitigation and water regulation	Upland peat	Water storage	Proportion of peat in good condition	18. Peats 19. Peat status
	Woodland	Water infiltration, impeding cross-land flows and aquifer recharge	Catchment water yield, peak/flood flows, summer low flows	94. BIBER
Recreation	All ecosystems		Number of visits	England Leisure Visits survey (76 and 77) Now data collected as: 86. MENE

Ecosystem Service	Ecosystem	Ecosystem function	Indicator	Datasets
Aesthetic	All ecosystems	Landscapes that offer: Sense of peace & quiet Sense of calm	Measure of appreciation of different landscapes	86. MENE
Climate regulation (carbon storage)	All ecosystems	Carbon sequestration	Carbon in soils	
	Woodland		Carbon in trees	74. Forestry type
Food production	Grassland	Biomass production	Production of meat (lamb/beef)	7.Density of breeding ewes 9.Density of cattle

We now discuss how the state of each of the ecosystem services in Table 5 could be measured in the pilot areas drawing on the datasets identified in Table 1 as those which could populate the indicators.

a) Erosion regulation

Using the indicator **sediment flux in streams** – The supply and transfer of sediment to and through, the aquatic system is a highly spatially and temporally dynamic process, which has been described as a "jerky conveyor belt" (Ferguson, 1981). , At any scale from the field to a large river basin there will be a cycle of supply-transport-deposition which will repeat in both space and time. Thus, sediments that are deposited at a point in a river basin may become part of the supply chain for sites further downstream or may remain deposited for long time periods.

The initiation of sediment movement depends on a supply of energy from raindrop impact, overland or river flow or a mass movement of soil. (White, 2008) Similarly deposition occurs when sufficient energy is not available to maintain sediment particles in motion. The energy thresholds for initiation and cessation of sediment movement are not the same, being influenced differently by a range of conditions such as flow depth, velocity and turbulence and sediment characteristics such as cohesion, particle shape and particle density. In practice for most rivers, most of the time, sediment transport is limited by a complex and dynamic pattern of sediment supply. The supply of sediment is controlled by a mix of factors relating to geology, rainfall distribution, land use and management, soil type and distribution, topography, landscape complexity and antecedent conditions and the relationship between them in space and time. Sediment supply will vary both in space and time, and sediments being transported through the river system today may have started their journey through the catchment recently or thousands of years ago. The tendency for sediment supply to be concentrated in high rainfall-runoff events, which coincide with high river flow and thus high sediment transport capacity, means that sediment transport (flux) is concentrated in high flow events, which also have the highest transporting capacity. A study by White *et al*, 2005 for several European rivers showed that typically 70% of suspended sediment transported moves in the top 20% of flows Peak high flow sediment concentrations are seen in steep mountain rivers, and, as a broad generalisation, peak concentrations decrease as rivers become less steep. Groundwater-fed rivers behave somewhat differently because flow is not dominantly supplied by overland routes which would deliver sediment and thus there is not such a marked increase in sediment concentrations at high flows – however given the geology of the catchments the rivers in the pilot areas will have very little contribution from groundwater.

In order to assess sediment flux through a river section, because sediment concentration varies across the channel and through depth, sampling on several profiles is required, concurrent with velocity measurement. To monitor sediment flux we would normally consider three sediment transport modes: Wash load (fine particles), Suspended bed material load and bed load. Suspended sediment load (the combination of wash and suspended bed material load) is measured at a number of sites within the pilot areas as part of the Environment Agency river sampling network. The sites included in the WIMS database are usually measured monthly but some apply to specific projects so will not be measured again. On Dartmoor there are 433 sampled sites in the database: 285 are not currently being sampled; of the rest the last time they were sampled varied from 2004 to 2009. Only 13 sites were sampled in 2009. For Exmoor there are 820 sampled sites in the database: 443 are not currently being sampled; of the rest the last time they were sampled varied from 1995 to 2009. 32 sites were sampled in 2009. In the South Pennines there are 1748 sampled sites in the database: 681 are not currently being sampled; of the rest the last time they were sampled varied from 1962 to 2009. Only 29 sites were sampled in 2009. For Bassenthwaite there are 290 sampled sites in the database: 87 are not currently being sampled; of the rest the last time they were sampled varied from 1978 to 2009. Only 14 sites were sampled in 2009. It is difficult to identify from the EA databases whether velocity measurements are available at the same time as the sediment load measurements –however several projects (see EA report Bellamy *et al*., 2009) have found it difficult to identify concurrent measurements (in space and time) within the EA databases.

White (2008) has shown that a sampling interval for sediment loads of 4 weeks can introduce a 600% error in estimation compared to estimates based on 15min samples; as stated above the EA data is based on monthly samples. It is clear that trying to estimate erosion regulation from EA data, which has been collected for other reasons, would have very large uncertainty and to estimate change in this regulation service due to landuse or land management change would be impossible.

A method for assessing erosion risk based on several risk factors, such as soil, climate, topography, landcover, and land management, has been developed at Cranfield (White *et al*., 2003). This methodology could be used to identify sources and pathways of sediment within the pilot catchments which could be driving a number of ecosystem services and which could be affected by changes in management. Take for example the peat grip blocking – this will remove a source of sediment but will also change the flow regime downstream of the peat bog – and this will change the erosion regulation service and the flood mitigation and water regulation service. This methodology would not allow the “erosion regulation” service to be quantified in terms of the kg/year of sediment or soil being eroded but would allow a change in risk to be determined. This type of methodology could be used to set up a BBN for erosion regulation.

Using the indicator **water colour** to determine the effect of change within peat areas on erosion regulation: Water colour is measured by the water companies within the pilot areas and would enable the estimation of the current state of erosion regulation within the areas of peatland by comparing the water colour with those levels obtained where peat is in a good condition. Dissolved organic carbon (DOC) measurements vary considerably in time and space. However, Yallop and Clutterbuck (2009) have been able to show a link between intensive burning and levels of DOC within the UK peatlands using DOC concentrations measured in streams draining 50 small-scale catchments (<3 km^2) in three discrete regions of the South Pennines. Methods of monitoring the effect of peat grip blocking and increasing peat cover on water quality are currently being developed within the SCAMP project within two areas of the UK uplands – information from SCAMP could be used to guide monitoring within the three pilot areas . This type of information from the literature can also help to build BNNs for the specific ecosystem services flood mitigation and water regulation.

Using the indicator **proportion of peat in good condition** to determine the state of flood mitigation and water regulation: There are datasets of the area of peatland within each area and the area under a range of status'. By estimating the area of deep peat (i.e. in good condition, holding water and minimizing runoff) compared to the total area of peat would enable an estimate of the state of the flood mitigation and water regulating service to be made. However there is still some debate about the impact of grip blocking on upland hydrology, for example, Burt (1995) showed that re-wetting peat increases flood generation, but Holden *et al*. (2007) show that the response to extreme rainfall events is "smoothed" in peats that are in good condition compared to drained peatlands. So although it may be possible to make an indirect estimate of the flood regulation service using this indicator, the direction of change of the indicator when the peat condition changes is not yet fully understood. The maps of peat area and peat status are derived from soil maps, altitude, slope and aerial photographs so are dependent on the accuracy of these spatial datasets. The peat status maps would need to be updated on a regular basis to determine change in the status over time.

Using the indicators of **catchment water yield, peak/flood flows, summer low flows** to determine the state of flood mitigation and water regulation under woodland/forestry. There are measurements of flows throughout the pilot areas within the EA BIBER database with which these indicators could be populated. The monitoring frequency of the sites depends on the project they were measured for; some sites will have been monitored over a long period but others only for a short period. The consistency of the data in this database is not high (Bellamy *et al*., 2009) as the methods used to determine flow and velocity vary from site to site. On Dartmoor there are 7 gauging stations, on Exmoor there are 11, the South Pennines there are 7 and Bassenthwaite 4. Detailed analysis of these datasets would need to be carried out to determine if changes would be detected when changing areas of land to woodland.

A recent Defra project (O'Connell *et al*., 2004), which reviewed impacts of rural land use and management on flood regulation concluded that changes in land use and land management practices affect runoff generation in a complex way at the local scale and that these local changes propagate downstream but these are difficult to detect once combined with the rest of the surface water network at the catchment outflow. O'Connell also states that there is no generally-accepted theoretical basis for the design of a rainfall-runoff model suitable to predict impacts and that more measurements need to be made to estimate the impacts of changes in land use on flood regulation. Haines Young *et al*. (2010) gives a *simplified* conceptual model for factors influencing flood regulation in the uplands (see Figure 2) showing the complexity of the system but also how BBNs can be developed using current state of knowledge which can be improved when more data and process understanding are available.

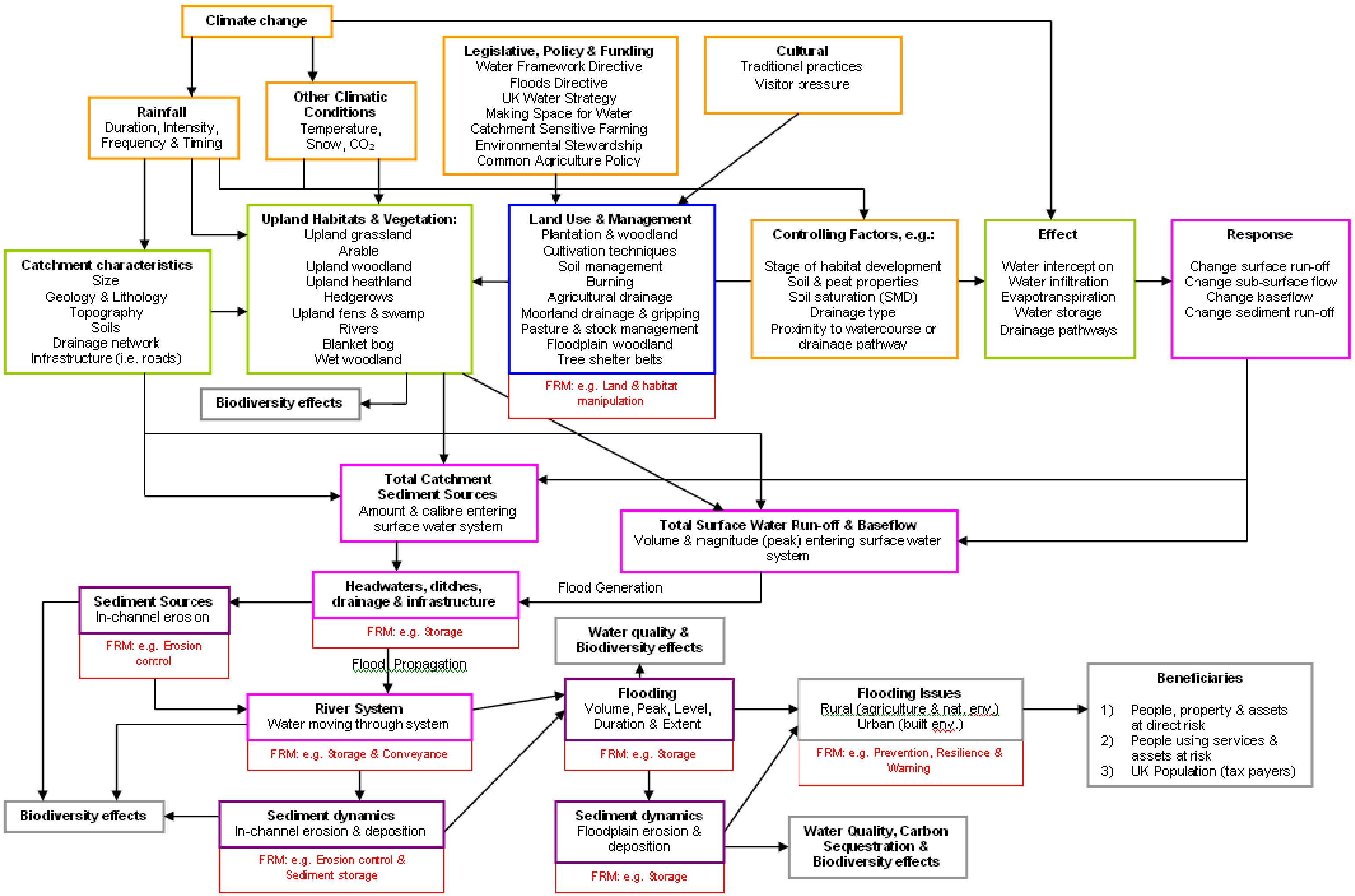

Figure 3 Conceptual model for the factors influencing 'flood regulation' in the uplands (taken from Haines Young 2010)

b) Recreation

Using the indicator **Number of visits** to quantify the state of the recreation service: There are measurements of visitor numbers to the national parks (visitor survey data) which covers three of the four areas. However, we have been unable to find any information on visitor numbers for the South Pennines as this character area is not within a national park. The visitor survey for national parks was carried out in 1994 by the Centre for Leisure research and in 2002/3 and 2005 by Natural England. The confidence in the results of the survey will depend on the size of the sample used in each of the surveys. To determine whether significant changes in the numbers of visitors to the pilot areas have occurred, the visitor survey will need to be repeated with a big enough sample to ensure a change is detectable compared to earlier surveys. The Monitoring Engagement with the Natural Environment (MENE) survey carried out by NE offers some potential for collecting this information.

Recreation was one of the ecosystem services investigated by Haines Young *et al*., (2010) They found it particularly difficult to operationalise the recreational model because of considerable uncertainties or gaps in the evidence base – in particular they identified gaps in the level of physical and mental health benefits and what the drivers are in context of use of an upland environment, and gaps in the links between geographical location of the uplands and the location of the benefits (health).

c) Aesthetic service

Using the indicator **Measure of appreciation of landscape** to quantify the state of the Aesthetic service: The Monitoring Engagement with the Natural Environment (MENE) survey carried out by NE has measured people's appreciation of a number of different landscapes which should enable this indicator to be populated. However this survey is carried out at a regional level so it would be difficult to relate changes in peoples appreciation to specific areas. The confidence in these measurements depends not only on the number of people surveyed but also on the design of the questions so that all the people surveyed understand in the same way the questions being asked. It would be important to carry out this survey before land use or land management changes are implemented, i.e. establish a baseline, to determine how people's appreciation of the landscape might change.

d) Climate regulation (carbon sequestration)

Using the indicator **Carbon in soils** to quantify the carbon sequestration function: The amount of carbon in the soil and how this changes with land management can contribute to the quantification of the climate regulation service as it measures one part of the climate regulation service. There are other factors that should be included such as above ground biomass and sources of other greenhouse gases (GHG).

There are data at a 1km grid scale of soil carbon stocks in GB (Bradley *et al*., 2005) and this has recently been updated to support the estimation of GHG emissions at a regional level (Defra/EA, 2009) however this data would not be at a fine enough scale within the pilot areas to enable an estimate to be made which would change with land use/land management change. There are also data from the National Soil Inventory (Bellamy *et al* 2005) for which samples have been taken within the pilot areas on two occasions (1980 and 2003). However, this inventory was not designed to estimate soil properties at the local scale so trying to estimate soil carbon concentrations and changes in carbon within the pilot areas from this data is not valid. The change in carbon in the soils could be modelled within the pilot areas using one of the many process models available such as ROTHC or CENTURY but these can only be run at the scale of the data available (see section on modelling) and also are not designed to model high carbon soils; given the dominance of peat soils in the pilot areas these models are unlikely to be applicable.

Haines Young *et al*., (2010) also looked at carbon stocks and sequestration service and used the Bradley *et al*., (2005) 1km grid map to make their BBN spatially relevant and highlighted several problems with this dataset including the fact that organic carbon is only estimated to 1m depth and that only the soil carbon is considered, not that that occurs above ground

Using the indicator **Carbon in woodland** to quantify the carbon sequestration function: Detailed maps of woodlands are available for all of the pilot areas (Smith, 2005) including all woodland larger than 2ha and wider than 50m. These could be used to estimate the carbon stored in the woodlands within the pilot areas when combined with a measure of the woodland age structure. However the change in areas due to at least some of the land use/land management changes being considered in these areas would fall below the threshold of the mapping (i.e. <2ha or narrower than 50m) so would not be reflected in changes in the mapping. These maps are produced every 10years.

e) Food

Using the indicator **Production of meat (lamb/beef)** to quantify the food provisioning service: The production of meat is available at a regional scale from Defra statistics but this would not be useful for the pilot areas as it would include areas outside the pilot areas where changes are being instigated. Another way to estimate this would be to use the density of breeding ewes (with some measure of number of lambs per ewe) and density of breeding cattle (datasets available on a 1km grid). These datasets have some problems in that the information is not available in some areas particularly within the Dartmoor pilot area. Secondly, they are estimated in such a way that it would be difficult to determine whether changes had occurred due to the local decrease in stocking rates on some farms. Yet a third way to estimate the amount of production would be to use the area of grassland for grazing within the pilot areas with some estimate of “typical” stocking rates for the areas. This would introduce considerable uncertainty into the estimates. The best way would probably be to access the Defra survey data at the individual farm level identifying those farmers within the pilot areas so a detailed inventory of animal numbers could be made. This would then give more precise estimates of the production of the pilot areas and changes in stocking density would be reflected in subsequent estimates.

6. A way forward to quantify the ecosystem goods and services for the pilot areas

a) Current delivery

We have identified in this report that quantifying ecosystem services is complex and imprecise, we cannot quantify the services directly but need to consider the functions driving the delivery of the services and all the factors that determine those ecosystem functions. It is apparent that the monitoring systems currently in place are not sufficient to allow the quantification of ecosystem services and their changes. To be able to quantify the ecosystem services currently being delivered by the pilot areas and to monitor how these change with changes in land management requires the use of modelling based on data already available supported by the collection of new datasets from a network of sites set up to monitor a number of critical properties of the pilot areas. The initial quantification of the current ecosystem services delivery will be imprecise but should identify those areas where the variability is large or the data particularly sparse or inaccurate – so that the monitoring network can be targeted at those areas for particular properties.

b) Change in delivery

Detecting change in ecosystem service delivery will be very difficult against a background of ad hoc measurements of, for example river flows, in the timescale of the pilot area project (3 years). Any new monitoring network would need to record the current situation for at least 5 years before any change in land management can be introduced if we want to be able to measure the effect of that change. So initially models will have to be used to predict change and to identify areas where the land management changes could be applied to increase and maintain the ecosystem service delivery for the pilot areas – however to use the models effectively there is still a need to collect a number of important variables to ensure that the models can be calibrated and validated. The monitoring network needs to be designed to be adaptable so that after the initial samplings new sites can be added and others dropped to ensure that the data collected is useful to improve the model predictions. Areas that have been predicted to change faster than others will need to be monitored more intensively in both space and time. It is important not to forget that the modelling and monitoring will be taking place in the context of a changing climate. The factors that will need to be monitored are, for example:

- Ecosystem /land use boundaries
- Soil factors
    - Organic matter
    - Biology
    - Structural stability (aggregate stability, erosivity)
    - Structure/architecture (bulk density/porosity)
- Ecosystem characteristics
    - NPP (net primary productivity)
    - Architecture (pattern and form)
    - Species richness
- Water factors
    - Flow
    - Quality
    - Sediment load

These will need to be part of any monitoring scheme, and measured at a scale and resolution appropriate to the scale of the management intervention.

7. Discussion and identification of gaps

In this project we have identified many ecosystem services, numerous datasets, and discussed the limitations of these datasets and those of modelling and monitoring. It is clear that some of the fundamental datasets that are required to estimate the state and change of the ecosystems service delivery are not available at the scale of the pilot areas. This is also true of the datasets that would be required to try to model the ecosystem services delivery. We have also identified that the monitoring currently being undertaken within the pilot areas would not be sufficient to determine changes in the ecosystem services delivery.

One of the major gaps in the data are soil data at a local scale. The national scale map for England and Wales (NATMAP) is based on soil association polygons (or map units). Each association represents a group of soil types that occur together in the landscape. The proportion of soil types (or series) within each association is known (at a national scale), but there is no spatial representation of these soil types. There are representative values of soil properties for each soil type (in some cases under a number of land uses) such as soil carbon content, soil pH, water holding capacity, bulk density etc. However as the soil types are not spatially explicit these soil properties are also not spatially explicit. Within Exmoor and Dartmoor some soil maps exist (covering less than a quarter of the pilot areas) mapping at the level of soil type ; these could be used to produce more detailed soil maps across the whole of the areas using digital soil mapping techniques. This would make the estimation of soil carbon stocks, peat areas, run-off estimation, erodibility etc. possible within the pilot areas albeit with a certain level of uncertainty as they will be estimated from derived data.

The use of visitor surveys to estimate cultural and amenity services has problems in relating the responses to the pilot areas – At present the questions do not allow the part of the national park visited to be identified (they ask if a national park has been visited – not where in the national park they visited). As those pilot areas within national parks do not cover the whole national park it would be useful to identify the pilot areas in the surveys to ensure the data is applicable

Derived map data appears to be produced on an *ad hoc* basis and will be of limited use in determining changes if it is not recalculated on a regular basis. For example to estimate how the aesthetic service changes with changes in land management the tranquillity map produced by the CPRE would need to be updated following the land management changes to understand the effect these have on this service. -

Monitoring needs to include soil biology as well as biodiversity (already being measured by Natural England. A recent Defra project has identified soil quality indicators which could be measured within the pilot areas (Black *et al*, 2008, Defra Project SP0529). A properly designed soil monitoring scheme could be set up across each of the pilot areas combined with current monitoring of river flows and water quality and biodiversity to ensure changes in all ecosystem services can be estimated.

i. Recommendations

- A detailed soil map should be produced for each of the pilot areas using a combination of soil survey and digital soil mapping.
- The Environment Agency data from the gauging stations and water quality sampling should be statistically analysed to investigate whether changes could be detected

within the pilot areas. Continuation of the network should be encouraged collecting data at shorter time intervals than at present.

- A model based on a Bayesian Belief Networks approach within a GIS framework to model the effects of land use /land management changes on ecosystem services should be built which can be applied across the pilot areas using a spatial scale relevant to the land use/land management changes to be instigated. The first ecosystem services to be included in this framework are those identified in this project as being important within the pilot areas (see Table 5) This would be based on a series of biophysical drivers (based on Haines Young *et al*., 2010) including:

    - Land cover – use the satellite derived land cover mapping from CEH (new version to be released in 2010)
    - Topography – use the 10m resolution DTM (Ordnance survey)
    - Soil – use the most detailed soil maps available (currently 1:250,000 soil association maps)- possibly enhanced by digital soil mapping
    - Climate – modelled output on 1km grid

  Along with other datasets specific to different ecosystem services.

- A monitoring network should be set up to address some of the gaps in the data and process understanding identified by Haines-Young et al., (2010) and this report. The network should consist of a number of sampling sites within each pilot area where a wide range of samples would be taken measuring land use, species richness, soil biology as well as other soil properties This network could be stratified by land use or by topography or based on a rectangular grid depending on the objectives. The network should be able to be adapted as areas of uncertainty are identified by the modelling and the monitoring.

- The home omnibus survey within MENE should be extended and spatially referenced so that visits and attitudes that specifically refer to the pilot areas can be measured.

- Once the above are in place trial land use/land management change interventions should to be made to gauge their effects

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Main Internet Resources:

National Statistics: http://www.statistics.gov.uk/hub/index.html
Lake District National Park: www.lakedistrict.gov.uk/
Exmoor National Park: http://www.exmoor-nationalpark.gov.uk/
Dartmoor National Park Authority: http://www.dartmoor-npa.gov.uk/
Environment Agency: http://www.environment-agency.gov.uk/
Natural England: http://www.naturalengland.org.uk/
The moors for the future partnership: http://www.moorsforthefuture.org.uk/
Met Office: http://www.metoffice.gov.uk/
Forestry Commission GB: http://www.forestry.gov.uk/

Appendix 1 Preliminary list of ecosystem services

Biodiversity	**Cultural services**
	• a wildlife-rich environment • inspiration through contact with landscape • mental and physical health • recreation and tourism • knowledge (traditional and formal) • education • spiritual and religious values • aesthetic values • social relations • sense of place • cultural heritage
	Regulating services
	• air quality regulation • climate regulation • flood regulation • erosion control • water purification and waste treatment. • disease control • pest control • pollination • natural hazard regulation (non-flood)
	Provisioning services
	• food • fibre • fuel • genetic resources • biochemicals, natural medicines, and pharmaceuticals • ornamental resources • fresh water
	Supporting services (underpinning ecosystem functioning)
	• nutrient cycling • soil formation • primary production • landform creation