A review of ecosystem service mapping within Scottish Government RESAS-funded research

Aitkenhead, M.J., Black, H.I.J., Squire, G., McLeod, K., Hastings, E., Troldborg, M., Aalders, I.H., Towers, W., Lilly, A., Brown, I., Coull, M.C., Castellazzi, M., Matthews, K., Baggaley, N.J.

The James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH

matt.aitkenhead@hutton.ac.uk

01224 395257

Executive summary

This report provides a review of recent and ongoing work relevant to ecosystem service mapping in Scotland. We have provided a reference resource for future research and a list of example methodologies used in this area, while at the same time demonstrating the depth and breadth of the work being carried out. Individual pieces of work have been summarised and their relevance to ecosystem service mapping in a particular policy area and service type given. An assessment of each has been carried out in relation to a number of knowledge frameworks, with scoring of the suitability of each framework given using expert judgement of the relevance of the mapping to the suitability criteria of each framework. This has allowed us to identify the suitability of individual pieces of work in relation to knowledge frameworks, and to provide a comparison in relation to the utility for informing policymakers. We have also identified key data and knowledge gaps and identified likely priority areas of work for the future.

Relationships between services types and policy areas

Strong relationships between some ecosystem service-relevant mapping and policy area combinations are visible within the research reviewed. This is partly due to the nature of the ecosystem services, which are, or are perceived to be, more closely related with certain purposes or requirements. There is also evidence that some ecosystem service types are less likely to be related to certain policy areas.

There is good data availability and understanding for biodiversity- and community-related research associated with Cultural services, but less so for other work relating to these services. There is also evidence here for good data and understanding for Natural Capital & Supporting, Provisioning and Regulating services except in the areas of biodiversity and recreation. This broadly agrees with the cultural divide concept of Norris et al. in the UK NEA, which we give here in revised form:

- Good mapping, monitoring and modelling is available on **biodiversity and recreational** activities associated with cultural services, but not on the services themselves;
- Good mapping, monitoring and modelling is available on Natural Capital & Supporting services and on Provisioning and Regulating services, but not on the **biodiversity** underpinning these or on the **recreational activities** dependent on them.

Frameworks

We have made use of several knowledge frameworks for handling ecosystem service-relevant information in this review. Overall, we have found that none are perfect. There is also evidence that there will never be a ‘perfect’ framework for handling ecosystem knowledge, due to the constantly-changing landscape of information and requirements. However, we also found that there is a strong need for the development and/or adoption of a framework for handling spatial data relevant to ecosystem services in Scotland, which is accessible to all and which can be used to facilitate the science and policy development that needs to be carried out.

Data integration and spatial representation is a major issue that needs to be addressed at multiple levels. Visualisation is only one reason for spatial representation of ecosystem services and associated factors; the main reason is to allow relationships with other descriptors of the landscape

to be identified and described and for this reason some kind of framework, even if it is not perfect, is required.

Natural Capital and Supporting ecosystem services have been well mapped across Scotland, but ecosystem service frameworks do not handle the information about these types of service as well as they do for Provisioning and Regulating services, for which they appear more clearly designed. Frameworks appear less suited for managing Regulating services if they relate to the Low Carbon Economy and Sustainable Food Production policy areas. Regulating services that relate to Sustainable Water Management and Halting Biodiversity Loss policy areas are better handled and represented. We see that mapping work relevant to Regulating services tends to also fit better within the frameworks designed for managing multifunctional landscapes if this work is itself relevant to policy areas that are more normally associated with Regulating services.

Overall, if mapped work is categorised by ecosystem services and policy areas that are more obviously aligned with one another, existing frameworks tend to be more suitable for the understanding of that work. We have also identified that a relationship exists between where a body of work lies in terms of ability to inform decision-making, and how well it fits into ecosystem frameworks that can integrate it with other information for discussion and explanation. This leads to the conclusion that ecosystem service mapping should consider the criteria used to assess knowledge frameworks at an early stage, to ensure better suitability and utility of information.

Trade-offs, synergies and uncertainty

We could not find many pieces of work relating to trade-offs and synergies between services, or between policy areas in Scotland. Those that were identified related more to trade-offs than synergies.

The handling and quantification of uncertainty is seen to be a priority in future work in ecosystem service mapping. Lots of the existing research and data available are secondary to ES, and were developed for other purposes, meaning that uncertainty quantification is not standardised (and also that the fit between the work and the service is not always as clear as it could be).

Concerns surrounding the abuse or misuse of data acquired from specific sites means that often this information exists but cannot be used or made available at the level of detail to which it is present (e.g. land management data merged to the postcode address level in IACS data).

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1. Introduction

1.1. Objectives

In this Introduction, we provide an overview of the current state of the art in relation to ecosystem service-related mapping, and demonstrate how research in Theme 1 ("Scotland's environmental assets, biodiversity and ecosystem services are identified and valued to inform decision making") of the Strategic Research Programme fits into this. We also provide a rationale for the work and explain its purpose and overall goals, and give the specific objectives of the review, which are as follows:

- To provide a reference resource for future research and ecosystem service mapping and valuation, by allowing interested parties to determine what ecosystem service mapping information already exists and who are the people working in their field of interest.
- To provide baseline data and relevant information about methodologies for future work in ecosystem service mapping.
- To demonstrate the work (done and ongoing) of relevance to ecosystem service mapping, and to demonstrate the capabilities of researchers whose work lies within Theme 1 or is closely relevant to that Theme. It is important to highlight at this stage that the mapping work investigated is predominantly not of ecosystem services themselves, but of environmental characteristics of relevance to ecosystem services. This is an important distinction, as it would be misleading to state or imply that ecosystem services have been mapped for Scotland.

1.2. Rationale

The data used to produce maps of ecosystem services has a strong impact on the nature of these maps, particularly if it was not acquired for the purposes of ecosystem services mapping in the first place. Naidoo et al. (2008) provided a review of theory, data and analysis behind ecosystem service mapping. They showed that data availability was a key restriction to the development of global maps of ecosystem services. This paucity of data at a global scale is likely to be less of an issue at national levels for some countries, particularly those that have developed good-quality national datasets of environmental characteristics. However, the interpretation and integration of data to produce maps of ecosystem services is still an issue. Martinez-Harms & Balvanera (2012) carried out a review of different ecosystem service mapping approaches, using multiple criteria for comparison. They showed that the majority of work to date has used secondary data (i.e. collected by someone else and already available), and that is has been applied at coarse resolution and with little validation or ground-truthing. They argued that better linkages between social and biophysical processes are required to improve ES mapping.

Eigenbrod et al. (2010a) showed that the use of secondary data and proxy information has been predominant in ES mapping, rather than primary data obtained by the researcher. This has led to generalisation errors and often the inability to communicate the derived ecosystem service information using consistent language, as the results are highly dependent on the information available. These errors are compounded when single ecosystem service maps are integrated into maps of bundled services or trade-offs between services. Another work by the same researchers showed that often poor relationships exist between primary and secondary data, although proxy data can be used for identifying broad trends in ecosystem service change (Eigenbrod et al., 2010b).

These works indicate that more targeted primary data need to be obtained if ecosystem service mapping accuracy is to be improved.

While issues with the use of secondary data are well-known, their use is often the only option and does produce useful information. Zhan et al. (2009) showed that advanced statistical and modelling approaches (in this case neural networks) can be used to develop models of relationships between multiple indicators and types of ecosystem service 'zone'. This demonstrates the possibility of mapping ecosystem services, and relationships between services, based on integrated secondary datasets and other data such as remote sensing.

Several examples of the use of secondary data for ecosystem service mapping show how effective it can be. Civantos et al. (2012) used bioclimatic envelope models to predict the distribution of a number of vertebrate species associated with pest control, under different climate change scenarios. Their work highlighted the changes in pest impacts in areas dependent upon agriculture caused by the likely reductions or increases in populations of the species providing pest control. Van Wijnen et al. (2012) integrated several properties of Dutch soils, compared to reference values of those properties, to produce a proxy indicator map for pollution attenuation. They also demonstrated that the approach used, which involved stepwise regression analysis of multiple parameters, could be applied to mapping other services. The approach used was based on the digital soil mapping techniques described by McBratney et al. (2003). Siaulys et al. (2012) carried out ecosystem service mapping of the marine environment in relation to fish feeding grounds in the Baltic, using integrated data on prey distribution and importance. Lavorel et al. (2011) carried out a study analysing the simultaneous provision of ecosystem services. They related plant functional traits to single services and, from this and other information, generated maps of multiple service provision. This is another example of the many ways in which translation from environmental biophysical characteristics to intermediate or final services is possible.

The majority of the work demonstrated in the later chapters of this review provides ecosystem service-relevant maps that have been derived from proxy or secondary data. There are several reasons why this is so, including some that can be considered strengths and others that may be weaknesses. In relation to other nations Scotland has a relatively long history of mapping and monitoring. In recent years a large number of spatial datasets have been developed for a range of purposes in Scotland, including soil surveying, topographic mapping, land cover mapping and agricultural policy monitoring objectives amongst others. As a result, we are relatively rich in terms of legacy data resources, many of which can be used not only for their initial purpose but also for many others, including ecosystem service mapping. Ecosystem service mapping research therefore relies heavily on this secondary/proxy data, and while much of these data are useful, it was often developed for a specific purpose that does not always match very well with the development of new maps.

One important type of existing dataset that is often used to derive information about ecosystem services is land cover. Burkhard et al. (2012) described an approach linking spatially explicit landscape units to ecosystem service parameters, and demonstrated the utility of this approach for mapping ecosystem service supply and demand. Key to this work is the integration of land cover information from a wide range of sources. Haines-Young et al. (2012) also described an approach to mapping indicators of ecosystem service supply, and applied this approach across the majority of

Europe. This work relied on underlying assumptions regarding the relationships between land use, land use change and ecosystem service supply, and also produced information about the trade-offs taking place between services in different areas.

The links between land cover and ecosystem service supply in Scotland are just as strong as in other parts of the world. Land cover mapping in Scotland is a prime example of the strong mapping and monitoring activities that have been carried out, as mentioned above. High-resolution and accurate land cover maps have been developed for Scotland for over twenty years, from the LCS88 (Land Cover of Scotland 1988) to more recent inclusion within the CLC2006 (CORINE Land Cover Map for 2006) of Europe and the LCM2007 (Land Cover Map 2007) of the UK. Within this review, we demonstrate several examples of using land cover maps with other datasets to produce ecosystem service maps.

Remote sensing data is also a useful source of information about landscape character providing, as it does, the most direct and obvious approach of monitoring large areas. One of the advantages of using remote sensing data is that it is now relatively cheap compared to field survey methods and can provide information about wide areas rapidly and consistently. Ayanu et al. (2012) reviewed the potential of remote sensing to quantify and map selected ecosystem services and concluded that remote sensing provided opportunities for mapping a variety of ecosystem services. Krishnaswamy et al. (2009), for example, demonstrated the utility of remote sensing-derived data to provide proxy information for ecosystem service mapping in a forest environment. However, challenges to the use of remote sensing include the fact that it cannot be the sole source of data and that ground-based surveys are still required to provide (A) functional descriptions of the landscape being viewed, and (B) ground-truthing of maps that are generated.

However, this is an issue that can be overcome to a large degree if a multidisciplinary approach is taken. Vihervaara et al. (2012) demonstrated the effectiveness of integrating information from a variety of sources, including field surveys, remote sensing and biotope descriptions, to inform land management and achieve multiple land use objectives. Sutton & Costanza (2002) produced a global map of estimated total ecosystem service supply from a combination of remote sensing imagery and land cover maps, which correlated well with maps of environmental sustainability. The potential of linking remote sensing imagery with other datasets to produce estimates of single or multiple ecosystem service provision is worthy of exploration, although a proper understanding of the relationships between environmental character and service supply is vital to developing information about the impacts of management and planning decisions. Locatelli et al. (2011) emphasised the importance of ecosystem service flows, with the spatial distribution of service sources and sinks being important to the identification of processes and functions that are key to specific services and without which their supply would be threatened (e.g. forests in catchments of hydroelectric schemes). This highlights the need to be able to trace back from end benefits, through final services, to the underlying functions and processes that sustain these services.

The use of remote sensing for ecosystem service mapping in Scotland has, historically, been through the development of land cover and other landscape character maps that have then been applied to ecosystem service mapping as secondary data. Ecosystem service mapping directly through the use of remote sensing has not been carried out, although there are efforts underway to promote this type of activity. Many of the ecosystem service maps and datasets demonstrated in this report have been developed using information derived from remote sensing, and the importance of Remote Sensing (RS) as a data source for mapping Scotland's ecosystem services is covered in the Conclusions.

The primary target audience of this review of ecosystem service mapping in Scotland is the Scottish Government and affiliated organisations; our intention is to provide a document that provides an overview of the ecosystem service mapping work for reference purposes and that also demonstrates the breadth and depth of recently-completed and ongoing work. The review will allow a better understanding of the current 'state of the art' in relation to ecosystem service mapping in Scotland, and will highlight areas of progress and areas of future development.

We have attempted to maximise the value and usefulness of this review wherever possible. This includes the implementation of an assessment framework allowing the maps and information to be described in a common manner and in relation to one another, rather than being considered as single, unrelated outputs. One of the key considerations that must be made when mapping ecosystem services is the manner in which the services themselves, and the underlying environmental processes and functions interact. We have pointed out in the literature review above that an understanding of the interactions between services is extremely important. In addition to identifying relationships between the underlying processes and functions and the services themselves, we have attempted to answer the following questions for every service mapping demonstrated in this work:

1. How was this work carried out?
2. What use is this map or dataset by itself?
3. What limitations does it have (e.g. scale, level of detail, uncertainty, appropriateness for multiple uses)?
4. How does it relate to the other work demonstrated here?
5. What additional questions could be answered, or problems solved, by combining this new knowledge with other mapping work in the review or with other data/information/knowledge?

This report is divided into six Chapters, of which this Introduction is the first. Chapter 2 provides an overview of work relating to the underpinning Natural Capital and Supporting Services within Scotland, and is subdivided into the broad areas within which this capital and services lie (e.g. geology, soil, air etc.). Chapter 3 covers the other ecosystem services types in their own sub-chapters, each of which is subdivided into sections covering the main policy objectives relating to ecosystem services (low carbon economy, halting biodiversity loss, sustainable water management, sustainable food production, communities better connected to the land). Chapter 4 covers Synergies and Trade-offs between different ecosystem services, while in Chapter 5 we review current understanding of Knowledge Gaps in relation to different service types and policy objectives. Chapter 6 provides Conclusions to the review.

Within the chapters, mapping of ecosystem services in Scotland has not been carried out in relation to every policy objective, or to the integration of multiple services. Tables 1.2.1 and 1.2.2 show where maps and/or mappable information have been given in this review in relation to the intersection of service types/interactions and these objectives. Other work about policy areas and ecosystem services has been described in this review, but has not been considered 'map-related'. As can be seen, mapping-related work relevant to Regulating services has been carried out, or is ongoing, across all policy areas, while work on the mapping of Cultural services has only been done in relation to Communities better connected to the land. Similarly, work on knowledge gaps appears to be lacking in all areas except for the integration of ecosystem services. Reflecting the 'incomplete' structure shown in Tables 1.2.1 and 1.2.2, some chapters have more information in these subsections than others.

Table 1.2.1. Combinations of services types and policy areas found in the review.

Policy area	Provisioning	Regulating	Cultural
Low carbon economy	Land excluded from woodland expansion under biophysical constraints and national designations and policies which impose constraints. Suitability for biomass crops Map of commercial & natural forestry Distribution of biofuels in Scotland Energy from crops, timber and agricultural residue Hydropower suitability	Potential carbon storage of Scotland's cultivated soils. SNH carbon richness map Soil carbon stock Aboveground biomass map Simulated changes in soil carbon stocks between 2010 and 2019, assuming a high level of disturbance on afforestation under different mitigation strategies Probability (%) of peat in Scotland being vulnerable to erosion under given current circumstances	Landscape sensitivity for the northern Highlands derived from combined scores for a range of visual receptors Map of designated blanket bogs with degradation status
Halting biodiversity loss	Relationships between broad habitat type and species abundance of Scottish medicinal plant species Abundance distribution of Scottish medicinal plant species within 10km squares	Risk map of soil erosion	RAMSAR & Designated Areas maps Impact of heather moorland restoration on plant species community
Sustainable water management	Maps of water bodies extent and quality	Map of the relative proportion of sediment and attached pollutant in overland flow that is delivered to receiving waters Modelled total annual load of sediment eroded from agricultural and forestry land to surface and ground waters Assessment of iron & aluminium leaching risk for Scotland Integral modelled likelihood of river nutrient demand concentrations meeting chemical water quality standards River water bodies that were assessed as being at risk through WFD environmental objectives	Water recreation (canoeing, fishing etc.)
Sustainable food production	Changes to distribution of 'prime' land as defined by Land Capability for Agriculture using climate data for 1958-1978, and the 2050s using the UKCIP02 medium-high emissions scenario Distribution of points where predictions of soil compaction risk and uncertainty have been made with Bayesian Belief Network	Soil nitrification potential (dry weight basis) in Scotland Soil AOA abundance in Scotland Soil AOB in Scotland Liver fluke mapping in the UK	

	approach 2050s change in Summer runoff for the q3 and q16 climate model PPE members LCA classes for Scotland (excluding soil-climate interactions) under different climate change scenarios Projected 2050s drought risk class map for Scotland for wheat and potatoes, under different climate change scenarios Livestock stocking rates in 2009		
Communities better connected to the land			Number of sites interpreted as having historic interest reported by (a) landscape character polygon, (b) 1 km x 1 km grid square Number of forces for change as identified in the Landscape Character Assessment reports

Table 1.2.2. Combinations of services types and environmental factors found in the review.

	Geology	**Soil**	**Air**	**Water**	**Biodiversity**	**Habitats**	**Other**
Supporting		Map of soil types Map of mineral, organo-mineral & organic soils Map of metal binding capacity for Fife Risk map of soil erosion, using a rule-based approach Risk map of soil erosion, using a process-based approach Elemental status of Scottish Soils compared with soil-based risk assessment	Map of nitrous oxide emissions	Map of groundwater nitrate contamination risk Distribution of HOST classes, a classification of the dominant pathways of water movement through soils and substrates Mean annual precipitation, evapotranspiration, runoff and nitrate concentration for the observed baseline (1961–1990) climate for Scotland Change in modelled seasonal runoff for 2050 climate based on model runs of the GCM–RCM 11-member Perturbed Physics Ensemble Modelled annual average overland flow (mm) for Scotland (1989 to 1998)	Effects of land management on insect nutrient cycling functional groups Core areas for conservation of aquatic vascular plants, based on the distribution of 164 species Appraisal and Revision of Genetic Conservation of our Caledonian pinewood	The potential for native woodland in Scotland: the native woodland model Map of land suitability for native woodland Map of suitable land for forestry and Short Rotation Coppicing/Short Rotation Forestry	Suitability for wind farms using biophysical considerations
Natural Capital		Spatial distribution of C stocks calculated from soil			The impacts of changing land use on lichen diversity, and linking	Land uses on IACS registered land by LCA class Suitability map	Spreadsheet relating ES to multiple Scottish, UK and

		organic content (SOC), and potential losses and potential gains in SOC Distribution of potatoes and other fruit and vegetable crops that are normally irrigated based upon the baseline year of 2010			biodiversity data directly with ecosystems as mapped using the CEH's LCM2007, at the scale of river catchments Three decades of change in functional traits and functional diversity in a globally rare semi-natural grassland. Investigating national and regional-scale shifts	for forestry compared with Scenic Areas, National Parks and World Heritage Sites Suitability for housing development based on biophysical limitations Landscape change indicator applied to Scotland for the period 2001 to 2005 Development pressure indicator applied to Scotland for 2005	international policy directives

1.3. Methodology

1.3.1. Framework

Sheate et al. (2012) argue that the spatial representation of ecosystem services is vital for providing evidence during decision-making processes. They demonstrated a methodology for mapping ecosystem services that included analysis of the relationships between individual services and development of stakeholder engagement approaches, in order to allow improved definition of services and service interactions. While the importance of spatial representation may be more true for services that are easily mapped than for others (particularly cultural services), it is undoubtedly true that any cultural services, regardless of type, need to be related to the landscape in which they reside.

Ecosystem Service mapping can help to assists planning and management decisions by visualising where trade-offs or hot-spots may occur or in filtering in/out important areas to maintain certain goods and services (e.g. Towers & Sing, 2012). Frameworks are therefore needed that can integrate available knowledge, thus allowing stakeholders to make use of the secondary data that they already have in an optimal manner. Tallis et al. (2008) and Isely et al. (2010) developed an online tool (INVEST Integrated Valuation of Ecosystem Services Tool) which can be used as a framework for the processing and integration of information for the development of ecosystem service maps. INVEST is intended primarily as a tool for informing decisions about planning and land management, but can also be applied to the development of ecosystem service maps and the valuation of services.

Guerry et al. (2012) applied the INVEST tool to a test marine area around the west coast of Vancouver Island in Canada, and demonstrated its utility for informing decision making for marine spatial planning. Goldstein et al. (2012) discussed methods of informing decisions that involve trade-offs between services, and demonstrated the application of the INVEST tool in evaluating the implications of a range of planning scenarios for a large private landowner in Hawaii. The tool allowed trade-offs between specific services to be explored, and gave a practical demonstration of how planning tools can incorporate ecosystem service considerations.

Other frameworks and mechanisms exist, although they are often designed for specific purposes or biomes. Rees et al. (2012) investigated the potential for the development and management of Marine Protected Areas, which are a mechanism for the conservation of marine ecosystem services, to be informed by better understanding the relationships between services, processes and functioning of marine species. They showed that mapping of ecological function onto ecosystem services cannot be done directly, due to the complexity of the relationships between the different species and processes. Individual functions relate to more than one service, and also to other functions, making it difficult to describe the trade-offs between different services. Egoh et al. (2011) also showed that linkages between biodiversity conservation and ecosystem service supply can be formed for grassland areas, when determining conservation targets and plans. The identification and definition of ecosystem service co-benefits are key to this type of planning.

Chen et al. (2009) used a GIS-based framework to map the economic value of ecosystem services at a regional scale in China, and showed that such a framework could be used to inform decisions on resource and environmental management. Maynard et al. (2011) described an ecosystem services framework applied to planning and environmental management in South East Queensland, Australia. This framework has been incorporated into planning policy in the area, and relies on expert participation and subjective expert judgements on the relationships between relevant parameters and services. It also includes the ability to revise baseline datasets and include new decision-making information, and so can incorporate changes required by new circumstances and policy objectives. The importance of integrating relatively simple expert-based relationship understanding at an early stage in the development of an ecosystem services framework is worth highlighting; the complexity of the overall system may require more sophisticated approaches eventually but if simple relationships can be captured at initial stages then they provide a foundation for later developments in frameworks for understanding ecosystem services and including them in planning policy.

For many examples of service/function/process mapping that have been described in this review, we have assessed the mapping in relation to existing frameworks for understanding and managing multi-functional landscapes. Information on these frameworks has been taken from ongoing work in the James Hutton Institute by a group of researchers examining frameworks within Theme 1 (Squire, pers. comm.). This group was formed in parallel to other groups working on for example indicators, biodiversity, decision making, and scenarios, in order to develop ideas on a potential generic framework for understanding and managing multi-functional landscapes. Initial discussion by a range of experts concluded that any framework for use in Theme 1 should satisfy the following requirements:

- A description of ecosystem services and their social, environmental and economic components;
- Based on an understanding of the ecological mechanisms linking ecosystem services, the ecological processes they depend on and the underlying biodiversity and management;
- Operational over a range of spatial and temporal scales (field, country);
- Cyclical and iterative;

- Participatory throughout, with explicit mechanisms to involve stakeholders and to allow feedback and evaluation;
- Contains a tool or tools to guide or support decision making for both policy and for management and through this facilitate communication and knowledge exchange;
- Structured as to allow knowledge gaps and uncertainty to be determined.

Many frameworks for examining environmental issues were already known to exist. A range of frameworks were therefore selected on the basis of being considered likely candidates to satisfy the above list of requirements (see below). Participants in the study had themselves developed, or had experience of, frameworks that had been constructed to satisfy one of more of the purposes set down above. These frameworks ranged from general to specific and theoretical to practical. Many (but by no means all) were cyclical and iterative and included some capacity for decision making and some involvement by stakeholders. The frameworks, with key references, are as follows:

- Risk Framework Frameworks (Ruitenbeek & Cartier, 2001; Dietz et al., 2003; Olsson et al., 2004; Folke et al., 2005; Plummer & Armitage, 2006).
- UK NEA (UK National Ecosystem Assessment) (UK NEA, 2011).
- MEF (Model Ecosystem Assessment) (Aspinall et al., 2010).
- DPSIR (Drivers-Pressures-State-Impact-Response) (Rapport & Friend, 1979; OECD, 1993; Berger & Hodge, 1998; Smeets & Weterings, 1999; EEA, 2003; Bell & Morse, 2008; Svarstad et al., 2008; Rounsevell et al., 2010; Atkins et al., 2012).
- MA (Manual for Assessment practitioners).
- TEEB (The Economics of Ecosystems and Biodiversity) (2010).
- Adaptive co-management.
- Resilience Alliance (Resilience of socio-ecological systems) (Gunderson & Holling, 2002; Holling & Gunderson, 2002; Carpenter, 2003; Elmqvist et al., 2003; Peterson et al., 2003; Olsson et al., 2004; Walker et al., 2006).
- Landscape Functions.
- Integrated Assessment – climate change (Forrester, 1961; Forrester, 1969; Meadows et al., 1972; Rotmans at el., 1990; Rotmans & VanAsselt, 1996; Ewert et al., 2009).
- Institutions of Sustainability (Hagedorn et al., 2002; Hagedorn, 2008; Prager et al., 2011).
- Participatory GIS (Elwood, 2006; Dunn, 2007).
- Environmental risk assessment of novel crops (EFSA, 2010).
- GM coexistence (Squire, G.R., 2005; Messean et al., 2009).
- Sustainable crop systems.
- DEXiPM Integrated Management (Bohanec, 2012).

A list of criteria was drawn up to evaluate and compare these frameworks and to assess whether any of them would be suitable in total or in part for Theme 1. This list is given in Table 1.3.1 below:

Table 1.3.1. List of questions used to assess frameworks relevant to ecosystem services.

Topic	No.	Question
Communication and Knowledge Exchange	1	Who is the target audience (e.g. policy makers)?
	2	How clear and comprehensible is it?
	3	How familiar is it to your audience?
	4	Is communication with stakeholders explicit?
Decision making	5	How useful is it for describing decision making?
	6	How useful is it for supporting decision making?
Framework description	7	Does it assess relationships between stocks and flows?
	8	Does it include/describe drivers and pressures?
	9	Does it describe dynamics, thresholds and disturbance?
Scale	10	At what spatial scale can the framework be applied?
	11	At what temporal scale can the framework be applied?
	12	How useful is it for cross-scale spatial analysis?
	13	How useful is it for cross-scale temporal analysis?
Functions	14	How useful is it for valuing services (monetary/non-monetary)?
	15	How good is it at linking ecosystem function and biodiversity?
	16	Can it be used to assess ecosystem service trade-offs?
	17	Does it capture abiotic and biotic components of functions?
	18	Does it relate ecosystem services to well-being?
Internal assessment	19	Does it support a participatory approach?
	20	Does it incorporate feedback and evaluation?
	21	Is there any consideration of uncertainty?
	22	Does it include indicators?

It was evident from the results of the framework assessments (Table 1.3.2) that no single framework scores highly for all or even most criteria, indicating none could be used as they stand to satisfy the demands of Theme 1. However, the fact that the assessments produced different results for each framework indicated that it could be possible to assess individual pieces of work (i.e. ecosystem service mapping) in relation to a common set of frameworks, thus allowing differences between both the frameworks and the mapping work outputs to be identified and highlighted.

Some of the above questions are more relevant than others to specific mapping work that has been carried out, meaning that a low or high ranking in relation to some questions may not mean that a framework's assessment is unsuitable or suitable for representing the mapping in question. In order to provide an assessment of framework suitability in relation to each mapping work given in this review, we have assigned a value to the relevance of each of the above questions, on a scale of 1 (irrelevant) to 3 (highly relevant), to each study (Appendix A). This value assignment is to a certain extent subjective and depends on available information about how and why the work was carried out. We then multiply the 'relevance' value for each question by the weighting given in Table 1.3.2 for that question (for the framework being assessed), to achieve a list of weightings between 1 and 9 for each framework. These weightings are summed across all questions to produce a final score for each framework.

As there are 22 questions in the above table, this implies a score in the range between 22 (low relevance) and 198 (high relevance). Scores for frameworks in relation to different ES-relevant map are given in later sections of this report. As none of the frameworks received a score of 3 (high relevance) for all questions, the maximum score in each case is less than 198. The score given for each framework therefore relates to both the overall relevance of the framework itself as a tool for managing multifunctional landscapes, and the relevance of the mapping that has been carried out. For some of the questions used to assess a framework, the assessment response has been qualitative rather than quantitative. In these cases, the range of the response (e.g. is it restricted to one group of stakeholders, or useful for all groups) has been used to provide a value from 1 to 3. Table 1.3.2 gives the weightings given for each of the 16 frameworks assessed.

Table 1.3.2. Assessment weightings given to frameworks relevant to ecosystem services.

Question	Risk framework	NEA	MEF	DPSIR	MA	TEEB	Adaptive co-management	Resilience Alliance	Landscape Functions	Integrated Assessment - climate change	Institutions of Sustainability	Participatory GIS	Environmental risk assessment of novel crops	GM Coexistence	Sustainable Crop Systems	DEXiPM Integrated Management
1	2	2	1.5	2	2	2	3	3	2	2	2	2	2	2	2	3
2	3	3	2	3	3	1.5	2	1.5	2	2	2	2	3	2	2	3
3	3	3	2	3	1	2.5	2	1.5	3	3	1.5	1.5	3	2	1	2
4	2	1	3	3	2	1	3	3	2	3	3	3	2	2	2	3
5	3	1.5	3	2	2	1	2	2	2	2	3	2	1	1	1.5	1.5
6	3	2	3	3	2.5	2	3	2.5	2.5	3	2	3	2	3	2	3
7	1.5	2	2	2	2	2	2	2	2.5	1.5	1.5	1.5	2	1.5	3	1.5
8	2	3	2.5	3	3	1	2	3	2	2	2	2	2	1.5	3	2
9	2	1.5	2	1	2.5	1	2	3	1.5	3	2	1	2	1.5	3	1
10	3	3	3	2	3	3	3	3	2	3	2	2	2	2	2	2
11	3	3	3	2	2	2	3	3	3	3	2	2	2	2	2	2
12	2	1	3	1	2	1	1.5	3	2	3	3	2	2.5	3	2.5	1.5
13	2	3	3	1.5	2	1	1.5	3	2	3	3	2	2.5	3	2.5	1.5
14	1.5	3	2	1	2	2.5	2.5	2.5	2	2	1	1	1.5	1	1.5	2.5
15	2	2	1.5	1.5	1.5	1	2.5	2.5	2	2	1	1.5	2	1	3	1.5
16	3	1.5	3	3	2	1.5	2.5	2.5	3	2	2	2.5	1.5	2	2	3
17	3	2	2	1.5	1	1	2	2	3	2	1	2	3	2.5	3	3
18	1.5	3	3	1	3	2	2	2	2	2	2	2	1.5	2	2	3
19	2	1.5	2.5	1.5	2	1.5	3	3	2.5	3	3	3	1	3	1	3
20	3	3	3	1.5	2	1	3	3	1.5	3	3	3	2.5	3	1	3
21	3	1	2	1	3	1	3	3	1.5	3	2	1	3	3	2	1.5
22	3	1	1.5	3	3	1	2.5	2.5	2	2	2	3	3	2	3	3

1.3.2. Integration of data

So what is the current state of affairs, and how do we take it forward? Hermann et al. (2011) reviewed the state of the art in defining, classifying, quantifying, mapping and valuing ecosystem services. They emphasised the importance of further research into the integration of new and current knowledge about ecosystem services into environmental planning and land management decision frameworks. Haygarth and Ritz (2009) argued for the development of better resources for the communication of the value of soil-related ecosystem services to planners and policymakers in the UK, including map and dataset generation and the setting up of long-term monitoring networks. Meanwhile, Daily & Matson (2008) identified three areas in which advances need to be made in order to allow more informed decisions about investment in natural capital and ecosystem services. These are: (1) the science relating underlying functions and processes to ecosystem services, and the mapping of these services; (2) the design of appropriate financial, political and legal frameworks to accommodate this science; (3) improved methods of implementing these frameworks across different biophysical and socioeconomic conditions.

1.4. Policy areas

While it is important to provide a linkage between a piece of mapping work and the services that it is most relevant to, it is also important to identify which policy areas are relevant in each case. Throughout this review, we have related ecosystem service-relevant mapping to policy areas within each sub-chapter, with the policy areas themselves being taken from stated land use strategy objectives:

- Low carbon economy
- Halting biodiversity loss
- Sustainable water management
- Sustainable food production
- Communities better connected to the land

The relationships between environment and services can be explored in a variety of ways, of which the most directly effective is often simply to ask people for their opinion. Raymond et al. (2009) demonstrated the effectiveness of expert assessment interviews to produce information about the relationships between environmental parameters and stakeholder perceptions. This approach is useful for developing non-monetary valuations of ecosystem services and can be applied to mapping the valuation of those services. Koschke et al. (2012) used an expert assessment approach to integrate multiple criteria with different weightings, in order to demonstrate the impacts of land cover change on ecosystem services. This work also explored the problems of making the ecosystem services concept relevant to planning processes. Swetnam et al. (2011) used a GIS approach to map the impacts of land cover change scenarios on ecosystem service provision, based on intermediate rules that integrated stakeholder and expert information on the land cover changes expected as a result of specific drivers with information about the possible spatial distribution of certain land cover classes. Several examples of ecosystem service mapping using stakeholder or expert knowledge have been given in later chapters. These have proved useful not only in terms of the end product in each case, but also in terms of the expertise gained in relation to stakeholder interaction. Very often a multidisciplinary approach is required to acquire all of the stakeholder information necessary to complete a piece of work in this way, and the experience of doing this has expanded levels of expertise in this area significantly.

In addition to understanding the relationships between processes, functions and services, the visualisation and communication of these links is vital for their use in planning and land management. Ericksen et al. (2012) used a framework distinguishing intermediate services, final services and benefits to quantify and map ecosystem services in Northern Kenya. In order to describe the supply of multiple services at any one point, services were bundled according to land use and geographical location prior to quantification. This bundling of services requires subjective decisions to be made regarding which services are being provided at each point, but also provides a potential method of categorising different parts of the landscape as supplying specific 'bundles' of services.

Chan et al. (2011) discuss findings that show that ecosystem services may be best integrated with management and conservation planning when considered as substitutable co-benefits (e.g. soil quality improvements as a result of plant species conservation), rather than as targeted benefits (e.g. attempts to improve soil quality through appropriate selection of plant species). This implies that ecosystem services could be substituted for one another in the planning process provided that their benefits are correctly quantified and that double-accounting is avoided. It also implies a greater need to understand and define the characteristics of, and relationships between functions, intermediate and final services and benefits.

1.5. Trade-offs

There is a need to understand not only the 'vertical' relationships when moving from biophysical parameters and processes to socioeconomic end-benefits, but also the 'horizontal' relationships, particularly when attempting to understand the trade-offs between services and/or benefits. Kroll et al. (2012) investigated the gradient of ecosystem service supply and demand between rural and urban areas in Germany. They showed that agricultural intensification in rural areas and increased urbanisation has resulted in changes to the gradients of different services over time. Potential implications of changing supply/demand gradients including changes to ecosystem services flows, a topic that is becoming more relevant but where several questions need to be answered. In particular, changes that have taken place to service supply over time are poorly understood. This is in part due to a lack of consistent and accurate information about historical land use change, forcing researchers to develop novel approaches to improve their understanding of past impacts of land management on ecosystem services. Dearing et al. (2012) for example used paleoenvironmental analysis of lake sediment to reconstruct information on a range of regulating services in a part of China over more than 200 years. This longer timescale allowed trends in regulating ecosystem service provision to be more thoroughly investigated in relation to socioeconomic and climate records, and to determine the sustainability or otherwise of existing management practices.

Haines-Young (2011) discusses the use of Bayesian Belief Networks as a possible method of representing relationships between ecosystem services and socioeconomic systems, and of developing map-based representations of ecosystem services that are of use to stakeholders and policymakers. Mehaffey et al. (2011) demonstrated an approach for integrating multiple spatial datasets to produce information required for spatial mapping of trade-offs between different ecosystem services. Key to the development of such a system is the incorporation of information that is at an appropriate scale and that is relevant – datasets must often be adjusted and reinterpreted to make them suitable for integration into such a framework. Lautenbach et al. (2012) contrasted the effectiveness of mapping ES indicators versus mapping ecosystem service supply directly, and also investigated the effectiveness of mapping the same services at different spatial scales. As different planning levels require different levels of scale and different types of information, it would seem appropriate to consider different spatial and informational scales when mapping services.

1.6. Valuation

Key to the inclusion of services within a planning framework is some form of valuation (both monetary and non-monetary), without which no comparison between different services and benefits can be made. The scale at which valuation is carried out varies, with some work at a national level. Shi et al. (2012) carried out a mapping and valuation of change to ecosystem services across China between 1999 and 2008. They considered not only the change in value spatially but also the total stocked value of services, thus allowing the full range of services to be considered. Jung et al. (2011) used an ecosystem service mapping approach to determine the loss of ES value in currency terms to South Korea between 1985 and 2005.

Sherrouse et al. (2011) demonstrated an approach to non-monetary evaluation of social values of ecosystem services, and showed how these evaluations could be statistically linked to landscape metrics. The potential for mapping the social ‘importance’ of ecosystem services using indices derived from landscape parameterisations is a potentially important step towards quantifying and mapping cultural as well as regulating, supporting and provisioning services.

2. Natural capital and supporting services

2.1. Introduction

This section aims to provide information on the Natural Capital and Supporting services that underpin all the other types of service. Examples of available information are presented and analysed to demonstrate the status and trends and their relevance to different policy areas.

2.2. Geology

"Geodiversity is the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes which form and alter them" (Gordon & Barron, 2013; from Gray, 2011). Gordon et al. (2012) discuss the importance of taking an ecosystem approach when integrating geodiversity into decision-making about the environment. In terms of natural capital, geology not only provides the underpinning physical basis for the landscape, but it also along with geodiversity has a strong influence on the nature and characteristics of the landscape. In terms of the value of geology for supporting services, it is vital for soil formation, nutrient and water cycling, the provision of nutrients and minerals for vegetation growth, and the intrinsic nature of many habitat types (Gordon & Barron, 2012). Gordon & Barron (2013) provide an inventory of the contribution of geology to ecosystem services, from which we have duplicated the information given in Table 2.2.1. with their permission.

Table 2.2.1. Inventory of the contribution of geology and geodiversity to natural capital and supporting services.

Ecosystem service	Service detail
Soil formation	The rate of soil formation through the weathering of rocks and other parent materials (including those derived from erosion and sediment deposition) is a key factor in providing a medium for plant growth and supporting habitats.
Photosynthesis	Photosynthesis produces oxygen necessary for most living organisms, and this process is only possible due to nutrients provided by mineral weathering of soil parent material.
Primary production	The assimilation or accumulation of energy and nutrients by organisms.
Biogeochemical cycling	The continuous natural circulation of vital elements (e.g. carbon and nitrogen), comprising exchanges between the atmosphere, geosphere and living organisms.
Hydrological cycling	The continuous natural circulation of water, comprising exchanges between the atmosphere, oceans, ice sheets, surface water and groundwater, is essential to support a wealth of other ecosystem services.
Rock cycling and geomorphological processes	Rock cycling and geomorphological processes support soil formation, habitat creation, transport of water, sediments and nutrients, and climate regulation.
Habitat creation and maintenance	Geodiversity provides the physical template to support a diverse range of habitats and species; geology, landforms and geomorphological processes (weathering, erosion, transport, deposition) influence habitat type, condition and diversity, as well as soil formation, flows of energy, water and nutrients. Landscape inheritance and geomorphological sensitivity affect catchment processes.
Waste disposal and storage	Geological formations and topography can offer suitable locations for waste disposal or storage and water storage. This includes landfill and storage of nuclear waste and carbon capture and storage in suitable geological repositories. Glaciated glens and deep rock basins can be excellent topographic locations for water storage for both drinking water and hydro-electric power, often facilitated by dams. Health benefits include reduced risks from safe disposal of wastes.
Building platform	Geology provides a platform for building and infrastructure (e.g. flat land on raised beaches or river terraces).

2.3. Soil

The concept of soil as a reservoir of natural capital is important within the Ecosystems Approach, and has been defined by Robinson et al. (2009) as "the stocks of mass, energy and their organisation (entropy) within soil". Mass within the soil can be compartmentalised into solid (inorganic material further subdivided into mineral and nutrients, and organic material further subdivided into organic matter and organisms), liquid and gas. Each of these mass components serves one or more roles. Energy in the soil falls into thermal (soil temperature) and biomass (chemical/biological energy). The "organisation" component of soil as natural capital covers the various structural aspects of the soil, including the physical and chemical structure/distribution, the distribution and organisation of the soil biology, and the larger-scale distribution of soil characteristics in space and time.

Lilly & Baggaley (2013) produced maps of potential changes in carbon stocks in mineral soils, based on observed median, minima and maxima for specific soil series in Scotland. Summary statistics calculated from national scale legacy data were used to make these predictions, which are dependent on distributions not only of soils but also of land management strategies across Scotland.

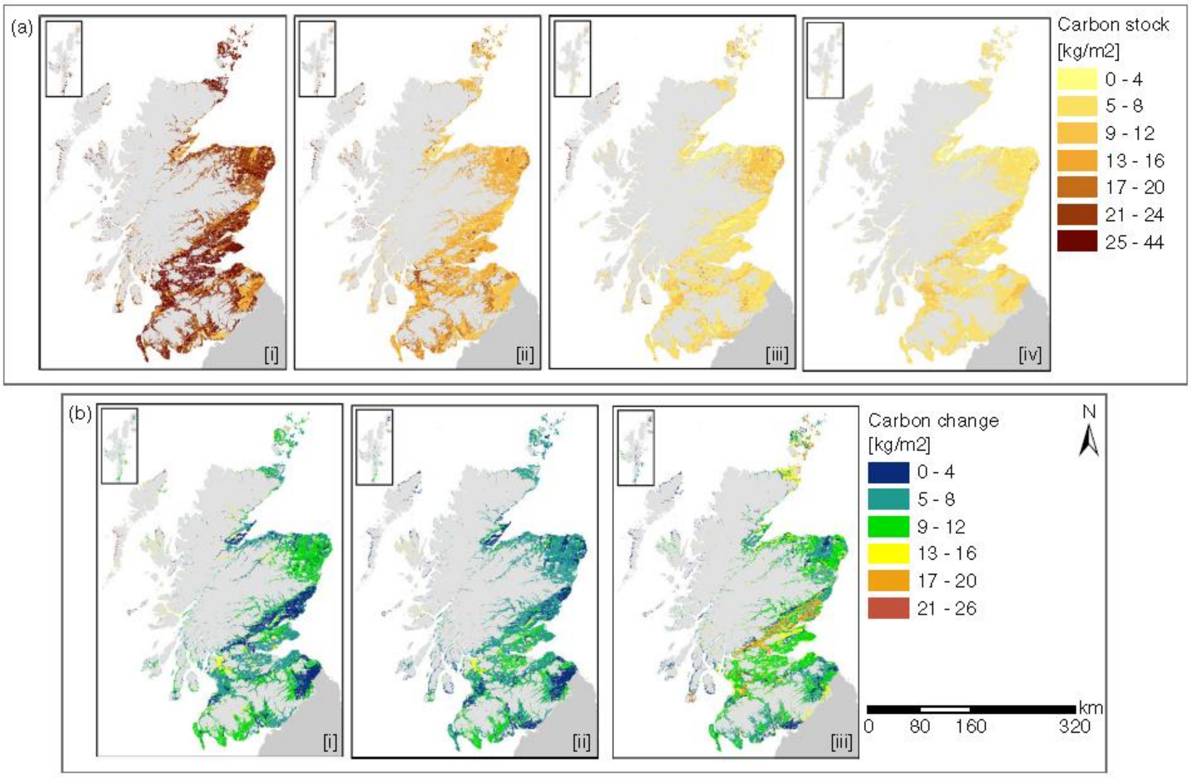

Figure 2.3.1. (a) Spatial distribution of C stocks calculated from (i) maximum SOC content; (ii) median SOC content, (iii) observed minimum SOC content; [iv] SOC in <20 µm mineral fraction. (b) Potential losses and potential gains in SOC: (i) loss using <20 µm mineral fractions; (ii) loss using observed minimum; (iii) storage potential. This map is only applied to mineral soils in Scotland, hence the large areas of 'no data' in grey.

For the mapping shown in Figure 2.3.1, Table 2.3.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping shown in Figure 2.3.1 is to each framework assessment criterion (Section 1.3.1). Table 2.3.1 shows that the most suitable framework is Integrated Assessment – Climate Change, with a score of 102 out of a maximum 163.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 83.25 out of a possible 130.5.

Table 2.3.1. Scores of the assessed effectiveness of the mapping given in Figure 2.3.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	101.5	63.24
NEA	141	86	60.99
MEF	160.5	96.75	60.28
DPSIR	130.5	83.25	63.79
MA	145.5	88.25	60.65
TEEB	100.5	63.5	63.18
Adaptive co-management	159	97.5	61.32
Resilience Alliance	169.5	101.75	60.03
Landscape Functions	144	89.25	61.98
Integrated Assessment – Climate Change	163.5	102	62.39
Institutions of Sustainability	138	82	59.42
Participatory GIS	135	81	60.00
Environmental risk assessment of novel crops	141	89.75	63.65
GM Coexistence	138	84.75	61.41
Sustainable Crop Systems	141	86	60.99
DEXiPM Integrated Management	151.5	93	61.39

2.4. Air

Air provides several ecosystem services but can also be considered a natural capital as it comprises stocks of important atomic and chemical components. In the most obvious sense, air provides a source of oxygen to much of the life on Earth, but it also performs many other functions. The atmosphere, as the reservoir of air, has a composition and structure that, if lost, would result in ecosystem collapse. At the same time, the atmosphere's natural capital role underpins multiple provisioning, regulating and cultural ecosystem services.

Chapter 13 of the UK NEA report focusses on supporting services, including the water cycle which relies on the atmosphere as a transport mechanism for water vapour (UK NEA, 2011). Chapter 23 of the UK NEA report also mentions the health benefits of clean atmosphere, although the UK NEA does not specifically consider the atmosphere as a habitat type.

2.5. Water

The concept of water as a form of natural capital can be split into components in a similar manner to those of soil, namely mass, energy and organisation. The mass of water can be considered as the various phases and locations that it occupies in these phases, i.e. solid (glaciers, snow, polar ice), liquid (fresh water in lakes, rivers and streams, within the soil and in aquifers, and seawater), and as a gas (water vapour). In each of these forms, water can be considered as capital as it is available for future functionality. The energy stored in water (thermal, potential and heat of vaporisation/sublimation associated with phase changes) is also a form of capital that has a strong influence on the environment and is stored for future release. And the organisation of water within various locations on, above and within the Earth’s surface and within the oceans results in a number of reservoirs of various utility. The functionality of water as an important solvent and transporting medium also implies a natural capital characteristic.

Lilly et al. (2001) developed a method for designating groundwater nitrate vulnerable zones in Scotland. This work used a rule-based approach to integrate information from a conceptual model of nitrate dynamics in soil and groundwater, data on sources of nitrate contamination in agricultural land and information about aquifer permeability derived from geological information. The approach developed allowed predictions to be made of sensitivity of groundwater to nitrate contamination, in terms of relative concentration expected. This work therefore integrated data from a number of different sources, and provided a means of identifying threats to water as a Natural Capital.

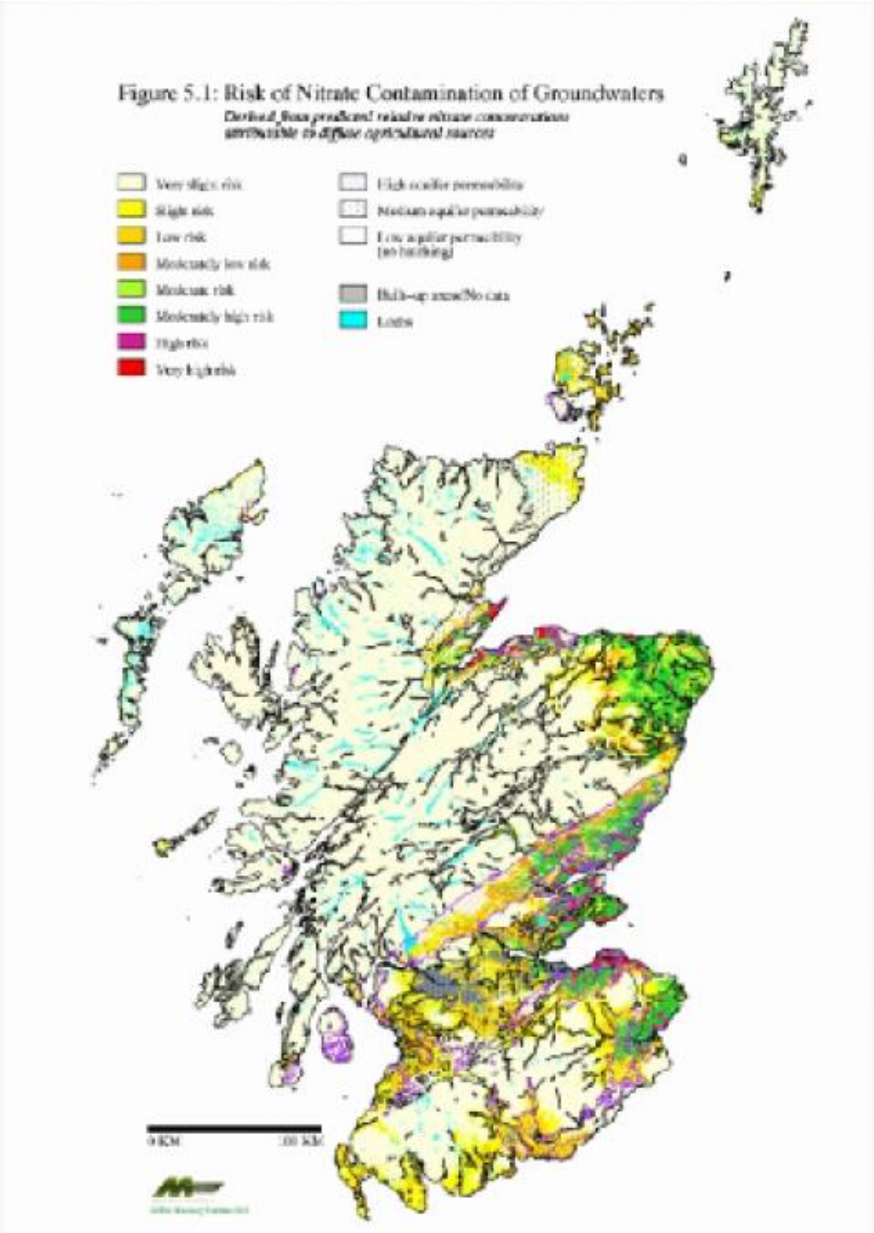

Figure 2.5.1. Map of groundwater nitrate contamination risk.

For the mapping shown in Figure 2.5.1, Table 2.5.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion (Section 1.3.1). Table 2.5.1 shows that the most suitable framework is Resilience Alliance, with a score of 98.5 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is TEEB, with a score of 60.25 out of a possible 100.5.

Table 2.5.1. Scores of the assessed effectiveness of the mapping given in Figure 2.5.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	93.25	58.10
NEA	141	83	58.87

MEF	160.5	92.75	57.79
DPSIR	130.5	77.5	59.39
MA	145.5	85.75	58.93
TEEB	100.5	60.25	59.95
Adaptive co-management	159	92.25	58.02
Resilience Alliance	169.5	98.5	58.11
Landscape Functions	144	84.25	58.51
Integrated Assessment – Climate Change	163.5	95	58.10
Institutions of Sustainability	138	78	56.52
Participatory GIS	135	77.75	57.59
Environmental risk assessment of novel crops	141	83.5	59.22
GM Coexistence	138	79.5	57.61
Sustainable Crop Systems	141	83.5	59.22
DEXiPM Integrated Management	151.5	90	59.41

Work on the hydrology of soils by Lilly et al. (1996), Lilly et al. (2001) and Ball et al. (2005) has produced information about the categorisation of soils according to their hydraulic properties. This information is useful for predicting river flow levels, water quality and land suitability for different uses. Figure 2.5.2 demonstrates that mapping that was carried out of identified soil types in terms of hydrology using HOST (Hydrology Of Soil Types), a classification designed for this purpose. The classification of a soil according this system depends on multiple factors, including permeability, soil texture and parent material amongst others. Each of these factors is important in influencing the hydrology of a soil, and were either calculated directly or derived from other information available.

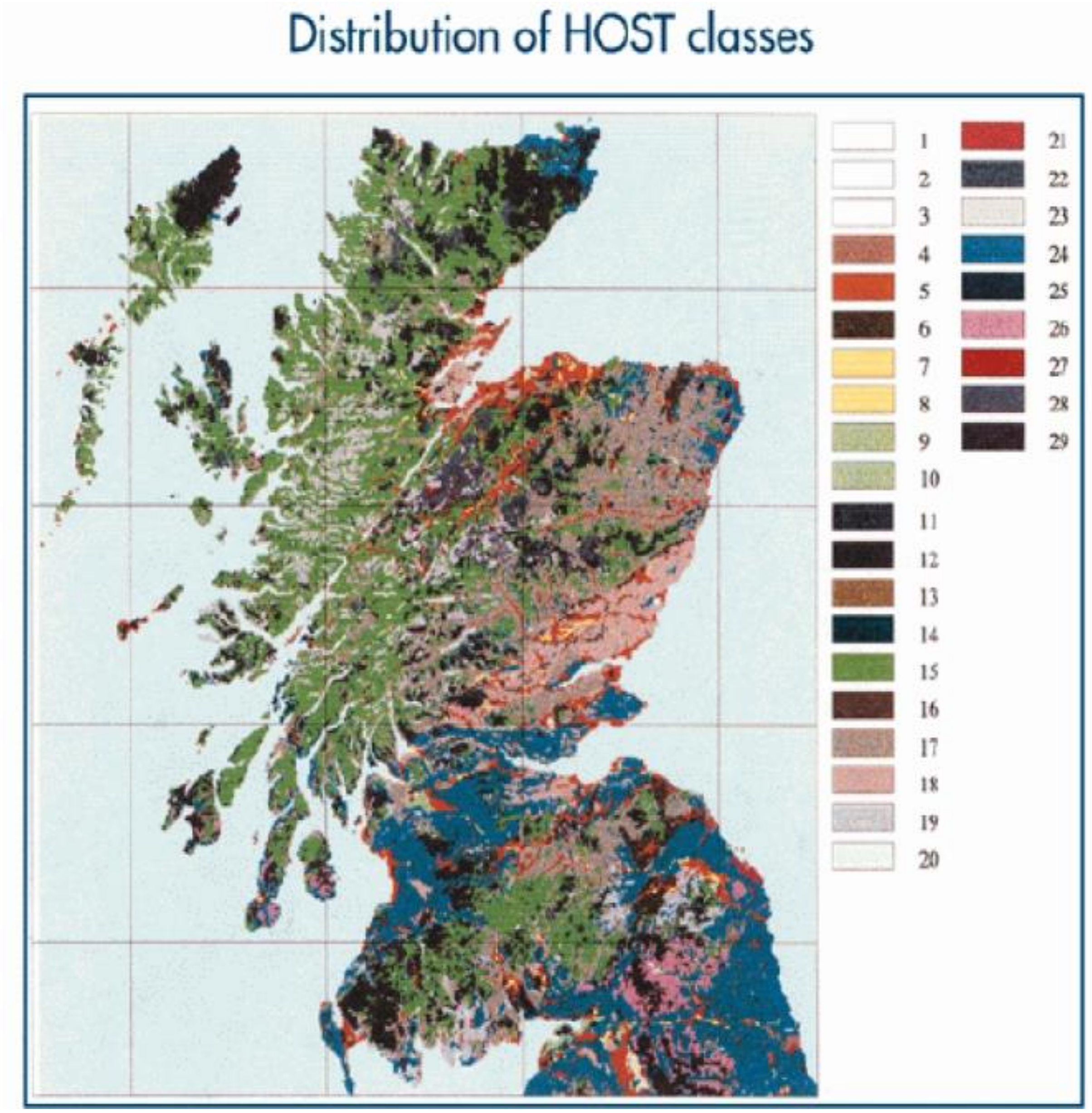

Figure 2.5.2. Distribution of HOST classes, a classification of the dominant pathways of water movement through soils and substrates. The classification system does not represent a scale in any one parameter relating to soil hydrology, but is instead based on several criteria. As such, it is useful for multiple questions relating to soil hydrology.

For the mapping shown in Figure 2.5.2, Table 2.5.2 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion (Section 1.3.1). Table 2.5.2 shows that the most suitable framework is Resilience Alliance, with a score of 99.75 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 80.25 out of a possible 130.5.

Table 2.5.2. Scores of the assessed effectiveness of the mapping given in Figure 2.5.2 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	94.5	58.88
NEA	141	86	60.99
MEF	160.5	96.25	59.97
DPSIR	130.5	80.25	61.49
MA	145.5	85.25	58.59
TEEB	100.5	61.5	61.19
Adaptive co-management	159	93.25	58.65
Resilience Alliance	169.5	99.75	58.85
Landscape Functions	144	86.75	60.24
Integrated Assessment – Climate Change	163.5	95.75	58.56
Institutions of Sustainability	138	80.25	58.15
Participatory GIS	135	78.75	58.33
Environmental risk assessment of novel crops	141	83.25	59.04
GM Coexistence	138	80.25	58.15
Sustainable Crop Systems	141	83.5	59.22
DEXiPM Integrated Management	151.5	88.75	58.58

2.6. Biodiversity

The Natural Capital Declaration, launched at the UN Conference on Sustainable Development (Rio+20) in 2012, is a joint statement by many financial organisations committing to integrate natural capital considerations into private sector reporting, accounting and decision-making by 2020. An important component of the Declaration (http://www.naturalcapitaldeclaration.org/the-declaration/) is a statement that work carried out through the TEEB (The Economics of Ecosystems and Biodiversity) initiative will be used for this. Chapter 2 of the TEEB report Ecological and Economic Foundations (TEEB, 2010) covers relationships between biodiversity and ecosystem services, and lists several examples of natural capital and supporting services supplied by biodiversity.

Brooker et al. (2013) carried out a review of available information on how ecosystem services and goods are underpinned by natural system processes and biodiversity. A list of plant species considered to have medicinal properties (courtesy of Heather McHaffie, RBGE), as well as Plant Att database data to assign species to broad habitat type was used to develop information about the distribution of these species. The methodology, while simple (a count of species from the list of medicinal plants within each broad habitat type), has produced an informative set of results.

This was intended as a simple illustration of bioprospecting potential, and to show that distribution of "useful;" species might not be readily predictable across habitats. However, there is a substantial underlying assumption that what people consider to be medicinal plants actually have some health benefit. This may not be true, and this caveat is in the BaBU (Biotic and Biophysical Underpinning) review by Brooker et al. (2013) as well. However, the concept is a good one, if the genuine health benefits of the species can be checked (and if people are aware of these species and are actually using them).

Figure 2.6.1 provides an insight into the distribution of these species in relation to key habitat types, and could be used to produce a map of the spatial density distribution of medicinal species across Scotland using existing habitat maps. The importance of certain habitats for these species, particularly inland rock (which is predominantly hill scree slopes), boundary features (e.g. hedges) and broadleaved or mixed woodland is immediately apparent. The relatively small overall area of these specific habitats within Scotland, and their fragmented and often isolated nature, implies sensitivity of these species to local change and disruption. The number of 10 km squares in Scotland that have a relatively low number of medicinal species is itself relatively small, and a higher proportion of 10 km squares have relatively more species. This shows that the distribution of these medicinal species is fairly even across Scotland, at least at the 10 km scale.

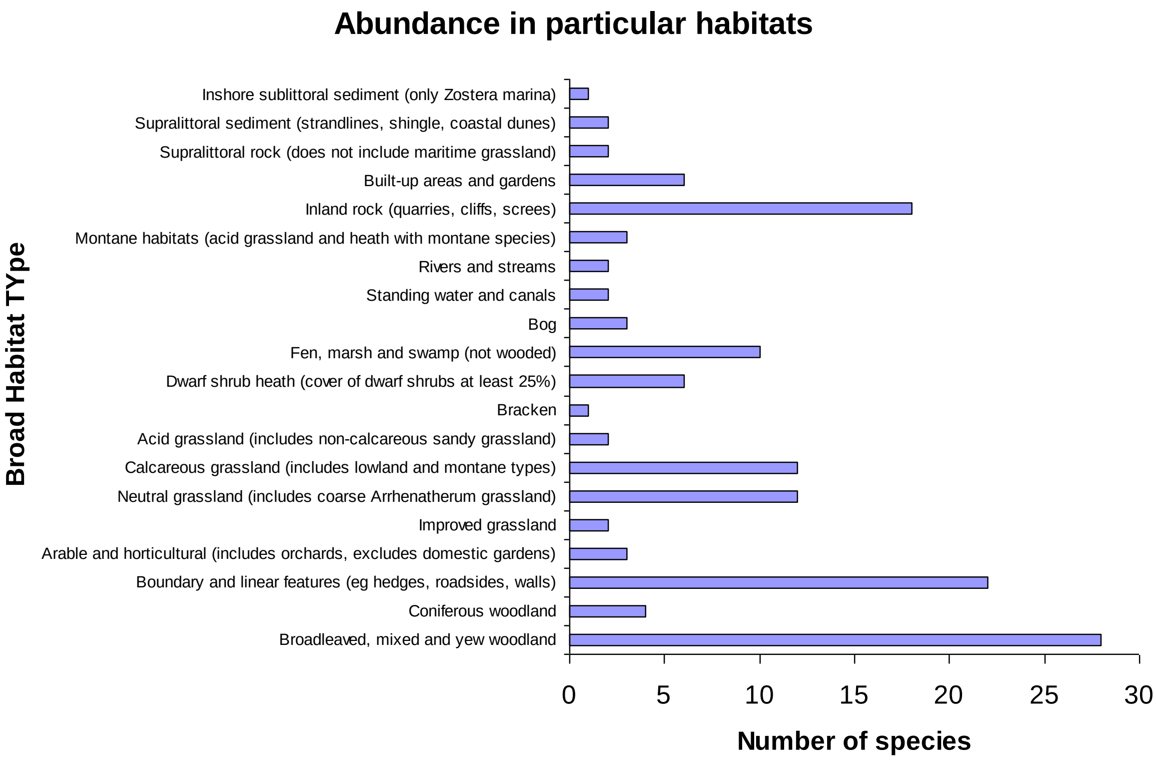

Figure 2.6.1. Relationships between broad habitat type and species abundance of Scottish medicinal plant species.

For the graph shown in Figure 2.6.1, Table 2.6.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion (Section 1.3.1). Table 2.6.1 shows that the most suitable framework is Resilience Alliance, with a score of 109.5 out of a maximum 169.5. The framework that ‘lost’ the lowest proportion of points is Sustainable Crop Systems, with a score of 94 out of a possible 141.

Table 2.6.1. Scores of the assessed effectiveness of the mapping given in Figure 2.6.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	102.75	64.02
NEA	141	92	65.25
MEF	160.5	103	64.17
DPSIR	130.5	86	65.90
MA	145.5	95.75	65.81
TEEB	100.5	65.5	65.17
Adaptive co-management	159	104.25	65.57
Resilience Alliance	169.5	109.5	64.60
Landscape Functions	144	93.75	65.10
Integrated Assessment – Climate Change	163.5	103	63.00
Institutions of Sustainability	138	85.25	61.78
Participatory GIS	135	86.5	64.07
Environmental risk assessment of novel crops	141	89.25	63.30
GM Coexistence	138	85	61.59
Sustainable Crop Systems	141	94	66.67
DEXiPM Integrated Management	151.5	99.5	65.68

With respect to mapping biodiversity and halting biodiversity loss, an important issue known to researchers is the poor data that we have for many organismal groups, particularly soil organisms that might be crucial for service delivery. Much of the focus of current research tends to be on charismatic species/groups, as per the 'Cultural Service Divide' concept by Norris et al. in the UK NEA.

2.7. Habitats

The Office for National Statistics (ONS, 2012) produced a report giving a roadmap for developing natural capital accounting in the UK. In the Annex to this report, a list of the major UK habitats is given with information about the natural capital characteristics of each. Examples of natural capital supply given here include: drinking water and soil carbon by mountains, moorlands and heaths; soil nutrients for agriculture in enclosed farmland; timber supply and carbon storage in woodlands; fresh water from rivers, wetlands and flood plains; coastal defences from the coastal margins; and fisheries from marine areas.

Brooker et al. (2013) note that upland habitats generally provide more carbon storage (trees and peat) than lowland habitats, while lowland habitats generally provide more food and fibre, but these broad generalizations hide much local variation. The most common conflicts or trade-offs occur around land use and land management; for example, decisions are required on how best to manage land as a limited resource in providing different crops (food or biofuels) or protected habitats, and ecosystem service mapping is invaluable in this respect. However, there are gaps in our understanding of how biodiversity and biotic/biophysical processes underpin the delivery of ecosystem services relevant to a low carbon economy.

Towers et al. (2002) mapped the potential supply of land for housing in Scotland. Scottish Homes, (later Communities Scotland), wanted to acquire information on the availability of land for housing development. Land supply for housing is a matter which local authorities had a duty to identify through Structure and Local Plans to meet projected demand over a five year period. Not all of Scotland is covered by a Local Plan and therefore the total area of land available for housing development remains unknown. Communities Scotland was abolished on 1 April 2008. On that date, most of its non-regulatory functions were transferred to the Scottish Government's Housing and Regeneration directorate. The work of Communities Scotland's Regulation and Inspection division has been transferred to the new Scottish Housing Regulator. However, this does not affect the scope or meaning of the work presented here. The aim of the research was to identify how much land in Scotland was available at the time and capable of being developed using a set of consistent and transparent rules and to identify where that land was.
The core datasets used to identify land suitable for housing development were:

- 1:250,000 scale digital soils map of Scotland,
- The Macaulay Institute Scottish Soils Database (now SSKIB),
- Land Capability for Agriculture data, (1: 50 000 (for pilot) & 1:250 000),
- Ordnance Survey Landform Digital Elevation Model (DEM) and
- Land Cover of Scotland 1988 (LCS88).

Knowledge and expertise in soil properties were relevant to this work, particularly in relation to the 1:250 000 National Soil Map and the associated Scottish Soils Database. This primarily included physical properties, e.g. mineral and organic content, wetness, variability within the soil map units etc., landforms and climate associated with the Soil Map Unit. Additionally, knowledge of the Land Cover of Scotland 1988 dataset and categories, and (from Communities Scotland) of engineering involved in house building in relation to the maximum degree of slope which could be built upon within normal economic constraints. After an initial sift to exclude area where development would definitely not be possible, a series of decision rules were derived that classified land on the basis of the biophysical constraints imposed. These classes are:

- Housing Development (HD) Class 1. Land where biophysical limitations are not limiting.
- HD Class 2. Land where biophysical limitations are limiting.
- A third class, HD Class 3, represents areas of land with an intimate mixture of HD Classes 1 and 2 and which are not distinguishable at the scale of mapping. It does not represent land which is intermediate in quality between HD classes 1 and 2, but contains areas of both.

Although the decision rules are not hierarchical, land is sequentially excluded as each rule is applied. The land that remains is, in effect, land where biophysical constraints do not limit housing development. The results were used to highlight areas where development where housing development could be targeted and so where investment could be directed towards. There were no economic or environmental factors considered other than assuming that any development would be within normal economic constraints at the time.

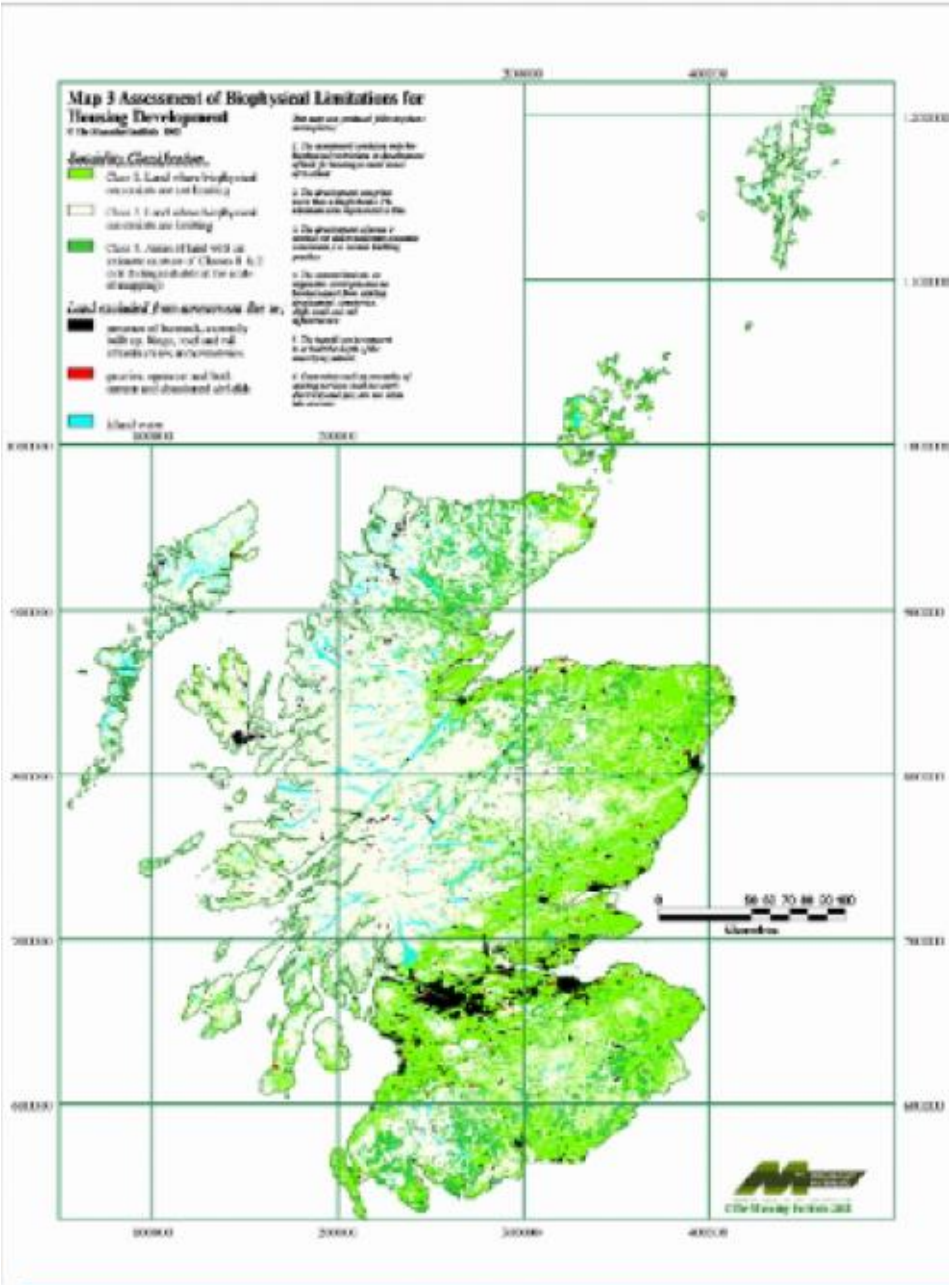

Figure 2.7.1. Suitability for housing development based on biophysical limitations.

For the mapping shown in Figure 2.7.1, Table 2.7.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion (Section 1.3.1). Table 2.7.1 shows that the most suitable framework is Resilience Alliance, with a score of 116.5 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is MEF, with a score of 115 out of a possible 160.5.

Table 2.7.1. Scores of the assessed effectiveness of the mapping given in Figure 2.7.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	111.5	69.47
NEA	141	98.5	69.86
MEF	160.5	115	71.65
DPSIR	130.5	92.75	71.07
MA	145.5	101.5	69.76
TEEB	100.5	71	70.65
Adaptive co-management	159	110.5	69.50
Resilience Alliance	169.5	116.5	68.73
Landscape Functions	144	100	69.44
Integrated Assessment – Climate Change	163.5	115	70.34
Institutions of Sustainability	138	97.75	70.83
Participatory GIS	135	95.25	70.56
Environmental risk assessment of novel crops	141	95.5	67.73
GM Coexistence	138	97.25	70.47
Sustainable Crop Systems	141	93	65.96
DEXiPM Integrated Management	151.5	108	71.29

2.8. Summary

From Table 1.2.1 and the examples given above, it is clear that with the exception of geology and air, environmental characteristics relevant for Natural Capital and Supporting Ecosystem Services have been well mapped across Scotland. This mapping does not always take the form of spatial representation, but can also include the identification of relationships between habitat types and species (e.g. Figure 2.6.1.). After all, visualisation is only one relatively minor reason for spatial representation of ecosystem services and associated factors; the main reason is to allow relationships with other descriptors of the landscape to be identified and described. The question remaining is whether the individual mapping exercises are relevant to ecosystem service frameworks, or if they are suitable only in terms of their initial purpose. One way of assessing this relevance is to evaluate the scores given in relation to individual frameworks. The maximum total score that could be obtained, if all framework-assessment criteria (Table 1.3.1) were considered highly relevant to a mapping example, is 2319 (summed across all 16 frameworks listed in Section 1.3.1). The total values for each example given in Section 2 are listed in Table 2.8.1 below:

Table 2.8.1. Total assessment scores relating ecosystem service frameworks to Natural Capital and Supporting Service mapping examples.

Table	Mapped example	Total score
2.3.1	Distribution and potential losses and gains of C stocks.	1426.25
2.5.1	Map of groundwater nitrate contamination risk.	1354.75
2.5.2	Distribution of HOST classes.	1374
2.6.1	Relationships between habitat and abundance of medicinal plant species.	1495
2.7.1	Suitability for housing development based on biophysical limitations.	1619

These total scores are relatively low compared with the scores obtained by mapping examples given in later sections of this review. This does not indicate that the mapping work carried out in these examples is not useful and relevant, but does indicate that the ecosystem service frameworks could be better designed if they are to incorporate information about Natural Capital and Supporting Services. In addition, it is difficult to assess which framework is 'best' for managing Natural Capital and Supporting Services, as the highest assessed scores (and the lowest losses from maximum score) are obtained by different frameworks in individual cases.

3. Ecosystem Services

3.1. Introduction

The following sections present a selection of maps of factors relating to ecosystem services across Scotland. These have been chosen to reflect provisioning, cultural and regulating services associated with the broad policy goals discussed previously, namely:

- Low carbon economies
- Communities better connected to the land
- Sustainable water management
- Halting biodiversity loss
- Sustaining food production

The intention is to provide information that will enable ecosystem services to be related forward to humans and back to environmental assets thereby providing a translation approach that is relevant to valuation and decision-making.

Each section focuses on work that has resulted in mapping relevant to ecosystem services at a national scale i.e. across Scotland, with some consideration of how spatial scale may change the outcomes. Where possible, we have explored approaches to mapping the current status and trends in stocks and flows of ES across spatial and temporal scales, the capacity to deliver current services from existing environmental assets, risks to these services from pressures and the capacity to maintain services under scenarios of change over annual to decadal timescales. This information is also summarised in Tables associated with each map. The later sections look at interactions in the supply of services (e.g. incompatibilities / synergies) to support the understanding of trade-offs and win/wins.

3.2. Provisioning services

3.2.1. Introduction

This section aims to provide information on factors relating to Provisioning services that have been mapped or evaluated for Scotland. Examples of available information are presented and analysed to demonstrate the status and trends and their relevance to different policy areas.

3.2.2. Sustainable food production

Figure 3.2.1 demonstrates work by Brown et al. (2008) that used an existing framework for land capability classification (the Land Capability for Agriculture framework) to map distribution of 'prime' (Class 1) land under current and future climate scenarios. They showed that climate change climate change is likely to enhance agricultural land use potential in Scotland, with the area of prime land increasing particularly in the east of the country. This work also explored the implications of changing patterns of prime agricultural land for biodiversity and carbon storage, and discussed possible amendments to the work. The benefits of using the existing LCA framework are that it is well-known to both land managers and policymakers in Scotland, and has been shown to provide a reliable approach to integrating information about soils, climate and topography for interpreting land suitability. A disbenefit is that the work involves projected climate change, with associated uncertainties in these projections.

Figure 3.2.1. Changes to distribution of 'prime' land as defined by Land Capability for Agriculture using climate data for 1958-1978, and the 2050s using the UKCIP02 medium-high emissions scenario, and with the HadRM3 'land' area overlain for reference (Brown et al. (2008)).

For the mapping shown in Figure 3.2.1, Table 3.2.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.2.1 shows that the most suitable framework is Resilience Alliance, with a score of 129.5 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is MEF, with a score of 124 out of a possible 160.5.

Table 3.2.1. Scores of the assessed effectiveness of the mapping given in Figure 3.2.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	121.75	75.86
NEA	141	107.5	76.24
MEF	160.5	124	77.26
DPSIR	130.5	96.75	74.14
MA	145.5	110.5	75.95
TEEB	100.5	75.75	75.37
Adaptive co-management	159	118.25	74.37
Resilience Alliance	169.5	129.5	76.40
Landscape Functions	144	107.75	74.83
Integrated Assessment – Climate Change	163.5	125	76.45
Institutions of Sustainability	138	104	75.36
Participatory GIS	135	98	72.59
Environmental risk assessment of novel crops	141	105.5	74.82
GM Coexistence	138	103.75	75.18
Sustainable Crop Systems	141	106.5	75.53
DEXiPM Integrated Management	151.5	109.5	72.28

Soil compaction is a major potential issue for agricultural soils in the UK, with impacts on crop productivity, water availability and erosion risk. The risk of compaction varies across different soils and sites, and for different types of land use. Troldbord et al. (2012) have investigated the risk and uncertainty of soil compaction across a network of survey points in Scotland, using Bayesian Belief Networks to integrate information from a wide range of sources. The aim was to develop a Bayesian Belief Network (BBN) model that combines available analytical and morphological data from standard soil surveys with qualitative expert knowledge to estimate and map the vulnerability and risk of soil compaction in Scotland. Soil and site specific data from NSIS as well as land use information data from IACS were used to produce this map (Figure 3.2.2), the development of was which used BBN modelling to combine risk assessment, soil mechanics and quality, land use, and soil hydrology information. The use of a BBN for this work allows the description of causal relationships through conditional probabilities.

A BBN is a probabilistic graphical model, where system variables and their conditional relationships are represented graphically as nodes and arrows in a directed acyclic graph. The causal relationships between nodes in a BBN are quantified by Conditional Probability Tables, which are built based on whatever information is available, such as actual data/observations, existing models or expert opinion. The fact that BBNs can integrate both quantitative and qualitative information and allow for uncertainties is seen as the main strengths of the method. In the case of the work by Troldborg et al., because the BBN is a representation of a large system it has nodes that cover all the Ecosystem Services apart from cultural services which were chosen to be left out. The nodes relating to the soil properties themselves are representative of the supporting services, the nodes to do with agricultural production are representative of provisioning services, while the inherent site properties nodes are closest to the regulating services (although there is some overlap with the supporting services). The manipulation of the model to identify which factors are most important in the control of soil compaction could also be seen as the act of identifying regulating services. The most relevant ES directly represented is probably food/energy production (compaction reduces crop yield and soil productivity), but compaction may also lead to increased emissions of greenhouse gases (due to poor aeration of soil), increased vulnerability of crops to diseases, and reduced water infiltration into the soil leading to accelerated run-off (which can be bad for surface water quality) and risk of soil erosion. The outputs given here are arguably at the level of benefits.

The map and the BBN model can mainly be used to say something about which areas are at risk of becoming compacted (and thus where ES may be lost), which may help ensuring that resources are targeted at areas at greatest risk as well as informing decision makers where changes to land management might be necessary to avoid compaction. Rather than using risk of compaction as the "end node"/target in the BBN, it might be possible to expand the BBN and address some ES directly as nodes in the network (e.g. by considering crop yield as a variable in the BBN, which then is linked to risk of compaction as well as other relevant nodes in the network). The BBN could also generally benefit from being validated/tested with more extensive data sets, potentially at a smaller scale.

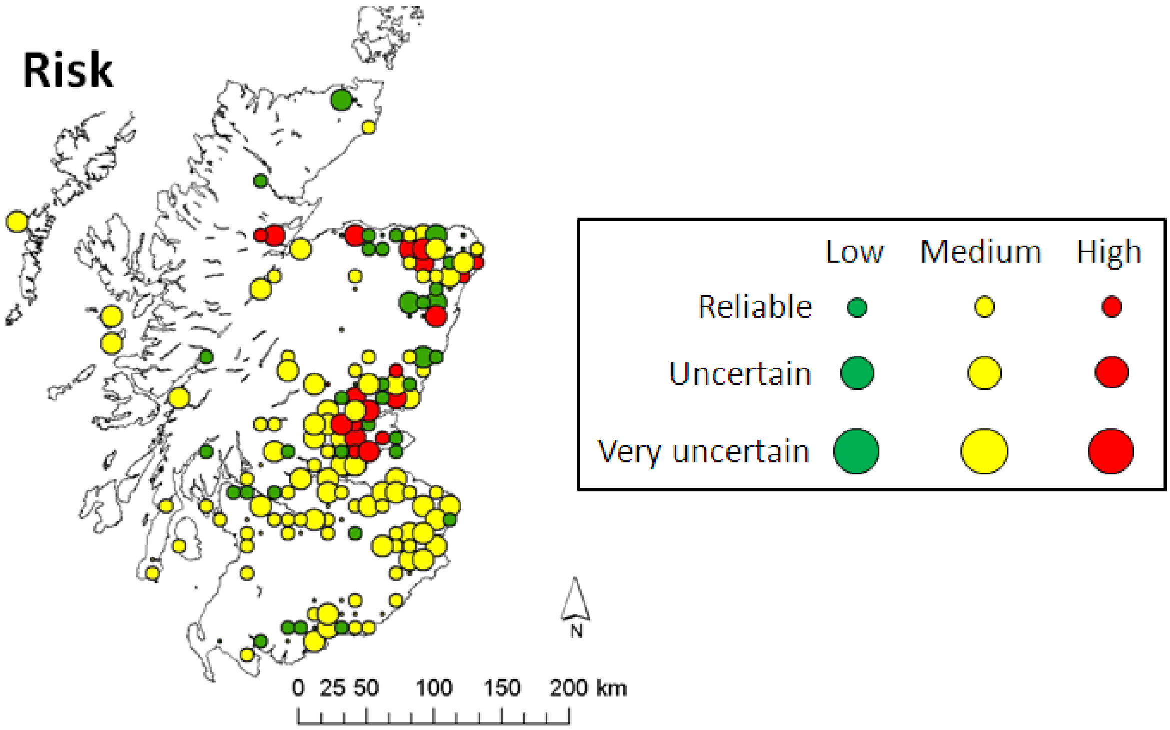

Figure 3.2.2. Distribution of points where predictions of soil compaction risk and uncertainty have been made with Bayesian Belief Network approach.

For the mapping shown in Figure 3.2.2, Table 3.2.2 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.2.2 shows that the most suitable framework is Resilience Alliance, with a score of 118.5 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is Environmental Risk Assessment of Novel Crops, with a score of 101.25 out of a possible 141.

Table 3.2.2. Scores of the assessed effectiveness of the mapping given in Figure 3.2.2 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	113.5	70.72
NEA	141	97.25	68.97
MEF	160.5	110.5	68.85
DPSIR	130.5	92.25	70.69
MA	145.5	103.5	71.13
TEEB	100.5	68.25	67.91
Adaptive co-management	159	110.5	69.50
Resilience Alliance	169.5	118.5	69.91
Landscape Functions	144	99.25	68.92
Integrated Assessment – Climate Change	163.5	114.5	70.03
Institutions of Sustainability	138	95.5	69.20
Participatory GIS	135	92.25	68.33
Environmental risk assessment of novel crops	141	101.25	71.81
GM Coexistence	138	96.75	70.11
Sustainable Crop Systems	141	100.5	71.28
DEXiPM Integrated Management	151.5	104	68.65

Brown et al. (2011) have studied the implications of climate change on land use in Scotland, in relation to drought and land capability. This work uses two different HadRM3 PPE simulations (labelled q3 and q16) which are consistent with the broader UKCP09 projections for climate shift towards warmer and drier summers (Figure 3.2.3).

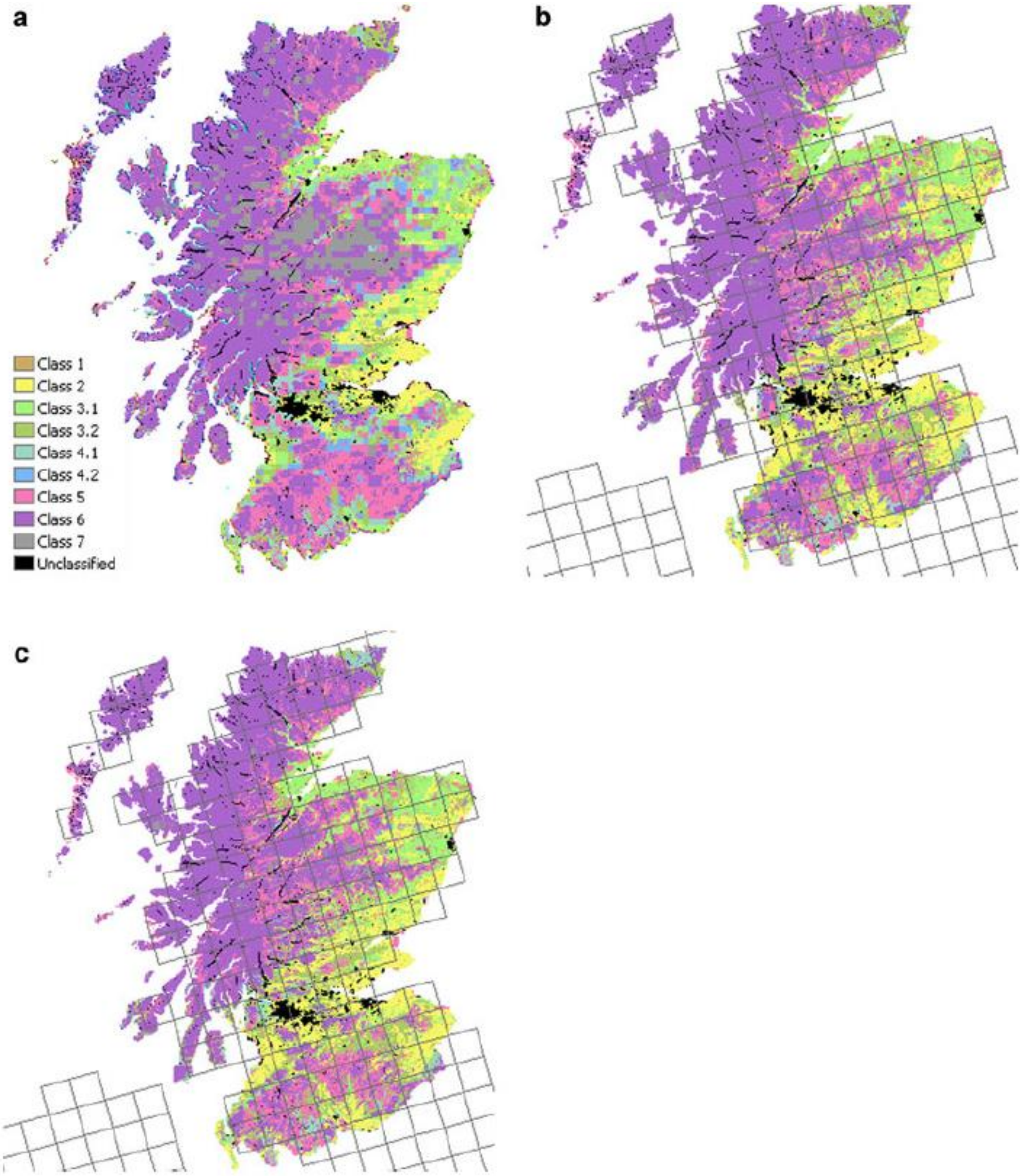

Figure 3.2.3. LCA classes for Scotland (excluding soil-climate interactions) (a) Baseline, (b) 2050s-q16, (c) 2050s-q3. HadRM3 'land' grid boxes shown for reference on future simulations. Soil series 1:250000 data.

For the mapping shown in Figure 3.2.3, Table 3.2.3 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.2.3 shows that the most suitable framework is Resilience Alliance, with a score of 129.5 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is MEF, with a score of 124 out of a possible 160.5.

Table 3.2.3. Scores of the assessed effectiveness of the mapping given in Figure 3.2.3 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	121.75	75.86
NEA	141	107.5	76.24
MEF	160.5	124	77.26
DPSIR	130.5	96.75	74.14
MA	145.5	110.5	75.95
TEEB	100.5	75.75	75.37
Adaptive co-management	159	118.25	74.37
Resilience Alliance	169.5	129.5	76.40
Landscape Functions	144	107.75	74.83
Integrated Assessment – Climate Change	163.5	125	76.45
Institutions of Sustainability	138	104	75.36
Participatory GIS	135	98	72.59
Environmental risk assessment of novel crops	141	105.5	74.82
GM Coexistence	138	103.75	75.18
Sustainable Crop Systems	141	106.5	75.53
DEXiPM Integrated Management	151.5	109.5	72.28

3.2.3. Sustainable water management

The SEPA River Basin Management Plans (http://gis.sepa.org.uk/rbmp/) mapping work provides a great deal of information about the nature and quality of, and the pressures on water bodies in Scotland. Much of this information relates to the status (past, present and future) of these water bodies, information that is directly relevant to water-based ecosystem services. There is also information relevant to sustainable water management and provisioning services in the SNIFFER (2006) report described in Section 3.3.3., as much of the underlying sediment transport and water quality processes mapped here impacts on provisioning as well as regulating services. The same is true of the HOST soil hydrology work by Lilly et al. (1996), also covered in Section 3.3.3. Work by Rebecca Badger at SEPA has also provided information about water regulation for flood risk management (http://www.scotland.gov.uk/Resource/0039/00396530.pdf).

3.2.4. Low carbon economy

Towers & Sing (2012) identified areas of Scotland that have most opportunities and fewest constraints on woodland expansion. A number of datasets were used to delineate the areas of interest – National Forest Inventory, LCS88, Soils map, Prime agricultural land (from LCA) – and the Forest Research Ecological Site Classification (ESC) model was used to produce the native woodland suitability assessment for the land that remains. The work mostly involved GIS overlay and sieving, and then application of the ESC model (see http://www.forestry.gov.uk/fr/esc). A series of criteria, represented by the datasets described above and others such as designated sites, were used to screen out areas of land that some degree of biophysical or policy constraint to woodland attached to it. This involved some heavy duty, but probably fairly straightforward GIS overlay and processing. The ESC model was then applied to the land that remains to produce an assessment of woodland suitability.

Biomass production (of native species) and of biodiversity associated with those woodland types are the main (final goods and services) indicated here. There are also some cultural services to be considered e.g. recreational, aesthetic, spiritual etc. associated with such woodlands. As a way of expressing the suitability of land for native woodlands and where networks of new and existing woodlands might be developed, the model can be applied to the whole of Scotland – not just the area on the map – and the model can be applied at species and NVC woodland type level and for a range of ‘commercial’ coniferous species. This would provide a wider range of options that could be assessed from the same basis.

Figure 3.2.4 demonstrates a wide range of useful information, including the identification of potential ecosystem service distribution, the conflicts that can occur between different services (in this case carbon sequestration through tree growth versus agricultural productivity, versus carbon sequestration in peatlands), and the integration of multiple datasets and sources of information using expert knowledge and rule sets derived from expert knowledge. This map shows not only where biophysical (Cairngorms, Highlands, the Western Isles) and socioeconomic (eastern agricultural lowlands) constraints exist, but also where land is available and suitable for forest growth in Scotland (Ayrshire, Dumfries & Galloway, the central belt). This kind of information could not be derived using biophysical information alone, or using existing maps of land cover, but *could* be derived using secondary data that was developed for a range of other purposes (Macaulay Scientific Consulting (2010)).

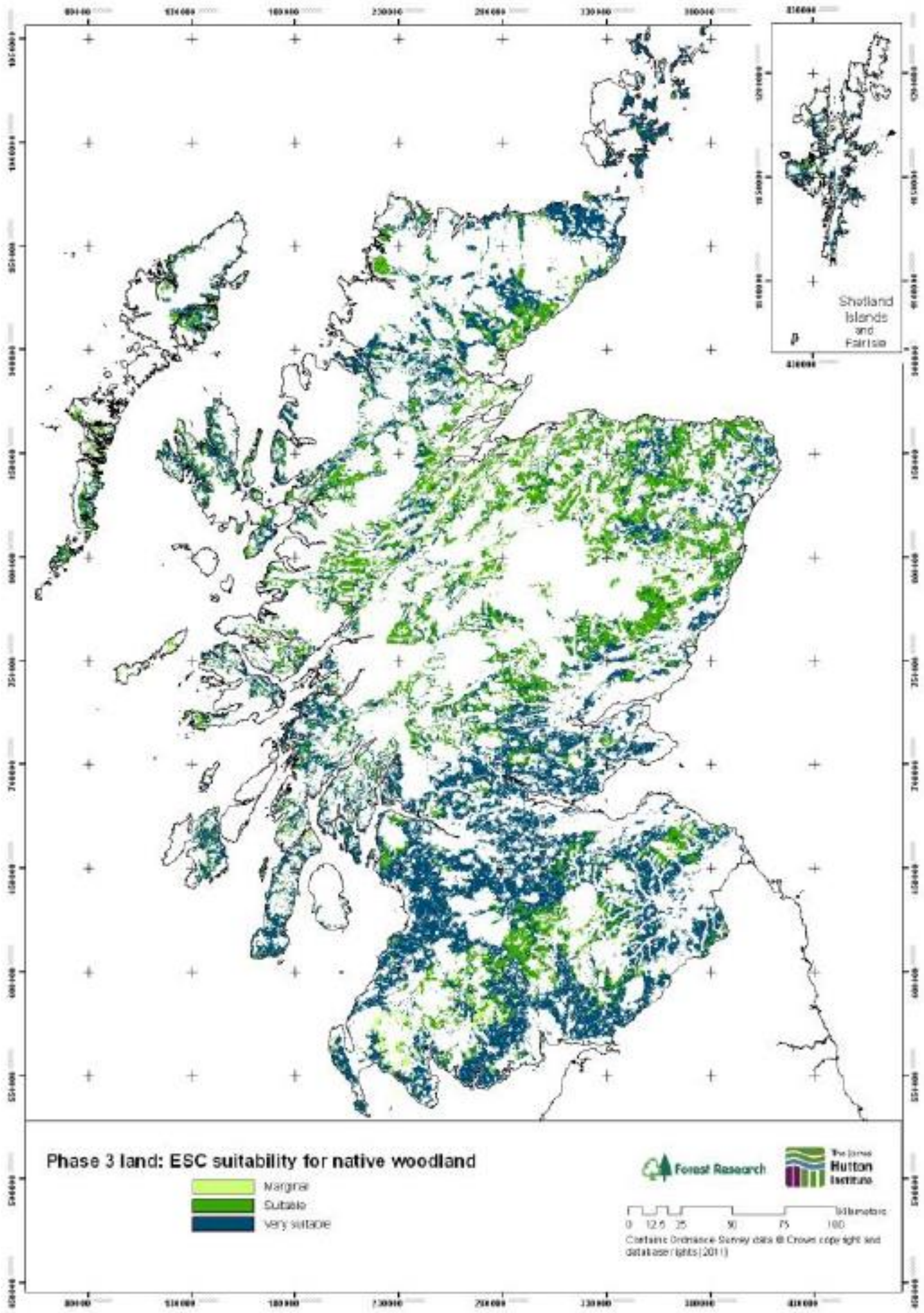

Figure 3.2.4. Map of land suitability for native woodland.

For the mapping shown in Figure 3.2.4, Table 3.2.4 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.2.4 shows that the most suitable framework is Resilience Alliance, with a score of 139.75 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 111.5 out of a possible 130.5.

Table 3.2.4. Scores of the assessed effectiveness of the mapping given in Figure 3.2.4 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	133.25	83.02
NEA	141	117.25	83.16
MEF	160.5	135.25	84.27
DPSIR	130.5	111.5	85.44
MA	145.5	122	83.85
TEEB	100.5	85	84.58
Adaptive co-management	159	131.75	82.86
Resilience Alliance	169.5	139.75	82.45
Landscape Functions	144	118.75	82.47
Integrated Assessment – Climate Change	163.5	136	83.18
Institutions of Sustainability	138	116.5	84.42
Participatory GIS	135	113.5	84.07
Environmental risk assessment of novel crops	141	114.25	81.03
GM Coexistence	138	113.75	82.43
Sustainable Crop Systems	141	112.75	79.96
DEXiPM Integrated Management	151.5	127.75	84.32

3.2.5. Halting biodiversity loss

The UK NEA technical report (UK NEA, 2011) includes consideration of wild food sources within several chapters. Chapter 23 of this report (Health Values from Ecosystems) specifically mentions health benefits associated with wild foods, while Chapter 4 (Biodiversity in the context of Ecosystem Services) emphasises the importance of biodiversity for food production and food security. A number of maps in this work demonstrate distributions and changes to distribution over time, for different species and habitats important to aspects of provisioning ecosystem services. A report by Spray & Tharme for SNH (http://www.snh.gov.uk/docs/A782494.pdf) demonstrates approaches linking habitats and other spatial information to ecosystem service mapping, particularly for provisioning services.

3.2.6. Communities better connected to the land

We have not found any work directly related to provisioning ecosystem services within this policy area that has been mapped, or that could be mapped. However, there are a number of activities relating to deer stalking/shooting about which there is potentially mappable information, such as shooting rates and venison production. However, this information is likely to be commercially sensitive and difficult to obtain for the whole country. Some organisations involved in Scotland's wild food, such as Scottish Fungi (https://sites.google.com/site/scottishfungi/) and the Scottish Wild Harvests Association (http://www.scottishwildharvests.org.uk/) provide information about wild food and sites where it can be found. The activities associated with these organisations are arguably cultural and recreational, in additional to being food-related. Other mapped or mappable landscape types that could potentially cover a number of services and policy areas include National Scenic Area information, machair and open farms. Information about these is available from a number of sources including SNH and VisitScotland.

3.2.7. Summary

From Table 1.2.1 and the examples given above, it is obvious that in relation to Provisioning ecosystem services, there is a bias towards the policy areas of Sustainable Food Production, Sustainable Water Management and Low Carbon Economy, with biodiversity and community/land connection having less of a focus. This is partly a reflection of the nature of Provisioning ecosystem services, which are perceived to be more closely related to food, water and fuel production than other requirements. The question remaining is whether the individual mapping exercises are relevant to ecosystem service frameworks, or if they are suitable only in terms of their initial purpose. To assess this relevance we evaluated the scores given in relation to individual frameworks. The maximum total score that could be obtained, if all framework-assessment criteria (Table 1.3.1) were considered highly relevant to a mapping example, is 2319 (summed across all 16 frameworks listed in Section 1.3.1). The total values for each example given in Section 3.2 are listed in Table 3.2.5 below:

Table 3.2.5. Total assessment scores relating ecosystem service frameworks to Provisioning service mapping examples.

Table	Mapped example	Total score
3.2.1.	Changes to distribution of ‘prime’ land using climate change scenarios	1744
3.2.2.	Distribution of BBN predictions of soil compaction risk and uncertainty	1618.25
3.2.3.	LCA classes for Scotland under different climate change scenarios	1744
3.2.4.	Map of land suitability for native woodland.	1929

These total scores are higher than scores obtained for Natural Capital and Supporting services, indicating perhaps that the work being carried out on food and fuel production is being more closely aligned with policy objectives and frameworks for understanding and managing the environment. Work carried out in relation to land suitability has indeed been deliberately targeted at policymakers, and from its inception has been intended to provide information for use in decision making.

3.3. Regulating services

3.3.1. Introduction

This section aims to provide information on mapping work for Regulating services, which underpin all the other types of service. Examples of available information are presented and analysed to demonstrate the status and trends and their relevance to different policy areas.

3.3.2. Sustainable food production

Yao et al. (2013), in work based on Yao et al. (2011) produced a map of soil nitrification potential (Figure 3.3.1) for Scottish soils, and of ammonia oxidising bacteria. Nitrification is the microbial conversion of ammonia to nitrate and a key step in the global nitrogen cycle. It is also an important soil ecosystem function as it is responsible for green-house gas emissions (N_2O) and N- losses in soils through leaching of nitrate. Little is known about the correlations of ammonia oxidising microbes that carry out the first step in nitrification with soil properties, landscape management and their spatial organisation. The main aim of this study was to investigate the ecological drivers affecting microbial community composition and consequences for soil nitrification processes. The work involved laboratory analysis data of microbial conversion of ammonia to nitrate in soil slurries and GIS data of NSIS grid coordinate soil sample references points, and required knowledge of soil microbial processes, laboratory expertise of potential nitrification assays, data processing and GIS software expertise. Sampling design and soil sample analysis was based on James Hutton Institute NSIS soil sample collection and archiving.

Nitrification process data were transformed into ranges classes of increasing size with increasing values and colour coded from green to red with increasing range values. Data were then projected on corresponding grid reference points. Estimation of map wide nitrification data by interpolation or modelling was not applied. Soils from the NSIS II archive were incubated as slurries in flasks with the addition of ammonia. Conversion of ammonia to nitrate in the slurries was analysed by colorimetric nitrate assays at several time points over 24h. Results were converted to rate of conversion per day per gram of soil and used for the map.

Nitrification is a fundamental soil function and process. Nitrification in soil may result in substantial losses of applied nitrogen through nitrate leaching. Low pH (peat lands, forest soils) suppresses nitrification and can lead to high soil ammonium concentrations. Nitrate leaching results in losses of farming N-fertiliser applications leading to reduction in farming productivity and may cause high groundwater nitrate concentrations, which has health implications. Knowledge of soil potential nitrification rates could influence decisions on timing and quantity of N-fertiliser applications and help understanding differences in productivity of different soil types. To take this work further, nitrification process data together with NSIS soil data could feed into a mathematical model for prediction of soil nitrification on a high resolution landscape scale.

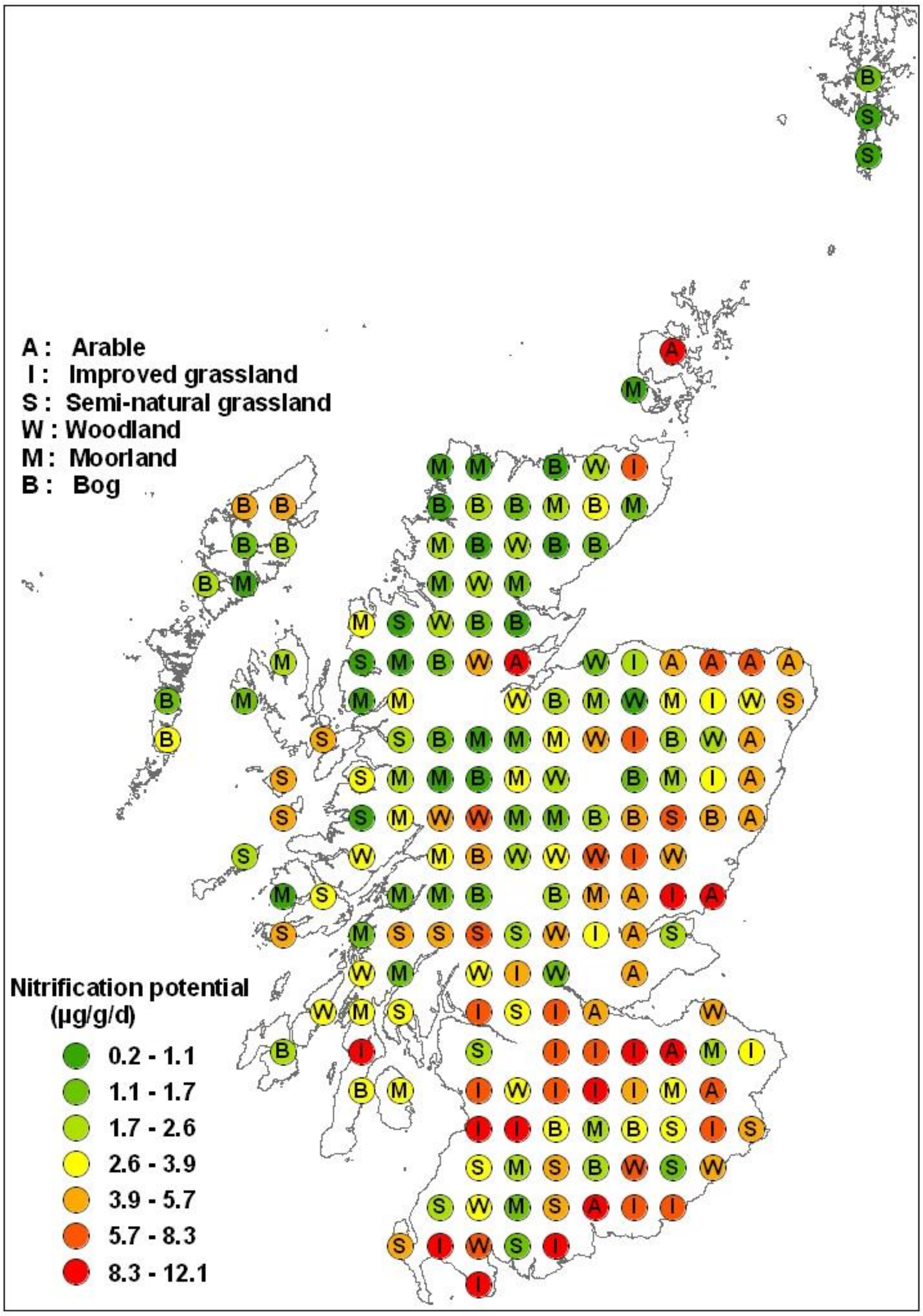

Figure 3.3.1. Soil nitrification potential (dry weight basis) in Scotland.

For the mapping shown in Figure 3.3.1, Table 3.3.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.1 shows that the most suitable framework is Resilience Alliance, with a score of 105.75 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 84.5 out of a possible 130.5.

Table 3.3.1. Scores of the assessed effectiveness of the mapping given in Figure 3.3.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	103.75	64.64
NEA	141	89	63.12
MEF	160.5	100.25	62.46
DPSIR	130.5	84.5	64.75
MA	145.5	90.5	62.20
TEEB	100.5	62.5	62.19
Adaptive co-management	159	100.75	63.36
Resilience Alliance	169.5	105.75	62.39
Landscape Functions	144	92.25	64.06
Integrated Assessment – Climate Change	163.5	101.5	62.08
Institutions of Sustainability	138	85	61.59
Participatory GIS	135	85.25	63.15
Environmental risk assessment of novel crops	141	91.25	64.72
GM Coexistence	138	85.75	62.14
Sustainable Crop Systems	141	91.25	64.72
DEXiPM Integrated Management	151.5	97	64.03

3.3.3. Sustainable water management

As part of a study into the impacts of climate change on Scotland's water resources, maps of nitrogen runoff and concentration in Scottish waters were produced (e.g. Figure 3.3.2). The maps were produced as outputs from a National Water Balance Model (Dunn et al., 2003, 2012) for Scotland and the Nitrogen Risk Assessment Model for Scotland (NIRAMS) (Dunn et al., 2004a and 2004b). Data that underpinned this model included: historic time-series of precipitation and meteorological variables (1961-90), soil physical data, HOST (Hydrology of Soil Types), land use (LCS88) and agricultural census data.

Hydrological expertise was used to develop and apply the model. The results of the model have been validated against observed historic data on river flows. Hydrological behaviour has been modelled at a 1 km^2 resolution for the whole of Scotland through the application of a water balance model. The water balance model uses inputs of precipitation and losses from evapotranspiration to calculate water storage and drainage from the soil to surface and groundwater bodies as a function of soil moisture conditions on a weekly time-step. Soil hydrological properties, including field capacity and saturation water content, are based on a database of properties for Scotland and control the thresholds for runoff occurrence. Modelling of the N balance is based on an assessment of land cover and agricultural practices to estimate inputs of N to the land. Simple N balance and leaching calculations are linked to the hydrological balance to estimate N losses to surface and groundwaters.

The ecosystem services represented by these maps include water resources availability and water quality (nitrate). Water resources might be considered "final services" whereas nitrate concentrations might relate to "functions and processes" (e.g. through the link with freshwater eutrophication) and "final services" in terms of drinking water quality, especially from groundwater sources. The data give an overview of the status of water resources, especially in the context of spatial differences across Scotland.

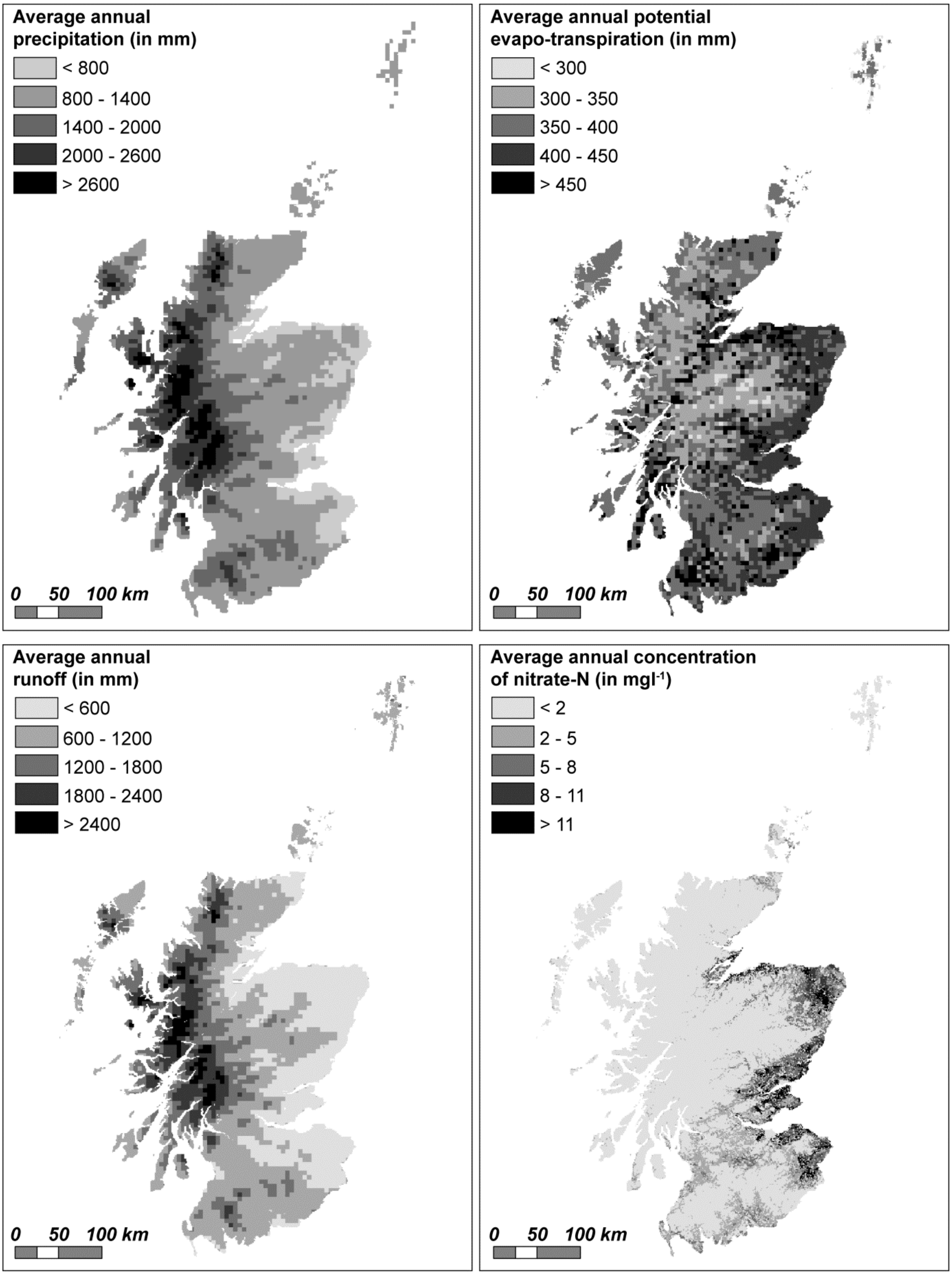

Figure 3.3.2. Maps of mean annual precipitation, evapotranspiration, runoff and nitrate concentration for the observed baseline (1961–1990) climate for Scotland (Note: nitrate concentrations are based on 1990s agricultural practice).

For the mapping shown in Figure 3.3.2, Table 3.3.2 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.2 shows that the most suitable framework is Resilience Alliance, with a score of 119.25 out of a maximum 169.5. The framework that ‘lost’ the lowest proportion of points is DPSIR, with a score of 99.5 out of a possible 130.5.

Table 3.3.2. Scores of the assessed effectiveness of the mapping given in Figure 3.3.2 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	117.75	73.36
NEA	141	102.25	72.52
MEF	160.5	114.25	71.18
DPSIR	130.5	99.5	76.25
MA	145.5	105.25	72.34
TEEB	100.5	75.25	74.88
Adaptive co-management	159	113.75	71.54
Resilience Alliance	169.5	119.25	70.35
Landscape Functions	144	105.25	73.09
Integrated Assessment – Climate Change	163.5	116.5	71.25
Institutions of Sustainability	138	97	70.29
Participatory GIS	135	96.5	71.48
Environmental risk assessment of novel crops	141	104.25	73.94
GM Coexistence	138	98.5	71.38
Sustainable Crop Systems	141	102.5	72.70
DEXiPM Integrated Management	151.5	109.25	72.11

A section of the SNIFFER (2006) project report was focussed on sediment loss and the loss of phosphorus through binding to mobile sediment. The approach used calculated the amount of soil detached via the impact of rainfall and overland flow and compared this to the runoff transport capacity. Additional information considered included the mitigation of rainfall impact by intervening plant canopies derived from modelled plant growth. The lesser of the total detached sediment and the runoff transport capacity indicates the total amount of sediment that is mobilised.

The result of these calculations was an amount of mobilised sediment and particulate bound phosphorus at the plot scale (1-10 m^2). Losses at the landscape scale (1 km^2) were calculated by multiplying the loss by the index of landscape connectivity to take account of retention. This work considers a number of different environmental characteristics, including soil, vegetation, climate and topography, and can be applied at fine spatial resolution for integration across national scales.

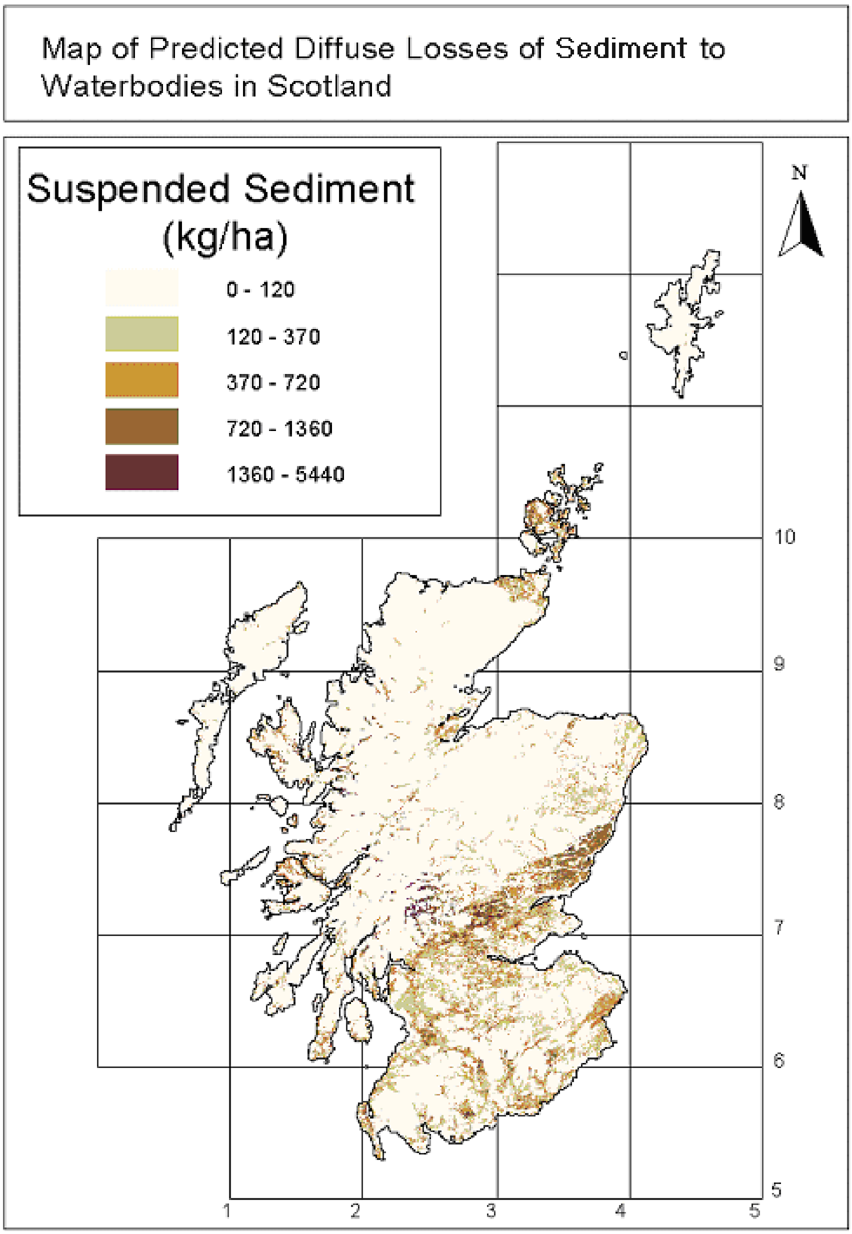

Figure 3.3.3. Modelled total annual load of sediment eroded from agricultural and forestry land to surface and ground waters, expressed as kilograms of sediment per hectare of all land, for Scotland.

For the mapping shown in Figure 3.3.3, Table 3.3.3 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.3 shows that the most suitable framework is Resilience Alliance, with a score of 127 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 103.75 out of a possible 130.5.

Table 3.3.3. Scores of the assessed effectiveness of the mapping given in Figure 3.3.3 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	123	76.64
NEA	141	108.25	76.77
MEF	160.5	123.25	76.79
DPSIR	130.5	103.75	79.50
MA	145.5	111.25	76.46
TEEB	100.5	78.25	77.86
Adaptive co-management	159	119.75	75.31
Resilience Alliance	169.5	127	74.93
Landscape Functions	144	110.25	76.56
Integrated Assessment – Climate Change	163.5	123.75	75.69
Institutions of Sustainability	138	104.25	75.54
Participatory GIS	135	102.25	75.74
Environmental risk assessment of novel crops	141	106.75	75.71
GM Coexistence	138	103.5	75.00
Sustainable Crop Systems	141	106	75.18
DEXiPM Integrated Management	151.5	115.25	76.07

3.3.4. Low carbon economy

Lilly et al. (2008) and Lilly & Baggaley (2013) carried out an assessment of carbon stocks across Scotland based on existing information about soil properties, and using the Scottish Soils Database which is held at the James Hutton Institute. Calculated median values of soil organic carbon were compared with maximum and minimum values found for comparable soils to produce estimates of the possible range of carbon content, and from this the possible loss or gain that could take place at each point. This work made extensive use of existing datasets and showed that while there is no clear trend in overall carbon stocks for Scotland, specific locations show potential to either lose or gain significant quantities of carbon from the soil (Figures 3.3.4 and 3.3.5).

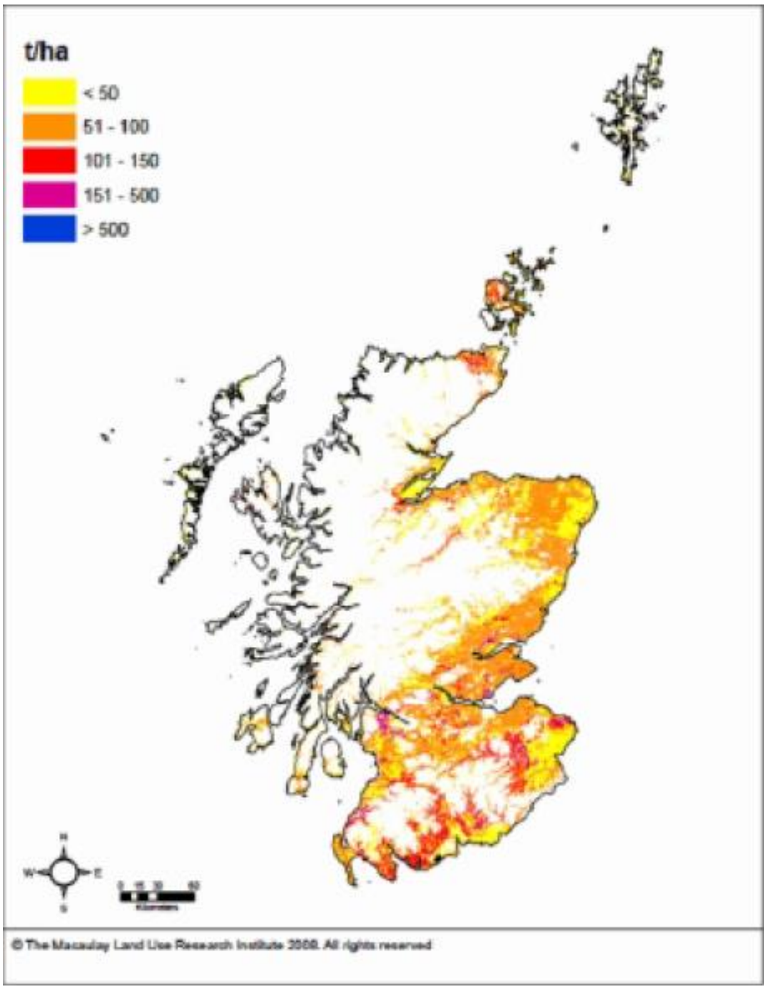

Figure 3.3.4. Potential carbon loss from Scotland's cultivated soils.

For the mapping shown in Figure 3.3.4, Table 3.3.4 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.4 shows that the most suitable framework is Integrated Assessment – Climate Change, with a score of 102 out of a maximum 163.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 83.25 out of a possible 130.5.

Table 3.3.4. Scores of the assessed effectiveness of the mapping given in Figure 3.3.4 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	101.5	63.24
NEA	141	86	60.99
MEF	160.5	96.75	60.28
DPSIR	130.5	83.25	63.79
MA	145.5	88.25	60.65
TEEB	100.5	63.5	63.18
Adaptive co-management	159	97.5	61.32
Resilience Alliance	169.5	101.75	60.03
Landscape Functions	144	89.25	61.98
Integrated Assessment – Climate Change	163.5	102	62.39
Institutions of Sustainability	138	82	59.42
Participatory GIS	135	81	60.00
Environmental risk assessment of novel crops	141	89.75	63.65
GM Coexistence	138	84.75	61.41
Sustainable Crop Systems	141	86	60.99
DEXiPM Integrated Management	151.5	93	61.39

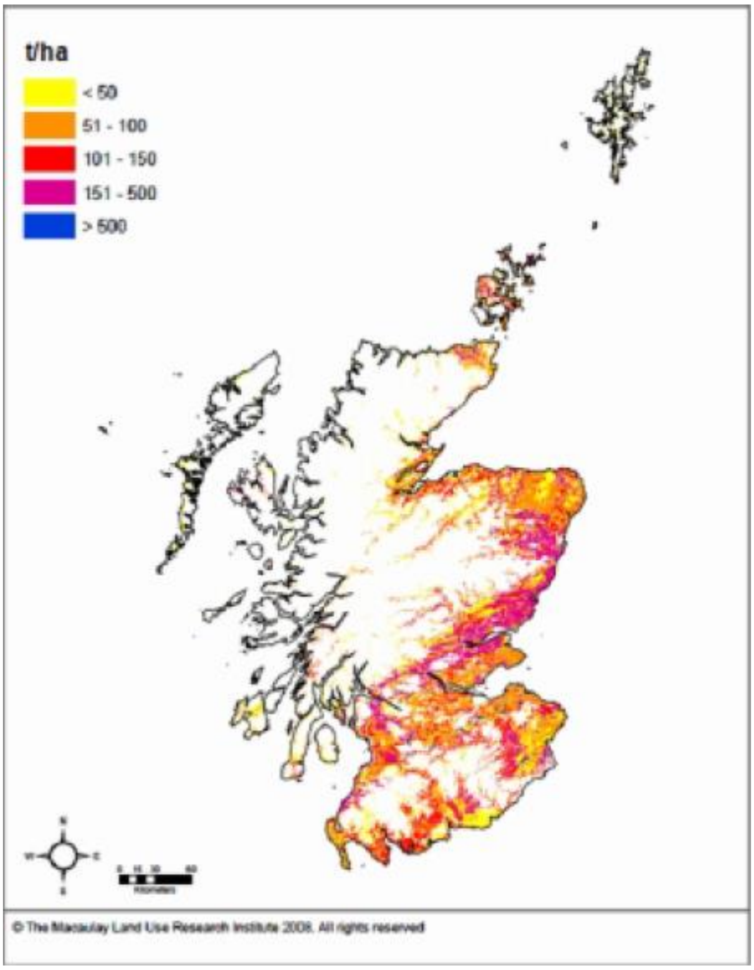

Figure 3.3.5. Potential carbon storage of Scotland's cultivated soils.

For the mapping shown in Figure 3.3.5, Table 3.3.5 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.5 shows that the most suitable framework is Integrated Assessment – Climate Change, with a score of 102 out of a maximum 163.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 83.25 out of a possible 130.5.

Table 3.3.5. Scores of the assessed effectiveness of the mapping given in Figure 3.3.5 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	101.5	63.24
NEA	141	86	60.99
MEF	160.5	96.75	60.28
DPSIR	130.5	83.25	63.79
MA	145.5	88.25	60.65
TEEB	100.5	63.5	63.18
Adaptive co-management	159	97.5	61.32
Resilience Alliance	169.5	101.75	60.03
Landscape Functions	144	89.25	61.98
Integrated Assessment – Climate Change	163.5	102	62.39
Institutions of Sustainability	138	82	59.42
Participatory GIS	135	81	60.00
Environmental risk assessment of novel crops	141	89.75	63.65
GM Coexistence	138	84.75	61.41
Sustainable Crop Systems	141	86	60.99
DEXiPM Integrated Management	151.5	93	61.39

Towers et al. (2011) examined the potential for using LCA as a potential mechanism for redistributing the Single Farm Payment (SFP) across Scotland based on an area rather than the historical commodity basis. The James Hutton Institute LCA dataset and various Scottish Government land use datasets (best summarised as Integrated Administrative and Control System (IACS)) were used, linking several complex and interlinked Scottish Government land use datasets. The work involved the use of GIS procedures to determine the relationship between agricultural potential and actual land use. The actual method has been developed over a number of projects and increased appreciation of the subtleties (and problems) associated with the SG datasets mean that that the relationship has become more robust over time. Much of the information related to this particular piece of work is relevant to the Pack Report (Scottish Government, 2010a) and related work (e.g. Matthews et al., 2013).

The ecosystem services represented are primarily related to food production. LCA ultimately helps determine the national capacity for food production (final service or benefit?) but LCA itself contains assessments of functions and processes, e.g. water retention, fertility etc. The results of this work and associated analysis are being widely used by SG in CAP reform discussions. In terms of improvements that could be achieved, neither dataset is entirely fit for purpose – LCA could be disaggregated into its component parts, e.g. wetness, droughtiness etc. – and the gaps in the IACS data mean that lots of assumptions are made.

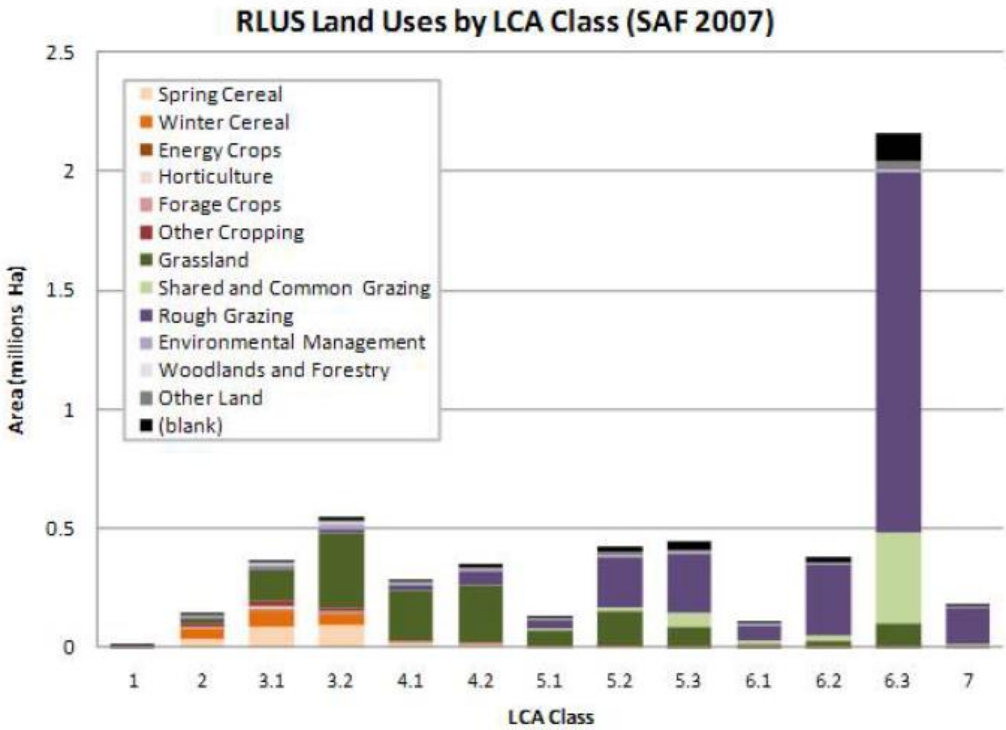

Figure 3.3.6. Area of LCS classes in IACS registered land

For the mapping shown in Figure 3.3.6, Table 3.3.6 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.6 shows that the most suitable framework is Resilience Alliance, with a score of 126 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 105.25 out of a possible 130.5.

Table 3.3.6. Scores of the assessed effectiveness of the mapping given in Figure 3.3.6 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	123.75	77.10
NEA	141	107.25	76.06
MEF	160.5	120.75	75.23
DPSIR	130.5	105.25	80.65
MA	145.5	109.75	75.43
TEEB	100.5	77.75	77.36
Adaptive co-management	159	123.25	77.52
Resilience Alliance	169.5	126	74.34
Landscape Functions	144	111.75	77.60
Integrated Assessment – Climate Change	163.5	121.5	74.31
Institutions of Sustainability	138	102	73.91
Participatory GIS	135	104.5	77.41
Environmental risk assessment of novel crops	141	106.25	75.35
GM Coexistence	138	101.25	73.37
Sustainable Crop Systems	141	106	75.18
DEXiPM Integrated Management	151.5	120.5	79.54

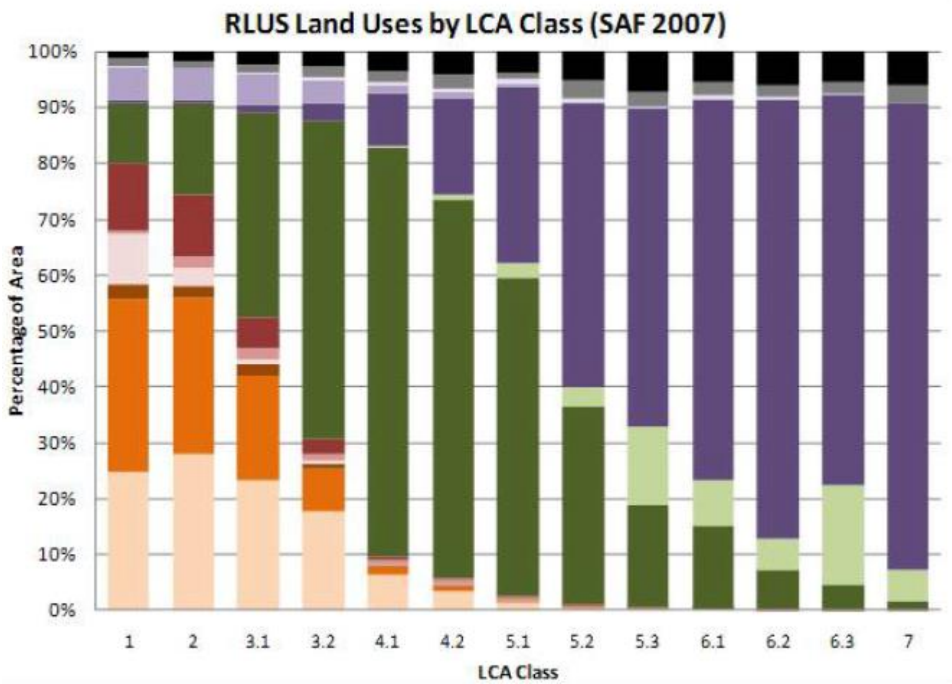

Figure 3.3.7. Land uses on IACS registered land by LCA class.

For the mapping shown in Figure 3.3.7, Table 3.3.7 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.7 shows that the most suitable framework is Resilience Alliance, with a score of 126 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 105.25 out of a possible 130.5.

Table 3.3.7. Scores of the assessed effectiveness of the mapping given in Figure 3.3.7 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	123.75	77.10
NEA	141	107.25	76.06
MEF	160.5	120.75	75.23
DPSIR	130.5	105.25	80.65
MA	145.5	109.75	75.43
TEEB	100.5	77.75	77.36
Adaptive co-management	159	123.25	77.52
Resilience Alliance	169.5	126	74.34
Landscape Functions	144	111.75	77.60
Integrated Assessment – Climate Change	163.5	121.5	74.31
Institutions of Sustainability	138	102	73.91
Participatory GIS	135	104.5	77.41
Environmental risk assessment of novel crops	141	106.25	75.35
GM Coexistence	138	101.25	73.37
Sustainable Crop Systems	141	106	75.18
DEXiPM Integrated Management	151.5	120.5	79.54

3.3.5. Halting biodiversity loss

Erosion is not an Ecosystem Service but an Ecosystem Disservice and is therefore still important to understand and map in relation to Ecosystem Services. Clearly erosion on cultivated mineral soils leads to loss of productivity and loss of organic carbon while erosion of peats is primarily a loss of organic carbon. Lilly et al. (2002) produced a risk map of soil erosion (Figure 3.3.8), based on work by Lilly et al. (1999). The primary aims of the project were to develop a rule-based model to predict the inherent erosion risk in Scottish soils and to apply this model to spatial datasets to provide a national scale map of erosion risk. The datasets used in the project were slope (from a national scale digital elevation model), runoff (from HOST) and texture (from national scale 1:250 000 soil map) and all were integrated at a spatial resolution of 1km^2 though the rule-base model is not scale specific. Mineral soils were treated differently from organic and organo-mineral soils in developing the rule base and vegetation cover was not taken into account. The rule-base model was developed from an analysis of the key factors used in various process-based models and a consideration of how the main driver of erosion in Scotland seemed to be saturation excess rather than infiltration excess. This observation was behind the use of HOST to determine the runoff characteristics of Scottish soils based of their rainfall acceptance potential. Once generated, the gain in erosive power of the runoff would depend on slope and the detachability of soil particles depended on the texture of the soil.

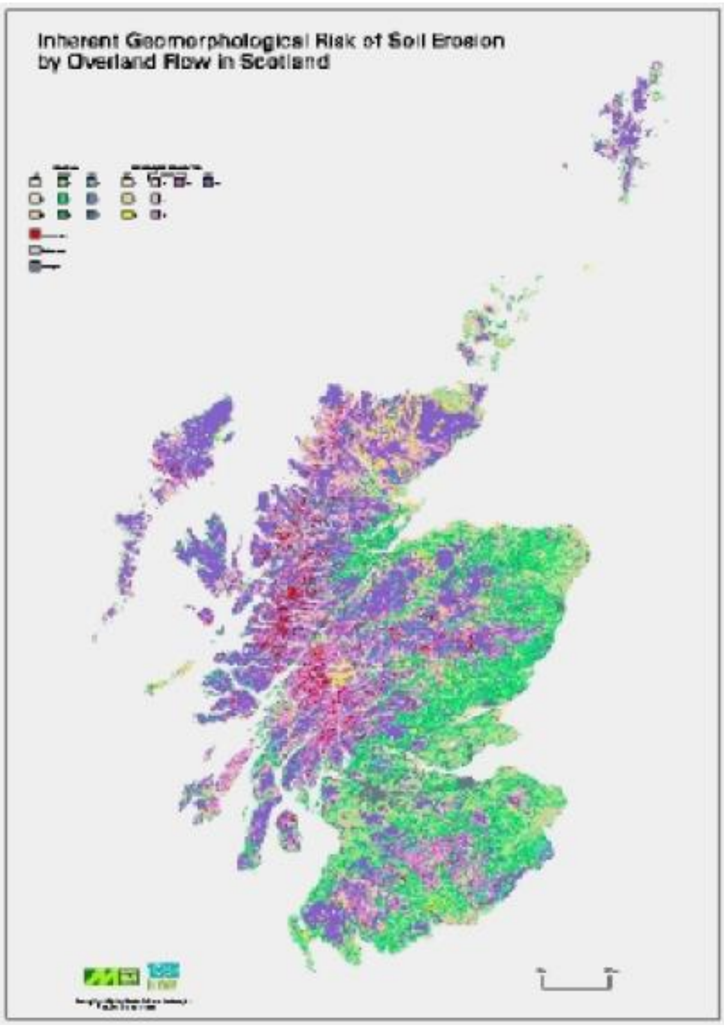

Figure 3.3.8. Risk map of soil erosion, using a rule-based approach.

For the mapping shown in Figure 3.3.8, Table 3.3.8 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.3.8 shows that the most suitable framework is Resilience Alliance, with a score of 122.25 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is MA, with a score of 106.75 out of a possible 145.5.

Table 3.3.8. Scores of the assessed effectiveness of the mapping given in Figure 3.3.8 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	117	72.90
NEA	141	102	72.34
MEF	160.5	115.75	72.12
DPSIR	130.5	95.25	72.99
MA	145.5	106.75	73.37
TEEB	100.5	73	72.64
Adaptive co-management	159	114.25	71.86
Resilience Alliance	169.5	122.25	72.12
Landscape Functions	144	102.25	71.01
Integrated Assessment – Climate Change	163.5	119.75	73.24
Institutions of Sustainability	138	99.5	72.10
Participatory GIS	135	96.25	71.30
Environmental risk assessment of novel crops	141	103.25	73.23
GM Coexistence	138	100.5	72.83
Sustainable Crop Systems	141	101.25	71.81
DEXiPM Integrated Management	151.5	107.25	70.79

Initially the slope angles were divided into 6 classes based on characteristic and limiting angles commonly found in erosional environments. The runoff characteristics were based on the soils potential for infiltration and divided the 29 HOST classes into 3 broad groups. The slope and runoff classes were combined to give seven categories of erosive power.

A three class system for mineral soils was devised, with fine textured topsoils being the least erodible and coarse textured mineral topsoils the most. This was based on a literature review of process-based models and reflects how well soil particles can form stable aggregates. The three texture classes were then combined with the erosive power classes to give a susceptibility of mineral soils to erosion. Organo-mineral and organic soils were treated separately and differently in that all peaty topsoils were assumed to be equally susceptible to erosion so the main discriminant was the erosive power classes. All peats were grouped into one class no matter what the erosive power was as the majority of peat soils are on less steep slopes.

3.3.6. Communities better connected to the land

We have not found any work directly related to regulating ecosystem services within this policy area that has been mapped, or that could be mapped. However, we have identified some activities that rely on regulating services, such as bath (quality of inland rivers and lochs) and hillwalking/rambling (access and site condition maintenance/erosion limitation). In relation to the impact of recreational activities on the landscape, an SNH report by Davidson & Grieve (2004) on soil erosion discusses the fact that most severe erosion instances in upland areas are linked to human activities, particularly footpaths and hillwalkers. Deer shooting is also identified as having an impact, through the number of deer and shooting parties in some areas. However, mapping of these impacts has not been carried out in this work.

3.3.7. Summary

From Table 1.2.1 and the examples given above, it is obvious that in relation to Regulating ecosystem services, there are examples of service-relevant mapping that are relevant for each of the policy areas with the sole exception being Communities Better Connected to the Land. This is partly a reflection of the nature of Regulating ecosystem services, which are more commonly understood and arguably cover a broader range of environmental factors. In relation to whether the individual mapping exercises are relevant to ecosystem service frameworks, or if they are suitable only in terms of their initial purpose, we carried out the same assessment as for Supporting and Provisioning services, and for Natural Capital. To assess this relevance we evaluated the scores given in relation to individual frameworks. The maximum total score that could be obtained, if all framework-assessment criteria (Table 1.3.1) were considered highly relevant to a mapping example, is 2319 (summed across all 16 frameworks listed in Section 1.3.1). The total values for each example given in Section 3.3 are listed in Table 3.3.9 below:

Table 3.3.9. Total assessment scores relating ecosystem service frameworks to Regulating service mapping examples.

Table	Mapped example	Total score
3.3.1	Soil nitrification potential in Scotland.	1466.25
3.3.2	Maps of mean annual precipitation, evapotranspiration, runoff and nitrate concentration for Scotland.	1677
3.3.3	Modelled total annual load of sediment eroded from agricultural and forestry land to surface and ground waters.	1766.5
3.3.4	Potential carbon loss from Scotland’s cultivated soils.	1426.25
3.3.5	Potential carbon storage of Scotland’s cultivated soils.	1426.25
3.3.6	Area of LCS classes in IACS registered land	1767.5
3.3.7	Land uses on IACS registered land by LCA class.	1767.5
3.3.8	Risk map of soil erosion, using a rule-based approach.	1676.75

It is apparent that while examples of Regulating service-relevant mapping exist across a broader range of policy areas, the total scores are widely distributed. Frameworks appear less suited for managing the Sustainable Food Production policy area, and are more suited for managing Sustainable Water Management and Halting Biodiversity Loss policy-relevant service maps. For mapping deemed relevant to Low Carbon Economy policy objectives, we see a mix of suitability assessment scores. However, Figures 3.3.6 and 3.3.7, which have been put into this category and which receive high total suitability assessment scores, could arguably also fit into Halting Biodiversity Loss. From these assessment scores, we see that mapping work relevant to Regulating services tends to also fit better within the frameworks designed for managing multifunctional landscapes if it is relevant to policy areas that are more normally associated with Regulating services, i.e. water sustainability and biodiversity, and lower scores if relevant to policy areas that are conceptually more in alignment with Supporting or Provisioning services (food production, low carbon economy). The picture is unclear for mapping relevant to regulating services and Communities better connected to the land, as no examples that fit into this category could be found.

3.4. Cultural services

3.4.1. Introduction

This section aims to provide information on mapping work that is relevant to Cultural services in Scotland and that can be mapped or incorporated into environmental assessments. Examples of available information are presented and analysed to demonstrate the status and trends and their relevance to different policy areas. There are many difficulties with the mapping of cultural services, some real and some perceived (Satz et al., 2013), beginning with the lack of a clear description of what cultural services are in the first place. Cultural ecosystem services are broadly the 'non-material' benefits gained from ecosystems, which can include a very wide range. One of the major issues with mapping or quantifying the supply of a cultural service at any point in space is that these services are often very personal and depend upon the person or persons involved – as such, supply of a cultural ecosystem service might be greater for one person than another, or may even be positive for some and negative for others.

3.4.2. Sustainable food production

The Crofting Commission (http://www.crofting.scotland.gov.uk/) provides online mapping of crofting in Scotland, which has a strong link to both cultural services and food production. Additional information related to crofting and food production/distribution in Scotland can be found on Scottish Government websites, including information about calving numbers in crofting parishes (http://www.scotland.gov.uk/Publications/2008/06/05104709/5) and food store locations (http://www.scotland.gov.uk/Publications/2009/06/25143814/6).

3.4.3. Sustainable water management

Much of the mapping work linking cultural services and sustainable water management relates to the use of Scotland's water bodies for recreational purposes. Examples include a map of Scotland's salmon fishing rivers (Fishlock, 2012), and maps of canoeing information for rivers, lakes, canals and coastline areas (British Canoe Union, 2014).

3.4.4. Low carbon economy

We have not found any work directly related to cultural ecosystem services within this policy area that has been mapped. There are also very few examples of work in this area that could conceivably be mapped, with the only example that could be found relating to peat extraction for horticulture/agriculture (licences for peat extraction at certain locations do exist, but are confidential). However, several potential cultural benefits of adopting low carbon economy-related strategies have been identified for Scotland, including: health benefits of lower pollution and more active travel (e.g. walking instead of driving) (Scottish Government, 2011); increased employment in rural areas, particularly in relation to agriculture (Scottish Government, 2011) and renewable energy production (Scottish Government, 2010b);

3.4.5. Halting biodiversity loss

SNH work on wetland condition monitoring for Ramsar sites has produced mapped information that allows detail on the biodiversity and condition of the 51 Ramsar sites to be viewed online (SNH, 2013). This is being done as part of the larger SNH Site Condition Monitoring programme, which has links to specific sites around Scotland for which a wealth of information is available.

3.4.6. Communities better connected to the land

Miller et al. (2006) developed a report commissioned by SNH that included information about historic landscapes and features. This information, derived from Historical Scotland and RCAHMS data, was mapped with the objective of understanding the consequences of pressures on landscape character over time. The maps, shown in Figure 3.4.1, allowed researchers to determine not only where historic landscapes and features may be under threat, but also begin developing a better understanding of the relationships people have with historic landscapes and a sense of place. This sense of place often comes from an association between the historic nature of a landscape and features that are visible in it, and can be important in considering the cultural significance of specific landscapes.

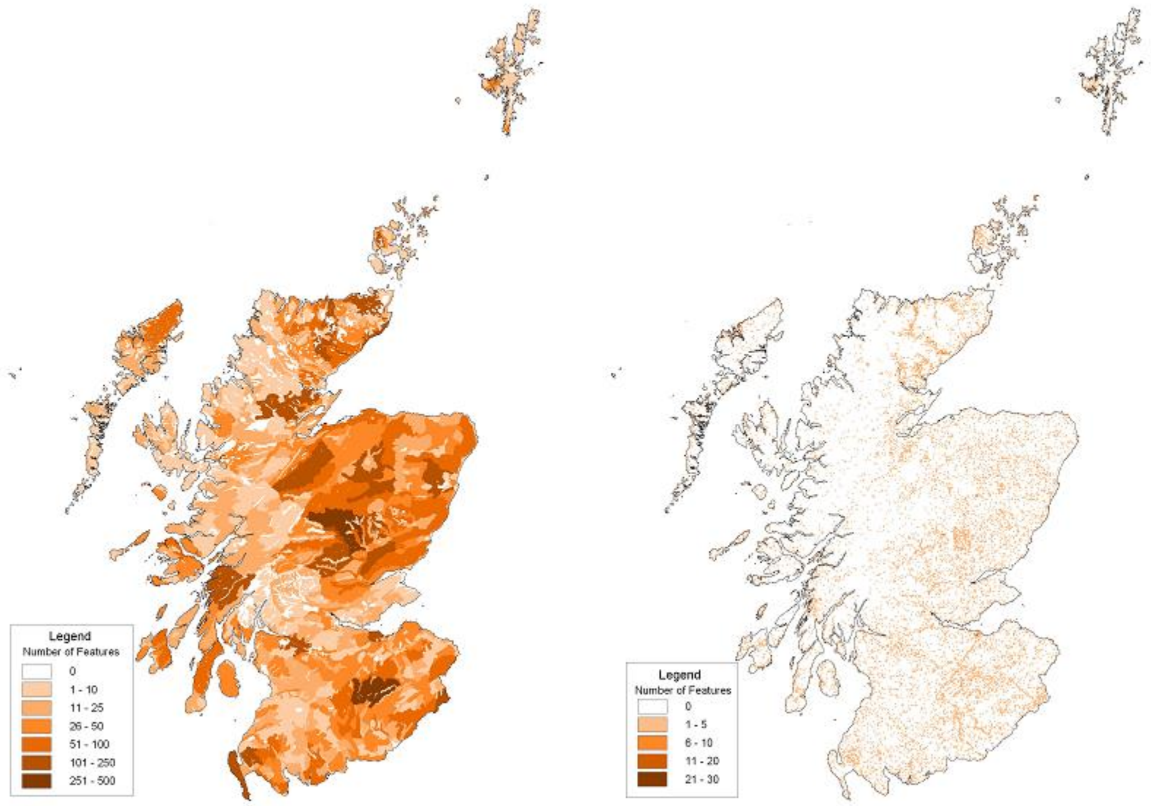

Figure 3.4.1. Number of sites interpreted as having historic interest reported by (a) landscape character polygon, (b) 1 km x 1 km grid square. (Data for 2005, reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown Copyright MLURI GD27237X2005).

For the mapping shown in Figure 3.4.1, Table 3.4.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 3.4.1 shows that the most suitable framework is Resilience Alliance, with a score of 137 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DEXiPM Integrated Management, with a score of 128 out of a possible 151.5.

Table 3.4.1. Scores of the assessed effectiveness of the mapping given in Figure 3.4.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	130	81.00
NEA	141	115	81.56
MEF	160.5	131.25	81.78
DPSIR	130.5	110	84.29
MA	145.5	119.75	82.30
TEEB	100.5	83.25	82.84
Adaptive co-management	159	131	82.39
Resilience Alliance	169.5	137	80.83
Landscape Functions	144	118	81.94
Integrated Assessment – Climate Change	163.5	131.5	80.43
Institutions of Sustainability	138	112.75	81.70
Participatory GIS	135	112	82.96
Environmental risk assessment of novel crops	141	111.75	79.26
GM Coexistence	138	110.5	80.07
Sustainable Crop Systems	141	112.75	79.96
DEXiPM Integrated Management	151.5	128	84.49

3.4.7. Summary

It is difficult to assess the effectiveness to which cultural services have been mapped in Scotland, as much of the work that could be called 'mapping' does not have a spatial element, or is restricted to a small regional extent/habitat type. The small number of examples that we have included are restricted to the policy area of Communities better connected to the land, which is certainly the most obvious policy area in relation to the service category. Based on the assessment carried out of the suitability of existing frameworks for managing multifunctional landscapes, the mapping carried out in relation to cultural services receives a relatively high total assessment score of 1894.5, with only two examples of mapping given in this review having higher scores. This high score may be the result of both a good fit with the existing frameworks, and also close compatibility between the service type and the policy area. We have seen in earlier sections that if mapped work is categorised by services and policy areas that are more obviously aligned with one another, existing frameworks tend to be more suitable for the understanding of that work.

4. Synergies and trade-offs

4.1. Introduction

This section examines interactions in the supply of services (e.g. incompatibilities / synergies) to support the understanding of trade-offs and win/wins. Interactions and synergies between different ecosystem services are examined both in relation to individual policy goals, and between different policy goals.

Petz & van Oudenhoven (2012) investigated the suitability of using land use descriptors to model the effects of land management on ecosystem services and ecosystem functions. They also showed that the stepwise analysis of ecosystem services is necessary to providing understanding of the interactions between services. Stepwise analysis involves the sequential addition and testing of combinations of services, to determine the relationships between them, rather than attempting to interpret all of the services in relation to one another at once. In its simplest form, this would involve a pairwise comparison/evaluation of all combinations of services, to determine the relationships, trade-offs and synergies that may or may not exist. Fisher et al. (2011) also argue for the importance of a spatial understanding of ecosystem services, including their definition, measurement and mapping. The interactions between individual services and between services and human welfare (i.e. the end benefits) are necessary to improving our understanding of how ecological and socioeconomic systems interact. The complexity of interaction requires scenario modelling, stepwise interpretation and other approaches in order to fully explore the ramifications of changes and policy decisions.

One of the most discussed trade-offs is between agricultural productivity and biodiversity. Maes et al. (2012) explored the potential for biodiversity and habitat conservation efforts to improve or maintain ecosystem service supply across Europe. They carried out a spatial assessment of biodiversity, ecosystem services and conservation status of protected habitats, and showed that indicators for biodiversity and overall ecosystem service provision were positively related. They also showed that conservation status and increased biodiversity had a stronger positive relationship with regulating and cultural services than with provisioning services, highlighting the trade-offs existing between agricultural in particular and services associated with higher levels of biodiversity.

4.2. Synergies and trade-offs within broad policy areas

4.2.1. Sustainable food production

Matthews et al. (2009) developed maps of stocking rates across Scotland as part of an assessment of the potential for displacement of livestock by forestry in the areas identified by the Woodland Expansion Advisory Group (WEAG) as "most likely to have potential for woodland expansion" (Phase 3). This mapping was carried out using numerical calculations in database and geographical information systems, by: (A) defining and mapping the potentially grazed forage area and attribute users; (B) deriving stocking rates for the potentially grazed area; (C) summarising the stocking rates shown within the map by groups of LCA classes and administrative regions. This work was based on earlier analysis and reporting (http://www.macaulay.ac.uk/LADSS/research_policy.html), and used the following datasets:

- Integrated Administration and Control System (IACS) –land use, ownership and rental data
- June Agricultural Census and December Survey – land use and livestock data
- Crofters Commission commons map
- Macaulay Land Capability for Agriculture map
- Administrative region map (agricultural regions)
- WEAG Phase 3 map

The ecosystem services represented here largely relate to the provisioning of food and fibre, and are at the level of final services. From additional interpretation of the underlying stocking rate map (Figure 4.2.1) and/or combining with other mapping it might be possible to define dis-services in terms of emissions of GHGs from livestock or other diffuse pollutants. This information has been used by WEAG in making recommendations in terms of the woodland expansion strategy, particularly in statements that within the extent of current targets the impact on provisioning services should be minimal.

The main limitation of the stocking rate analysis is the unit of aggregation at which the stocking rate is calculated. This is the business and thus tends to excessively average out stocking rates particularly for multi-holding businesses but also where there are strong contracts in grazing quality within holdings. The business level aggregation is necessitated by the recording of rented-in land only by business and not by the holding making use of the land (improvement here would need a change in how IACS rental in data is recorded). Options for improving the granularity of the analysis to holding level are being explored in the SG strategic work programme. Options for rules-based differentiation of stocking rates within holdings also exist but the diversity of livestock management systems means that these need to be carefully considered in case they introduce larger errors than they solve.

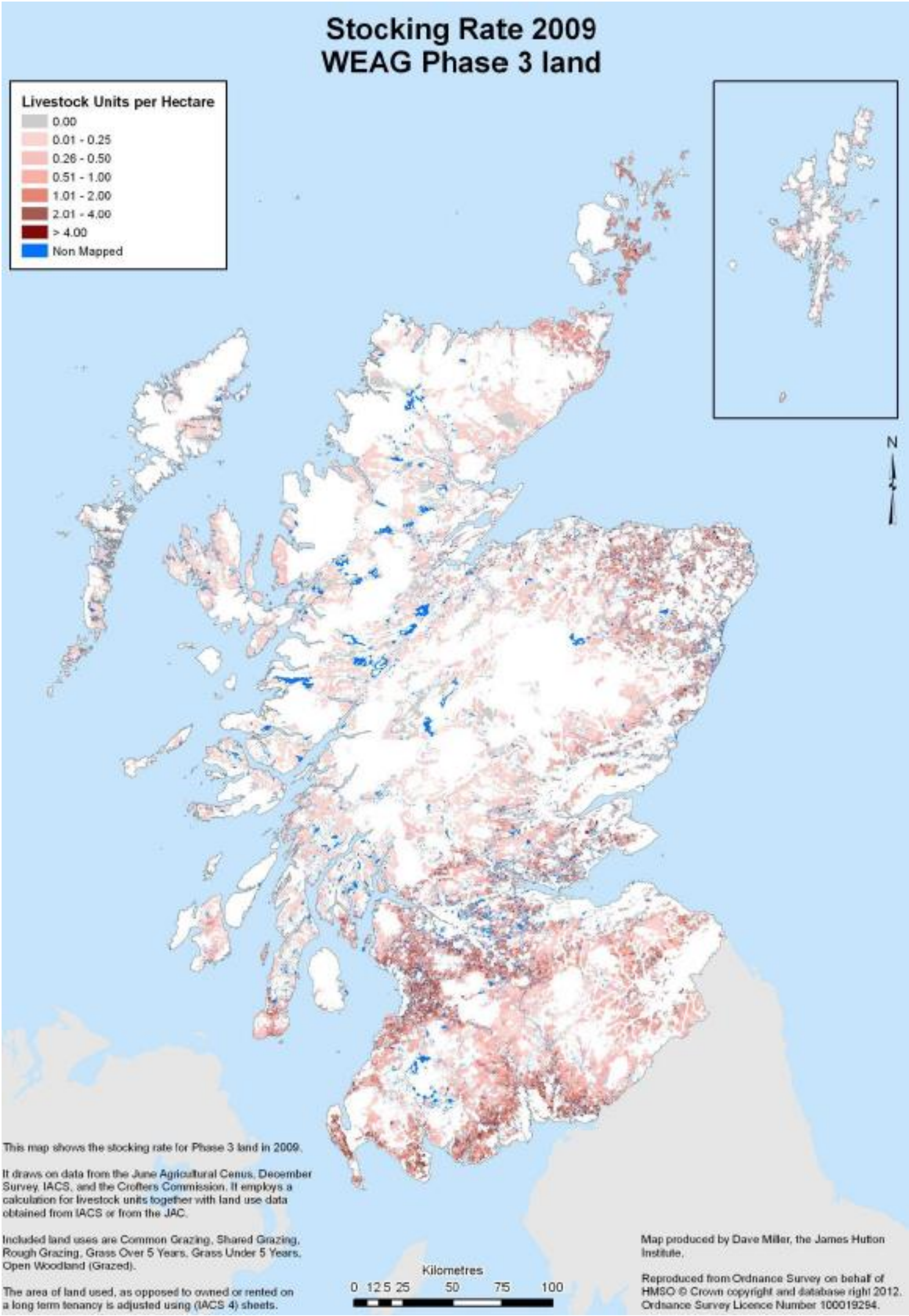

Figure 4.2.1. Livestock stocking rates in 2009. White areas represent areas discounted from woodland expansion under different biophysical, climatic and socioeconomic criteria.

For the mapping shown in Figure 4.2.1, Table 4.2.1 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 4.2.1 shows that the most suitable framework is Resilience Alliance, with a score of 126.5 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DPSIR, with a score of 103 out of a possible 130.5.

Table 4.2.1. Scores of the assessed effectiveness of the mapping given in Figure 4.2.1 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	123.75	77.10
NEA	141	107.5	76.24
MEF	160.5	123.25	76.79
DPSIR	130.5	103	78.93
MA	145.5	107.25	73.71
TEEB	100.5	76.25	75.87
Adaptive co-management	159	120.75	75.94
Resilience Alliance	169.5	126.5	74.63
Landscape Functions	144	109.25	75.87
Integrated Assessment – Climate Change	163.5	124.5	76.15
Institutions of Sustainability	138	107	77.54
Participatory GIS	135	104	77.04
Environmental risk assessment of novel crops	141	105.75	75.00
GM Coexistence	138	104.25	75.54
Sustainable Crop Systems	141	100.25	71.10
DEXiPM Integrated Management	151.5	114.75	75.74

4.2.2. Sustainable water management

Spray & Blackstock (2013) described a decision making framework to implement an ecosystem services approach (an extension of the ecosystem approach) at the catchment scale, in order to meet requirements of the Water Framework Directive. This report provided recommendations for how to implement freshwater management at the catchment scale in a manner that identifies and describes ecosystem services relevant to the changes being considered, and identifies changes that will result from these and ways to reduce the negative and increase the positive impacts on ecosystem services. The report does not provide any mapping as such, but the recommendations contained within it could be implemented in a spatial manner allowing services and impacts of changes on services to be incorporated into freshwater management decision making.

4.2.3. Low carbon economy

"Within the ecosystem services prioritised for a low carbon economy, the most common conflicts occur around land use and land management. Decisions have to be made over which crops (food or biofuels), management practices, or habitats (woodland or other habitats) to have on any given piece of land, with an acknowledgement that such decisions will influence the success of policies to implement a low carbon economy. Ecosystem service mapping is invaluable in this respect, allowing spatially explicit strategic visioning, explicit consideration of trade-offs, and decision-making" (Brooker et al., 2013).

Miller et al., 2010 carried out an assessment of the areas in northern Scotland in which wind turbine development may have the greatest effects on landscape views. This work was based upon assumptions about the types of places people visit, their movement through the landscape and where they stay. Geographic data were obtained for features identified as being of relevance, and field observations were made of landscape visual sensitivity, which was also represented as scores for the viewsheds. This work relates to trade-offs as it allows weightings to be given for different priorities, in this case energy production and the protection of sites/areas important for both tourism and environmental protection.

The visual receptors were combined into a single dataset, allocating the output to be mapped as the highest level of visual sensitivity at any point from any of the visual receptors (Figure 4.2.2). The map shows a concentration of land with high visual sensitivity in the south-east of the study area, particularly around the Moray Firth, the Dornoch Firth, and Loch Ness. There were some smaller areas of high sensitivity in Caithness, and in some parts of the north and west (e.g. in the vicinity of Durness, Tongue, and south-east of Ullapool). Most of the upland areas were low visual sensitivity or had no overviewing visual receptor. This included much of the areas designated as NSAs and AGLVs along the west coast and through Sutherland. The mapping of each of the types of visual receptor separately provided a basis for interpreting visual sensitivity at a regional level, and to group sub-areas according to broad similarities. Importantly, the visual receptors showed that some areas of low landscape character sensitivity have a high visual sensitivity. The interpretation of differences between areas with respect to visual and landscape character sensitivity enabled areas to be identified for which specific planning guidance could be prepared.

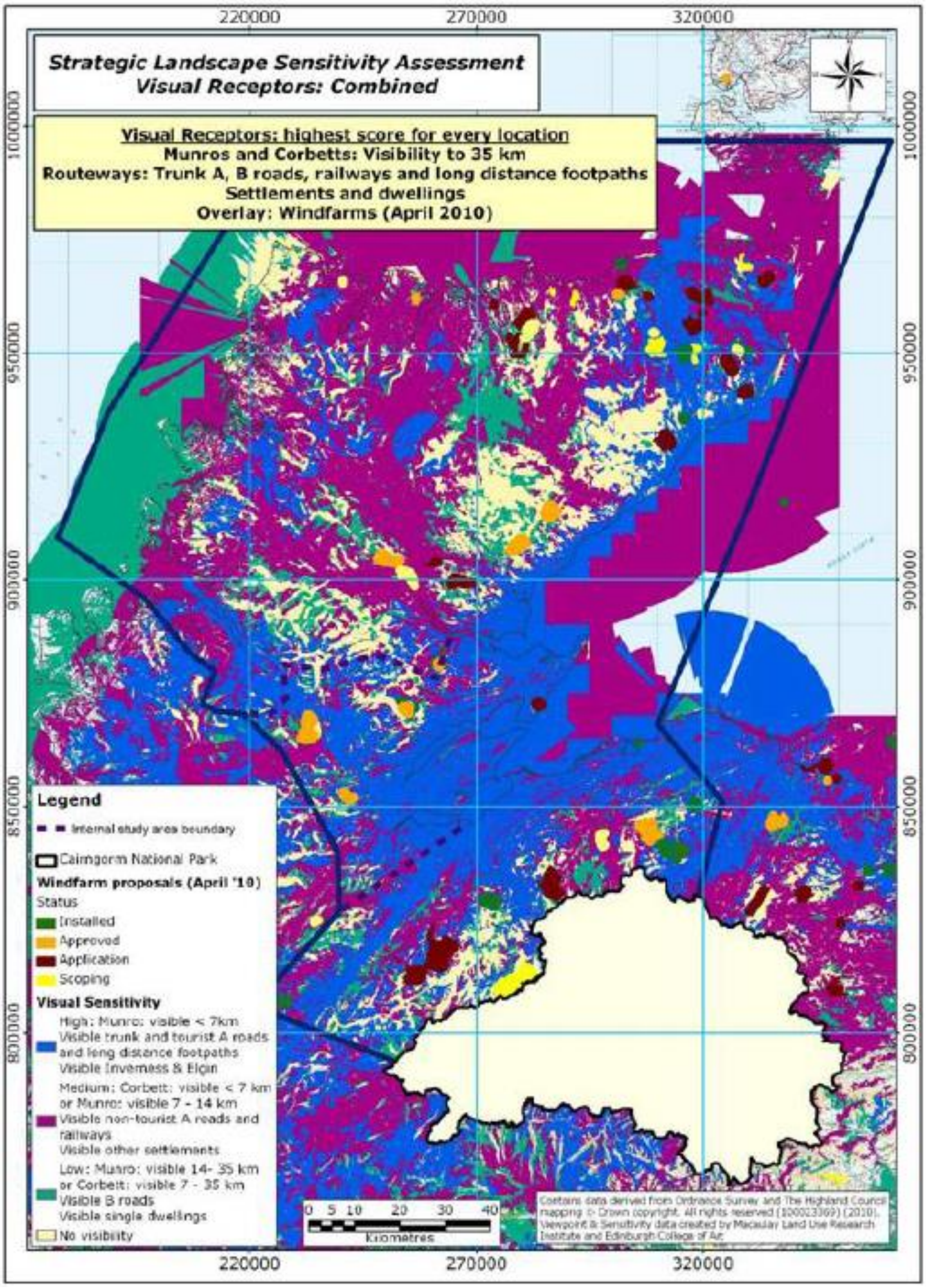

Figure 4.2.2. Landscape sensitivity for the northern Highlands derived from combined scores for a range of visual receptors.

For the mapping shown in Figure 4.2.2, Table 4.2.2 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 4.2.2 shows that the most suitable framework is Resilience Alliance, with a score of 147.5 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is MEF, with a score of 142.5 out of a possible 160.5.

Table 4.2.2. Scores of the assessed effectiveness of the mapping given in Figure 4.2.2 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	138.75	86.45
NEA	141	121.5	86.17
MEF	160.5	142.5	88.79
DPSIR	130.5	115	88.12
MA	145.5	127	87.29
TEEB	100.5	87.5	87.06
Adaptive co-management	159	137.25	86.32
Resilience Alliance	169.5	147.5	87.02
Landscape Functions	144	125.5	87.15
Integrated Assessment – Climate Change	163.5	142.5	87.16
Institutions of Sustainability	138	122.25	88.59
Participatory GIS	135	119.75	88.70
Environmental risk assessment of novel crops	141	119.25	84.57
GM Coexistence	138	120	86.96
Sustainable Crop Systems	141	120.75	85.64
DEXiPM Integrated Management	151.5	131.75	86.96

4.2.4. Halting biodiversity loss

Miller et al. (2006), as part of a larger study of landscape change indicators, produced maps of development pressure at a scale of 1 km for Scotland (Figure 4.2.3). The development pressures included agricultural intensification and abandonment, urban expansion, infrastructure development, tourism and recreation, mining and landfill. The information for this mapping came from a range of sources including the European Environment Agency, Antrop (2003) and Landscape Character Assessment reports of 1999. As would be expected, the greatest concentration of development pressures were associated with conurbations, but large areas of agricultural land were also identified as having more than one source of development pressure.

This work identifies areas where one kind of service is being supplied at the cost of one or more others, and is particularly relevant in showing where development pressures are being felt from areas associated with the provision of food and the supply of basic cultural services (e.g. accommodation). However, it also demonstrates areas where trade-offs within the policy area of halting biodiversity loss are present. Biodiversity is highly relevant for agriculture through plant pollination processes, and is also important for tourism and some other recreational activities, in the countryside and in urban greenspace. Areas where there are multiple development pressures are therefore likely to be trading one benefit of biodiversity for another.

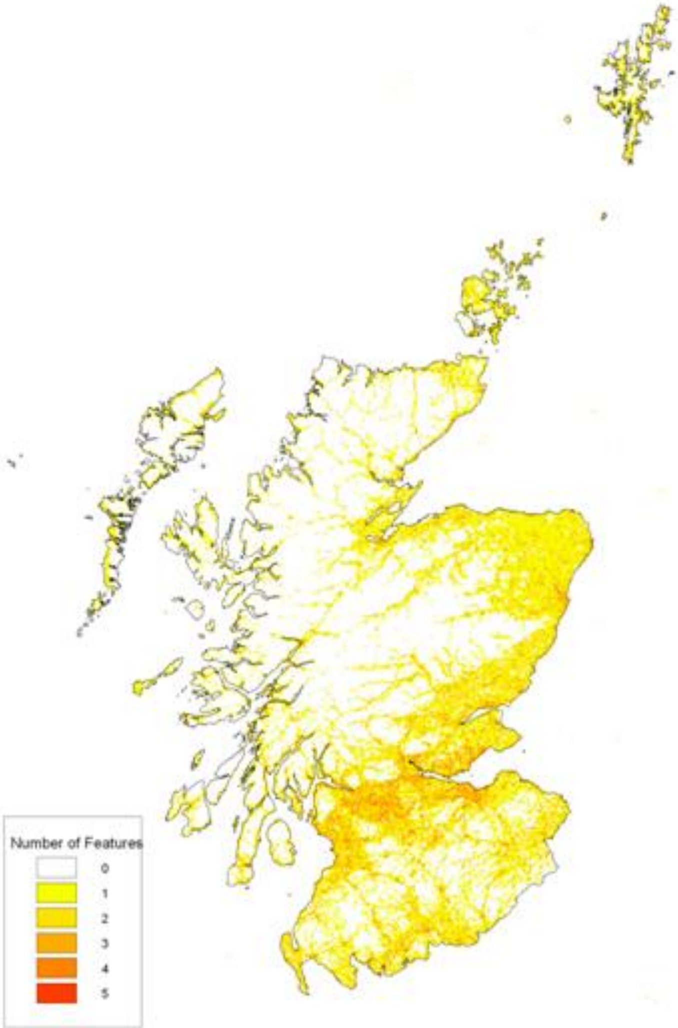

Figure 4.2.3. Development pressure indicator applied to Scotland for 2005: number of development pressures present in each 1 km x 1 km square.

For the mapping shown in Figure 4.2.3, Table 4.2.3 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 4.2.3 shows that the most suitable framework is Resilience Alliance, with a score of 137 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DEXiPM Integrated Management, with a score of 128 out of a possible 151.5.

Table 4.2.3. Scores of the assessed effectiveness of the mapping given in Figure 4.2.3 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	130	81.00
NEA	141	115	81.56
MEF	160.5	131.25	81.78
DPSIR	130.5	110	84.29
MA	145.5	119.75	82.30
TEEB	100.5	83.25	82.84
Adaptive co-management	159	131	82.39
Resilience Alliance	169.5	137	80.83
Landscape Functions	144	118	81.94
Integrated Assessment – Climate Change	163.5	131.5	80.43
Institutions of Sustainability	138	112.75	81.70
Participatory GIS	135	112	82.96
Environmental risk assessment of novel crops	141	111.75	79.26
GM Coexistence	138	110.5	80.07
Sustainable Crop Systems	141	112.75	79.96
DEXiPM Integrated Management	151.5	128	84.49

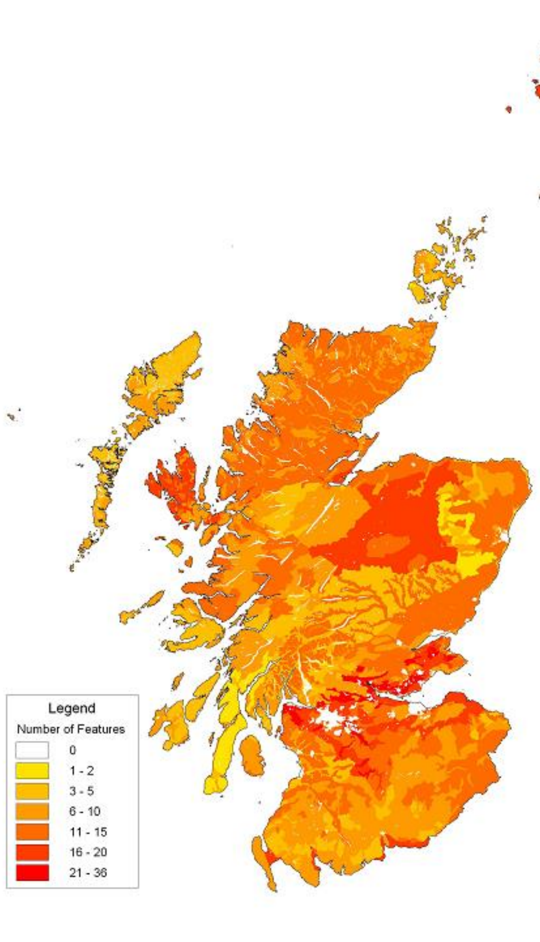

Figure 4.2.4. Number of forces for change as identified in the Landscape Character Assessment reports.

For the mapping shown in Figure 4.2.4, Table 4.2.4 provides an assessment of the suitability of each ecosystem framework, based on the information given in Table 1.3.2 and our assessment of how relevant the mapping is to each suitability criterion. Table 4.2.4 shows that the most suitable framework is Resilience Alliance, with a score of 130.25 out of a maximum 169.5. The framework that 'lost' the lowest proportion of points is DEXiPM Integrated Management, with a score of 123.25 out of a possible 151.5.

Table 4.2.4. Scores of the assessed effectiveness of the mapping given in Figure 4.2.4 being managed within each framework.

Framework	Maximum score	Assessed score	% of max
Risk framework	160.5	124	77.26
NEA	141	110.25	78.19
MEF	160.5	125.25	78.04
DPSIR	130.5	105.75	81.03
MA	145.5	114.5	78.69
TEEB	100.5	79.25	78.86
Adaptive co-management	159	125	78.62
Resilience Alliance	169.5	130.25	76.84
Landscape Functions	144	113	78.47
Integrated Assessment – Climate Change	163.5	125.5	76.76
Institutions of Sustainability	138	107.25	77.72
Participatory GIS	135	107.25	79.44
Environmental risk assessment of novel crops	141	107	75.89
GM Coexistence	138	106	76.81
Sustainable Crop Systems	141	107.25	76.06
DEXiPM Integrated Management	151.5	123.25	81.35

4.2.5. Communities better connected to the land

We have not found any work directly related to trade-offs with this policy area that has been mapped, or that could be mapped. However, work by some researchers has identified trade-offs involving recreational activities in other developed countries, particularly in urban areas (e.g. between urbanisation and greenspace for recreation) (Haase et al., 2012.) and agricultural areas (e.g. between crop production and forestry for tourism) (Raudsepp-Hearne et al., 2010). Potential synergies have also been identified involving recreational activities, for example health benefits from recreational activities and improved water quality associated with forestry (Raudsepp-Hearne et al., 2010).

4.3. Synergies and trade-offs between broad policy areas

While a significant number of pieces of research have been identified that provide mapped information relevant to one or more ecosystem services, there are only a few pieces of work we have found that could be used to demonstrate synergies and/or trade-offs between policy areas. In the cases that we have found, it is the trade-offs that are more obvious, rather than the synergies. The most easily-identified pieces of work in this area are those that demonstrate conflicts between Communities better connected to the land and Low Carbon Economy (i.e. sensitivity to the visual effects of wind farms), and between Halting Biodiversity Loss and Sustainable Food Production (i.e. pressures of agricultural intensification, identification of areas suitable for woodland expansion).

5. Data & knowledge gaps

5.1. Introduction

Several types of data & knowledge gaps exist in relation to mapping ecosystem services in Scotland. The most obvious kind is where no mapping can be found that is relevant to particular combinations of policy areas and service types. However, there are also different levels of relevance of mapped information, some of which is relevant but is not the mapping of a service per se, while some of which can be considered ecosystem service mapping. In addition, the quantity of work carried out varies from one ecosystem service and policy area to another, indicating the level of monitoring and emphasis placed on that area. Table 5.1.1 highlights where, according to this review, the levels of mapping information and overall monitoring/modelling work carried out of relevance to Scotland in recent years have been carried out. There is a parallel to be drawn here with work by Norris et al. for the UK NEA (2011) report, which relates the perceived importance of different biodiversity groups to the quality of monitoring data for those groups. The 'cultural divide' concept developed by Norris et al. argues that good data is available on biodiversity associated with cultural services, but not on the cultural services themselves, while at the same time good data is available on provisioning and regulating services, but not on the biodiversity underpinning these services.

Table 5.1.1. Mapped data and knowledge, and monitoring/modelling in combinations of ecosystem service types and policy areas.

	NC & Supporting	Provisioning	Regulating	Cultural
Sustainable food production	**&&	***&&&	**&&	**&&
Sustainable water management	***&&&	**&&&	***&&&	**&
Low carbon economy	***&&	**&&	***&&&	*&&
Halting biodiversity loss	*&&&	*&&	**&&	**&&&
Communities better connected to the land	**&	*&	*&&	***&

* - no mapping information found, ** - mapping found that is relevant but not direct, *** - direct mapping of this service type within this policy area. & - little or no monitoring work identified, && - moderate levels of monitoring work identified, &&& - significant levels of monitoring work identified.

The levels of mapping, monitoring and modelling shown throughout Table 5.1.1 provides a picture of good data availability and understanding for biodiversity- and community-related work associated with Cultural services, but less so for other work relating to these services. There is also evidence here for good data and understanding for Natural Capital & Supporting, Provisioning and Regulating services except in the areas of biodiversity and communities. This broadly agrees with the cultural divide concept of Norris et al. in the UK NEA, while at the same time changing it slightly:

- Good mapping, monitoring and modelling is available on **biodiversity and community** activities associated with cultural services, but not on the services themselves;

- Good mapping, monitoring and modelling is available on Natural Capital & Supporting services and on Provisioning and Regulating services, but not on the **biodiversity** underpinning these or on the **community activities** dependent on them.

Other types of knowledge gaps are covered below, including gaps in integration of data and knowledge, and uncertainties in the data and knowledge that we do have. There are also uncertainties in methodology and in scenarios of change, each of which is covered in a section below.

5.2. Data & knowledge integration

Much of the work presented in this report has relied on data from several sources, and within each mapping exercise a significant portion of the effort has gone into making these multiple datasets suitable for integration with one another. While the integration has been carried out successfully in each case, there is an implication that every time a piece of mapping work is carried out, a lot of effort is expended doing work that has already been carried out by someone else. If an approach could be adopted that standardised the integration of data from multiple sources, then this would relieve a lot of the effort; however, does a suitable approach or framework exist? The answer to this question is either 'yes' or 'not at all', depending on who is asked. Certainly spatial data frameworks exist. The problem is not finding one, it is choosing between them. The work carried out in compiling this report has shown that many different approaches have been used in integrating data, some of which have been developed from 'scratch' by the researchers in question. Where a new approach was developed, it was not because the researcher didn't know about available frameworks but rather because there didn't seem to be one that was suitable for their requirements. There is a strong need therefore for the development and/or adoption of a framework for handling spatial data in Scotland, which is accessible to all and which can be used to facilitate the science that needs carried out.

5.3. Data & knowledge uncertainty

The knowledge frameworks used in this work to assess mapping work are themselves a potential source of uncertainty. There may be uncertainty in answering the questions given in Table 1.3.1 correctly, in order to provide an assessment of the frameworks that have been selected (see the values that have been given in Table 1.3.2). However, in Table 1.3.1 there is specific mention of whether or not the framework incorporates uncertainty. If it does, then this consideration may improve the effectiveness of the framework. If it does not, then this can be another source of uncertainty and also can act as a knowledge gap. This is an example by which uncertainty can be 'captured' for later interpretation and resolution.

In Section 3.2, an example is given of mapping the potential of the soil for carbon storage/release. This work is based on existing 'legacy' mapping which was not carried out with the mapped example in mind. Many, in fact most of the examples given in this review of ecosystem service-relevant mapping are based on the use of different legacy data sources, and errors and uncertainties are introduced due to the nature of the datasets that have been used. Even if a dataset that is used is perfectly accurate (which we are not stating is the case) then the nature of the mapping carried out may not fit the ecosystem service mapping perfectly. Because of this, errors of categorisation and definition are introduced.

Ingraham & Foster (2008) produced an estimate of the ecosystem service valuation, in economic terms, provided by the US National Wildlife Refuge System, a system of protected areas across the United States. This was done by relating land cover classes to ecosystems, ecosystems to ecosystem service supply (for multiple services), and ecosystem services to Net Primary Production, from which a valuation estimate was achieved. They also highlighted that several potential sources of error existed due to the multiple translations carried out. However, it could be argued that nobody is going to get it right first time, and that a framework such as this could be adapted and improved over time to produce more accurate estimates. Concerns about the use of a framework where estimates of valuation can change rapidly due to the integration of new knowledge are arguably at the heart of why ecosystem service valuation has not been taken up more broadly as an aid to planning and land management. Land management planning decisions are in one sense a financial investment in the socioeconomic and biophysical infrastructure of society. Investment in a system that has high levels of uncertainty will be low, so the argument might be 'why make the system more uncertain than it already is?' The handling and quantification of uncertainty is therefore seen to be a priority in future work in ecosystem service mapping, as without quantification and valuation as a future end-point there is arguably little purpose in doing this in the first place.

5.4. Methodological uncertainty

In Section 3.3.3 and in many other sections of this report, we have given examples of processes and basic soil parameters that have been mapped, each of which is known to be relevant to functions, ecosystem services and societal benefits. However, the links in these connections from the lower level of parameters, through processes and upwards are usually only described qualitatively. A quantitative description of how the lower levels feed up through the hierarchy, including descriptions of synergies and interactions along the way, are usually unavailable. This introduces a great deal of uncertainty into any potential quantification or valuation of service provision.

Uncertainties also exist in the implementations of many of the maps shown here, in much the same way as described above. What has often been mapped is based on rule sets or incomplete quantified knowledge, with corresponding uncertainties relating to our understanding of the physical, chemical and biological interactions taking place. By necessity, these implementations are simplifications of the reality and therefore introduce errors and uncertainties when they are developed and carried out.

Brooker et al. (2013) state that:

"With respect to wild species diversity as a cultural service, one of the major challenges is in understanding which elements of the biota and biodiversity (genetic, species, habitat) are considered important for service delivery. In some cases, where iconic species are the focus for recreation, this is relatively straightforward. In others, where the cultural service is delivered by the wider environment (rather than obviously a single organism) it is much more complex. Developing this understanding is necessary before we can start mapping areas of conflict among contrasting cultural service goods, and learning how to prioritise certain goods where conflicts exist."

5.5. Scenarios of change

Work on sustainability requires estimation of future management and impacts, which implies an ability to create scenarios of future trends. Section 3.2.2 shows how these scenarios can be used to make predictions of change to the landscape and the services provided. However, these scenarios are not predictions of the future and contain uncertainties, even without consideration of the uncertainty in which scenario is actually going to be what happens in the future.

In Section 2.6, we see that while mapping has been achieved, there is not always agreement or certainty on the relevance of the mapped features or characteristics – this relates to the greater uncertainty in valuation of services, which is a problem all by itself.

In the same section (3.2.2) we have shown a map of soil compaction risk at various points across Scotland. The uncertainty associated with the risk assessment at each point has also been given, demonstrating that there are approaches that can be used to quantify uncertainty and to identify what the factors are that are leading to the uncertainty in the first place.

5.6. Discussion

One of the biggest areas of uncertainty that has not been mentioned here but is visible through the shortage of examples, is that surrounding cultural services. Translating from often highly accurate mapping of environmental parameters and processes upwards to an expression of service delivery in a socioeconomic sense is fraught with opinion, interpretation and statistically uncertain qualitative description. This is not a criticism of the attempt to derive maps of cultural services, but rather reflects our basic lack of understanding of many of the connections that exist between basic biophysical characteristics and higher-level cultural significance of the landscape, and of how society will respond to changes and drivers in the future.

A final factor that can cause uncertainty is due to the aggregation and upscaling of Scotland's agricultural socioeconomic data within existing frameworks. Concerns surrounding the abuse or misuse of data from specific farms mean that often site-specific information exists but cannot be used or made available at the level of detail at which it is held. The aggregation of the existing data results in a loss of information that could be useful for mapping ecosystem services at the farm scale. There are many ways in which uncertainty can enter into the mapping of ecosystem services, or of functions that relate to ecosystem services. It is important first to be able to understand what these uncertainties are, and then to attempt to address them.

6. Conclusions

It has been possible to identify work relevant to ecosystem service mapping in Scotland that on a case-by-case basis covers a large number of different policy areas and service types. Nearly all of this work has been carried out without consideration of its relevance to ecosystem services, and acts as information in a secondary sense. This is common to ecosystem service mapping, which until recently has relied on legacy information and maps derived for other purposes.

Almost all combinations of service types (Supporting & Natural Capital, Regulating, Provisioning and Cultural) and policy areas (Low Carbon Economy, Halting Biodiversity Loss, Sustainable Water Management, Sustainable Food Production and Communities better connected to the land) have been found to have work relevant to that combination. The exceptions relate to cultural services or activities, where it is has been difficult to identify work that is not specifically aimed at Cultural services and the policy area of Communities better connected to the land.

Several frameworks have been identified that are relevant for the management of information relating to ecosystem services, with the most 'successful' ones according to different criteria being Resilience Alliance (by total score achieved) and DPSIR (by percentage of maximum score attained for each framework). We have assessed the ecosystem service examples given in this report in relation to these frameworks, with the assessment criteria being a combination of the suitability of the framework for the handling of ecosystem service information, and the suitability of the mapped work for being managed within an ideal framework. This has allowed us to determine a level of 'fit' between the work carried out and its suitability for ecosystem service mapping, without consideration of the quality of the work itself. What we have found is that work relevant to combinations of service type and policy area that are more closely related to one another is more likely to fit well within existing frameworks, while work relevant to combinations that are less closely aligned is likely to fit less well. A significant proportion of the assessment of framework suitability relates to how relevant it is for stakeholders and policy makers. Mapping work that lies within more obvious combinations of ecosystem service and policy area appears more likely to be relevant to these groups. But why would this be?

A comparison between two extreme examples may shed some light on this. The work shown in Figure 2.5.1 shows the mapping that received the lowest total assessment score (groundwater contamination risk), while the work shown in Figure 4.2.2 received the highest assessment score (landscape sensitivity for a range of visual receptors). The lower-scoring work contains more fundamental science that could not be communicated as easily to land managers and policy makers, but which is of more use to researchers. The higher-scoring work is of immediate and obvious use to policy makers and people making decisions about land management, but due to the subjective nature of the landscape sensitivity assessment, it may be less relevant in informing fundamental research. We are seeing a relationship emerging in the data presented, as visualised in Figure 6.1, between where a body of work lies in terms of ability to inform decision-making, and how well it fits into ecosystem frameworks that can integrate it with other information for discussion and explanation.

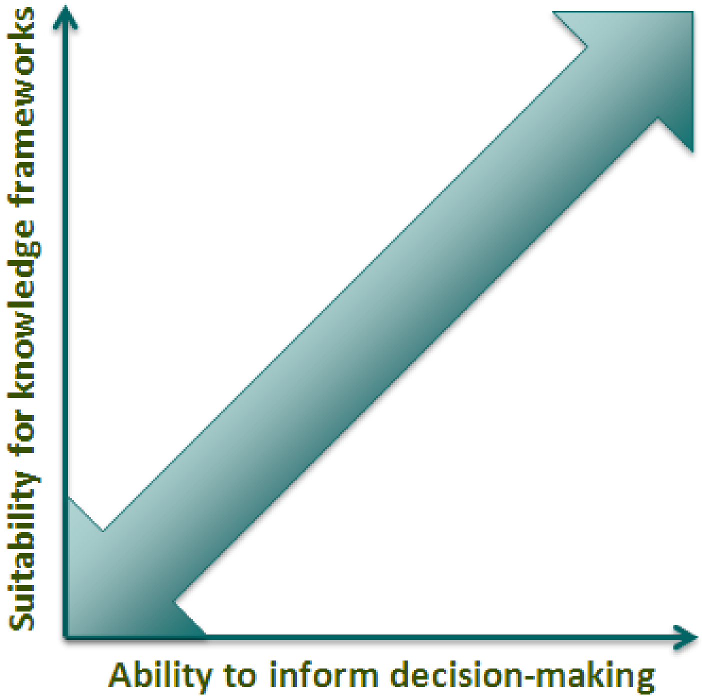

Figure 6.1. Visualisation of relationships between mapping's ability to inform decision-making and its ability to fit into knowledge frameworks.

There is an implication from this work that new ecosystem service mapping (or mapping that may provide useful information while not being specifically targeted at ecosystem services) should consider the criteria used to assess knowledge frameworks at an early stage, to ensure better suitability and utility of information. This may be easier to achieve for work that is relevant to more obvious combinations of service and policy area, as researchers are likely to be more aware of the policy relevance of this work and will be developing the methodology and dissemination approach accordingly. For work that is relevant to a less obvious combination of service and policy area, it is possible that this is of less immediate policy relevance and contains more 'fundamental' research.

The conclusion that could be drawn from this therefore is that basic research with a spatial nature may not fit within ecosystem frameworks, not because the science is unimportant but because the work is not providing information of immediate use to stakeholders. We would argue that this conclusion is wrong, and that thinking like this prevents some mapping research from being utilised to its full potential. Instead, it should be possible to improve the fit of a piece of mapping work into knowledge frameworks by considering, in the design stage, how best to maximise the assessment of the work as provided in Table 1.3.1. Further recommendations in this area can also be found in a report by the European Commission (EC, 2013) which develops and examines an analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020.

A point that has not been touched on during this work is the actual importance of the services and properties that have been mapped, both to people and the environment. For some, it is easy to formulate an argument for their importance but for others, it is often a matter of personal preference and priorities. An important activity to be undertaken before any mapping is carried out is the identification of the importance or usefulness of that which is to be mapped. This would perhaps lead to more politically relevant mapping taking place in preference to the mapping of Scotland's landscape that are less politically important, and would therefore more likely result in the mapping of features that fit better within the existing knowledge frameworks identified in this study. Whether or not this would be a good thing is open to debate.

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Appendix A: Table of assessment criteria evaluation for ecosystem service mapping examples

See below for a list of the questions 1-22, as presented in Table 1.3.1.

Table	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
2.3.1.	2	3	3	2	1.5	3	1	1	2.5	2	1.5	2	1.5	2	2	2	2	1	1	1	2	1.5
2.5.1.	2	2	2	2	1	2	1	2	2	2	1.5	2	1.5	2.5	1.5	2	2	2	1	1	1.5	2
2.5.2.	1.5	2	2	2	1.5	2	2.5	2.5	1	2	2	2	2	2.5	1.5	2.5	1.5	1	1	1.5	1.5	1
2.6.1.	1.5	1.5	1.5	2	2	2.5	2	3	2	1.5	1.5	1	1	3	3	2.5	2	2.5	1.5	1.5	2	2
2.7.1.	2	2.5	2.5	3	2	3	1	2	2	2	2	2	2	2	1	3	1.5	3	2	2	2	1
3.2.1.	2	2	2	2	2.5	2.5	1	3	2.5	3	3	3	3	2.5	2	3	2	2	1	1.5	3	1
3.2.2.	2	2	2	2	2.5	2.5	1	3	2.5	3	3	3	3	2.5	2	3	2	2	1	1.5	3	1
3.2.3.	3	3	3	3	3	3	2	3	2	3	2	3	2	2.5	1.5	3	3	2	2	2	2	1.5
3.2.4.	3	3	3	3	3	3	1	3	2	3	2	3	2	2.5	2	3	1.5	3	2.5	2	2	2
3.3.1.	2	2	2	2	2.5	2	2	2	1.5	1.5	1.5	1.5	1.5	2	2.5	2	3	1.5	1	2	2	2
3.3.2.	2.5	3	3	2	2	3	3	2	2	2.5	2	2	2	2	1.5	2.5	2	1.5	1	1.5	2	2.5
3.3.3.	2	2.5	3	2.5	2.5	3	2.5	3	2.5	2.5	2	2	2	2.5	1	3	2	2	1.5	2	2	2
3.3.4.	2	3	3	2	1.5	3	1	1	2.5	2	1.5	2	1.5	2	2	2	2	1	1	1	2	1.5
3.3.5.	2	3	3	2	1.5	3	1	1	2.5	2	1.5	2	1.5	2	2	2	2	1	1	1	2	1.5
3.3.6.	2.5	2.5	3	3	3	3	2	2.5	1.5	1.5	1.5	1	1	3	3	3	2.5	2.5	2	2	2	2.5
3.3.7.	2.5	2.5	3	3	3	3	2	2.5	1.5	1.5	1.5	1	1	3	3	3	2.5	2.5	2	2	2	2.5
3.3.8.	2.5	2.5	3	2	2	2.5	2	2	2.5	3	2.5	3	2.5	2	1.5	2	1.5	1.5	1	2	2	1
3.4.1.	3	3	2.5	3	3	3	2	3	2	2	1.5	2	1.5	3	2.5	3	2	3	3	2	2	2
4.2.1.	2	3	3	3	3	2.5	2	1.5	1	2	3	2	3	2.5	2	3	1	1	2	3	2	2
4.2.2.	2	2	2.5	3	3	3	2	3	2	3	3	3	3	2.5	2	3	2	3	3	2	2	3
4.2.3.	3	3	2.5	3	3	3	2	3	2	2	1.5	2	1.5	3	2.5	3	2	3	3	2	2	2
4.2.4.	2.5	3	2.5	3	2.5	3	2	3	2	1.5	1.5	1.5	1.5	3	2	3	2	3	3	2	2	2

Questions 1-22, as listed in Table 1.3.1.

Topic	No.	Question
Communication and Knowledge Exchange	1	Who is the target audience (e.g. policy makers)?
	2	How clear and comprehensible is it?
	3	How familiar is it to your audience?
	4	Is communication with stakeholders explicit?
Decision making	5	How useful is it for describing decision making?
	6	How useful is it for supporting decision making?
Framework description	7	Does it assess relationships between stocks and flows?
	8	Does it include/describe drivers and pressures?
	9	Does it describe dynamics, thresholds and disturbance?
Scale	10	At what spatial scale can the framework be applied?
	11	At what temporal scale can the framework be applied?
	12	How useful is it for cross-scale spatial analysis?
	13	How useful is it for cross-scale temporal analysis?
Functions	14	How useful is it for valuing services (monetary/non-monetary)?
	15	How good is it at linking ecosystem function and biodiversity?
	16	Can it be used to assess ecosystem service trade-offs?
	17	Does it capture abiotic and biotic components of functions?
	18	Does it relate ecosystem services to well-being?
Internal assessment	19	Does it support a participatory approach?
	20	Does it incorporate feedback and evaluation?
	21	Is there any consideration of uncertainty?
	22	Does it include indicators?