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National Ecosystem and Ecosystem Service Mapping Pilot for a Suite of Prioritised Services

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National Ecosystem and Ecosystem Service Mapping Pilot for a Suite of Prioritised Services

Neil Parker, Elsa-Kristin Naumann, Katie Medcalf, Roy Haines-Young, Marion Potschin, Conor Kretsch, Jacqueline Parker and Benjamin Burkhard

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The NPWS Project Officer for this report was: Gemma Weir; gemma.weir@ahg.gov.ie

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Executive Summary

Although the importance of ecosystem services has been widely acknowledged as a way of communicating the contribution that biodiversity makes to human well-being, there are considerable practical challenges in applying the idea for policy and management purposes.

This project has drawn on existing tools, approaches and data to demonstrate the kind of mapping that assists in the assessment of the state and trends of ecosystem services in Ireland. It was commissioned by the National Parks and Wildlife Service (NPWS), and is a step towards establishing a framework for a National Ecosystem Assessment for Ireland within the context of the EU's Biodiversity Strategy to 2020. Like all EU Member States, Ireland is requested under Action 5 of the strategy and the subsequent MAES (Mapping and Assessment of Ecosystems and their Services) Process to implement the action by mapping and assessing the state of ecosystems and the services they supply in their national territory. Information generated under the MAES Process will be used to value ecosystems and their services in the entire EU and promote the recognition of their economic worth into national and EU-level accounting and reporting systems.

This report describes how the project team worked with local stakeholders to identify which ecosystem services should be prioritised as part of the pilot, to identify what needs to be mapped and what can be mapped, taking into consideration existing national spatial data sources and developing indicators for national ecosystem service mapping. It sought to identify indicators that are appropriate for quantifying ecosystem service supply and demand, and document how they relate to different habitats and their associated characteristics. A series of maps have been produced and recommendations are made for taking forward the approaches demonstrated.

The ecosystem service "cascade" provides the conceptual framework for this project, and the basis for classifying ecosystem services using the Common International Classification of Ecosystem Services (CICES). CICES has been used widely for supporting mapping and assessment projects; its standardised nomenclature enables regional comparisons to be made and it has been adopted as a framework for MAES.

The mapping tool chosen for this project was SENCE (Spatial Evidence for Natural Capital Evaluation), selected primarily for its ability to be manipulated to accept a wide range of data sources at different scales and its ability to deliver outputs for a variety of ecosystem services. It is a GIS system, which allows for stakeholder weighting to be applied and, therefore, local knowledge to be included.

In developing an ecosystem services framework for Ireland, it was essential to incorporate the contributions of a range of stakeholders, including organisations likely to be involved in

implementing projects to restore ecosystems in Ireland, people with existing knowledge of environmental and societal issues and policy in Ireland, and technical experts and other stakeholders with knowledge of relevant data and projects. There were three main opportunities for stakeholder input; two stakeholder workshops and a review of modelling data and rules during mapping.

A workshop resulted in the identification of prioritised ecosystem services for Ireland which became the focus of the mapping work, namely the regulation of water quality and climate regulation through carbon storage. Biodiversity was identified as a factor of fundamental importance in underpinning ecosystem functioning and it was incorporated into the mapping to take account of its contribution in supporting the provision of ecosystem services.

Using the outputs of the stakeholder consultation workshops as a starting point, the project team examined the relevance of ecosystem services to stakeholder concerns within Ireland, and to policy areas that are the focus of current concern. This enabled the team to identify which of the many ecosystem services should be prioritised for consideration by the project, and which, given currently available data, could be analysed and mapped. An assessment was made of national and regional policy priorities and related work programmes. This helped identify principal areas of economic activity, including sectors and markets utilising living natural resources, which could be linked to the benefits from, or status and trends in, ecosystem services. In many areas, this review revealed a number of important cross-cutting issues. To bring together the many different policy driver and ecosystem themes, a table was created to define areas of interest which can be taken forward into the development of CICES sub-classes for Ireland.

Selected ecosystem services were then modelled using the SENCE tool to create maps of:

- Land temporarily storing water
- Areas of land promoting good water quality
- Vegetation carbon
- Soil carbon
- Terrestrial food
- Terrestrial biodiversity: Habitats, management, ecological networks, and species
- Marine areas that provide food
- Marine carbon
- Marine biodiversity: Habitats and management

Over 300 spatial datasets were made available to the project, with many being identified and commented upon as part of the first stakeholder workshop. In the majority of cases, no single dataset was readily available, appropriate to use, simple to map and fully representative of an individual ecosystem service. Mapping and assessment work relied on the use of 'indicators' or 'surrogate' measures that can be used to quantify provision in a more indirect way. Information has been brought together using a geoinformatics approach that considers the available data both spatially and quantitatively by use of a scientific 'rule-base' system based on scientific literature and local knowledge. This enabled bespoke maps to be developed which illustrate the spatial variation in service provision. Limitations and gaps in the datasets have been identified and discussed in this report.

A key feature of data collation was to create a seamless and comprehensive habitat dataset, known as a Habitat Asset Register, as an indicator of the underpinning living systems that support ecosystem services. It is suitable for re-use by the NPWS and with very few licence restrictions. In addition, an Ecosystem Services Information Database (designed to incorporate datasets throughout Ireland, i.e. an All-Ireland Matrix of datasets) was produced to facilitate further ecosystem service mapping. It helps users identify their data needs for mapping a particular service and can identify which service can be mapped given the data available. It also facilitates effective communication of the findings for Ireland by linking the name of the CICES service to corresponding names under the other ecosystem service classifications.

By looking at indicators in the context of the SENCE tool, the work has demonstrated how these indicators can be cross-referenced to the different elements of the 'ecosystem service cascade' so that users can see how service outputs can be quantified using different direct and proxy measures. This approach is particularly important because it enables the role of 'biodiversity' in service outputs to be more clearly demonstrated and potentially monitored.

In order to ensure that the description and naming of ecosystem services relates to Ireland, this project has developed and extended the CICES framework. The results principally list what has been identified as the specific ecosystem service benefits that are relevant in the Irish context, given our understanding of stakeholder concerns and policy needs. These ecosystem service benefits are listed as sub-classes within the CICES structure. The list represents those services at sub-class level that were prioritised through our work with stakeholders and through our analysis of policy needs. In naming these sub-classes an attempt has been made to use terminology that is appropriate to current concerns in Ireland. In addition the mapping that has been suggested would assist in the assessment of the state and trends of these services and which key habitats or features might be used as the basis for quantitative indicators.

The steps that can be taken in the future to further advance the incorporation of ecosystem services into policy and decision making in Ireland have been identified and recommendations have been made on further development of methods.

Main Recommendations:

While the overall structure of CICES seems appropriate, it is recommended that the ecosystem services classification for Ireland be developed further with regards to sub-classes, a process started for prioritised services during this pilot. It is useful in an operational context to break down the class level (the most detailed within the current CICES structure) to more specific sub-classes nested into the overall structure. These sub-classes are at the level of ecosystem goods and services that can actually be measured 'on the ground' and which have particular policy or management relevance. This would provide users with the kind of flexibility they would need to develop geographically specific applications, and the experience in Ireland is valuable in showing how this can be done. For higher level policy work more aggregated indicators would be useful (at the CICES Group and Division levels); this might be especially useful in the context of the MAES Process and any associated reporting commitments. A further aspect of this work would be to look at user-needs more generally and explore how, in an Irish context, policy or sector relevant reporting categories can be constructed using CICES classes, groups and divisions.

This work was used to identify *potential* ecosystem service classes, which are a subset of the CICES classification, and metrics that could be used to assess the status and trends of selected ecosystem service benefits. Further dialogue with stakeholders would allow the appropriateness of these indicators to be reviewed, and others added where gaps are felt to exist.

In addition, it would now be valuable to identify the next set of indicators that can be quantified and mapped given current data resources, and where data gaps exist, to develop monitoring and measurement strategies that can be put in place to overcome these. For example, in order to develop cultural ecosystem services, it would be useful for any future study to review the range of material available and develop understanding of the important factors that drive the need to map and assess these at different scales, as well as developing strategies for overcoming data and knowledge gaps.

To verify the usefulness of the indicators and potential ecosystem services classes at a local level, it would be good to carry out a local pilot in a data-rich region and seek conversation with local stakeholders.

The existing maps could be developed further in the future, as they can be seen as the first step towards an economic evaluation. Furthermore, opportunity mapping, showing where ecosystem services could be enhanced, could be carried out.

The species data collated for this project could be used to carry out more detailed analysis into functional groupings; relationships between species groups and ecosystem service provision could be investigated.

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The project was co-ordinated for NPWS by Gemma Weir, who provided technical and scientific advice and co-ordinated scientific/technical input of staff at NPWS.

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NPWS staff and contractors contributed data and advice to the project. Other organisations which kindly provided data and input include:

Bat Conservation Ireland (BCI), Birdwatch Ireland, Bord Na Móna, Botanical Society of Britain & Ireland (BSBI), Central Statistics Office (CSO), Coastal and Marine Research Centre (CMRC), Department of Agriculture, Food and the Marine, Department of Communications, Energy & Natural Resources - Petroleum Affairs Division, Department of Environment, Community and Local Government, Environmental Protection Agency (EPA), European Environment Agency (EEA), European Marine Observation Data Network (EMODnet), Forest Service, Geological Survey of Ireland (GSI), Intermap UK, International Council for the Exploration of the Sea (ICES), International Maritime Organisation, Local Authorities of Ireland, Marine Institute, Moths Ireland, National Biodiversity Data Centre (NBDC), National Botanic Gardens, North East Atlantic Fisheries Commission (NEAFC), Office of Public Works (OPW), Ordnance Survey of Ireland (OSi), OSPAR Commission, Sustainable Energy Authority of Ireland (SEAI), Teagasc, University College Dublin (UCD), Trinity College Dublin (TCD).

1. Introduction

1.1 EU Policy Context

Like all EU Member States, Ireland is requested by the EU Biodiversity Strategy to 2020 Target 2 Action 5 to map and assess in its national territory the state of ecosystems and the services they supply (European Commission, 2011[1]). This information will be used to value ecosystems and their services in the entire EU and to promote the recognition of their economic worth into national and EU-level accounting and reporting systems by 2020. Suitable methods, information and data are necessary to fulfil the requirements of Action 5 and to understand the supply and use of ecosystem services and how they are dependent on biodiversity. The overall aim of the Biodiversity Strategy's Target 2[2] is to maintain and restore ecosystems. The strategy recognises that society depends on various ecosystem services (e.g. food, energy, raw materials, air, water) which are provided by healthy ecosystems. Mapping and assessment of ecosystems and their services delivers information, methods and data needed for a more sustainable management of our environment and for ecosystem restoration where it is needed.

To support the EU Member States with the tasks related to the implementation of Action 5, the EU-wide working group MAES[3] (Mapping and Assessment of Ecosystems and their Services) has been established. The group meets twice a year to discuss latest developments in the Member States and the European Commission and to jointly develop guidance on mapping and assessment of ecosystems and their services. At present there are three supporting documents that have been prepared by the MAES working group which include:

- 1st report providing the analytical framework;
- 2nd report on indicators for ecosystem assessments;
- 3rd report focusing on the conditions of ecosystems

These reports can be downloaded from the MAES website. Additional support is provided to the EU Member States by the EU Horizon 2020 project ESMERALDA[4] (Enhancing ecosystem services mapping for policy and decision making). The application of findings from related studies and

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[1] http://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm

[2] http://ec.europa.eu/environment/nature/biodiversity/strategy/target2/index_en.htm

[3] http://biodiversity.europa.eu/maes

[4] Enhancing ecosystem services mapping for policy and decision making: http://esmeralda-project.eu/

projects begins to set the tone for implementing Action 5. However, for national and local level implementation of Action 5, more detailed studies and understanding are needed.

In order to support policy and decision making, Action 5 promotes the creation of national and EU-wide knowledge bases that can be used as primary data sources for developing green infrastructure, for the designation of ecosystems suitable for restoration (15% restoration of degraded ecosystems is included in Target 2) and to promote strategies for ensuring "no net loss of biodiversity and ecosystem services".

Through documents and efforts such as the Millennium Ecosystem Assessment (MA)[5], MAES and Ireland's National Biodiversity Plan[6], the need to plan and manage for ecosystem services are gaining more attention by policy makers, planners and decision makers. Ecosystem services are generally split into three categories[7]:

- provisioning ecosystem services (goods directly gained from nature, such as food or timber);
- regulation and maintenance ecosystem services (e.g. the regulation of our climate, clean air and water); and,
- cultural ecosystem services (e.g. locations that support benefits such as recreation or sense of place).

All of these categories of ecosystem services rely on healthy levels of biodiversity and ecosystem conditions, the underlying determinants of all ecosystem services. The ecosystem service "cascade" (Potschin and Haines-Young, 2011, 2016) provides the conceptual framework for this project, and the basis for classifying ecosystem services using the Common International Classification of Ecosystem Services (CICES). CICES has been used widely for mapping and assessment purposes (Crossman et al., 2013). Its standardised nomenclature enables regional comparisons to be made (e.g. Busch et al., 2012), and has been adopted as a framework for MAES.

Due to the underpinning importance of biodiversity for ecosystem service provision, the resilience of ecosystem services is an additional consideration under the ecosystem approach. Resilience measures how healthy the ecosystems are and how likely they are to remain healthy when faced with environmental changes. Considering the resilience of a system is particularly important, as detectable changes in service provision can lag behind the changes in the environment that are ultimately causing them. The functioning biodiversity of Ireland's marine and terrestrial system are intrinsically

[5] http://www.millenniumassessment.org/

[6] http://www.npws.ie/legislation/national-biodiversity-plan

[7] Following CICES: http://cices.eu/

linked to the resilience of ecosystems and this project will provide a starting point to map and describe these functions.

1.2 Project Aims

This project aims to pilot national mapping and assessing of ecosystem services for Ireland, in order to identify the kind of mapping that assists in the assessment of the state and trends for a suite of prioritised ecosystem services in Ireland. It seeks to identify which indicators are appropriate for quantifying ecosystem service supply, and for documenting how they relate to different habitats and their associated characteristics. The study provides an evaluation of methods and data sources currently available for mapping and assessing ecosystem services in Ireland and also identifies data and knowledge gaps, which can guide future research. The aims of the project are therefore:

- Working with stakeholders to identify the most important ecosystem services in Ireland, and understanding which habitats or ecosystems support the delivery of these services;
- Developing indicators for selected ecosystem services, using existing and available data;
- Collating and preparing data, modelling and mapping the selected ecosystem services across Ireland;
- Presenting outputs and recommendations at stakeholder workshops, as well as preparation of this final report outlining methods and identifying key gaps in knowledge and data.

This project seeks to exploit existing data and local expert knowledge, as gained through stakeholder input into the project. Moreover, this project is an initial step towards establishing a National Ecosystem Assessment (NEA) for Ireland, to which the identified methods, data and stakeholders would eventually contribute.

1.2.1 *Overview of Project outputs.*

The project report should be read in conjunction with the suite of project outputs. Indicator documents describing the indicators developed for mapping the selected ecosystem services are included in the appendices to the main report.

- Rules-base provided in MS excel format contains the qualitative weightings assigned per class per indicator.
- Mapping outputs are presented as images in the report. These are also available for viewing and download in GIS format via the NPWS website. INSPIRE compliant metadata for the mapped outputs are included in the project NPWS Data Resource catalog in Adobe PDF format.

- A standalone MS Access Ecosystem Services Spatial Framework Database provides information on available Irish national datasets to facilitate further ecosystem service mapping with reference to the CICES classification.

A full list of the project deliverables are shown in Table 1.

Table 1: Project deliverables

Identify the most important ecosystem services in Ireland and determine which ecosystems support these services		
Deliverable	**Delivery Method**	
High level national matrix of ES for Ireland	Included in the report – Appendix F Full excel spreadsheet supplied	
Project overview diagram	Included in report - (Figure 1)	
Develop indicators for selected ecosystem services		
List of information required to map and assess the prioritised ES.	Included in the report: - Data Collation and Suitability Analysis	
Data gaps Reference list	Included in the report: Mapping outputs and Limitations and Next Steps Included in the report : References and bibliography	
Database	Microsoft Access data base included as a stand-alone deliverable The data base includes reference tables:	
	CICES for Ireland_fordb.xlsx	Lists CICES sub-classes developed during this project, including information on how they fit into the over-arching CICES framework and which maps they are included in.
	Data_Information.xlsm	Lists datasets used during this project, including data owners, licencing conditions, and links to the data or contact information for the data owner.
	Data_to_Map_Services.xlsm	Lists datasets used during this project and identifies if they are not needed, essential, or beneficial to mapping the ecosystem services that were prioritised for this project.
	Scale.xlsm	Lists datasets used during this project and identifies if they are suitable for mapping at local/catchment/regional/national/EU scale.
	Crosswalk.xlsm	Identifies how CICES classes fit into two other ecosystem service frameworks, MA and TEEB
	Theme_order.xlsx	Identifies the order that themes appear in the reports produced by Option 2
Collate and prepare data, model and map selected ecosystem services nationally		
Rule-bases	Stand-alone Excel spreadsheet	
Habitat asset register	Included in the report – Habitat Asset Register	

<table>
<tr><th colspan="3">Identify the most important ecosystem services in Ireland and determine which ecosystems support these services</th></tr>
<tr><th>Deliverable</th><th colspan="2">Delivery Method</th></tr>
<tr><td>Data audit for the habitat asset register</td><td colspan="2">Supplied as GIS raster files for HAR L2 with associated lookup tables (3010_MAES15-HAR_LookUp.xlsx)
Appendix I</td></tr>
<tr><td rowspan="2">Maps and Data Layers</td><td colspan="2">These are included in the report: Mapping Outputs
They are supplied in GIS format as:
• MPK files (ESRI Map Packages)
• JPEG files
• The individual raster .tif files; with the attribute tables (Where appropriate)
A 'Snap' raster for the terrestrial and Marine area has also been supplied to allow re-running of the data.</td></tr>
<tr><td>Ecosystem Service and Function maps:
• Areas of land that temporarily store water
• Water quality (Fresh water)
• Soil carbon
• Vegetated carbon
• Terrestrial food provision
• Terrestrial biodiversity
• Marine areas that provide food
• Marine carbon
• Marine biodiversity</td><td>Intermediate layer maps:
• Marine bathymetry
• Conservation designations
• Habitat Asset Register (HAR) Level1
• Habitat Asset Register (HAR) Level 2[8]
• HAR data sources
• Forestry Inventory and Planning System data
• Turloughs
• LPIS arable
• LPIS pasture
• Article 17 mosaics
• Networks combined
• Grassland network
• Upland network
• Wetland network
• Woodland network
• Slope
• Species conflation</td></tr>
<tr><td>Metadata</td><td colspan="2">NPWS Resource catalogue entries for each map layer</td></tr>
<tr><th colspan="3">Outputs and Communication</th></tr>
<tr><td>Report
Data gaps</td><td colspan="2">Final report and appendices
Included in final report: Limitations and next steps</td></tr>
<tr><td>Stakeholder consultation</td><td colspan="2">Appendix A and Appendix B Workshop 1 and 2 outcomes
(Appendix D: ES theme, pressure, policy matrix spreadsheet)</td></tr>
</table>

[8] Supplied digitally only

2. Approach

The overall approach to delivering the project aims is shown in Figure 1 and discussed further in this section. The role and activities for stakeholder consultation are described and an introduction to key tools used in the project for mapping ecosystem services is provided. Due to data at a national level being most suited for qualitative, rather than quantitative, ecosystem service mapping, this project did not undertake any economic valuation.

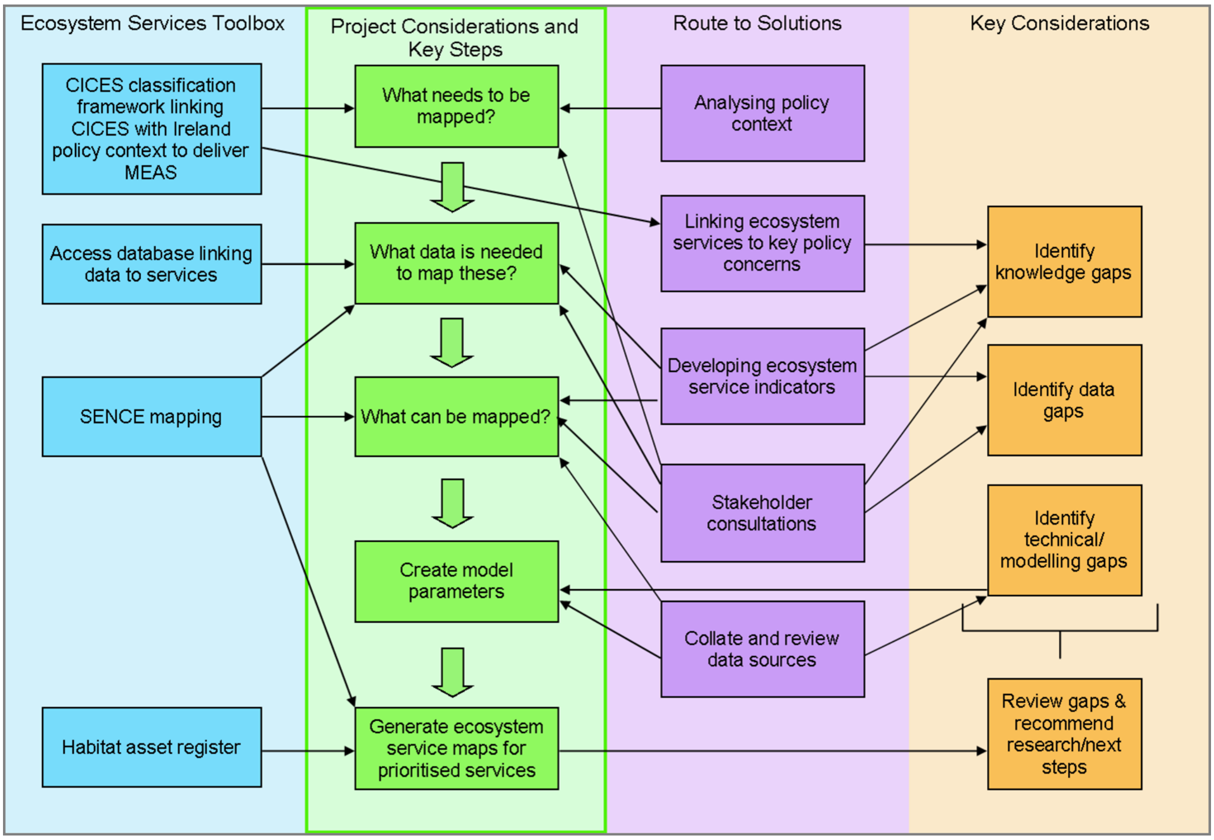

Figure 1: Project approach – tools, considerations and steps used by the project to support the analysis of ecosystem services in Ireland.

2.1 Talking about Ecosystem Services: Terminology

Talking about ecosystem services requires a clear terminology for the services themselves, as well as the pressures on them and the ecological structures, processes and functions that underpin their delivery.

2.1.1 *Conceptual Framework – the Role of the Cascade Model*

Although the importance of ecosystem services has been widely acknowledged as a way of communicating the contribution that biodiversity makes to human well-being, there are considerable practical challenges in applying the idea for policy, planning and management purposes. Apart from the availability of relevant data, the complexity of ecosystems themselves often makes the characterisation and assessment of ecosystem services a difficult undertaking. Moreover, since the factors that determine the demand and supply of services vary spatially, the mapping and valuation of those services is often intricate because it depends on understanding the way in which nature and society are linked causally. The MAES Process was therefore set-up to help the policy community overcome challenges detailed in the EU Biodiversity Strategy to 2020.

Figure 2 illustrates the ecosystem services 'cascade model' (Potschin and Haines-Young 2011, 2016) which sets out the way ecosystem services connect ecological structures and processes to the benefits and values realised by society, and hence the way human well-being depends on the underpinning characteristics of living systems or biodiversity.

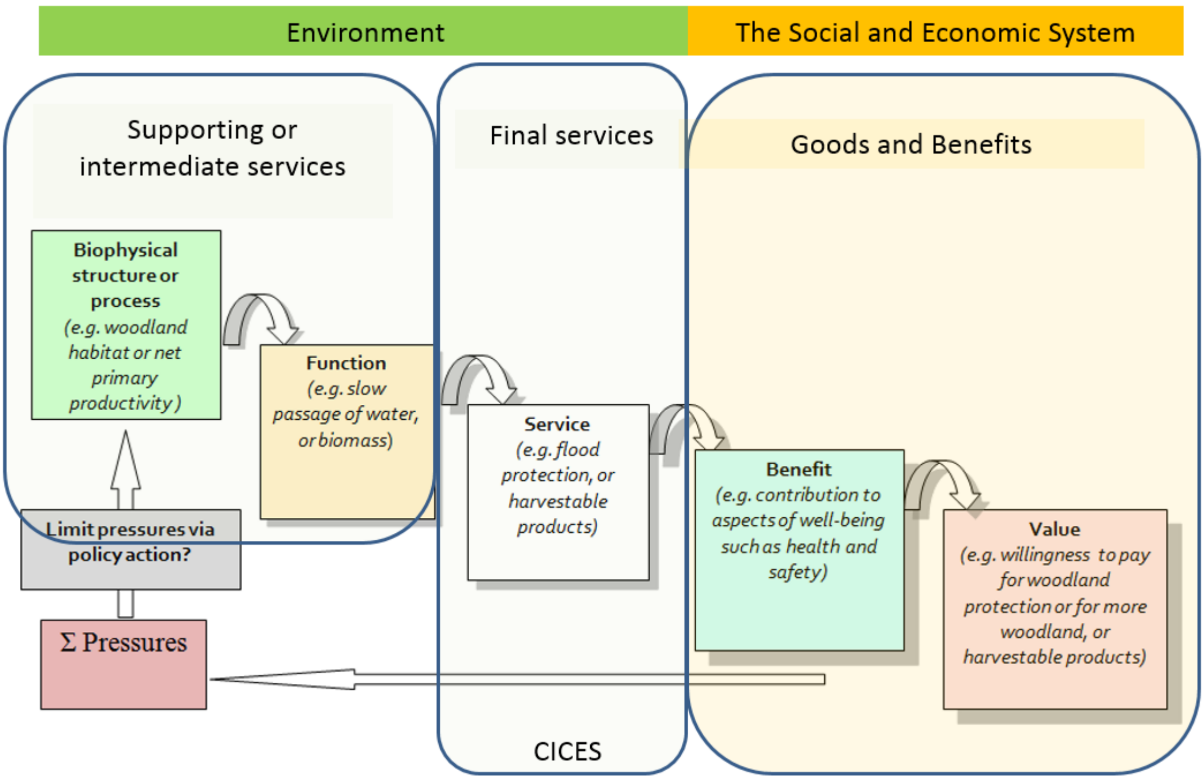

Figure 2: The cascade model (Potschin and Haines-Young, 2011, 2016).

A particular issue that the cascade model has sought to clarify is the way ecosystem services, benefits and values depend on the characteristics and behaviours of ecosystems. In the Millennium Ecosystem Assessment (MA, 2005), the ecological underpinning was captured in the notion of 'supporting services' which included elements like nutrient cycling and primary productivity. Other commentators (e.g. Saarikoski et al., 2015) have recognised that the links between these supporting services and the ecosystem outputs that ultimately benefit people may involve a number of steps and have therefore suggested that 'intermediate services' can also be identified (Boyd and Banzhaf, 2007). The cascade model that is used in the MAES Process seeks to clarify these types of relationships for practical purposes, by distinguishing only the 'final' outputs of ecosystems that benefit people as 'services'. The notion of an 'ecological function' is then used to identify those particular characteristics associated with a species or habitat on which that final service depends. These different conceptual elements are important in helping to quantify and map services and the benefits associated with them.

Figure 2 illustrates the way the cascade model can be used to describe how a habitat like woodland can contribute to human well-being by providing the service of 'flood protection'. In this case, the key ecological function is the capacity of the woodland to slow the passage of water through the woodland stand. Different types and ages of woodland will vary in the degree to which they can do this. Therefore, it is useful to distinguish this attribute from the other characteristics of woodlands and the ecological processes associated with them, because it helps us pick out what things might be measured in order to find out how the service is being delivered at a particular time and place. These functional characteristics may also be important for identifying what kinds of management intervention might be important.

The example used in the cascade model shown in Figure 2 also distinguishes the service of flood protection from the benefit that it generates and hence the value associated with it. It is here that the MAES framework differs from that of the MA, in that the latter regards services as benefits, whereas for MAES they are simply contributions to them. The reason why it is useful to distinguish services from benefits is that the implication of slowing the passage of water, and hence flood protection, will vary according to context. Clearly if it protects people and contributes to their security then this benefit would have quite a different value, than if it prevented the beneficial recharge of wetlands downstream. Services, in other words, can give rise to different types of benefit and the values associated with them can be different in different situations.

In the cascade and MAES framework, goods and benefits are things that can be valued, and if an overall understating of the importance of a service to a society is to be gained these are the factors that can be used to generate a kind of 'balance sheet'. And, as the cascade diagram (Figure 2) suggests, it is society's view of the changes in benefits and values that shape strategies to conserve or sustain the underpinning ecological structures and processes. Figure 3, which has been taken from Mace et al. (2012), illustrates the way in which the cascade can be used to frame the particular policy or management debate surrounding the issue of 'water purification'. This is particularly important in the context of the EU Water Framework Directive[9].

[9] http://ec.europa.eu/environment/water/water-framework/index_en.html

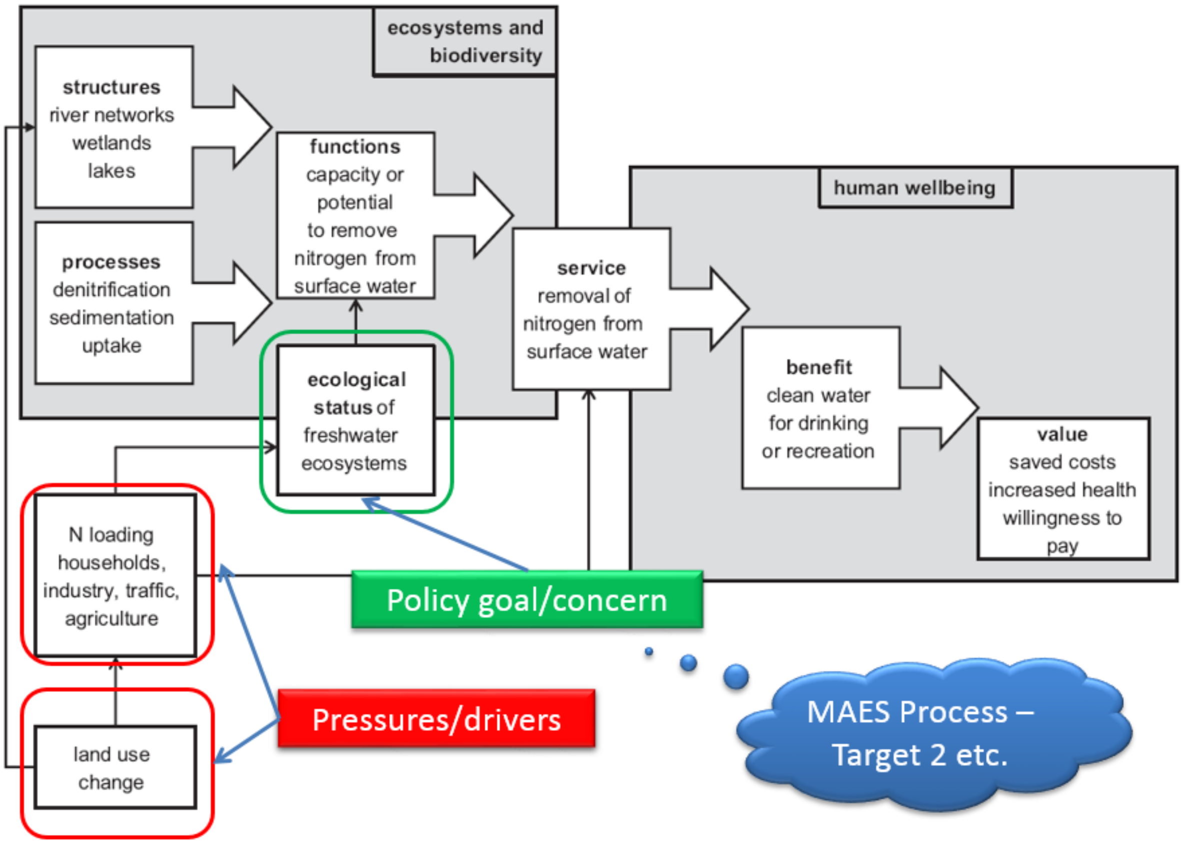

Figure 3: Application of the ecosystem services cascade framework to water purification (after Maes et al., 2012).

Although the cascade model has been found to be helpful in understanding the way nature and society are linked, it obviously greatly simplifies the way real socio-ecological systems work. For example, most habitats can generate a range of different services, and in this sense be viewed as 'multi-functional'. Moreover, within the suite or 'bundle' of ecosystem services associated with a particular ecosystem or habitat, some services can be positively associated with each other (in the sense that the factors that might cause one to increase will also enhance the other, thereby creating ecosystem services 'synergies'), while others might show more divergent types of association. This last situation is often described as involving ecosystem services 'trade-offs', in that the manager has to make choices about what types of intervention are needed according to the importance or preference that society has for the particular services on offer. Figure 4 illustrates how the cascade can begin to be used to describe some of the 'multi-functional', and hence 'multi-benefit', relationships that can arise in any particular situation.

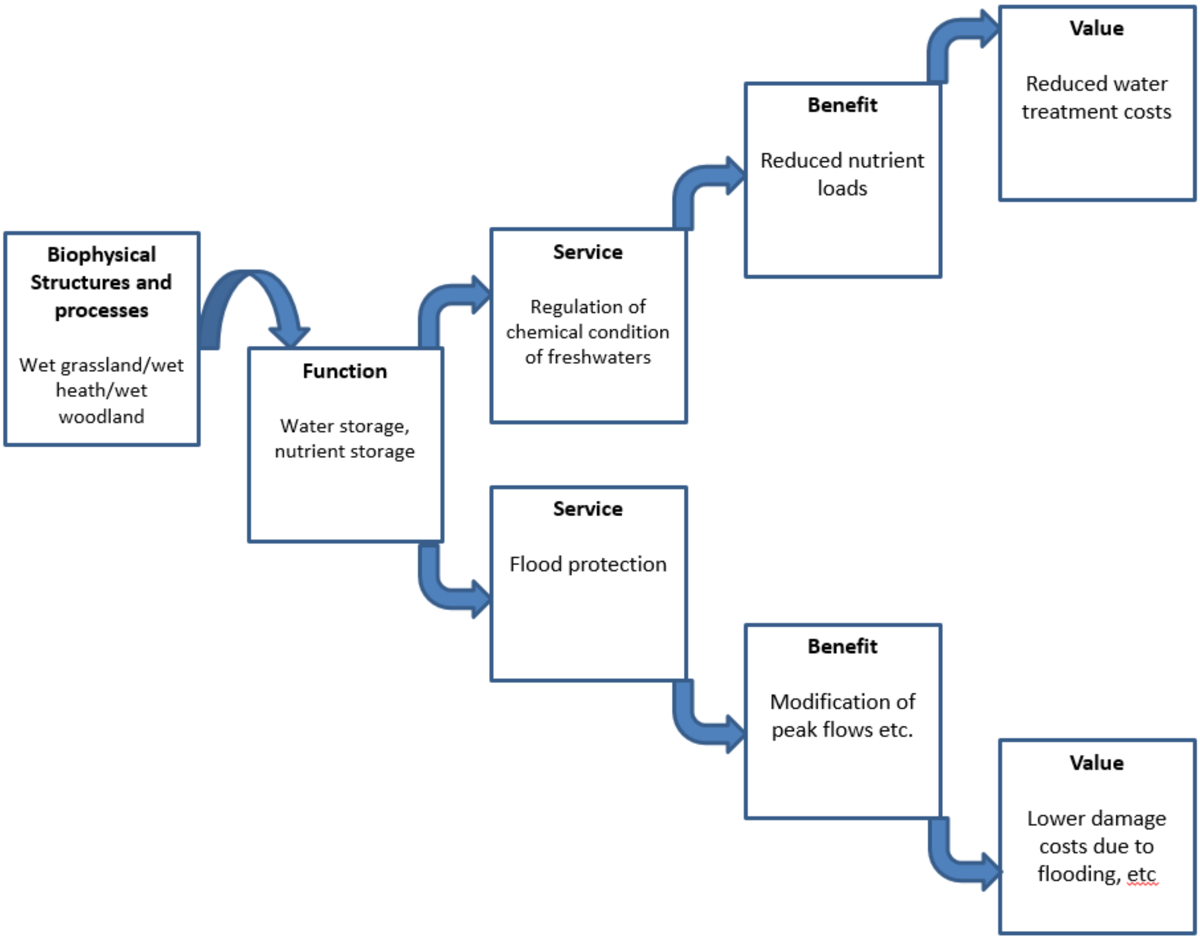

Figure 4: Ecosystem services and multiple benefits.

The cascade model can also be used to clarify the place of 'biodiversity' in the context of the ecosystem service debate. As Mace et al. (2012) point out, the concept can be multi-layered in the sense that biodiversity can have a role at various points throughout the cascade, namely, as a factor underpinning ecosystem processes; as a final ecosystem service; and finally as a good that can be valued through different valuation approaches. Thus, the variety or diversity of a grassland sward might be important in terms of the production of biomass, and thus underpin services that depend on forage production. In contrast, a harvestable entity such as an apple can be viewed as a final ecosystem service in that it can give rise to a number of goods and benefits such as food products or cultural heritage. Finally wild species, such as eagles or whales, can be treated as ecosystem goods that have value in their own right. In summary, therefore, the cascade model can help us clarify and communicate the different ways in which the conservation and management of biodiversity can be important for society.

2.1.2 Classifying and Measuring Ecosystem Services: CICES

One way in which the cascade model can be used to help measure and map ecosystem services is by providing a framework for naming and classifying them. A number of different typologies for ecosystem services have been used, including that of the MA (2005), that of *The Economics of Ecosystems and Biodiversity* (TEEB 2010)[10], and in the UK that of its own National Ecosystem Assessment (NEA-UK 2014)[11]. Because these typologies differ in a number of ways, and have often been quite selective in the services they identified, the *Common International Classification of Ecosystem Services* (CICES)[12] has been proposed as a way of more comprehensively listing services and defining them in a more consistent and transparent way.

CICES was initially put forward as part of the work on the System of Environmental and Economic Accounting (SEEA) that was led by the United Nations Statistical Division (Haines-Young and Potschin, 2013). Although initially proposed as a way of supporting the development of ecosystem accounts, subsequent work as has shown that it is also useful in the context of mapping and valuing ecosystem services. In Europe this wider role has been championed by the European Environment Agency (EEA), and most recently CICES has been proposed as the classification framework to be used in MAES[13].

The version of CICES that is now widely used was published in 2013, and is known as 'version 4.3' (Table 2). At the highest or most general level are the three familiar categories used in the MA: 'provisioning', 'regulating and maintenance', and 'cultural'. Below these major 'Sections' in the classification are a series of 'Divisions', 'Groups' and 'Classes'. Figure 5 shows the way in which the hierarchical structure works for Provisioning Services.

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[10] http://www.teebweb.org/

[11] http://uknea.unep-wcmc.org/

[12] ww.cices.eu

[13] see 2nd MAES report: http://catalogue.biodiversity.europa.eu/uploads/document/file/1230/2ndMAESWorkingPaper.pdf

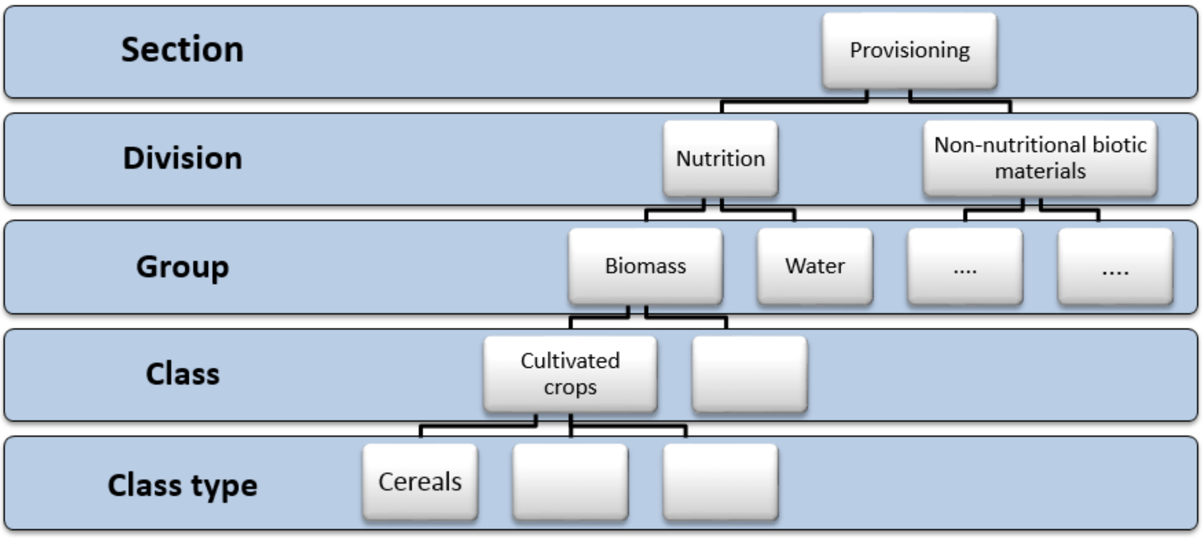

Figure 5: The hierarchical structure of CICES (Potschin and Haines-Young, 2016).

Ecosystem assessments have to be based on well-defined and credible metrics, which are often specific to particular geographical situations, land use or ecosystem types. For the purposes of reporting or comparison these may need to be aggregated and generalised. The hierarchical structure illustrated in Figure 5 allows users to go down to the most appropriate level of detail required by their application, but then group or combine results when making comparisons or more generalised reports. Thus moving down from Section, through Division, Group and Class, the 'service' is increasingly more specific, and these detailed service types are nested within the broader categories that sit above them. In the classification system there is therefore 'dependency', in the sense that the characteristics used to define services at the lower levels are inherited from the Sections, Divisions and Groups above them. There is also a sense of 'taxonomy', in that elements within the same Group or Class are conceptually more similar to each other, in terms of the ways they are used by people, than they are to services elsewhere in the classification. At any level in the hierarchy, the categories are intended to be exclusive and non-overlapping, so that CICES can be regarded as a classification system, rather than an arbitrary nomenclature.

CICES was developed through consultation with the potential user community led by the University of Nottingham and the EEA. A key initial requirement was that wherever possible the system should build on other widely used classifications so that it could be easy to understand and apply. Thus, CICES took as its starting point the typology used in the MA and refined it to reflect some of the key issues identified in the wider research literature. For example, it explicitly attempted to identify what are considered to be 'final services' (see Table 2), and was designed around the idea of a hierarchy, to accommodate the fact that people worked at different thematic as well as spatial scales.

Table 2: CICES V4.3 and the equivalence with the MA and TEEB typologies (Haines-Young and Potschin, 2013; Potschin and Haines-Young, 2016).

CICES V4.3					
Section	**Division**	**Group**	**Class**	**MA**	**TEEB**
Provisioning	Nutrition	Biomass	Cultivated crops	Food	Food
			Reared animals and their outputs		
			Wild plants, algae and their outputs		
			Wild animals and their outputs		
			Plants and algae from in-situ aquaculture		
			Animals from in-situ aquaculture		
		Water	Surface water for drinking	Water	Water
			Ground water for drinking		
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
			Materials from plants, algae and animals for agricultural use		
			Genetic materials from all biota	Genetic materials	Genetic materials
		Water	Surface water for non-drinking purposes	Water	Water
			Ground water for non-drinking purposes		
	Energy	Biomass-based energy sources	Plant-based resources	Fibre	Fuels and fibres
			Animal-based resources		
		Mechanical energy	Animal-based energy		
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals		
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems		
			Dilution by atmosphere, freshwater and marine ecosystems		
			Mediation of smell/noise/visual impacts		

CICES V4.3					
Section	Division	Group	Class	MA	TEEB
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	Erosion regulation	Erosion prevention
			Buffering and attenuation of mass flows		
		Liquid flows	Hydrological cycle and water flow maintenance	Water regulation	Regulation of water flows, regulation of extreme events
			Flood protection	Natural hazard regulation	
		Gaseous / air flows	Storm protection		
			Ventilation and transpiration	Air quality	Air quality
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	Pollination	Pollination
			Maintaining nursery populations and habitats		
		Pest and disease control	Pest control	Pest regulation	Biological control
			Disease control	Disease regulation	
		Soil formation and composition	Weathering processes	Soil formation (supporting services)	Maintenance of soil fertility
			Decomposition and fixing processes		
		Water conditions	Chemical condition of freshwaters	Water regulation	Water
			Chemical condition of salt waters		
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	Atmospheric regulation	Climate regulation
			Micro and regional climate regulation	Air quality regulation	Air quality regulation
Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	Recreation and ecotourism	Recreation and tourism
			Physical use of land-/seascapes in different environmental settings		
		Intellectual and representative interactions	Scientific	Knowledge systems and educational values, cultural diversity, aesthetic values	Inspiration for culture, art and design, aesthetic information
			Educational		
			Heritage, cultural		
			Entertainment		
			Aesthetic		
	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes	Spiritual and/or emblematic	Symbolic	Spiritual and religious values	Information and cognitive development
			Sacred and/or religious		
		Other cultural outputs	Existence		
			Bequest		

Although CICES seeks to be comprehensive, in drawing up the design it was recognised that ability to customise it so that it can be applied in different situations was important. This customisation can be achieved in two ways. Firstly, by nesting specific sub-class types that are specific to the application below the class level. Thus in Ireland, the Irish sub-class named 'Red, green, yellow, brown algae' would lie within the more general class named 'Fibres and other materials from plants, algae and animals for direct use or processing'. The way in which this approach was used in Ireland is explained in more detail in Section 3.4.2 Linking Ecosystem Services to Key Policy Concerns of this report.

The second way that customisation of CICES can be achieved is by grouping the classes into locally meaningful reporting categories that may also have a name that has resonance for the people working on that application. Thus, the surface and ground water provisioning services might simply be grouped as 'water supply'; the important point here is that the specific metrics used to assess 'water supply' are retained so that the transparency of the evidence-base can be assured.

Table 2 sets out the basic structure of CICES and also shows the equivalences with the typologies of the MA and TEEB. In many cases, there is a fairly simple read-across at the group level, but there are categories included in CICES, such as bioenergy, that are not explicitly covered by the others. Table 2 also emphasises the point that while the CICES categories can be used directly in a given study, it can also serve as a way of translating between the different systems in use; indeed, a simple prototype translation tool has been developed as part of the on-going EU-funded OpenNESS project[14].

The 'translation' role of CICES is important analytically because it can help people make consistent comparisons between different studies, even though they may have used different nomenclatures. This is especially important when comparing the status and trends of a service in different areas, or where comparison of value needs to be made between different places. CICES is also valuable analytically because it provides a framework within which people can link the indicators they have used to characterise particular services, as well as the datasets that have been used to measure them. For example, the MAES process has already begun to suggest indicators that can be used to characterise services in different thematic sectors, such as agriculture and forestry (Table 3).

[14] http://openness.hugin.com/example/cices

Table 3: Indicators for assessment of ecosystem services across different ecosystems (after MAES 2014).

Ecosystem services	Sector	Ecosystem Indicator	Marine Ecosystem indicator
Cultivated crops	Agro	Area and yields of food and feed crops	Yield Landings Catch per unit effort (where applicable)
Reared animals and their outputs	Agro	Livestock	
Wild plants, algae and their outputs	Forest	Distribution of wild berries (modelling)	
Wild animals and their outputs	Forest	Population sizes of species of interest	
Plants and algae from in-situ aquaculture	Water		
Animals from in-situ aquaculture	Water	Freshwater aquaculture production	
Water (Nutrition)	Water	Water abstracted	
Biomass (Materials)	Forest Agro	Area and yield of fibre crops Timber production and consumption statistics	
Water (Materials)	Water	Water abstracted	
Plant-based resources	Forest	Fuel wood statistics	
Animal-based resources			
Animal-based energy			
(Mediation of waste, toxics and other nuisances)	Forest	Area occupied by riparian forests Nitrogen and Sulphur removal (forests)	Nutrient load to coast Heavy metals and persistent organic pollutants deposition Oxyrisk
Mass stabilisation and control of erosion rates	Forest Agro	Soil erosion risk or erosion protection	Coastal protection capacity
Buffering and attenuation of mass flows			
Hydrological cycle and water flow maintenance			
Flood protection	Fresh	Floodplains areas (and record of annual floods) Area of wetlands located in flood risk zones	Coastal protection capacity
Storm protection			
Ventilation and transpiration	Agro	Amount of biomass	
Pollination and seed dispersal	Agro	Pollination potential	
Maintaining nursery populations and habitats		Share of High Nature Value farmland Ecological Status of water bodies	Oxygen concentration Turbidity Species distribution Extent of marine protected areas
Pest and disease control			
Weathering processes	Agro	Share of organic farming	

Ecosystem services	Sector	Ecosystem Indicator	Marine Ecosystem indicator
		Soil organic matter content pH of topsoil Cation exchange capacity	
Decomposition and fixing processes	Agro	Area of nitrogen fixing crops	
Chemical condition of freshwaters	Water	Chemical status	
Chemical condition of salt waters	Marine		Nutrient load to coast HM and POP loading Oxyrisk
Global climate regulation by reduction of greenhouse gas concentrations	Forest	Carbon storage and sequestration by forests	Carbon stock Carbon sequestration pH; Blue carbon Primary production
Micro and regional climate regulation	Forest	Forest area	
Physical and experiential interactions	Forest Agro Water Marine	Visitor statistics	
Intellectual and representative interactions			
Spiritual and/or emblematic			
Other cultural outputs		Extent of protected areas	

* For further details and explanations of terminology used in the MAES indicators please refer to the second MAES report (MAES et al. 2014)

A final way in which CICES and the cascade model can support the analysis of ecosystem services lies in the fact that although the aim is to measure ecosystem services directly, in some situations it may not be possible or appropriate to do so. For example, while a direct measurement of the reduction in the incidence of pests or disease clearly represents suitable measures of the level of pest or disease control provided by ecosystems, such measurements of changes in yield with and without the natural control agents might be difficult or costly to make. Instead, proxy or surrogate measures for other elements of the cascade can be used. Thus, in the case of these two examples, data on the distribution of semi-natural habitats and their proximity to the crops potentially receiving the service are often used. Thus, the cascade shows how an understanding of the ecological structures and processes (e.g. semi-natural habitats supporting populations of pest and disease control agents) and ecological functions (e.g. spatial patterning of habitats, or the structure of an ecological network in relation to the dispersal characteristics of the control agents) can be used as alternative ways of characterising the capacity of ecosystems to supply a given service.

In other situations, it may not be appropriate to characterise the service directly, because the focus of attention may be on the benefits or values that are associated with it. For example, it may be easier to count the number of trips and the costs people incur in making them as a way of characterising the recreational benefits that ecosystems provide rather than measuring the particular characteristics of different environmental settings (i.e. habitats/species) that affect people's experience in relation to this cultural ecosystem service.

In summary, therefore, the cascade model and the MAES framework provide a way of characterising the entire production chain linking the biophysical elements of nature to the benefits and values that they support, rather than just narrowly focussing on the services which are the interface between the two (cf. Pagella and Sinclair, 2014). As a result, a richer understanding of real-world problems can be built up, and using systems such as CICES a robust evidence base can be established. This is particularly important in the context of mapping ecosystem services, where an understanding of the key factors that influence patterns in the underlying ecological structures, processes and functions is required. This is a fundamental element of the SENCE approach proposed for this study (see Sections 2.2 Ecosystem Service Mapping Tools: SENCE and 5. Mapping Ecosystem Services in Ireland using SENCE.)

2.1.4 A note on trade-offs and costs associated with ecosystem services

Whilst the focus of this project is on the contributions of biodiversity and ecosystems to human well-being in Ireland, it is important to recognise that some interactions with the natural environment can have negative consequences for certain people or for society at large. These issues often arise as trade-offs, where the benefits of accessing or sustaining ecosystem services must be weighed against potential undesirable consequences. Such trade-offs can sometimes occur at a broad societal level. In some cases, trade-offs might be of concern to particular individuals, groups or communities. For example, many ecosystems and natural landscape features provide unique settings for recreation and sports tourism which create local employment and support regional economies, but at the same time the intensive use of lands for a few tourism activities may result in local nuisances such as noise or littering, or exclude other recreational users (the restorative benefits of experiencing nature may be hard to come by on a crowded tourist beach). From another perspective, whilst the strict conservation of bog ecosystems can have widespread benefits for Irish society, in terms of conserving vital genetic resources, preserving important cultural landscapes, reducing flood risks and protecting water supplies, it may limit the use of peatlands for local activities such as turf-cutting and forestry.

In some situations, natural ecosystem processes or specific elements of biodiversity may pose risks to well-being. A classic example of this from tropical regions is malaria, a disease caused by a wild parasite and spread by mosquitoes which naturally breed in wetland and forest habitats. In Ireland, a familiar example is hay fever, which some people suffer when they are exposed to pollen released into the atmosphere by some crops and wild plants. In cases where a negative impact on well-being can be related to specific ecosystem processes or functions, the term 'ecosystem disservice' is often used. However, this term is somewhat controversial as some so-called ecosystem disservices result more directly from the actions or choices of human communities, rather than from any ecosystem process. For example, trees in an urban landscape might provide a nuisance if their roots damage concrete or if they block the views from some residential properties, and this has been referred to as an ecosystem disservice (e.g. Lyytimäki 2014); however, such problems are arguably the result of a decision to plant certain trees in certain places or to manage the urban landscape in a particular fashion, and not really an impact of biodiversity or the direct result of ecosystem functioning. Confusingly, the term has also been used to refer to an impact upon the environment (i.e. a disservice *to* ecosystems) from a human activity, such as the impact which agricultural activities can have on wildlife or water quality (Swinton et al. 2007).

Regardless of the form that they take, the issue of trade-offs poses challenges for the sustainable use and conservation of biodiversity and ecosystem services, and may be linked to complex issues of ethics, fairness and social justice. Whilst this publication does not deal with such issues specifically, they have been considered in the review of policy priorities and assessment of economic and social needs associated with Ireland's ecosystems.

2.2 Ecosystem Service Mapping Tools: SENCE

There are a variety of tools available to map and assess ecosystem services (see reviews by Crossman et al., 2013; Martínez-Harms & Balvanera, 2012; Egoh et al., 2012). They have been developed as part of research projects by academic, government and non-governmental organisations or commercial businesses and, therefore, vary in their setup and application. Some are built as standalone pieces of software and others are toolkits designed to be used within existing commercially available and/or open source GIS (Geographic Information Systems). These mapping and assessment tools seek to depict ecosystem services by demonstrating the distribution of natural and anthropogenic processes. By capturing information about ecosystem services in this way, it is possible to use evidence of the provision of ecosystem services to benefit decision making processes, such as policy development.

Typically, a greater level of detail (both spatially and in terms of what the data inputs show) is needed to generate the information content required to support regional, or even local, decision making. At a national scale, a more generic set of information can be used to indicate ecosystem supply, and not all datasets cover such a wide spatial scale. Thus a local project might utilise a detailed map of soil types (e.g. 1:25,000 scale) that is available for a particular area (but maybe not for the rest of the country), whereas a national project is more likely to make use of a spatially consistent national soil map at a more generalised scale (e.g. 1:250,000). A GIS can accept data at many spatial scales and ecosystem services mapping requires the use of multiple data sources, so it is a necessity to understand the suitability of the data attributes at different spatial scales.

For this project, it was decided to carry out a short review of a range of suitably advanced mapping and assessment tools to assist in deciding which tool to use, to learn from previous work and to support the project and its requirements to:

- produce ecosystems services maps for the whole of Ireland including territorial waters;
- retain the ability for data to be revisited to produce ecosystems services maps at more detailed spatial scales;
- consider different biophysical characteristics of ecosystem services (at CICES Cascade levels 1 and 2);
- produce spatially explicit maps;
- utilise available datasets specific to Ireland in a range of data formats;
- combine datasets of differing spatial scales and levels of information content to represent ecosystem indicators;
- facilitate stakeholder input (by providing clear information);
- be flexible in considering different types of ecosystem services whilst retaining a consistent approach to deliver the spatially modelled maps;
- identify where data gaps exist and how data can be manipulated, but not misunderstood;
- produce ecosystem service maps.

The findings of the review of mapping tools are presented in Appendix A.

The process chosen for this project was SENCE (Spatial Evidence for Natural Capital Evaluation), which was selected primarily for to its ability to be manipulated to accept a wide range of data sources at different scales, and its ability to deliver outputs for a variety of ecosystem services. SENCE is a process of mapping ecosystem services developed by Environment Systems following successful projects to support research for natural resource management in Wales and for the Joint Nature Conservation Committee (JNCC) in their advisory role to the UK government[15]. It is a participatory GIS system, which allows for stakeholder weighting to be applied and therefore, local knowledge to be included. Further details of the use of the SENCE toolkit and how it was applied using the datasets available to the project is provided in Section 5. Mapping Ecosystem Services in Ireland using SENCE.

[15] http://ecosystemsknowledge.net/sites/default/files/wp-content/uploads/2013/05/A-Practical-application-of-SCCAN-in-Bridgend1.pdf

The concepts and approach that underpin SENCE are described in detail in two documents: 'Spatial framework for assessing evidence needs for operational ecosystem approaches' [16] and 'Further development of a spatial framework for mapping ecosystem services'[17]. SENCE has been applied both in the UK and overseas with the toolkit supporting the mapping and providing data output on ecosystem services to meet the needs of a range of stakeholders in widely differing environments [18].

2.3 Stakeholder Consultation

In developing an ecosystem services framework for Ireland, it was essential to incorporate the contributions of a range of stakeholders. Stakeholders involved in the project include:

- organisations likely to be involved in implementing the ecosystem services model in Ireland;
- stakeholders and interested parties with existing knowledge of environmental and societal issues and policy in Ireland;
- technical experts and other stakeholders with knowledge of data and projects that can support or inform the project.

During the project, there were three main opportunities for stakeholder input, which included two stakeholder workshops and a review of modelling data and rules during the SENCE process.

2.3.1 Consultation with the Project Steering Group

The initial Steering Group meeting, held in August 2015, considered prioritisation of different ecosystem service themes. Specific policy areas (such as agriculture, forestry, fisheries, water quality, flooding, etc.) were put forward for discussion. Stakeholders were then asked to provide details on why the policy area is important, how the policy area is currently applied and understood, and to identify likely high level interactions with other policy areas (e.g. increase in forestry or agricultural land take). The group then identified and ranked the different ecosystem themes/policy areas to determine their level of priority and create the drivers for mapping specific ecosystem services. The Steering Group included representatives from Teagasc, Environmental Protection Agency, University College Dublin and the National Parks and Wildlife Service.

2.3.2 Stakeholder Workshop 1

[16] http://jncc.defra.gov.uk/page-6241

[17] http://jncc.defra.gov.uk/page-6690

[18] http://www.darwininitiative.org.uk/documents/DPLUS022/23488/DPLUS022%20AR1%20-%20Edited.pdf

The first stakeholder workshop was held in September 2015 and had the following objectives:

- Create awareness and support for the project aims by the stakeholders;
- Discuss data availability and suitability with stakeholders;
- Provide a summary of the workshop outcomes suitable both for workshop attendees and stakeholders who could not attend; and
- Encourage further stakeholder input.

20 stakeholders attended the workshop in person, an additional five stakeholders provided feedback, comments and/or data via email. 12 organisations were represented: Bord Na Mona, Department of Communications, Energy & Natural Resources (Geological Survey of Ireland), National University of Ireland Maynooth, Office of Public Works, Trinity College Dublin, Department of Environment, Community and Local Government, and representatives from organisations in the Steering Group - University College Dublin, Environmental Protection Agency, National Parks & Wildlife Service and Teagasc.

Following the Steering Group meeting indictors to map specific ecosystem services were proposed. A review of available data was carried out to prepare a series of mapped outputs to support Workshop 1.

Workshop 1 comprised three sessions.

1. To make the best ecosystem service framework for Ireland, it was necessary to identify the key issues and services provided. In the first session, the candidate list of prioritised services (including pressures/ indicators) produced through consultation with the project steering group was put forward for discussion at the workshop. This candidate list contained ecosystem services that were considered suitable for mapping during initial assessments and that were considered important by the steering group.
2. In the second session, stakeholders identified further data sets with potential for use in the mapping as well as providing improved understanding of the datasets that had already been identified. To encourage engagement with the use of ecosystem mapping tools there was discussion at the stakeholder workshop regarding the use of different geospatial modelling techniques. This included additive modelling and data conflations.
3. The last session of the workshop sought to gather knowledge from local experts regarding considerations specific to Irish ecosystems, as this has an influence on how scoring is applied when mapping using the SENCE approach. For example, ecosystems in countries such as Ireland are influenced by land use patterns, with small field sizes and hedgerows leading to high spatial variation. This could lead to different approaches to scoring and evaluation between Ireland and continental countries.

A copy of the Workshop 1 outcomes is provided in Appendix B.

2.3.2 *Stakeholder Workshop 2*

The workshop was held on 25th November 2015. Over 40 participants attended, including participants from additional organisations including OPW, Department of Arts, Heritage and the Gaeltacht (DAHG) Built Heritage, Marine Institute, Department of Agriculture, Food and the Marine, DECLG – Spatial Planning, Dublin City Council, Birdwatch Ireland, Irish Water, Irish Forum on Natural Capital and Woodlands of Ireland.

As new stakeholders were present it was important to continue with generating support for the project as well as demonstrating progress by:

- Re-visiting the concepts, terminology and tools available for mapping ecosystem services;
- Providing detailed explanations of how data is used to map ecosystem service indicators;
- To introduce and provide the opportunity for stakeholders to review the draft priority ecosystem service maps based on those indicators;
- Complete a workshop session on how the GIS models and maps could support a range of work and decision making throughout Ireland.

Workshop 2 comprised three sessions:

1. In the first session the project and its aims were introduced. This explained further the concept behind categorising ecosystem services from Workshop 1, and how identifying biophysical characteristics of those services can be used. Examples of how ecosystem service mapping has been implemented elsewhere provided stakeholders with the opportunity to understand the approach taken and to generate discussion.
2. Following the Steering Group Meeting and Workshop 1, additional data such as Land Parcel Information Systems (LPIS) was made available which provides high resolution information on the distribution of pastoral and arable farming throughout Ireland. In addition more datasets were made available for key indicators such as habitat type and structure following Workshop 1 which enabled draft maps of the prioritised ecosystem services to be prepared for discussion. These maps were presented in a workshop session, with stakeholders invited to provide written comments on applicability of the maps, wording of what the services mapped actually show and to help identify where maps could be improved by introduction of new data or adaptations to the rules used in GIS modelling.
3. In a similar fashion to Workshop 1, the last session sought to gather knowledge from the stakeholders. The principal aim was to evaluate how ecosystem service mapping and

assessment can usefully contribute to environmental decision making in Ireland. To support the discussion, each stakeholder was requested to complete a questionnaire which included:

- Identification of opportunities for mapping ecosystems services in their current work;
- Ranking of the most useful components of ecosystem service mapping;
- Type of mapping outputs that would be useful;
- Which policy areas can ecosystem services be used by;
- Barriers to implementation of ecosystem services to support decision making.

The principal outcomes of the workshop provided further opportunities to include additional data and to adjust the Rule-bases for modelling of ecosystem services. A copy of the Workshop 2 feedback report is provided in Appendix C.

3. Applying Ecosystem Service Concepts in Ireland

3.1 Overview

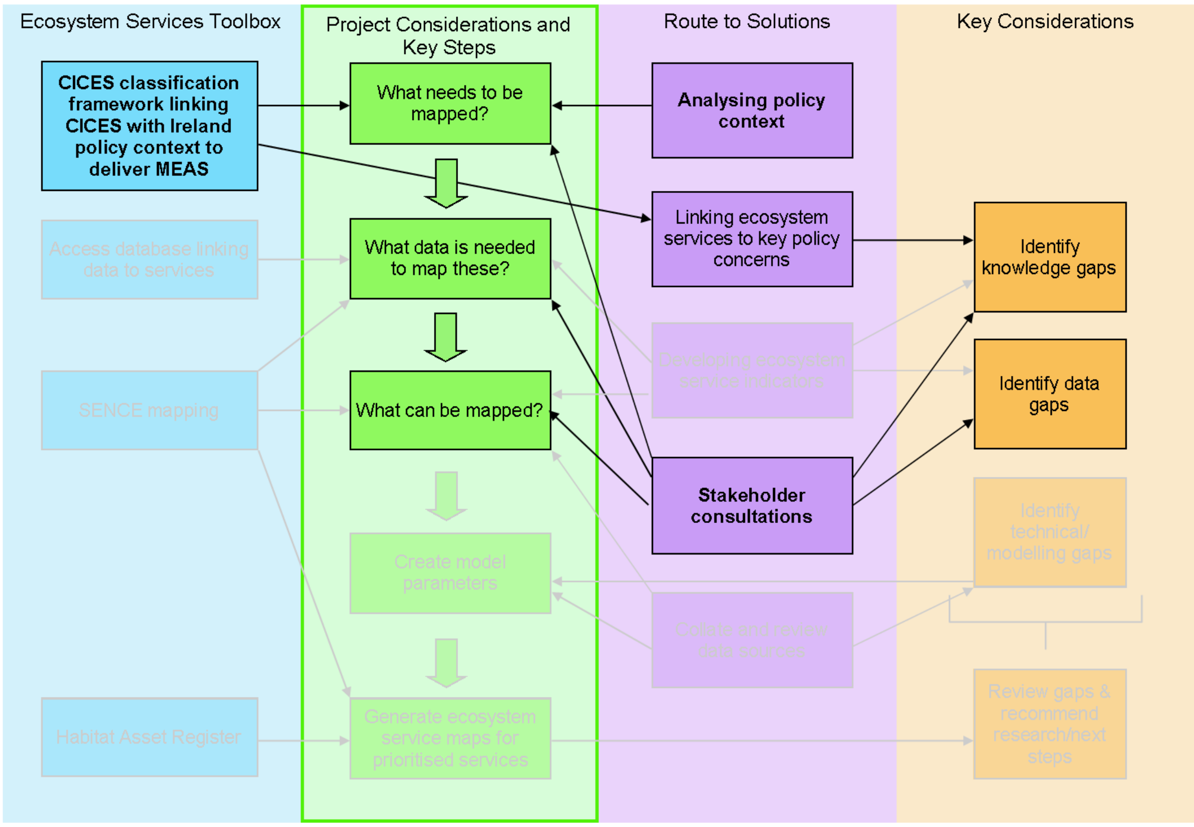

Figure 6: Project approach – tools, considerations and steps detailed in this section.

Although the EU Biodiversity Strategy's objectives for 2020 are a key focus of the MAES Initiative, the relevance of ecosystem services is much broader. Indeed, it may well be the case that these biodiversity objectives cannot be fulfilled unless the kind of cross-sectoral thinking envisaged in the Ecosystem Approach is applied. Therefore, this section examines in more detail the relevance of ecosystem services to stakeholder concerns within Ireland, and to policy areas that are the focus of current concern. The aim is to identify which of the many ecosystem services should be prioritised by the project, and which, given currently available data, can be analysed and mapped.

3.2 Outcomes of the Work Undertaken with Stakeholders

3.2.1 Prioritising of Ecosystem Services – Steering Group Meeting and Workshop 1

To make the best ecosystem service framework for Ireland, it is important to identify the key environmental issues and ecosystem service themes in Ireland. A candidate list of prioritised services (including pressures/ indicators) was produced through consultation with the project steering group and put forward for discussion at the workshop. This list was based both on the suitability of the service for mapping and the importance that the steering group attributed to the service and comprised:

- Provisioning services: Timber, Food
- Regulating services: Water quality, Coastal flooding and erosion regulation, Soil erosion regulation
- Cultural services*:* Sense of place, Recreation

In addition, the mapping of biodiversity represented by functional ecological networks, species diversity and habitats were also considered important factors to model and map as they have the potential to provide useful spatial information on the biophysical characteristics supporting those aforementioned services.

Discussion at the workshop identified ecosystem type priorities which confirmed the candidate list. A particular link was made to the number of services and functions relating to water quality in the freshwater and marine environment. In addition, the importance of peat in the rural economy was identified. Suggested key factors and indicators, as well as the ecosystem services they are linked to, are shown in Table 4.

Table 4: Indicators identified as influencing the prioritised ecosystem services.

Service	Considerations
Water quality (regulating service) • Terrestrial (freshwater) • Marine water Erosion Risk / Sediment (P)	Land use (Pressure) / septic tanks (Pressure) Peat degradation (Pressure) Agriculture (pasture and arable) (Service) Forestry (Service) Land cover (Service/Pressure)
Carbon sequestration / Climate change mitigation Soil Carbon (Function) Vegetation Carbon (Function) Marine Carbon (Function)	Peat soils (Service) Erosion (Pressure) Woodland / Forestry (Service)
Biodiversity → Underpinning all ecosystem services Terrestrial Marine	Land use (e.g. agriculture, forestry, conservation) (Service) Habitat condition (Service, Function) (e.g. water quality measures, invasive species)

3.2.2 *Generating support and gathering feedback - Workshop 2*

The review of the draft maps based on the steering group Meeting and Workshop 1 yielded constructive comments and identified further data sources as well as modifications to the scoring of the modelling Rule-bases. Further consultation with the steering group was undertaken on the Rule-bases (see Section '5.5.1 Steering Group Consultation on Rule-Bases).

Results of the questionnaire and discussion session provided confirmation that the prioritised services which were to be mapped would be those related to strategic planning and resource management (i.e. water, forestry aquaculture, agriculture, etc.). These were the key policy areas for which ecosystem service mapping should be implemented during this project (Figure 7). Further areas of importance included flood risk management, national economic and spatial strategies and the biodiversity strategy. However, it was also considered that ranking was generally even across the categories represented which gives confidence that the implementation of ecosystem service modelling and/or mapping can be considered a useful aid for environmental decision making.

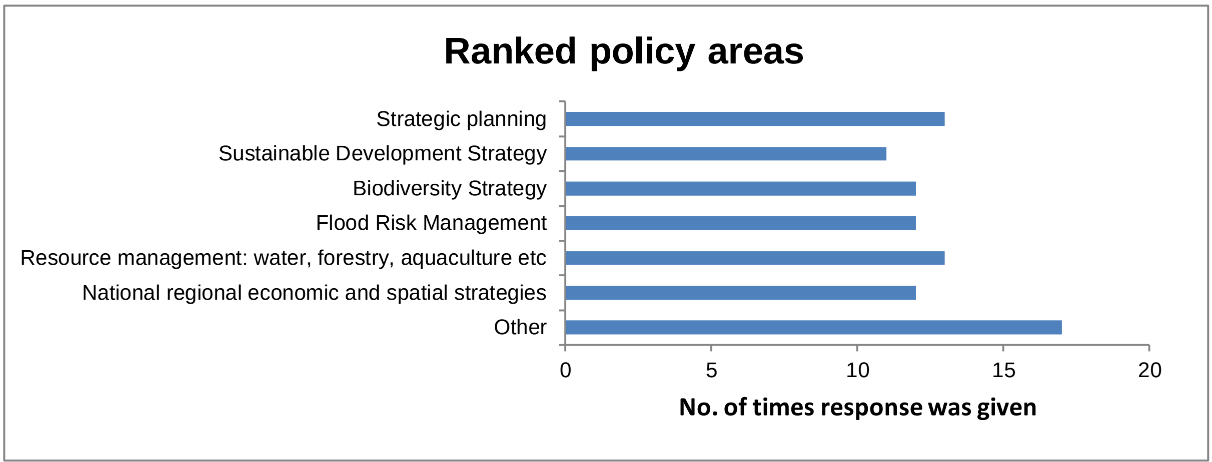

Figure 7: Ranked usefulness of ecosystem service mapping for use in environmental policy decision making.

3.3 Analysing Policy Needs

Using the outputs of the stakeholder consultation workshops as a starting point, the project team carried out an assessment of national and regional policy priorities and related work programmes. Those at Government and semi-state level were considered in order to identify areas of particular significance from the perspective of a national ecosystem service assessment. In essence, this sought to identify those policies, plans and programmes that either depend upon, or impact upon, stocks and flows of ecosystem services in the delivery of their respective strategic objectives. This review focused only on ecosystem services generated by Irish biodiversity and ecosystems. Whilst it is acknowledged that many important areas of economic and social activity are connected to ecosystem services produced outside the Irish State, these were considered to be outside the scope of this project.

The policy priority study involved a review of the current or most recent strategic policy documents (and related implementation reports where relevant) published by key Irish government departments, and included an analysis of the key pressures reported as impacting upon species and habitats protected under the Birds and Habitats Directives in Ireland. This was augmented by a review of key social, economic and environmental data produced by government offices and semi-state bodies, including a review of recent national economic and social statistics held by the Central Statistics Office. These reviews helped to identify principal areas of economic activity (including sectors and markets utilising living natural resources) which could be linked to the benefits from, or status and trends in ecosystem services. In many areas, this review revealed a number of important cross-cutting issues, which were incorporated into the policy review. For example, whilst participants in the consultation workshops identified the cultural heritage significance of landscape elements and unique uses of land as priority issues, the policy review determined that this related to priority initiatives in the tourism sector, which seek to better capture the value of these elements to tourism throughout Ireland and particularly to rural economies. Similarly, the review of policies related to recreation, which was also highlighted by the stakeholder workshop, identified connections to national public health priorities associated with physical activity and social engagement.

The policy review considered several key regulatory instruments at the EU level, including amongst others, the Water Framework Directive, Marine Strategy Framework Directive, and the Floods Directive, and these were noted, where relevant, as key drivers of Irish policy pertaining to ecosystem services. However, a detailed review of the full range of connected EU policy instruments, and of the full suite of implementing legislation in Ireland, was beyond the scope of this project. Certain regulatory instruments and EU policies were considered to have an over-arching importance across all social and economic policy areas (including the Birds and Habitats Directives and the EU Biodiversity Strategy to 2020), whilst others were considered to be most important as tools for implementing protections for biodiversity and ecosystems rather than as primary drivers of policies affecting ecosystem services (for example, the Environmental Liabilities Directive[19], the Environmental Impact Assessment Directive[20], and Strategic Environmental Assessment Directive[21]).

This assessment also took account of relevant 'headline' issues of public concern, as far as was possible, based on a review of national, local and specialist media reports on policy priorities and related issues in the previous decade (i.e. since 2006). Particular attention was also paid to recent reports on the state of the Irish environment produced by inter alia the Environmental Protection Agency, the Heritage Council, the National Biodiversity Data Centre, and the NPWS, as well as a review of relevant scientific literature (both peer-reviewed journal articles and commissioned reports for government and semi-state bodies, stakeholder groups and non-governmental organisations). The project was further guided by outputs from the UK National Ecosystem Assessment and the TEEB project, and an assessment of the social and economic costs and benefits of biodiversity in Ireland, carried out for the NPWS in 2008 (Bullock et al., 2008).

To compile the many different policy driver and ecosystem themes and pressures, a table was created to provide clarity and define areas of interest which could be taken forward into the development of CICES sub-classes for Ireland. A graphic overview of the matrix is provided in Table 5 and the full details of the interactions are provided in Appendix D and as an element in the MS Access Database.

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[19] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02004L0035-20130718

[20] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0052

[21] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32001L0042

Table 5: Ecosystem Theme, Pressure and Policy Matrix; 'x' indicates that there is a policy / document addressing the issue in regards to the policy and non-policy drivers

	Policy Drivers												Non-policy Drivers						
Issue	Biodiversity	Sustainable Agriculture	Water Management	Soil Protection	Rural Spatial planning and land use	Coastal Zone management	Marine	Urban development	Forestry / Woodland management	Landscape quality	Cultural heritage	Pollution and related health risks (e.g. air quality)	Health Promotion	Climate Change	Energy	Tourism	Economics	Natural Hazards	Societal Considerations
Aquaculture + coastal area (marine, terrestrial and interface)	X	X	X			X	X			X	X	X			X	X	X	X	
Agriculture		X	X	X	X					X	X							X	
Peat Industry and smaller scale turf harvesting	X	X	X	X	X					X	X						X	X	X
Forestry	X		X	X	X				X	X	X					X			X
Renewable energy					X		X		X	X	X				X				
Flooding		X	X	X	X	X	X	X		X	X	X						X	X
Water quality (inland and coastal)		X	X				X			X	X	X	X				X	X	X
Integrated Coastal Zone Management			X				X	X		X	X		X	X					

3.4 Developing CICES in the Irish Context

3.4.1 *Background*

While the cascade and CICES described in Section '2.1.1 Conceptual Framework – the Role of the Cascade Model' and '2.1.2 Classifying and Measuring Ecosystem Services: CICES' can be valuable analytically, it is also apparent that CICES can be useful in the context of reporting the outcomes of assessment and mapping exercises. It was in this context that the notion of 'CICES-Ireland' was suggested in the proposals for this work.

While the hierarchical structure of CICES enables ecosystem services to be defined in a very detailed way, these may not be appropriate for reporting the outcomes in a given policy or management context. Thus it is possible to use the basic elements of CICES as building blocks, and to aggregate or group them in ways that are appropriate to a given problem or issue. There is also the possibility of naming these groups in ways that can be understood or have resonance with the different stakeholder groups involved in particular situations. Providing the links back to the underlying CICES classes are retained, a transparent and flexible structure can be created that would allow wider comparisons to be made and results transferred to other situations.

An example of the way CICES can potentially support the reporting task is provided by work in Belgium, where a consultative process was used to develop a set of categories using CICES for assessment work (Turkelboom et al., 2013). The outcome, which has been referred to as 'CICES-Be', largely aggregates classes into broader categories and uses terminology to describe them in a way that has meaning to the people that will be using the assessment. The Symposium in Ireland on the *Mapping and Assessment of Ecosystem Services*, held at the Waterford Institute of Technology in February 2015 jointly organised by the National Biodiversity Data Centre, the Environmental Protection Agency and the Department of Arts, Heritage and the Gaeltacht, initiated a similar kind of process, although the outcome did not result in as complete a set of proposals as in Belgium.

The Waterford meeting reviewed CICES and suggested potential adaptations for Irish land use, environment and data, and potential indicators. Although a report from the Symposium is not yet available, a draft summary was made available to the project team (Murray and Malone, 2015). It included some suggestions for possible merging and regrouping of the CICES classes to produce more suitable categories for work at the national scale. The results are shown in Appendix E. Several features of the outcome of the Symposium are of particular interest here.

In relation to CICES, participants at the Waterford Symposium felt that the classification required greater explanation and interpretation with respect to Ireland, and that to make progress there was a need to develop a set of case studies illustrating its application in MAES in the Irish context. The outcomes of the current project will clearly begin to provide some of this material, and in particular provide guidance on how it can be applied in a way that is relevant to current policy and management concerns. Therefore, section 3.4.2 Linking Ecosystem Services to Key Policy Concerns describes how a set of specific subclasses can be identified that link the major ecosystem services to different policy areas.

During the Waterford Symposium the participants considered issues in relation to agricultural, forest, freshwater and marine ecosystems, and made recommendations for which services were considered to be a priority within each sector. They also suggested how CICES might be modified to handle them.

There were clear differences between ecosystem types in terms of what were considered to be the most important services generated in each type. In general terms, provisioning services outputs from wild plants and animals were flagged as being of particular interest in forest, freshwater and marine ecosystems; cultivated crops and reared animals were highlighted as important provisioning services in agricultural ecosystems. Water supply for drinking and other uses from surface and ground waters were also identified as being an important focus for work. Finally within provisioning services, plant-based sources of biomass energy were prioritised.

There was a considerable spread of interest within the regulating services, but there was clear agreement on the importance of global climate regulation, with the recommendation that it might be grouped with micro-climate regulation. The hydrological cycle and water flow maintenance were also seen as especially significant across all the ecosystem types. Amongst the cultural services, scientific uses were highlighted as a priority across all ecosystem types considered, along with the experiential use of plants, animals, landscapes and seascapes, by virtue of the recreational activities that they support.

The current project has worked with stakeholders, and it is clear that the findings largely confirm the prioritisation made at the Waterford meeting. In terms of taking the recommendations on modifying CICES that were made, it is recommended that these are most usefully addressed by not changing CICES directly, but instead using the hierarchical structure to identify policy or management relevant *reporting* categories by aggregating classes and sub-classes as appropriate. It is suggested that this work builds on the effort to identify 'Irish relevant' services at the sub-class level, which is addressed in the next section.

3.4.2 Linking Ecosystem Services to Key Policy Concerns

In order to ensure that the description and naming of ecosystem services speaks specifically to Irish concerns, this project has developed and extended the CICES framework. The results are shown in Appendix F, which principally lists which specific ecosystem outputs have been identified that are relevant in the Irish context, given the understanding of stakeholder concerns and policy needs. These ecosystem service outputs are listed as sub-classes within the CICES structure.

In reviewing the information in the policy review it is important to note that while the sub-classes identified are cross-referenced to corresponding classes and groups, not all CICES classes are represented in this table. Rather, this list represents those services at sub-class level that were prioritised through our work with stakeholders and through our analysis of policy needs. In naming these sub-classes an attempt has been made to use terminology that is appropriate to current concerns in Ireland, and to make this as transparent as possible, against each of the particular sub-classes the rationale for choosing them has been set out. In addition it has also been suggested which kinds of mapping would assist in the assessment of the state and trends of these services and which key habitats or features might be used as the basis for quantitative indicators.

In the context of the current Project, the CICES Sub-classes for Ireland forms the basis of the mapping work that has been undertaken to show how spatial assessments of ecosystem services can be made using currently available data. In more general terms, however, it is also important in taking forward the discussions on the need for 'CICES-Ireland', that is a classification that has greater resonance with national concerns. The ability to customise as many 'locally relevant' categories at the sub-class level was always intended as one way in which CICES could provide a flexible approach to characterising ecosystem service. Thus the CICES Sub-classes for Ireland (Appendix F) represent a first draft of what CICES for Ireland might look like. As other data becomes available or as other concerns arise, further Irish-specific sub-classes can be added as required. The important point to note is that the upper levels of CICES do not need to be modified to make them relevant to Irish concerns. The descriptors at the sub-class level can take the definitions at these upper levels and provide the kind of explanation that was called for in the Waterford workshop. Moreover, the approach does not preclude the construction of broader or more aggregated reporting categories, such as ‘water supply’ or ‘climate regulation’. Indeed, clarity in the way in which the service at class and sub-class level are ‘merged’ into these reporting classes ensures that the evidence-base represented through these reporting categories is as transparent as possible. Preservation of the overall structure of CICES also means that the ability to cross-reference cases and sub-classes to the MA and TEEB classification frameworks is maintained.

4. The Theory of Mapping Ecosystem Services

4.1 Overview

This section deals with the theoretical framework used for mapping in the project and the development of spatially explicit information on biophysical properties to model ecosystem service provision. Additionally, the section describes how this information is captured within a database, the All-Ireland Matrix, for future users with an interest in ecosystem service mapping.

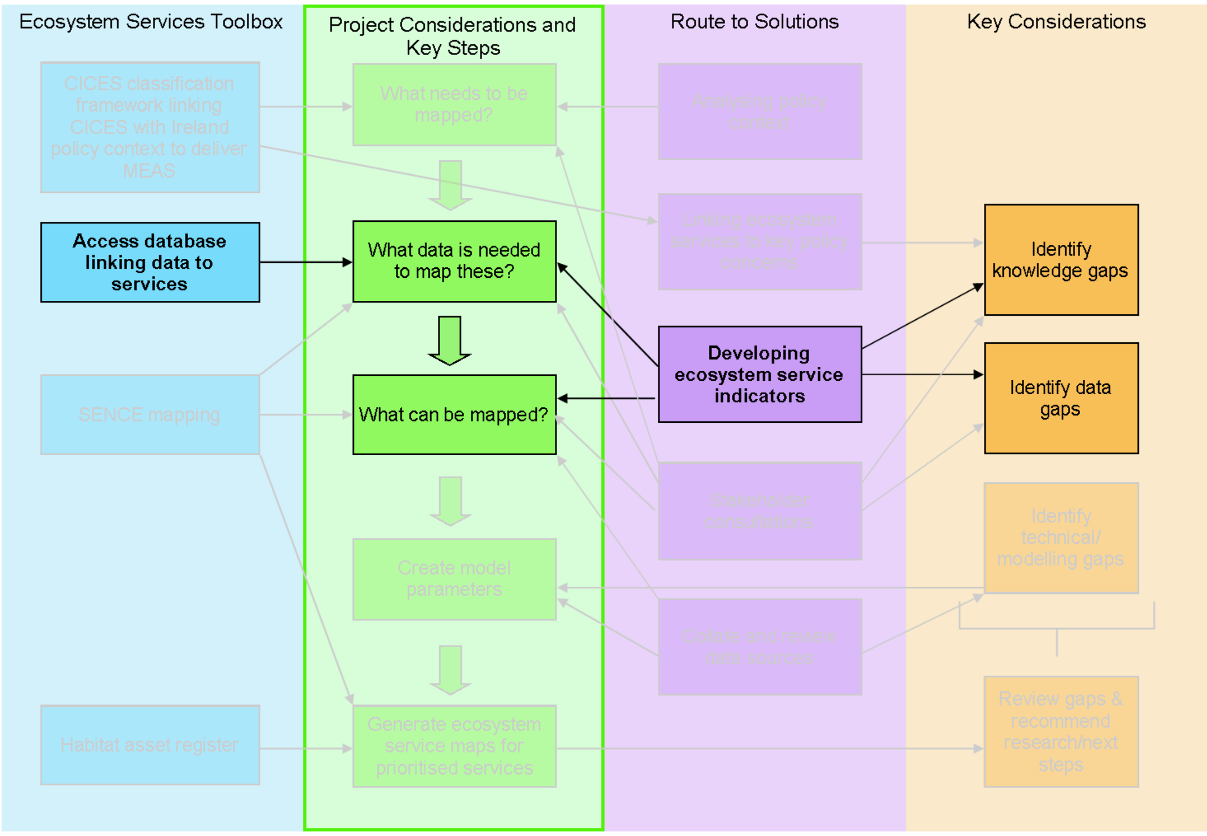


Figure 8: Project approach – tools, considerations and steps detailed in this section.

Application of ecosystem service tools, i.e. tools for visual depiction, assessment and/or valuation of ecosystem services, is an emerging discipline. This mapping project for Ireland, therefore, needed to consider all the information available and review its suitability for use. It is important that available spatial datasets can be assessed for its quality and applied to produce a clear picture of the spatial extent of ecosystem services.

In creating a crosswalk between the CICES ecosystem service sub-classes and the classes of the existing CICES, TEEB and MA frameworks it is possible to see where and how Ireland specific ecosystem services exist. The ability to register the datasets used or generated in this project alongside other frameworks provides opportunities to contribute towards EU reporting under the Biodiversity Strategy to 2020.

Whilst understanding how different frameworks correspond it is also important to know what data is available. To this end, an Ecosystem Services Information Database was created. This is a Microsoft Access database which can be operated by a non-GIS specialist to understand what spatial data is available and/or required to assist in mapping the indicators of ecosystem services and for which category under the different framework classifications they will apply.

4.2 Developing Ecosystem Service Indicators

Whilst the ability to clearly classify and describe ecosystem services is an essential part of any assessment on the contribution they make to human well-being, this is only a first step in the process of measuring them quantitatively and understanding patterns of supply and demand. It is not always the case that a service can be measured directly. Often relevant data is not available, or it is difficult or expensive to collect. Thus instead, mapping and assessment work has to rely on 'indicators' or 'surrogate' measures that can be used to quantify provision in a more indirect way.

Section 2.1.1 Conceptual Framework – the Role of the Cascade Model discussed the cascade model and the fact that the capacity of ecosystems to deliver services depends on the underlying ecological structures and processes associated with an ecosystem, and the particular ecological functions that give rise to the service. Thus important insights into that capacity to supply a service can be gained by mapping say, the stock (amount) and distribution of an ecosystem represented as a specific habitat or group of habitats, and of the condition of those individual habitat parcels, in terms of their productivity, size or isolation. Similarly, the demand-side of ecosystem services can be represented by looking more directly at the goods and benefits that the services support. For example the capacity of an ecological setting to supply cultural services can be assessed by the amount or value of recreational activity that it supports, where recreation is understood as a benefit in terms of the cascade model.

In short, to assess and potentially to 'map an ecosystem service', data across some or all the elements of the cascade may need to be looked at to build up a complete picture. The situation is illustrated in Figure 9, where the cascade has been used to look at the kinds of relationships that exist between the ecological functions, structures and processes that underpin climate regulation and water quality regulation. The diagram also illustrates how the various drivers and pressures for change can be factored into the analysis.

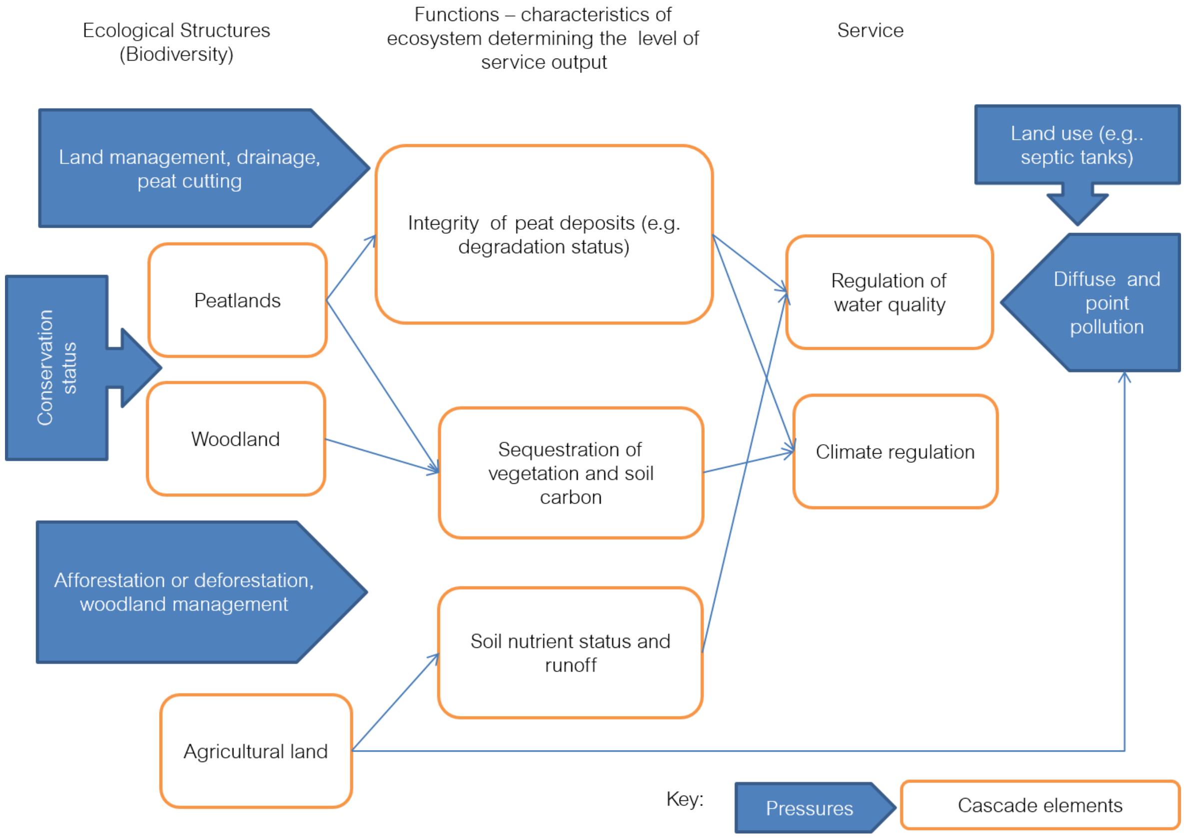


Figure 9: Ecological structures, functions and ecosystem services in the Cascade Model.

The necessity to look at services across all the elements of the cascade has been recognised by a number of recent studies, such as that of Mononen et al. (2016) who used it as a framework for developing a set of national ecosystem service indicators for measuring socio-ecological sustainability in the context of the Finnish National Ecosystem Assessment. These works argued that the CICES classes represented, in a sense, a set of themes or issues that could only be characterised by looking at the relationships the services had to the other elements of the cascade that determined ecosystem service supply and demand. The indicators of these different elements are the kinds of proxy or surrogate measures that can be used in this study to map the ecosystem services that are important to Ireland.

Therefore, this notion of proxy or surrogate measures to identify the kinds of mapping and mapping units that can be useful in characterising different services has been used. This provides the foundation for the SENCE mapping approach used in this study, which relies on understanding the key factors that influence patterns in the underlying ecological structures, processes and functions so that the likely service output can be inferred or predicted.

The SENCE approach is described more fully in the Sections 2.2 Ecosystem Service Mapping Tools: SENCE and 5. Mapping Ecosystem Services in Ireland using SENCE of this Report. Its application is contingent on the availability of data for services or their relevant proxies, and so in order to identify which of the priority ecosystem services could actually be taken forward for more detailed quantitative assessment, a review of available information has been undertaken (see Section 5.2 Data Collation and Suitability Audit).

4.3 An Ecosystem Services Information Database

The Ecosystem Services Information Database (designed to incorporate datasets throughout Ireland, i.e. an All-Ireland Matrix of datasets) helps to facilitate further ecosystem service mapping to be carried out for Ireland through two principal functions:

- The users can choose an ecosystem service of interest, input the scale at which they would like to map this service, and obtain a report detailing which data would be required.
- The user can input the type of data available and obtain a report detailing which service could be mapped from that data, and at which scale.

One important part of ecosystem service mapping is the effective communication of findings. Therefore, the database has a third functionality:

- The user can input a service and the classification system that the name of the service was derived from (CICES). The tool will then output the corresponding name under the other ecosystem service classification system and a report with relevant scientific background regarding the service in question.
- As an additional functionality, the tool can be used to obtain information regarding the methodology of the ecosystem service maps produced during this pilot project (see section '6. Mapping outputs').

The Access tool is underlain by information specifying which type of data is needed for the mapping of which ecosystem service, and for which scale individual datasets are suitable. Additionally, a table specifies which TEEB and MA categories ecosystem services from the CICES framework fall into. Examples of the type of report output by the tool are provided in Appendix G.

Table 6 lists the source tables in which all relevant information for the access database is recorded.

The data base is supported by a set of documents which outline the scientific conceptual background of each of the services and functions mapped. These documents are intended to provide sufficient information for non-specialists from other disciplines to understand the way the service has been mapped and scored, based on scientific literature. They are not developed as an Ireland-specific set of references, although this could be built into the system in the future.

Table 6: Source tables for the access database forming the All Ireland Matrix

Table	Information recorded
CICES for Ireland_fordb.xlsx	Lists CICES sub-classes developed during this project, including information on how they fit into the over-arching CICES framework and which maps they are included in.
Data_Information.xlsm	Lists datasets used during this project, including data owners, licencing conditions, and links to the data or contact information for the data owner.
Data_to_Map_Services.xlsm	Lists datasets used during this project and identifies if they are not needed, are essential, or are beneficial to mapping the ecosystem services that were prioritised for this project.
Scale.xlsm	Lists datasets used during this project and identifies if they are suitable for mapping at local/catchment/regional/national/EU scale.
Crosswalk.xlsm	Identifies how CICES classes fit into two other ecosystem service frameworks, MA and TEEB
Theme_order.xlsx	Identifies the order that themes appear in in the reports produced by Option 2

5. Mapping Ecosystem Services in Ireland using SENCE

5.1 Overview

This section deals with the practical approach to ecosystem service mapping taken in this project, including data collection/audit, the creation of any intermediate layers, and rule-base development.

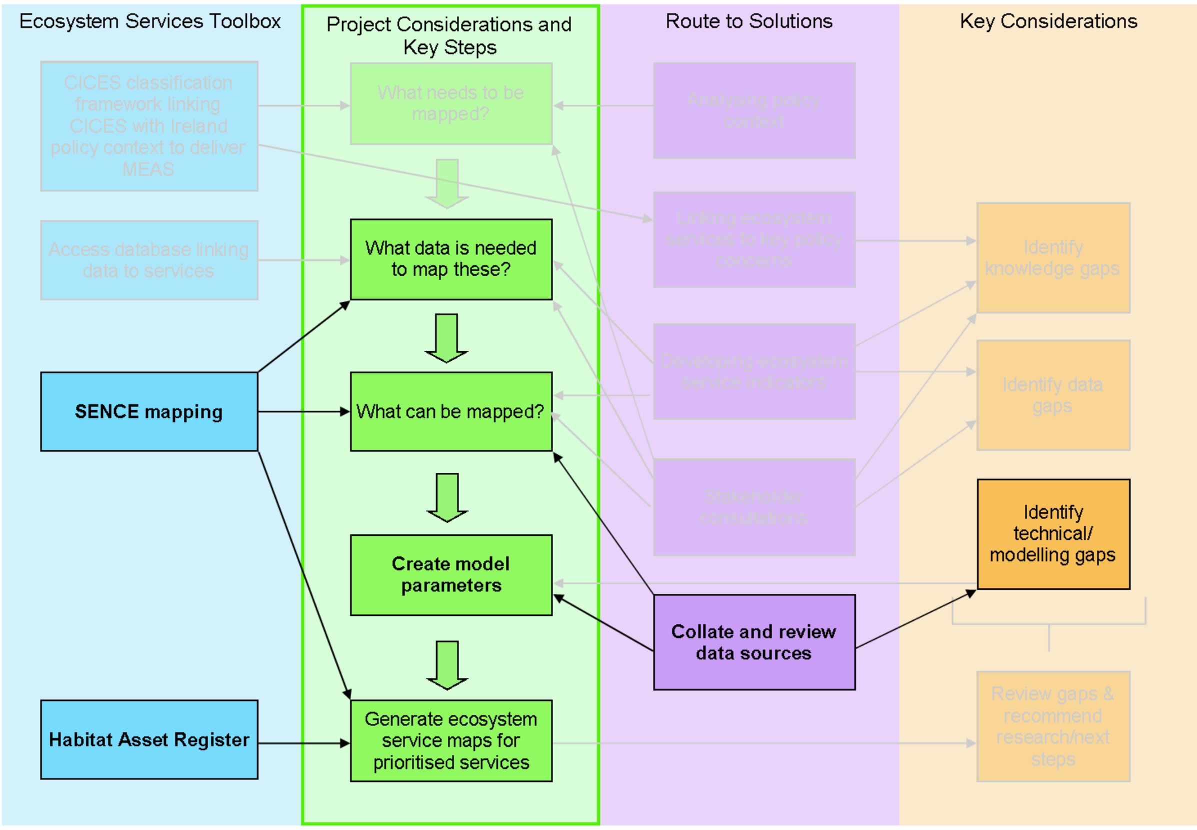


Figure 10: Project approach – tools, considerations and steps detailed in this section.

Spatial Evidence for Natural Capital Evaluation (SENCE) is based on the concept of identifying the key factors which affect the contribution to a service of any area of land. These key factors include habitat, soil/geology, landform, and management/cultural factors. The SENCE tool builds on developments from the JNCC ecosystem service Spatial Evidence Mapping work (Medcalf et al., 2012 and 2013).

In the majority of cases, there is no single dataset that is readily available, appropriate to use, simple to map, and fully representative of an individual ecosystem service. Instead, the ecosystem service provision is modelled using different proxies. Information is brought together using a geoinformatics approach that considers the data both spatially and quantitatively by use of a scientific ‘rule-base’ system. The rule-base is based on scientific literature and local knowledge, allowing bespoke maps to be developed that consider local subtleties in service provision.

Terrestrial ecosystem service mapping was carried out at a national level, covering the whole of the Republic of Ireland, with a total of 69,880km^2. Marine mapping approximately followed the outline of the continental shelf and Ireland's Exclusive Economic Zone, whichever reached farther, creating a total coverage of 712,268km^2.

5.2 Data Collation and Suitability Audit

The data available for use with the SENCE mapping method are spatial datasets, including both point and polygon vector data and raster data, collected at a variety of different scales, and with a variety of accuracies and resolutions.

Once data has been collated the suitability and appropriateness of the data for use in the project was assessed by considering:

- Quality (in terms of coverage, topology and map projections);
- Suitability (whether appropriate information is included within the dataset);
- Availability and licensing, and the quality of the metadata supplied;
- Coverage (only national coverage data considered, as local data could skew the results on the national scale).

Metadata quality is an important component of data, as it explains to the end user how the data was captured, the limitations of the data and the confidence within the information provided. Those datasets which were not provided with sufficient accompanying information were not considered for the analysis.

In addition to these criteria, spatial scale is an important overarching factor to consider. Data must be fit for purpose; 'coarse' data is most suitable for use at a national strategic level to inform national policy and planning issues. At a local level, coarse data could potentially over-simplify the context and does not often include the suitably detailed information required to support local decision making. To overcome this, highly detailed local data on environmental and social assets are needed and can be considered in combination to reflect the situation.

NPWS sourced over 300 datasets which were provided to Environment Systems Ltd. for use in the project. Many of these were identified and commented upon as part of the 1st stakeholder workshop (see sections 2.3.2 Stakeholder Workshop 1 and 3.2 Outcomes of the Work Undertaken with Stakeholders). A list is provided in Appendices H and I. This data was from a variety of different sources, was at varying spatial and temporal resolutions, and was in a number of coordinate reference systems. The majority of data was collated up to autumn 2015, additional species distributions were collated up to February 2016, so it is possible that there are datasets or projects which became available only after this period that were not included. Full details of the data temporal extent and creation date for outputs are detailed per resource in the associated metadata.

Once data collection had been completed, an audit of applicable data took place, collating information regarding who owns the data, any licence restrictions, whether metadata was provided, and what the scale and coverage of the data are. The information available was quite variable and examples from the data log are provided in Table 7 to illustrate this.

Table 7: Examples of data collation and audit.

Theme	Data set	Dataset Owner / Provider	Data reliability*	Spatial resolution	Licensing
Geology	National Draft Generalised Bedrock Map (Groundwater Rockunits)	DCENR – GSI	Medium	Medium	Free for commercial, research and public use. Acknowledge the material.
Soils	Teagasc Soils	Teagasc	Medium	Scale (vector) 1:100,000 – 1:150,000	Must acknowledge source and does not include Commercial use
Habitats	Saltmarsh Monitoring Project 2006 - 2008	NPWS	High (mostly derived from field survey)	High (GPS data collected on site, supported by OSi data)	Must acknowledge source
	National Survey of Native Woodlands 2003 - 2008	NPWS	High (mostly based on field survey, with original survey site selection using FIPS)	20m*20m is minimum mapping area	Must acknowledge source
	Corine Landcover 2012	EPA	Low	Low	Must acknowledge source and does not include Commercial use
Land form	NextMap 5m DTM	NPWS	High	5m	Must acknowledge Intermap Technologies Inc.
Designated Sites	Terrestrial Special Areas of Conservation (SAC's)	NPWS	Not assessed – no meta data	Not assessed – no meta data	Must acknowledge source
	Natural Heritage Areas (NHA's)	NPWS	Not assessed – no meta data	Not assessed – no meta data	Must acknowledge source

*Reliability assessment was taken from existing metadata, where available, or from an analysis of the attributes within the data set in combination with its spatial scale and currency.

5.3 Habitat Asset Register

Habitat data can be harnessed to map many ecosystem services. The spatial variation of the geology and soil profiles of Ireland gives rise to a complexity of habitat types. For example, thin, acidic soils support dry heath communities in a complex mosaic with other vegetation and where drainage is impeded on gently sloping valley sides and depressions, wet heath and bog communities occur. Identifying these biophysical characteristics or 'living systems' provides an indication of ecosystem service provision.

Ireland currently has no standardised national terrestrial habitat mapping. This means that although there is a widespread range of habitat data available, these are collected by different organisations for differing purposes. Numerous habitat datasets were made available, however, each of these datasets had varying characteristics in terms of coverage (whole or partial), age, scale, nomenclature, quality and resolution (polygons, point data, fuzzy data). Therefore, a significant proportion of the project resources were required to address this deficit, in order to create a seamless and comprehensive terrestrial habitat dataset, known as a Habitat Asset Register as an indicator of the underpinning living systems that support ecosystem services. The Habitat Asset Register was to be suitable for re-use by the NPWS, and with very few licence restrictions.

Data to be included in the Habitat Asset Register was chosen after an audit of over 150 habitat datasets. In order to identify the most suitable datasets thematic suitability, metadata quality, spatial extent, and resolution were examined and an extensive process of stakeholder consultation took place. During this process, the most suitable data for national scale mapping and a range of data gaps and limitations were identified.

Spatially explicit data representing the actual habitat boundaries in polygon format were given precedence, as the usage of point data introduces error into the map, with the exception of Turloughs, which were incorporated into the register at the 50m cell level.

In addition, the evaluation covered relevance at a national scale. Data for discrete habitats (covering only very small, disjunct areas) was not included; for example, despite being spatially explicit, the Article 17 data[23] (NPWS, 2013) on Juniper scrub (5130) was not incorporated into the Habitat Asset Register, as the presence of individual Juniper bushes cannot be used as proxy for overall ecosystem functions in an area. The overall ecosystem function will depend on the type of habitat the Juniper bushes are found within, such as acid grassland or limestone pavement. However, the habitats that were not suitable for inclusion in a national habitat map can still be of relevance for national scale

[23] 'Article 17' refers to Habitats Directive Annex I Habitats, for which their national distributions have been mapped nationally and reported under the Habitats Directive Article 17 report on National Conservation Status

provision of some ecosystem services. In this case, they were added into the mapping process as a layer of their own, alongside the Habitat Asset Register, as they modify the service provision as determined by the main habitat rather than define how strong service provision is at the site.

A full list of the data provided and evaluated, including information on the data selected for use, is provided in Appendix I.

A different approach was taken for marine habitat mapping, where the coverage of habitat layers was very different to the terrestrial situation. Here the two datasets with the largest spatial extent were used. They were not conflated in the same way but as part of the analysis process.

Note - Whilst the Habitat Asset Register (HAR) is based on the best data currently available, it does contain some inherent limitations due to the manner in which LPIS categorises permanent pasture. This may lead to an underestimation of semi-natural grassland and heaths. For details, please refer to the section on data gaps and the section on the preparation of LPIS data for usage in the HAR.

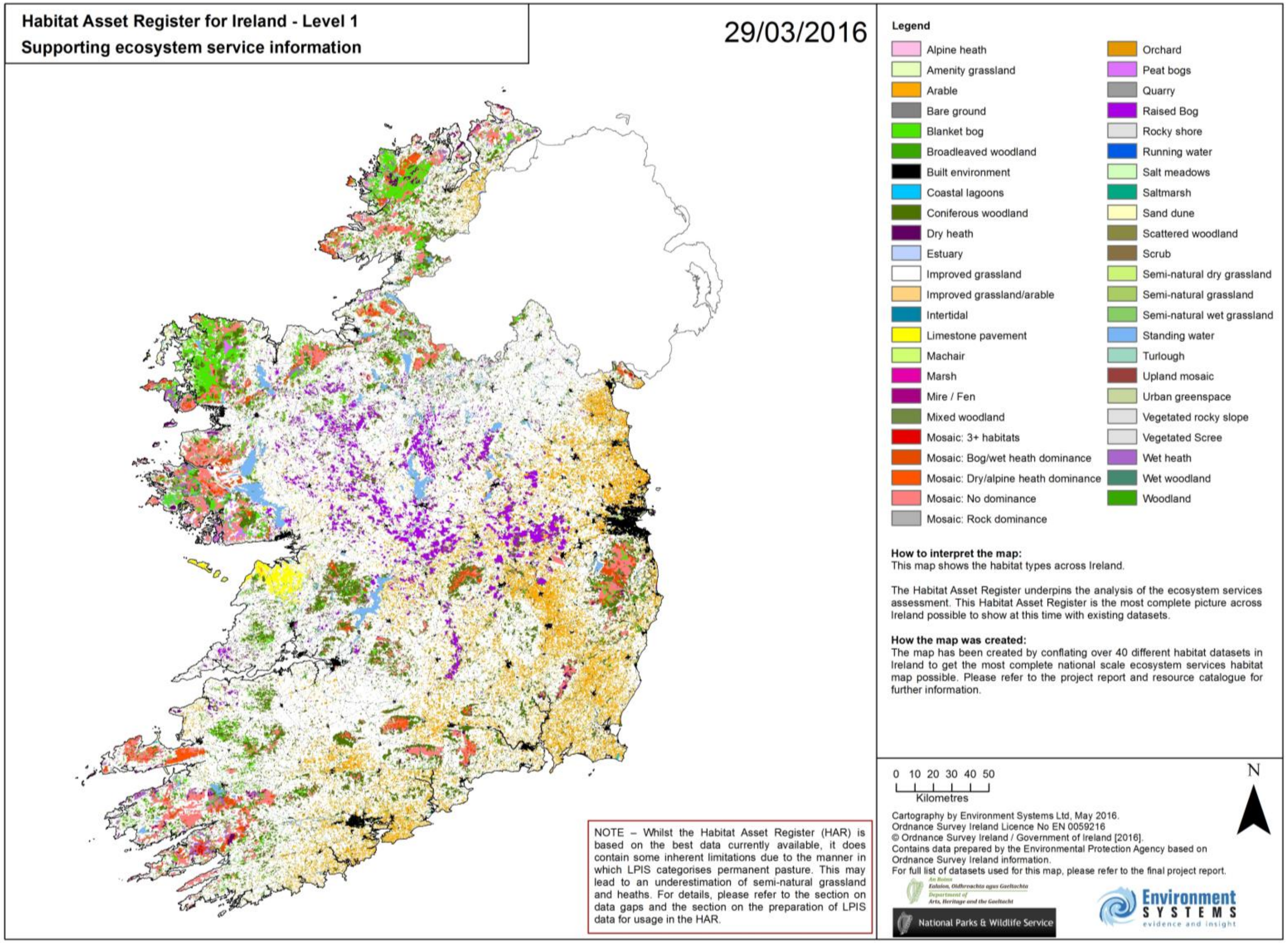


Figure 11: Habitat Asset Register for Ireland - Level 1

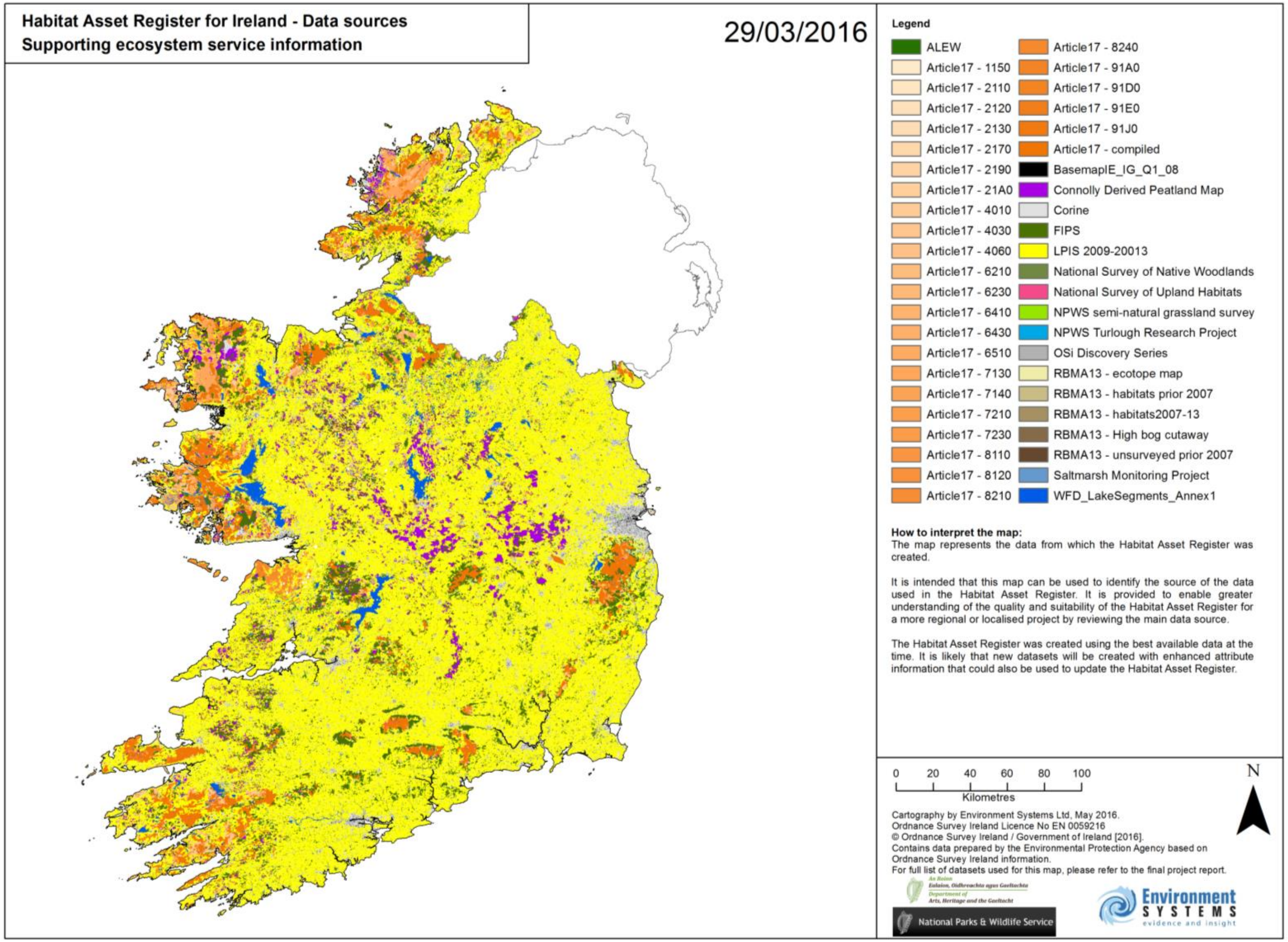


Figure 12: Habitat Asset Register for Ireland - Data sources

5.3.1 Preparation of the Habitat Asset Register (for terrestrial habitats)

The final version of the Habitat Asset Register was created from a conflation of over 45 datasets (Figure 13). The best data available for each habitat type was used, which, in some cases, required the creation of primary intermediate layers (see Section '5.4 Primary Intermediate Layers'). Each of the datasets was subject to the data suitability review (as described in section '5.2 Data Collation and Suitability Audit').

The intermediate layers (generated from LPIS, FIPS, Article 17 and Turlough datasets) and the remaining datasets were conflated using a stacking approach. Corine 2012 dataset was used as the 'base layer', being in effect the first layer; it is important that the first layer provides continuous cover across whole area of interest, in this case the Republic of Ireland (Figure 12).

The next dataset used supersedes the base layer. The second data layer used was the 'Connolly' derived peatland map. It only covers part of the area of interest, and only in these areas is the Corine data overwritten by the Connolly peat map layer in the conflation process. As processing is carried out with rasters, the output of the data conflation is a seamless and continuous raster surface, in this case representing habitats. This process is then repeated for dataset three and so on, until all the data is included in the seamless dataset, with the data from the data layers being added later always superseding those that are already conflated.

A full table of area coverage by input data sources in the final, conflated layer is provided in Appendix J. In the first iteration, before more data was added, 60% of the habitat map was still covered by Corine data, meaning that in these areas during the stacking process the base layer had not been an overwritten one. In the final iteration, where, amongst others, LPIS data had been added into the stack, only 11.8% of the area remained covered by Corine data. The remaining 88.2% of area have been superseded by at least one other dataset, with the different classes derived from LPIS now covering 61.8% of Ireland.

A data map is provided to show which data source underlies the Habitat Asset Register in each area. The conflation process and the creation of a data map enables an understanding of the certainty and suitability of the data forming the source for the Habitat Asset Register.

The output of the conflation is a raster dataset consisting of approximately 200 habitat classes (known as 'Habitat Asset Classes'), e.g. all the various habitat attributes used in all layers included in the habitat conflation. Due to the number of classes, this initial conflation output is unsuitable to be displayed; additionally, habitats in this layer can appear twice, if, for example, one input layer refers to "Coniferous woodland" and another input layer to "Woodland (coniferous)". Therefore, Habitat Asset Classes are split into two levels of detail (Level I and Level II) (Table 8) to support both a strategic overview of habitats across Ireland (Level 1) and a detailed understanding of the habitats present with regards to their potential for ecosystem service provision (Level 2). Level 2 is not suitable to be coloured up at a national scale, as there are too many habitat classes. Depending on what purpose the layer is used for, the user could colour up the different types of raised bog, or other habitats of interest. Table 8 illustrates how strategic scale habitats from Level 1 are split into more detailed habitat classes used for ecosystem scoring in this project (Level 2).

Table 8: Example Habitat Asset Classes (attribute table fields) in the Habitat Asset Register; classes resulted from grouping of all original classes appearing in the input data sources

Habitat Asset Class	Level I	Level II	Data Source
Coniferous forest	Coniferous woodland	Coniferous woodland	Corine
Discontinuous urban fabric	Built environment	Built environment - Discontinuous	Corine
Low-level Atlantic Blanket Bog	Blanket bog	Blanket bog - Low-level	Connolly Derived Peatland Map
GS2	Semi-natural dry grassland	Semi-natural dry grassland	NPWS semi-natural grassland survey
RBMA13 (Raised Bog Monitoring and Assessment Survey 2013)-Cutaway Bog	Raised Bog	Raised Bog - Cutaway	RBMA13 - High bog cutaway
Coniferous	Coniferous woodland	Coniferous woodland	FIPS
Marginal	Raised Bog	Raised Bog - Marginal	RBMA13 - habitats2007-13
Active Flush	Raised Bog	Raised Bog - Active Flush	RBMA13 - habitats2007-13
NationalSecondaryRoad	Built environment	Built environment	OSi Discovery Series
7130	Blanket bog	Blanket bog - Active	Article17 - 7130

To ensure future users of the Habitat Asset Register can understand the dataset, a full resource catalogue of metadata was also prepared in addition to a readme crib sheet (MS Excel lookup) referenceable to the number codes in the raster dataset. This ensures that the original datasets for this derived product can be identified to give the user confidence if applying future updates, or if it is used in later projects.

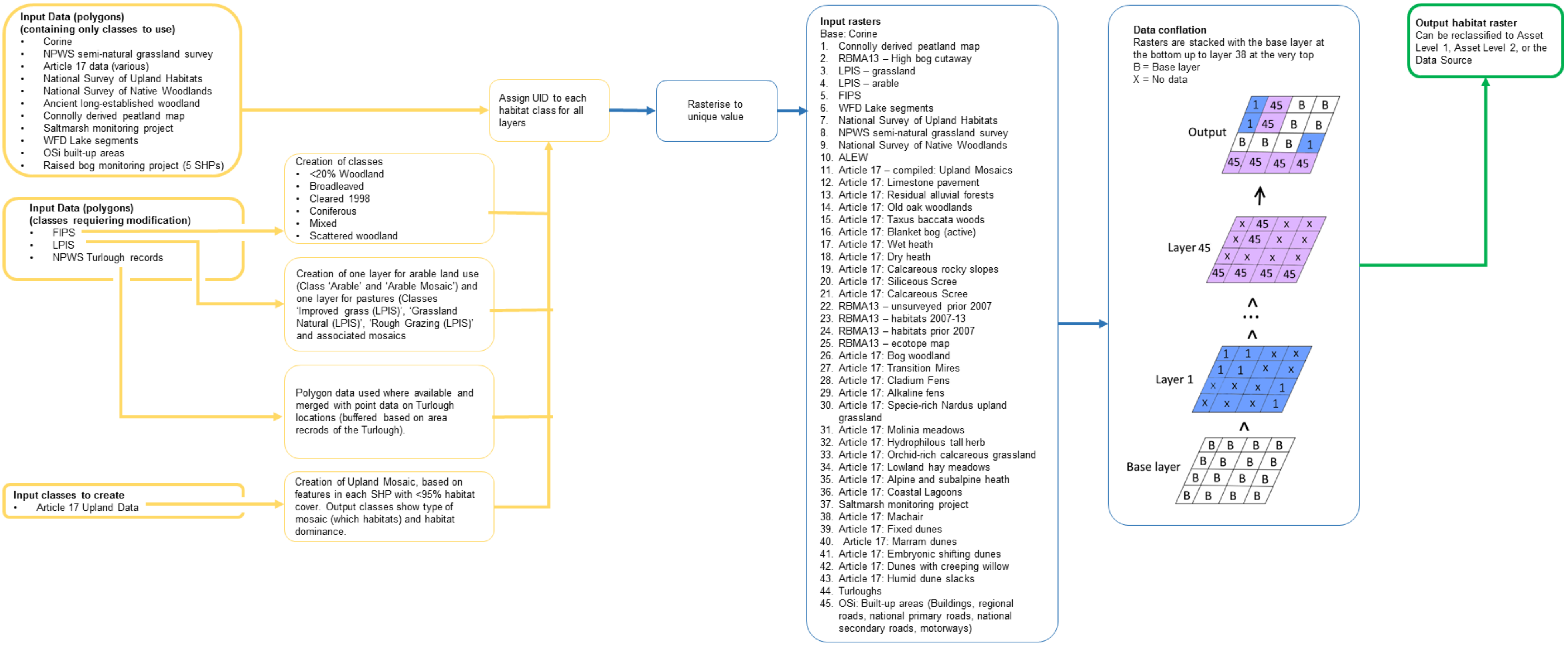


Figure 13: Creation of the Habitat Asset Register.

5.4 Primary Intermediate Layers

Intermediate layers were created for some of the datasets, as they required manipulation in order to be used in the data conflation to create the Habitat Asset Register (see Section '5.3 Habitat Asset Register') or as supporting layers for final ecosystem service mapping (see Section'5.6 Creation of ecosystem service maps'). In these datasets, data was recorded in a format unsuitable for unmodified inclusion in the mapping process (e.g. classes too detailed; percentage cover of each species recorded, instead of overall habitat type; data split into several files; etc.). Datasets that required modification are listed in Table 9, with the resulting maps displayed in Appendix L. For the remaining datasets, one, or a combination of two attribute columns of the original dataset could be used.

Table 9: Datasets that were modified to create intermediate layers.

Original data	Primary Intermediate layer	Why modification was required	Secondary Intermediate Layer	What the layer was used for	How the layer was created
Land Parcel Information System (LPIS) data	Arable land use & Pastoral land use	Original classes exceeded detail required; Identification of land use required consideration of 5-year arable rotation	Habitat Asset Register	All terrestrial ecosystem services mapped	See section '5.4.1 Land Parcel Information System (LPIS) Data'
Forest Inventory and Planning Systems (FIPS) data	Forest cover based on LPIS	Percentage of individual species recorded, instead of habitat type; merge of 2012 data into 2007 data due to some corruption in 2012 layer			See section '5.4.2 Forest Inventory and Planning Systems (FIPS) data'
Article 17 data	Article 17 mosaics	Presence of mosaics indicated through overlap of different Article 17 map layers			See section '5.4.3 EU Conservation of Habitats and Species Directive – Habitat (Article 17) Data – Mosaic habitats'
Turlough data (points and polygons)	National coverage of turloughs	Data in polygon and point format			See section '5.4.4 Turlough data'
Species records	Species coincidence layer	Over 1000 individual species records at varying resolutions	-	Terrestrial Biodiversity	See section '5.4.5 Species Coincidence Layer'
Habitat Asset Register	Ecological Networks	Not previously existing	-	Terrestrial Biodiversity	See section '5.4.6 Habitat Networks'
Designated sites layers	Designated sites layer	Previously one SHP per designation type	-	Terrestrial ecosystem service maps	See section '5.4.7 Designated Sites Layer'
Bathymetry data /	Bathymetry in 2 depth	Partial coverage of the marine AOI		Marine biodiversity	See section 'Bathymetry'

Original data	Primary Intermediate layer	Why modification was required	Secondary Intermediate Layer	What the layer was used for	How the layer was created
Marine Institute CTD	classes				
DTM data	Slope in 4 classes	Slope needed to be calculated and grouped, to be usable for ES mapping		Terrestrial ES maps	See section 'Slope'

5.4.1 Land Parcel Information System (LPIS) Data

LPIS data was included into the HAR to refine some of the CORINE classes. However, as the primary purpose of LPIS is for administration of agricultural subsidies, there are some limitations for its use as a proxy for landcover, landuse and management purposes.

The native LPIS classes (CROP_DESC_class) are given in Table 10. This attribute describes the type of crop and/or land use within a polygon for the purpose of subsidy payments.

For the purpose of ecosystem service mapping it was necessary to generalise these groups into a more manageable set of Habitat Asset Classes as shown in Table 10.

Table 10: Grouping of original LPIS classes to create Habitat Asset Classes.

Habitat Asset Class	CROP_DESC classes
Arable	Accord, Acrobat, Activ, Aladin, Alaska, Alfalfa, Aligator, Almea, Arabella, Arable Habitat, Arable Silage, Ark, Avant, Barley, Basalte, Beans, Beet, Beryl, Bingo, Boni, Briol, Bristol, Bucwheat, Bullet, Camelina, Ceres, Certified Seed, Corniche, Early Potatoes, Ebony, Ecudor, Falcon, Fallow, Felix, Fidelio, Flax, Flowers, Fodder Barley, Fodder Beet, Fodder Wheat, Forage Rape, Forage Rape, Forte, Fruit, Galaxy, Garrison, Granit, Green Cover, Hanna, Hemp, Hybridol, Idol, Inca, Iris, Jaguar, Kabel, Kale, Kulta, Liaison, Liason, Libravo, Limpet, Lineker, Linseed, Lucerne, Madora, Maincrop Potatoes, Maize, Maja, Mangolds, Manta, Mars, Millet, Nimbus, Non-Food, Nursery, Oats, Oilseed, Ole, Orelia, Orion, Orphee, Pactol, Pallas, Peas, Plumbshot, Polo, Potatoes, Prelude, Quartz, Rafaela, Rally, Rapier, Re-generation, Rocket, Rosette, Rye, Sabrina, Seed Potatoes, Senta, Setaside, Silex, Sisu, Spring Barley, Spring Oats, Spring Oilseed Rape, Spring Wheat, Star, Starlight, Sugar Beet, Sunflower, Susana, Swede, Sweet Lupins, Symbol, Synergy, Triticale, Turnips, Unica, Valo, Vega, Vegetables, Vivol, Wheat, Winter Barley, Winter Oats, Winter Oilseed Rape, Winter Wheat, Wotan, Zorro
Improved grass (LPIS)	100% Destocked Area, Clover, Foliage, Grass, Grass Seed, Grass Silage, Mixed Grazing, Permanent Pasture, Species Rich Grassland, Trad. Sustainable Grazing, Traditional Hay Meadow
Grassland Natural (LPIS)	Designated Habitat, Former REPS 3 New Habitat, Former REPS 4 New Habitat, Habitat, Linnet Habitat, REPS 3 Habitat, REPS 4 Habitat, REPS 3 New Habitat, REPS 4 New Habitat, Scrub, Wild Bird Cover
Rough Grazing (LPIS)	Rough Grazing

Single value fields:

In order to create these Habitat Asset Classes, all single values were classed as Arable and Non-Arable (for arable land use) and as Improved grass (LPIS), Grassland Natural (LPIS), Rough Grazing (LPIS), and Non-grass (for pasture land use) (yellow section of Figure 14).

Multi value classes:

Polygons may contain multiple values per polygon, where the parcel has had multiple uses in the given year, (e.g. Spring Barley, Maincrop Potatoes, Permanent Pasture). Where polygons contained more than one value, a set of rules was used to determine which class they should be assigned to as illustrated in the blue boxes for multi value fields in Figure 14:

- For arable land use:
  - If the field lists different types of arable crops and no non-arable classes (e.g. Spring Barley, Maincrop Potatoes, Vegetables) the whole field is classed as arable, as the polygon as a whole is under Arable Rotation.
  - If the field lists one or more types of arable crops, but does also include non-arable classes (e.g. Spring Barley, Maincrop Potatoes, Permanent Pasture) the whole field is classed as Arable Mosaic, as only part of the polygon is under arable rotation.
  - If the field lists only non-arable classes, the field is classed as Non-arable.
- For pasture land use:
  - If the field lists only different types of grassland that fall within the same grassland class, the whole field is classed as this class.
  - If the field lists different types of grassland that fall within the same grassland class and some non-grassland classes, the field is classed as mosaic of the grassland class present
  - If the field lists only non-grassland classes, the field is classed as Non-grass.
  - If the field lists different types of grassland that fall within different grassland classes, Improved grass (LPIS) takes precedence over Grassland Natural (LPIS) and Rough Grazing (LPIS), because the improvement of part of the management unit will impact upon adjacent areas. Similarly Rough Grazing (LPIS) takes precedence over Grassland Natural (LPIS), as grazing in direct vicinity will impact on the natural grassland.

  The same set of precedence rules applies to mosaics of grassland classes.

As the data does not record percentage cover of the individual classes, these classes are conservative estimates. In case of a mix of an arable class and a grassland class, the area will appear as arable, even though in reality 90% of the area could be grassland. However, in the final HAR only ~1.5% or

Ireland's terrestrial extent are covered by mosaic classes from LPIS, making this a minor issue with regards to overall accuracy for ecosystem service mapping.

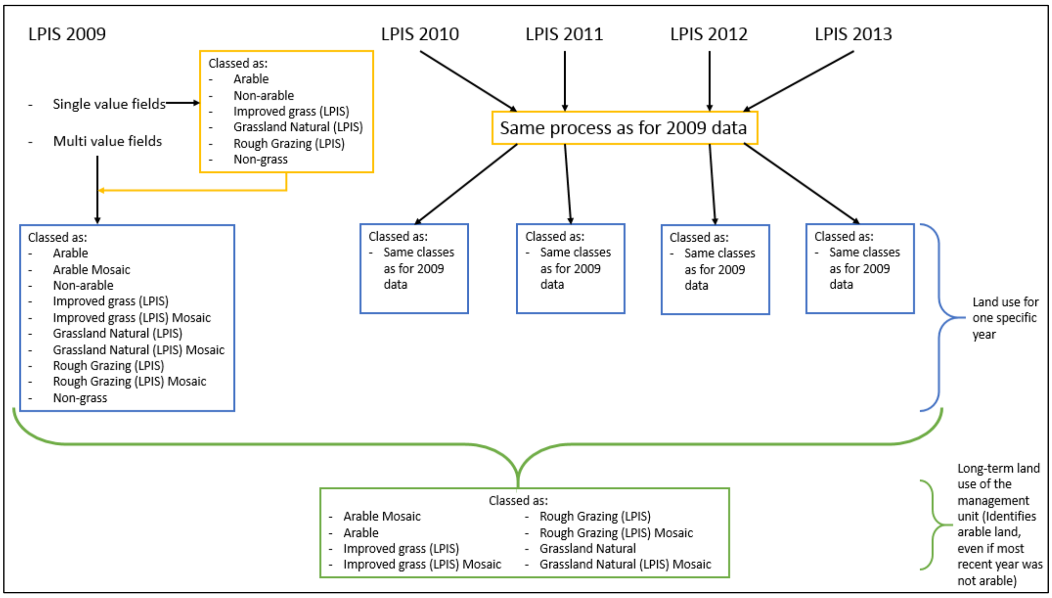


Figure 14: Manipulation of LPIS data (2009-2013) into Habitat Asset Classes.

Data from five consecutive years (the approximate length of arable rotation in Ireland (Stuart Green, pers. comm.)), needed to be considered in order to accurately differentiate arable land from permanent grassland (green section of Figure 14). This five year rotation was incorporated by:

- For arable land use:

If the land use was "arable"/"arable mosaic" in at least one of five years, the polygon is assumed to be part of the arable rotation and is classed as "arable" or "arable mosaic".

If both "arable" and "arable mosaic" occur within the last five years, the land is classed as "arable" (Figure 15).

- For pasture land use:

If the land was improved within the last three years, the land is classed as improved. If improved land use ceased more than three years back, the land is considered to have reverted back from its improved state.

If no "improved" exists in the last three years, the grass-class of the last year is used.

If, of this class, mosaic and non-mosaic classes occur, the class is set to "mosaic". (Figure 16)

How the individual, LPIS-derived classes are valued from an ecosystem service perspective is detailed in Appendix K.

There are known issues with the use of LPIS as a proxy for habitat and land management. For example the LPIS class Permanent Pasture includes areas that are used to grow grasses or other herbaceous forage. These may be self-seeded or cultivated (DAFM, 2011 & 2015). However the discrimination between areas that are sown from those that self-seed is important for the purposes carbon sequestration, and also the discrimination of areas that are mown from those that are not.

Furthermore, this class can include a range of different habitat types and management intensities; from improved grass dominated areas (such as productive rye grass swards) to less productive areas which may be dominated by non-grass species such as heathers. Therefore permanent pasture class could range from Fossitt GA1: Improved Grassland habitat to Semi natural grassland classes, Heath classes and potentially Bog classes (GS, HH, PB), each of which may perform quite differently in terms of different ecosystem services.

If, in the future, more suitable data on particularly pastoral land use was collected, this could further improve the Habitat Asset Register. With currently available data, however, incorporating LPIS data is the best available option. Figure 14 shows the workflow used to create one intermediate layer for agricultural and one for pastoral land use from LPIS data.

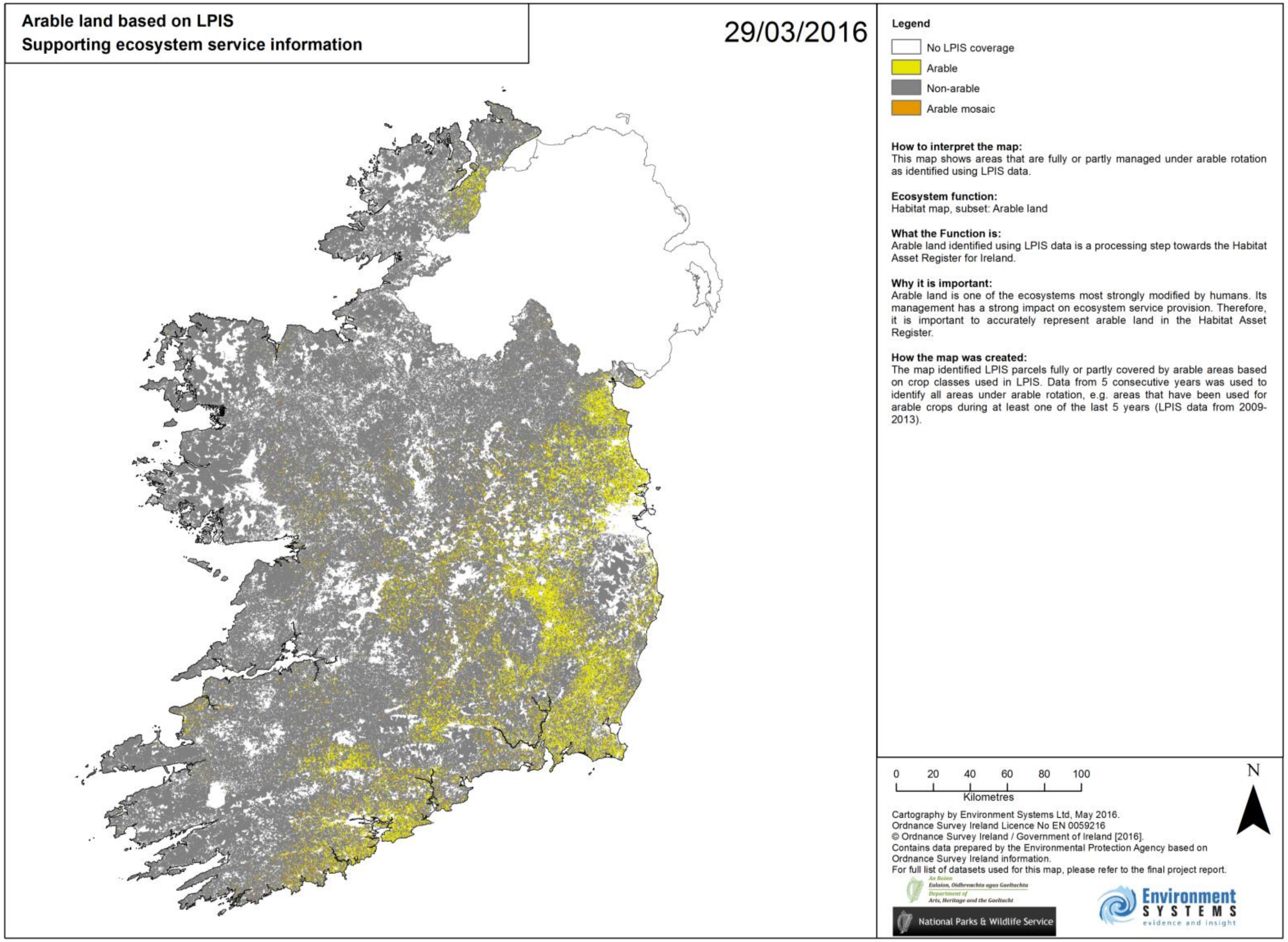


Figure 15: Arable land based on LPIS

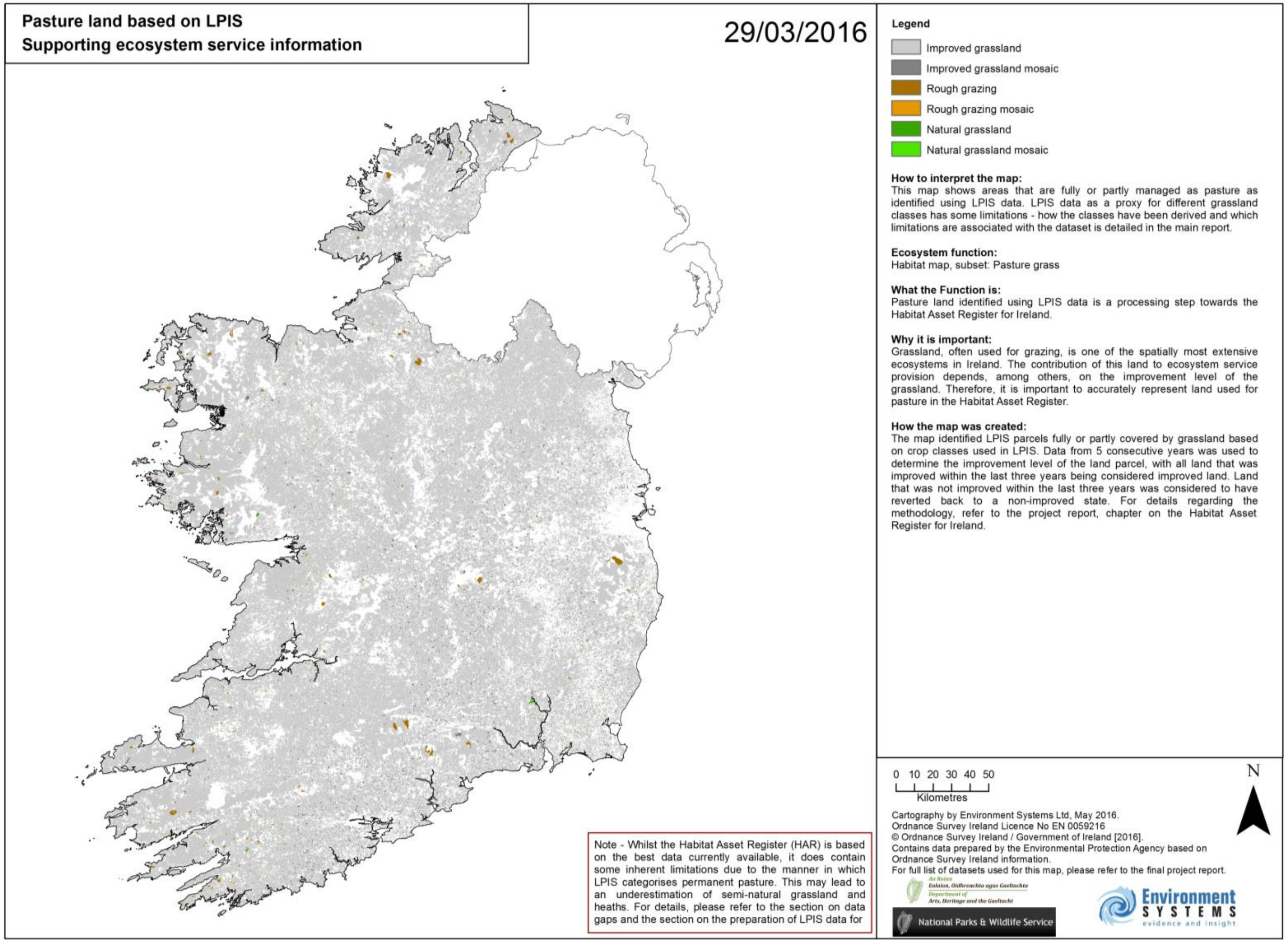


Figure 16: Pasture land based on LPIS

5.4.2 Forest Inventory and Planning Systems (FIPS) data

Due to some corrupted data, the FIPS dataset from 2012 could not be used in its entirety. Therefore, post-2007 entries from this dataset were merged into the 2007 dataset. Resulting slivers of polygon overlap were removed (Figure 17)

The information recorded within the composite FIPS dataset (percentage cover of 30+ species) was then grouped into classes relevant for a strategic scale map:

- Broadleaved: Over 75% cover of broadleaved species
- Coniferous: Over 75% cover of coniferous species
- Mixed: Over 75% listed as 'mixed' in the original data or over 75% cover of coniferous and broadleaved species combined
- Scattered woodland: Over 20% woodland and less than 75% of any other classes, such as 'BIO – Biodiversity'
- <20% woodland: Less than 20% woodland and less than 75% of any other classes, such as 'BIO – Biodiversity'
- Cleared 1998: Field classes as 'Cleared 1998' in the original dataset

The 75% cut-off value is based on Fossitt Habitat Descriptions (Fossitt, 2000) of woodland habitats.

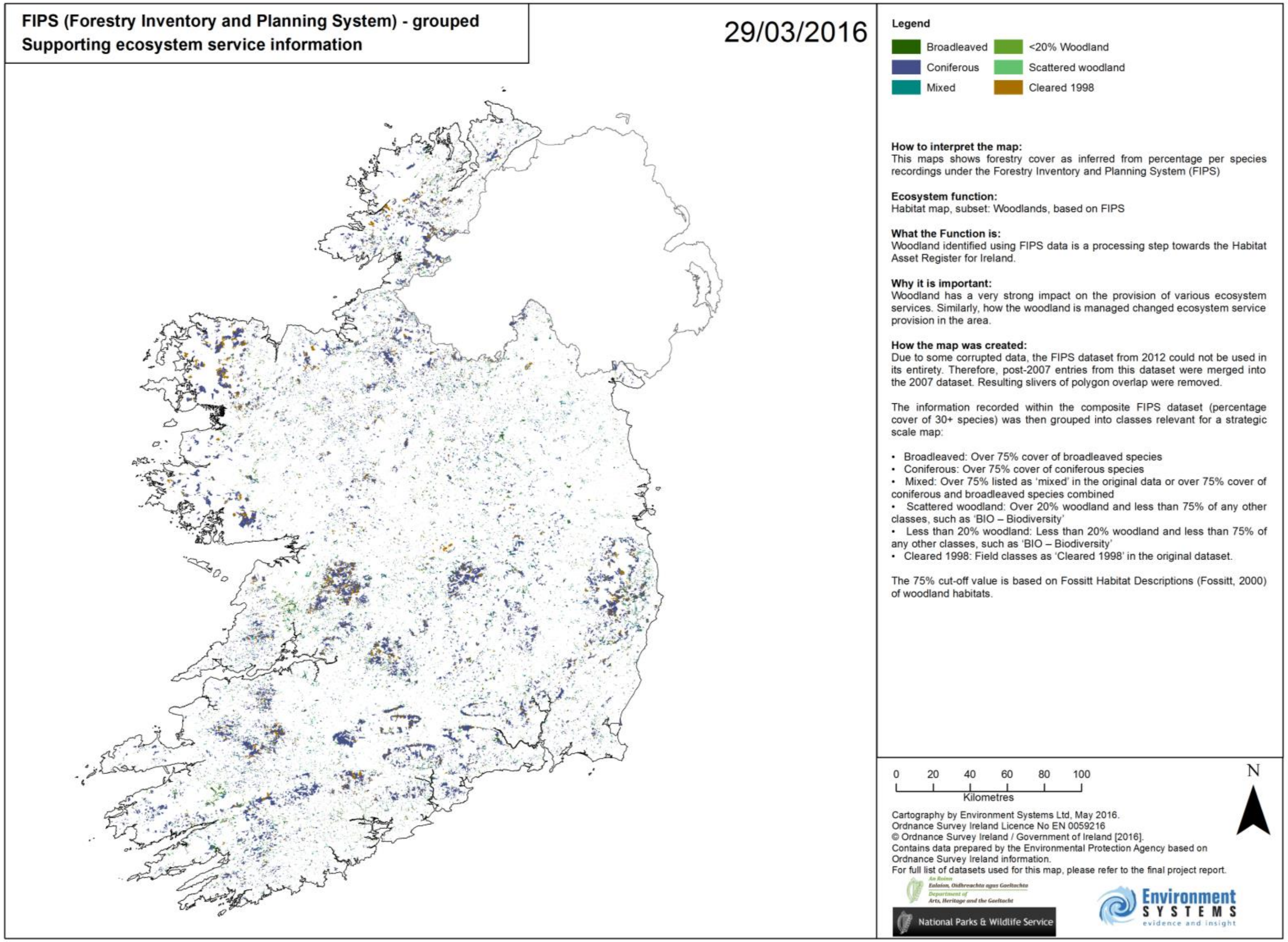


Figure 17: FIPS (Forestry Inventory and Planning System)

5.4.3 EU Habitats Directive – Habitat (Article 17) Data – Mosaic habitats

Article 17 data was provided as one shapefile per habitat. Areas with habitat mosaics are not recorded as mosaic classes, but indicated through the overlap of shapefiles for two or more habitats. As mosaics were considered important on a national scale, a layer spatially specifying the presence of mosaic habitats was created based on the following Article 17 shapefiles:

- 4010: Wet heath
- 4030: Dry heaths
- 4060: Alpine and subalpine heath
- 7130: Blanket bog (active)
- 7140: Transition mires
- 7210: Cladium fen
- 7230: Alkaline fens
- 8110: Siliceous scree
- 8120: Eutric scree
- 8210: Calcareous rocky slopes
- 8220: Siliceous rocky slopes

Selection of datasets for inclusion in the Article 17 mosaic was based on the percentage cover of the habitat. Where a habitat was confirmed through the dataset as being more than 95% cover, it was excluded and included higher up in the conflation as a single habitat. The higher up in the order of the conflation the more the dataset will supersede what has been included before it. This thereby ensures that the most dominant Article 17 habitat with its specific ecosystem service provision is represented (Figure 18).

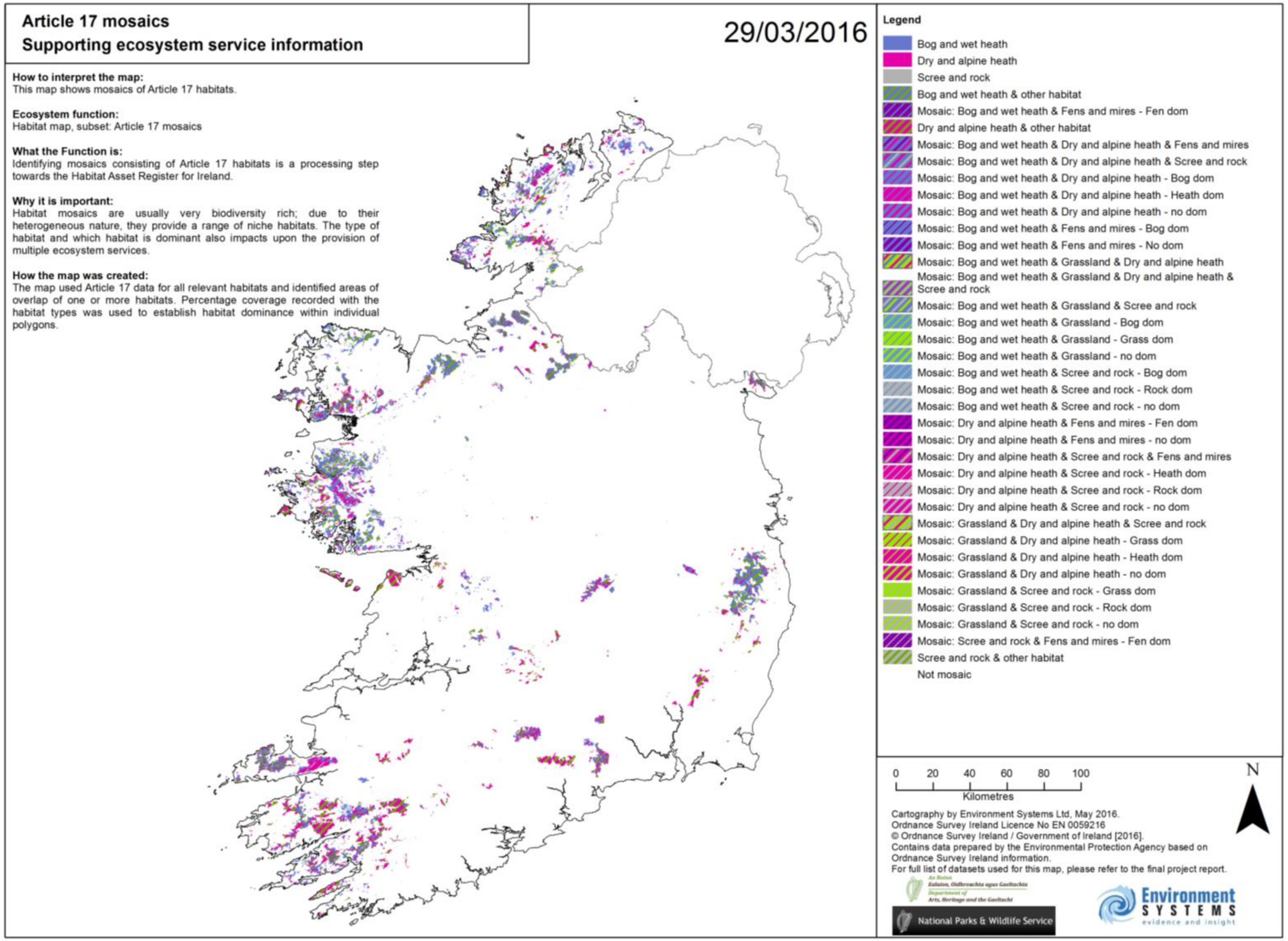


Figure 18: Article 17 mosaics

5.4.4 Turlough data

Turloughs are an important Irish ecosystem (HD Annex I habitat) which has a major impact on several ecosystem services. Therefore, it was decided to include them in the Habitat Asset Register despite no comprehensive, spatially explicit dataset being available. The data used is a merge of two datasets. One contains 22 turloughs mapped spatially explicitly for the NPWS by Trinity College Dublin. Additionally, a point shapefile with information on 446 additional turloughs has been incorporated after buffering the points based on the area attributed to each turlough; this approach ensures that turloughs are included in the Habitat Asset Register to the best extent facilitated by the data available at this time. However, there is a risk of Turloughs being misplaced based on a point location and of area being under-represented (Figure 19).

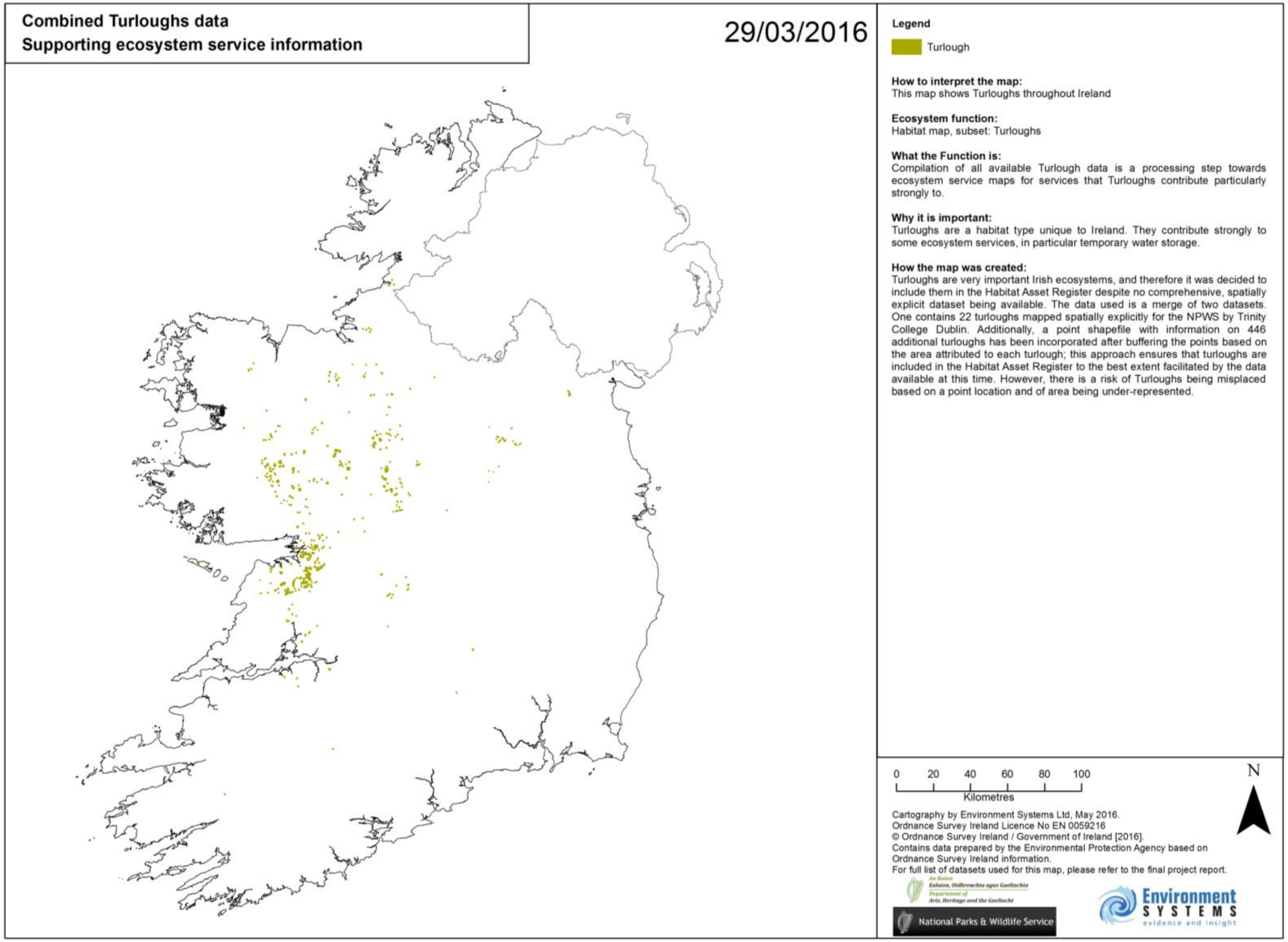


Figure 19: Combined Turloughs data

5.4.5 Species Coincidence Layer

Species records are direct observations of a species in an area and can aid in identifying species hotspots within the landscape. Therefore, a layer was created to illustrate the coincidence of legally protected species and a further layer of other species which are regarded as being of policy relevance because they fall into one of the three IUCN threatened categories or are classed as amber or red on the list of Birds of Conservation Concern for Ireland list. The coincidence layer combines national distributions of over 1000 different species derived from over 1.5 million records. Each species was associated with a national terrestrial grid of 50m*50m squares.

The coincidence is limited to terrestrial environment due to the lower availability of marine records and the extreme mobility of many of the recorded marine species which means it is extremely difficult to assign them to a specific geographic location.

The records were compiled from a number of data sources:

- EU Article 17 data (Annex II, IV & V species distributions) (NPWS)
- NBDC (National Biodiversity Data Centre) protected and threatened species data
- Bat Data (Bat Conservation Ireland & NPWS)
- Selected Bird Species (Birdwatch Ireland)
- Bryophyte Data (NPWS)
- Flora Protection Order Vascular Plants and Lichens (NPWS)
- Freshwater mussel data (NPWS)
- Mollusc data (NPWS)
- Butterfly data (Regan et al., 2010; Asher et al., 2001; Fox et al., 2006)
- Moth Data (Moths Ireland)
- Odonata (Dragonflies) (Nelson et al., 2011)
- Water Beetles (Aquatic Coleoptera) (Foster et al., 2009)
- Molluscs (Byrne et al., 2009)
- Bees (Fitzpatrick et al., 2006)
- Mayflies (Ephemeroptera) (Kelly-Quinn and Regan, 2012)

The output layer does not take account of how many times an individual species has been recorded in each unit, it only records its presence. This ensures that sufficient weight is given to rare, but important species. Many grid squares contained multiple records for the same species; in these cases the records were simplified to provide only a single record per cell.

In total, records for over 1000 species were incorporated to create a single layer. This involved bringing together data that had originally been recorded at varying resolutions, from point data to

10km*10km polygons. In a first processing step, a single dataset was created for each species. In cases where a species had been recorded both in a high (≤50m) and in a low resolution dataset (>50m) for the same area, preference was given to high resolution data, with only the highest resolution record being taken forward.

These datasets were then scored to reflect the resolution of the source data for the record. High resolution records (species recorded at ≤50m) were scored at 300, whilst low resolution records (species recorded at >50m resolution) were scored at 150. This means that the most accurate records have a stronger impact on the score of the pixel, whilst lower resolution records acknowledge the presence of a species in the general vicinity but do not have as strong an impact on the overall score. After scoring, all of the individual species datasets were combined through addition, creating the final layer of 'species coincidence' (Figure 20).

Two examples of scoring are given in Table 11.

Table 11: Scoring examples for creation of the species coincidence layer where: 'records' lists all species records present within one 50m*50m area that forms one pixel in the final raster dataset. Record resolution relates to the number of digits contained in the grid reference for the species record.

Grid cell 1		Grid cell 2	
Records	Score	Records	Score
Species 1 (at 50m)[1]	300	Species 1 (at 50m)	300
Species 2 (at >50m)	150	Species 6 (at 50m)	300
Species 3 (at 50m)	300	Species 7 (at 50m)	300
Species 4 (at 50m)	300	Species 8 (at 50m)	300
Species 5 (at >50m)	150		
Total	1200	Total	1200

[1] Species 1 also has a record at >50m resolution but the methodology excluded this record from the coincidence layer to ensure consistency in the weighting process for each species

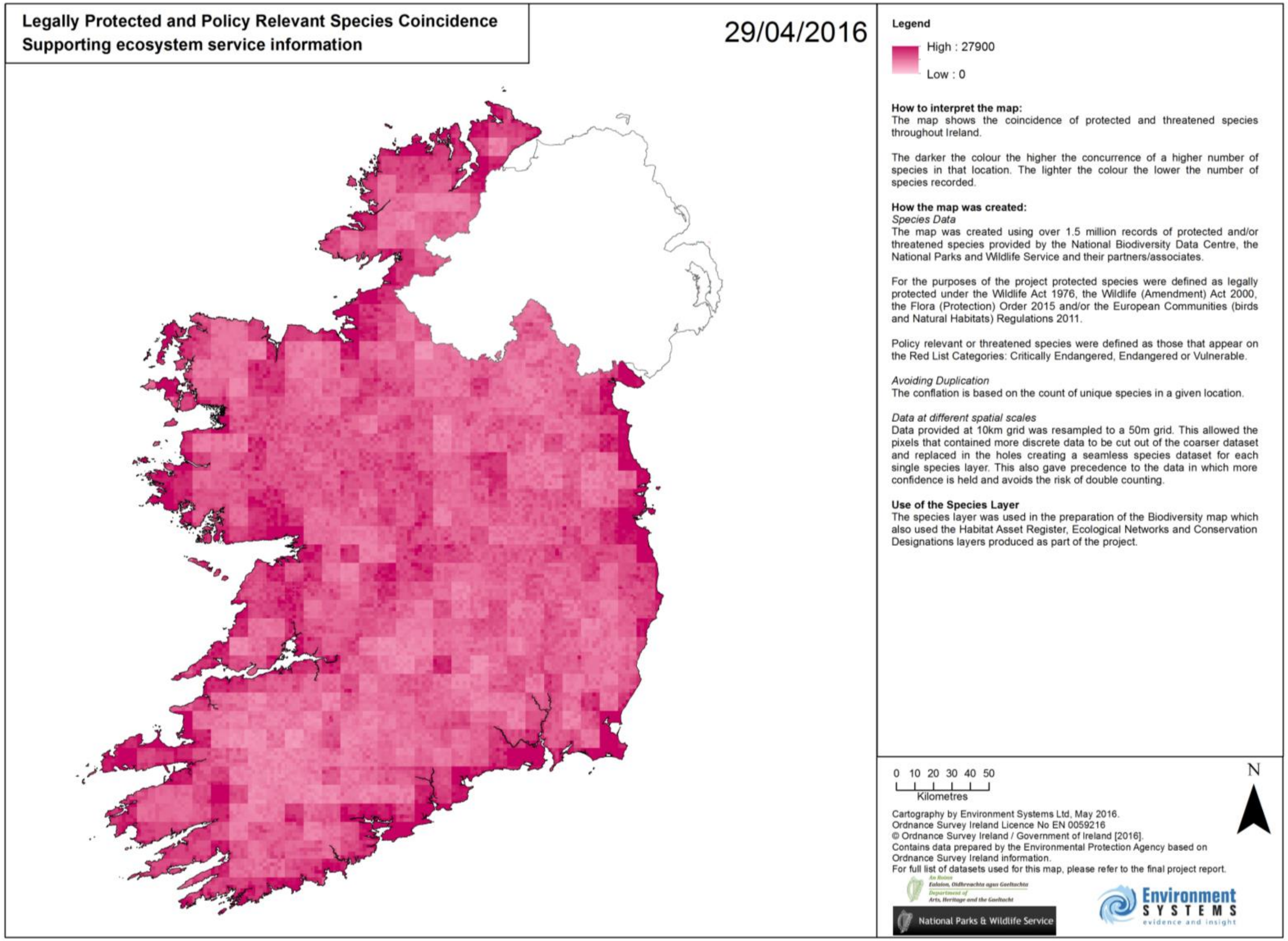


Figure 20: Protected and Threatened Species Conflation

5.4.6 Habitat Networks

Habitat patches that are spatially linked to other areas of habitat that can support the same species or, at least, allow for their movement, are ecologically well-connected. Connectivity increases the level of biodiversity expected to be found in an area, as it increases the overall area of habitat that is available, enabling populations requiring larger areas to persist, and facilitates species recovery after local extinction events.

Four ecological networks for Ireland were produced for compilation into a single layer, expressing the contribution a particular area makes to ecological networks, with sites contributing to several networks scoring highest for their biodiversity value (Figure 21).

The four component ecological layers are: grassland (Figure 22), upland (a mixture of different habitats occurring in upland regions) (Figure 23), wetland (Figure 24) and woodland (Figure 25). Each ecological network was created using the information in the Habitat Asset Register for Ireland (HAR, see section 5.3 Habitat Asset Register). They were created as follows:

Upland ecological network:

All habitat classes were first assigned as being either improved (such as improved grassland) or non-improved (such as semi-natural acid grassland). Then only 'non-improved' areas at elevations over 600m were assigned to the upland ecological network. This cut-off value was chosen based on areas extending at least 600m above their surroundings being classified as mountain in Britain and Ireland (Lake, 2015); the value was confirmed on an Ireland-specific website (AskAboutIreland, 2016), as well as through point checks in upland habitats with an overlay of elevation data. An elevation of 600m above sea level rather than a difference of 600m was used, as this ensures that plains at high elevations are included within the mask.

Grassland, woodland and wetland ecological networks

Core habitats are areas of semi-natural vegetation, such as broadleaved woodland, which are large enough to support resilient populations of species. They provide sufficient ecological niches for the population to maintain genetic diversity and, therefore, provide the capacity to adapt to change. At the edge of these habitats conditions are often not ideal for specialist species, due to the ingress of, for example, fertiliser from surrounding fields. For less specialist species, genetic diversity can often be maintained if the habitats around the core area are permeable enough to allow the species to move from one block of core habitat to another. This is often facilitated by smaller patches of core habitats acting as stepping stones. This combination of core habitats, permeable habitats and stepping stones is referred to as an ecological network. In order to suggest the extent of the network, a pseudospecies (Watts et al., 2010) is used, which equates to a species reliant on the habitat in question, but able to move through sufficiently permeable habitats from one patch of core habitat to another. This allows the functional network to be described, which will be relevant to most of the species of interest. In addition, the network can also be regarded as the best place to re-instate habitats. This is because seed banks, relevant pollinator species and soil microbial communities are all near enough to move into the newly established habitat and create a functioning community in a relatively timely manner.

To create the three ecological networks, all habitats in the HAR were first assigned as 'core' or 'non-core' for the network in question. It should be noted that a particular patch of core habitat might be assigned to more than one type of ecological network. For example, wet grassland can be core habitat both for the grassland network and for the wetland network; so the core networks may overlap in some areas.

Utilising GIS layers, a cost-distance model was used to calculate how difficult it is for species associated with each core network to move between habitats surrounding the core habitat, with difficulty depending on the distance to the next patch of core habitat and on the type of habitat it moves through. The type of habitat is incorporated on the basis of permeability scores given to all non-core habitats. These scores express how usable the type of habitat is for pseudo-species associated with the network of interest, with some types of habitats forming barriers against species movement (such as roads and water).

Within the output from the cost-distance model, a cut-off value was determined, beyond which movement becomes so difficult for the species group that the area is considered to not form part of the network. The cut-off values are aimed to create habitat belts around the core patches that approximate to the maximum dispersal distance of species associated with the habitat (Table 12).

The resulting networks were reviewed visually by local experts and, following consultation, permeability scores were reviewed, networks re-calculated, and final cut-off values determined.

Table 12: Approximate maximum dispersal distances (m) of species associated with different habitat types; table adapted from Bowe et al. (2015).

Network type	Maximum Dispersal Distance (m)
Broadleaved woodland	750
Grasslands (non-acid, non-improved)	500
Heathland and Acid Grassland	600
Fen, Marsh and Swamp	400

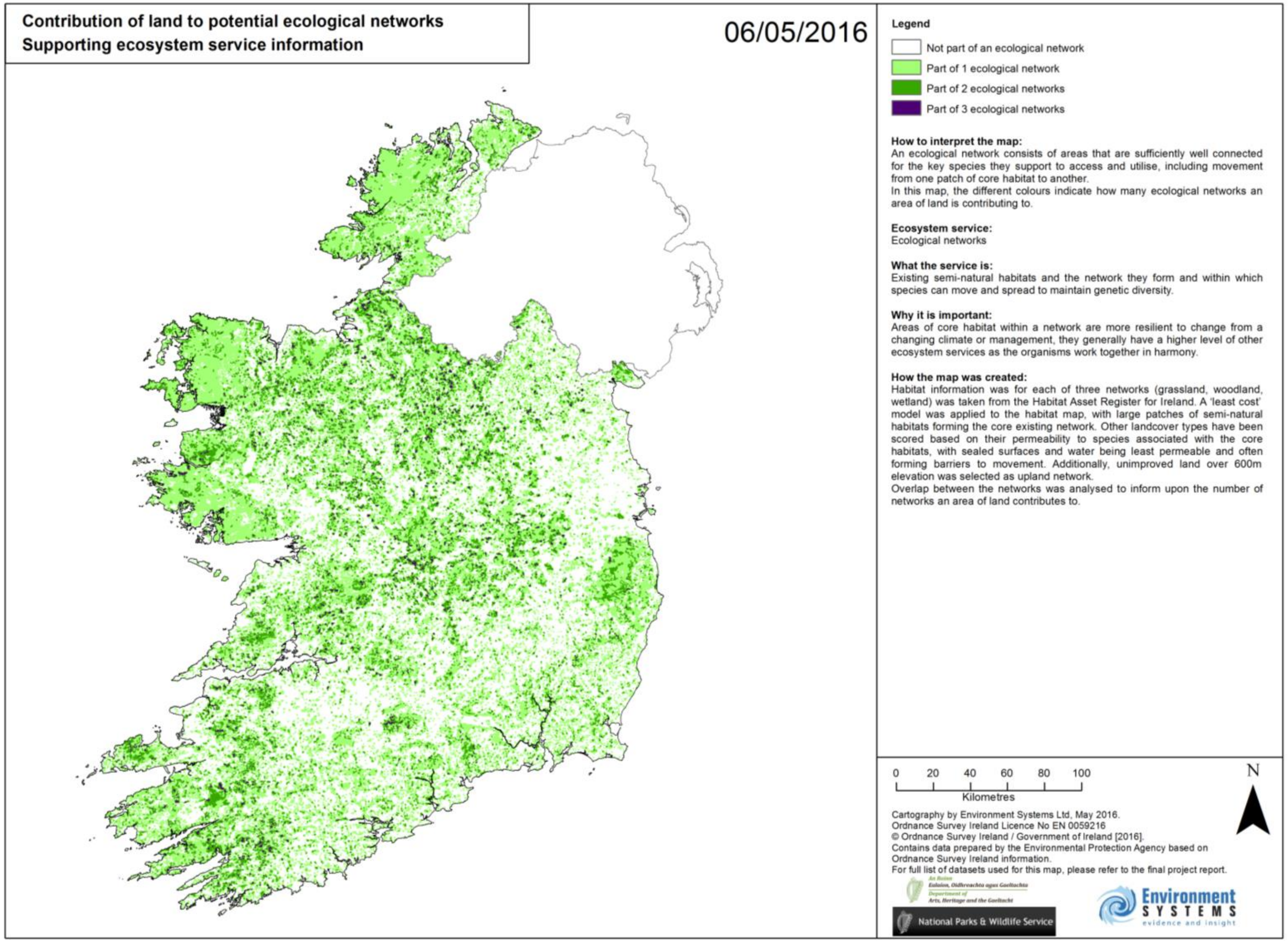


Figure 21: Contribution of land to potential ecological networks

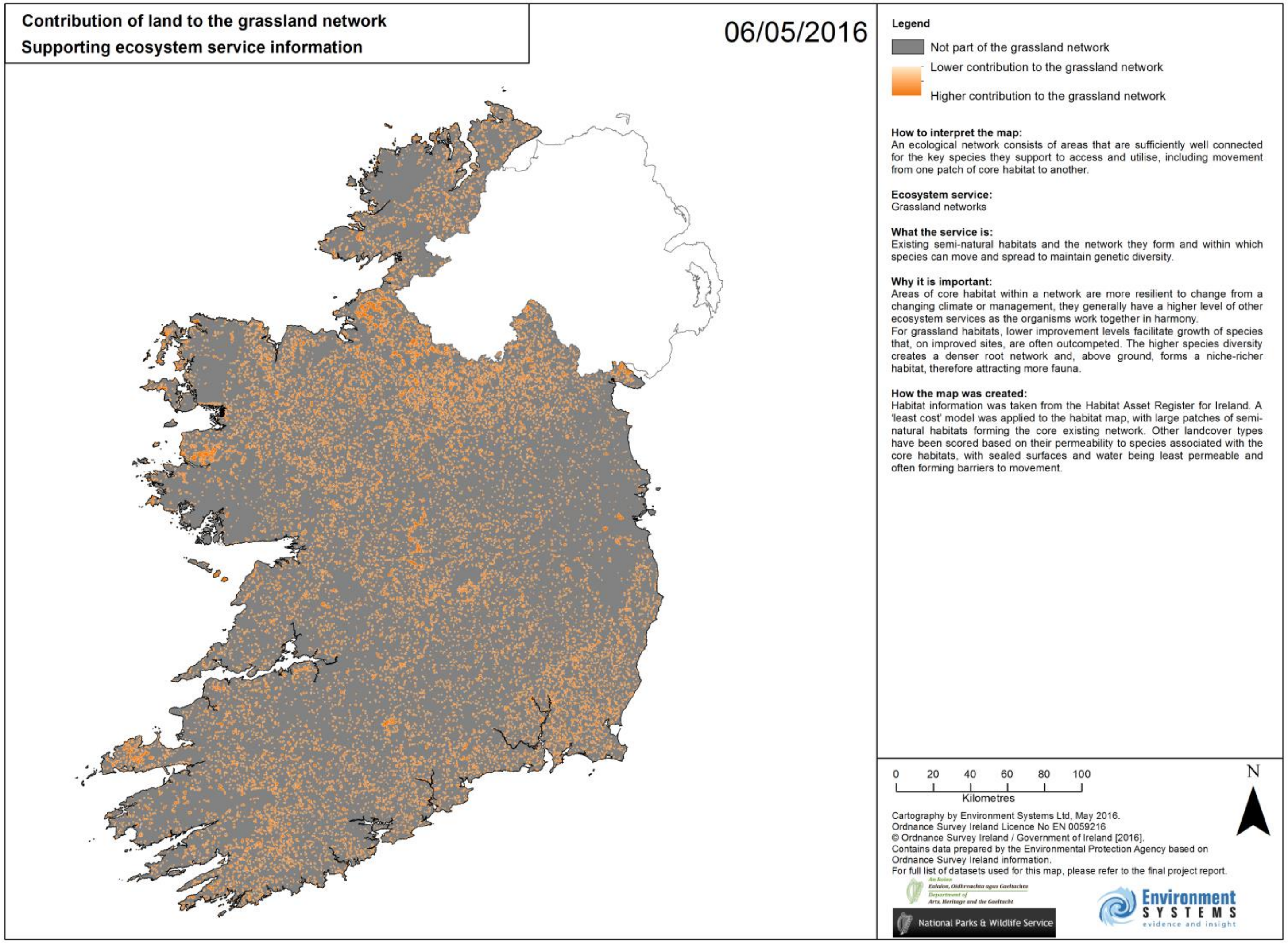


Figure 22: Contribution of land to the grassland network

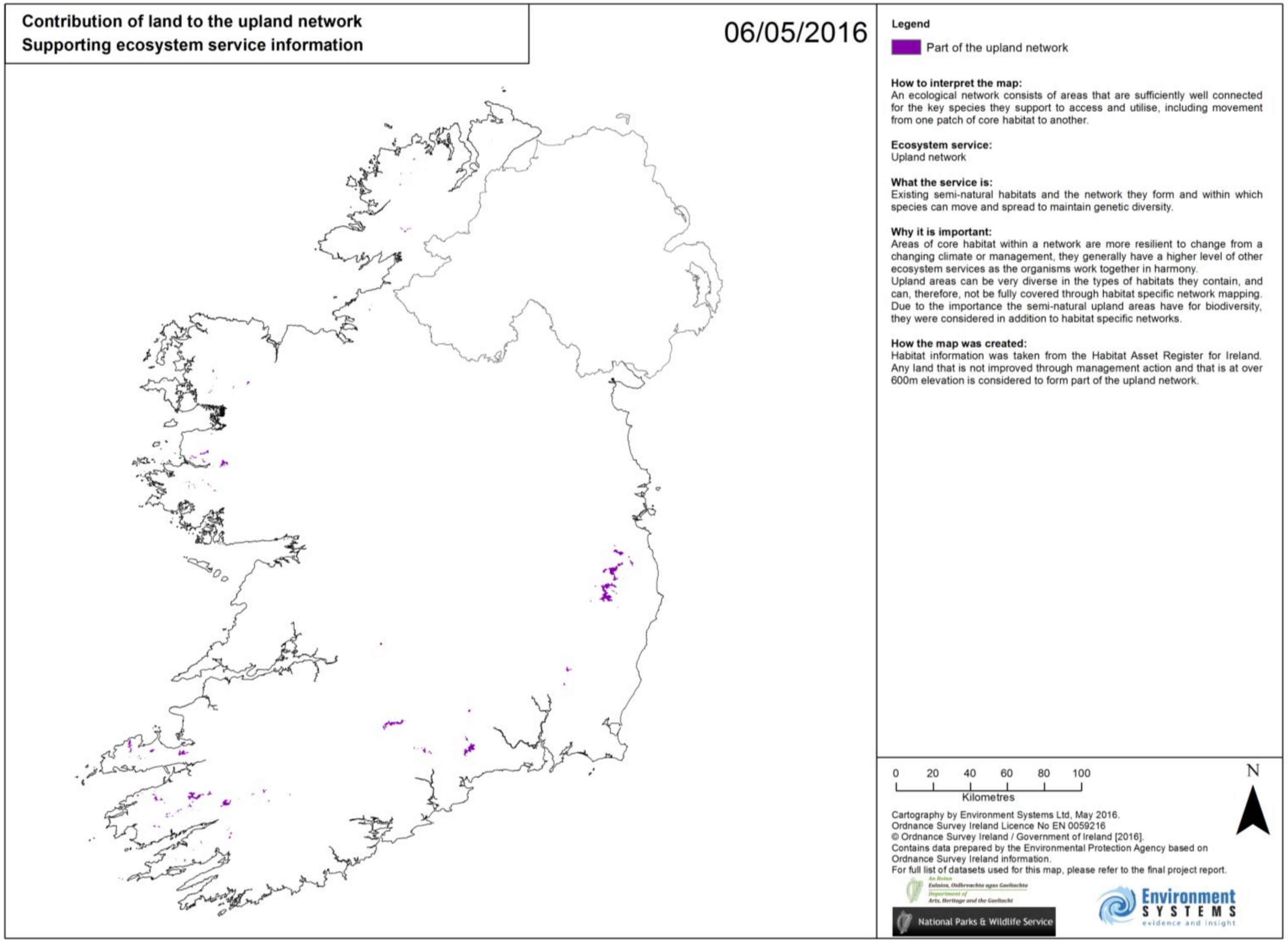


Figure 23: Contribution of land to the upland network

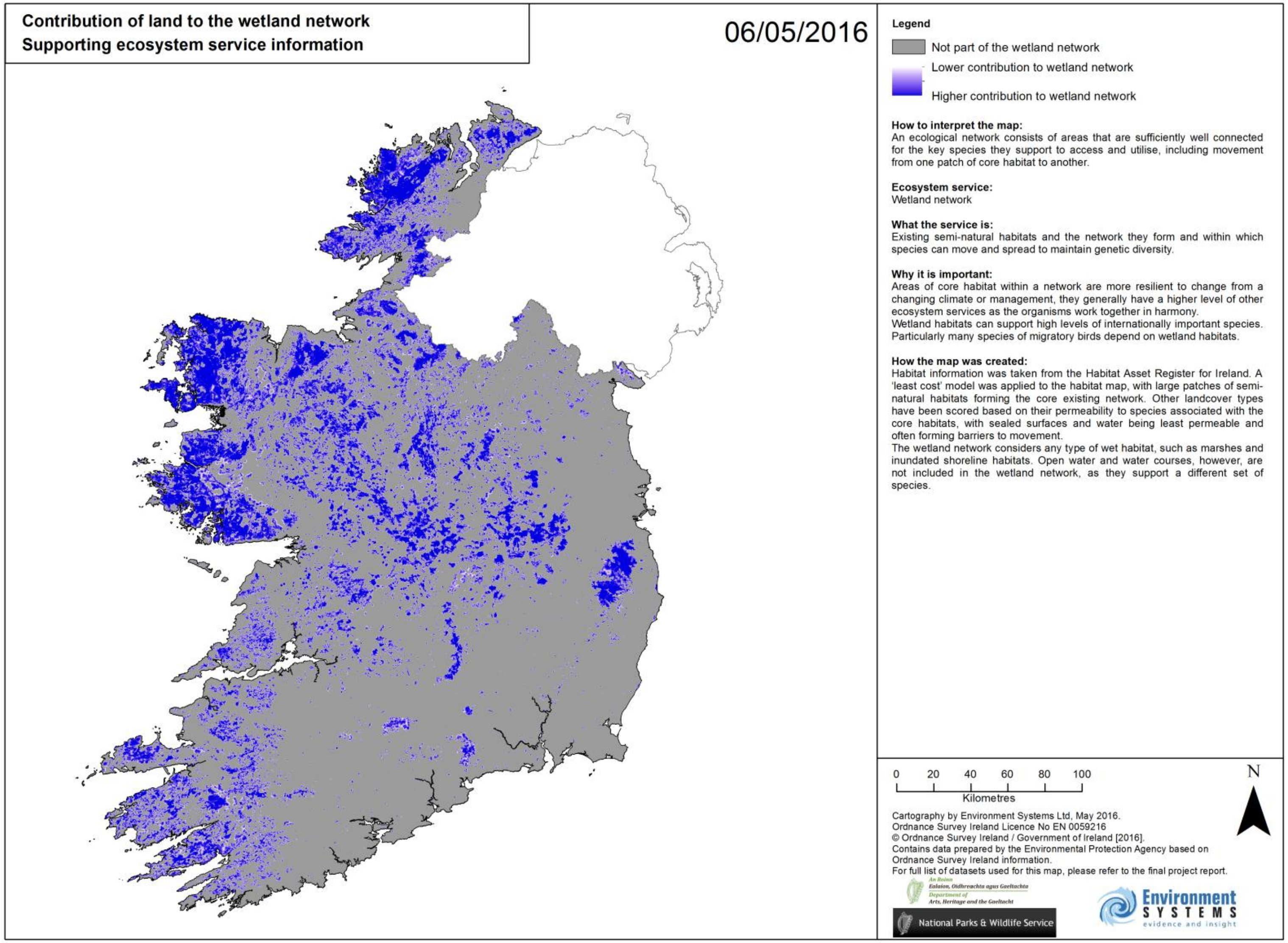


Figure 24: Contribution of the land to the wetland network

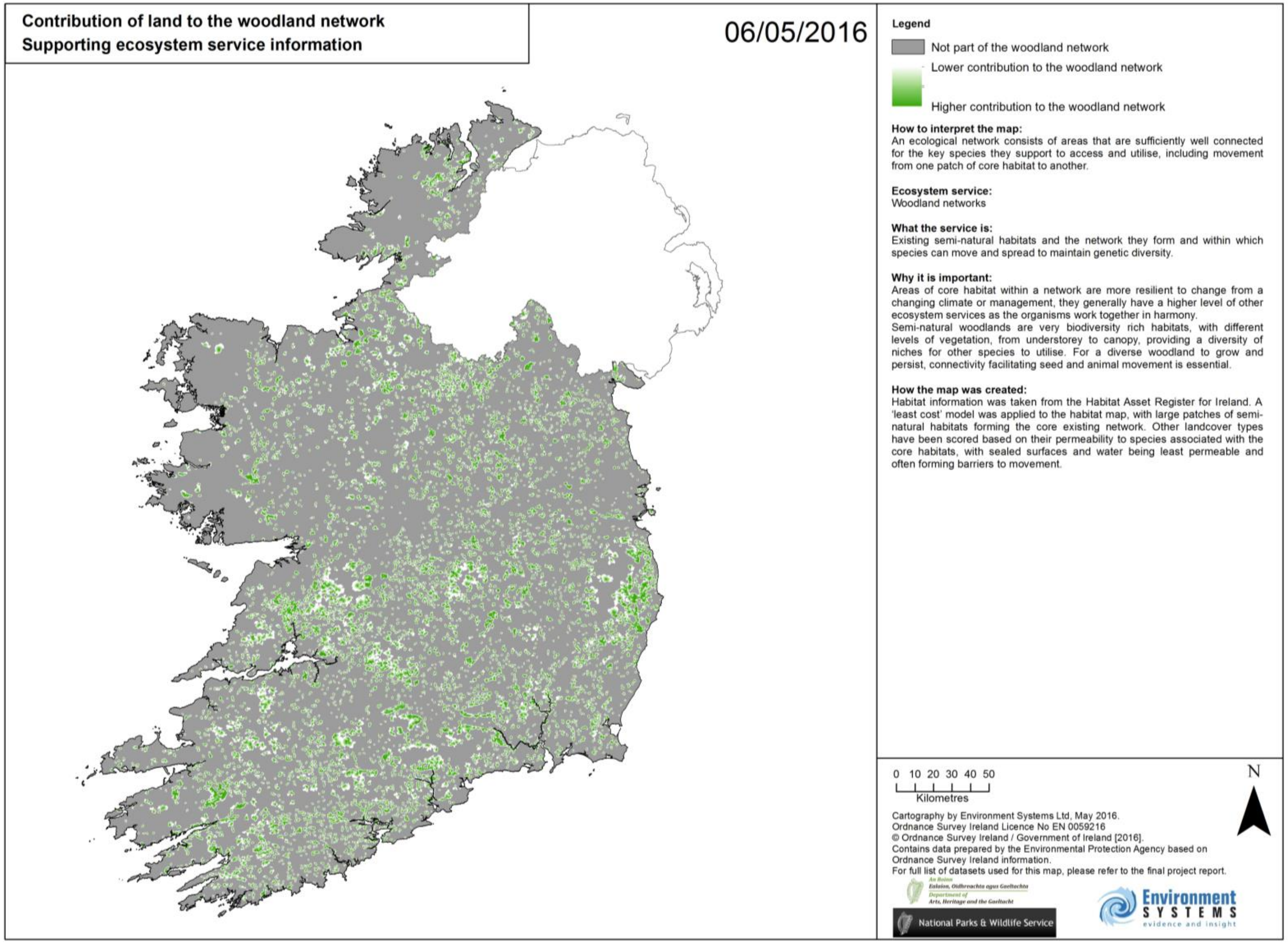


Figure 25: Contribution of the land to the woodland network

5.4.7 Designated Sites Layer

Designated sites are in place to help ensure appropriate management to protect biodiversity and they indicate locations where some of the best functioning ecosystems throughout Ireland can be found. However, the actual level of protection varies between designations.

In order to reflect the value arising from management under designated status, a combined weighted designated sites layer was created. Higher scores were assigned for areas afforded more protection and specifically targeting biodiversity conservation. The scoring system used is summarised and described in Table 13 and reflects the tiered structure of international, national and local wildlife designations that reflect the expected value of the land for biodiversity.

Table 13: Scores given to different designation types for creation of the designations layer.

Designation	Score
Special Protection Areas (SPA)	4
Special Areas of Conservation (SAC)	4
Natural Heritage Areas (NHA)	4
Wildfowl Sanctuary	2
Proposed Natural Heritage Areas (pNHA)	2
Refuge for Fauna	2
National Park	+1 Modifier
Nature Reserve	+1 Modifier

A file combining Special Protection Areas (SPAs), Special Areas of Conservation (SACs), Natural Heritage Areas (NHAs), Wildfowl Sanctuaries, Proposed Natural Heritage Areas (pNHAs) and Refuges for Fauna was created. The lowest scored layer was used as base layer. The base layer was then overwritten by higher ranking layers, so that the higher ranking designations superseded lower ranking ones. Additionally, a modifier layer was created, with the value 1 in areas covered by National Parks and/or Nature Reserves. These two layers were added using raster maths to create and output with all areas being scored between 0 (no designations) and 5 (SPA/SAC/NHA that is managed for conservation in a National Park/Nature Reserve).

If an area is part of both the SPA and SAC network, the score is still 4, as being part of both networks is not considered to increase the overall level of protection afforded.

Refuges for Fauna were provided as a point file. In order to rasterise the point file, as a rough approximation the points were buffered by the radius required to create polygons equal in size to the area of the Refuge. Size of area was generated either form the attribute table or from information on the protected site.

This intermediate layer (Figure 26) is provided to inform the reader as to the level of protection offered by each area of the Irish environment. It is intended to be used to aid interpretation of the other layers.

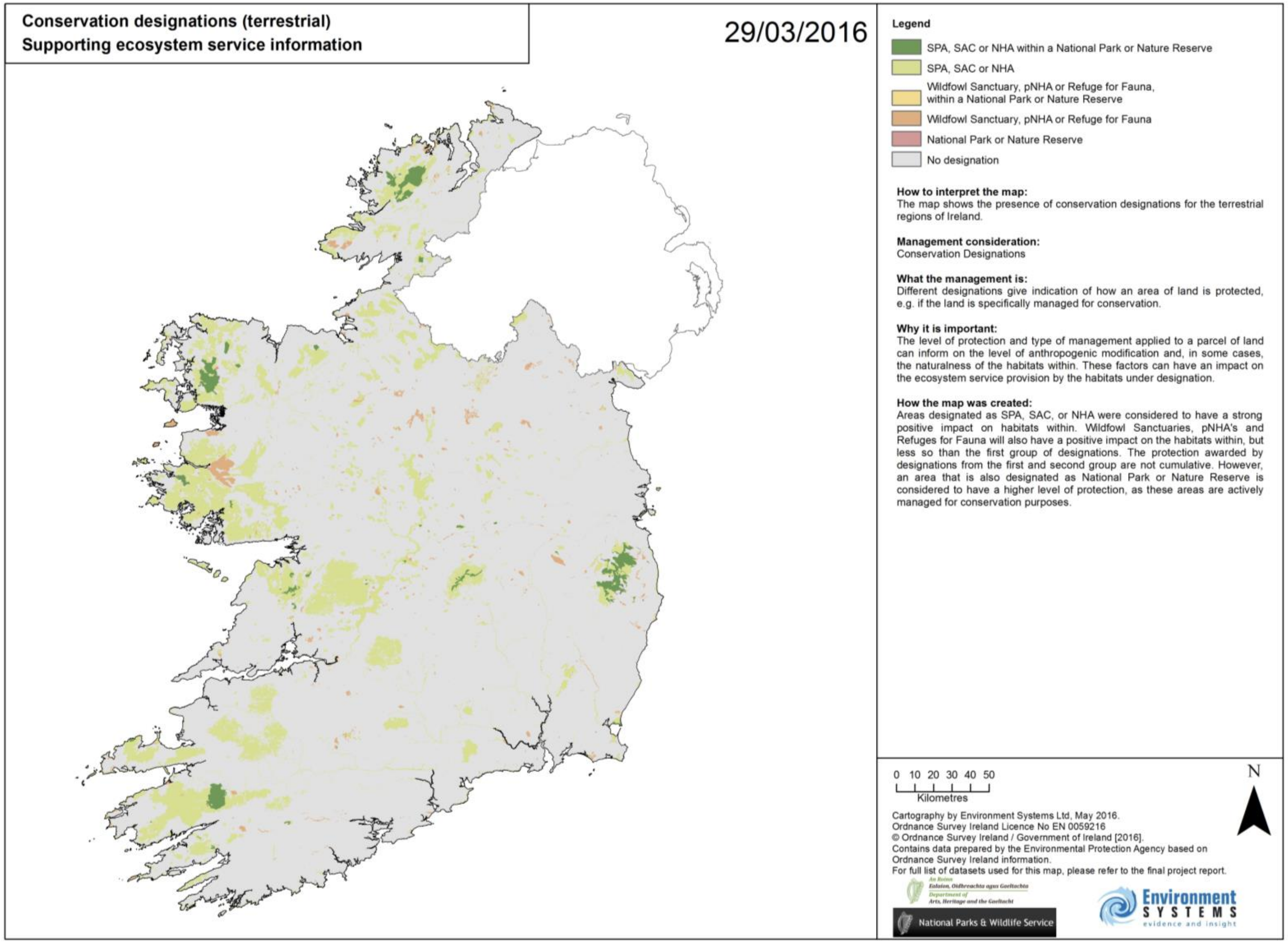


Figure 26: Conservation designations (terrestrial)

5.4.8 Bathymetry

Bathymetry for the marine area of interest was derived primarily from the INFOMAR survey (**IN**tegrated Mapping **FO**r the Sustainable Development of Ireland's **MA**rine **R**esource (INFOMAR). Where data gaps existed CTD (Conductivity, Temperature, Depth) point data collected by the Marine Institute to form a depth profile was interpolated to form a depth profile. The interpolated data covers 6.2% of the total marine AOI; these areas can be seen as the NoData areas in the INFOMAR data layer.

The resulting, seamless layer was then re-classified to form two depth classes: “Shallow (<10m)” and “Deep (>10m)” (Figure 27).

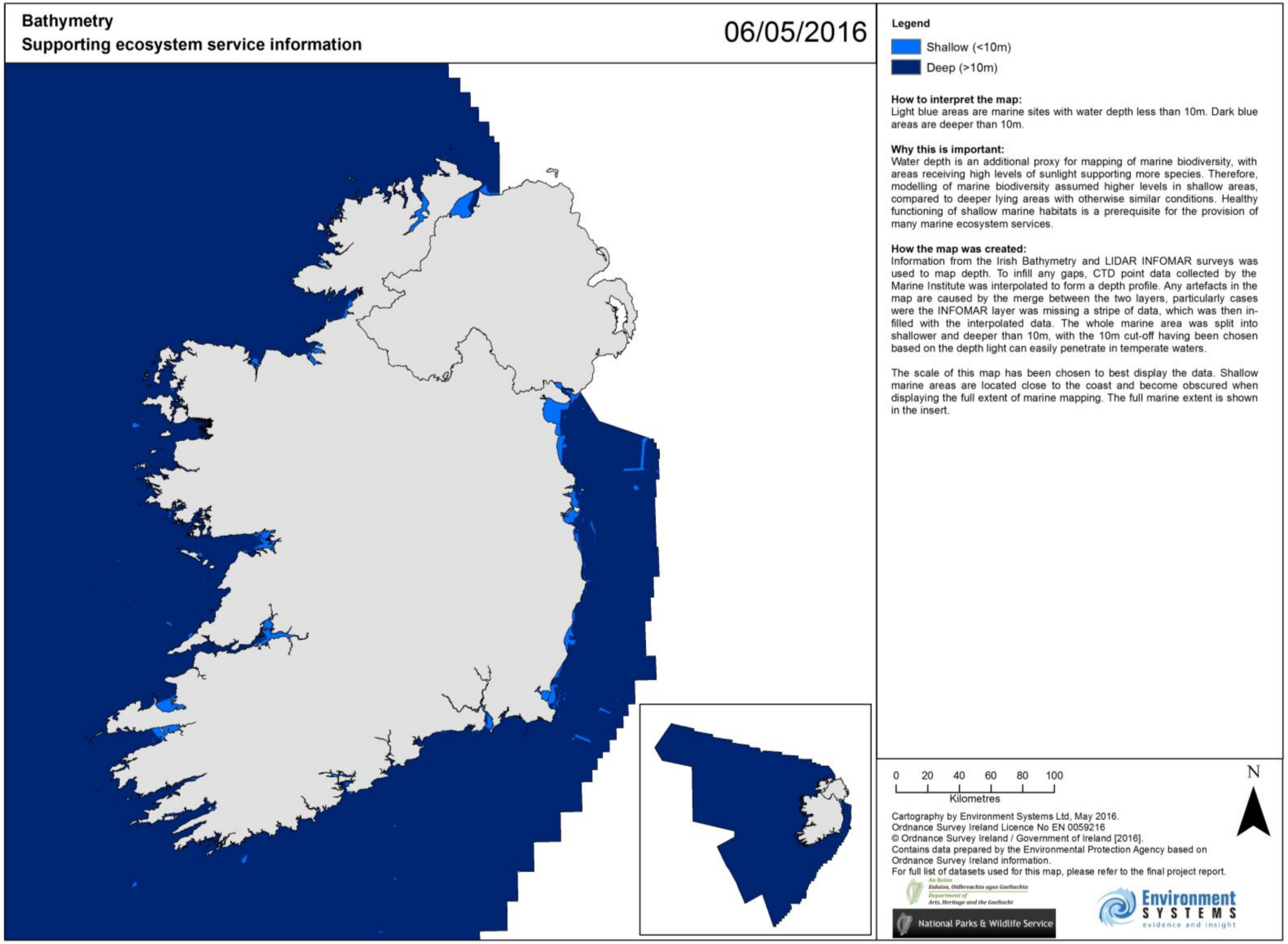


Figure 27: Bathymetry

5.4.9 Slope

For the terrestrial area of Ireland a seamless DTM layer was created from 5,000m^2 IfSAR tiles at a resolution of 5m (Intermap Technologies Inc.). The slope was calculated in ENVI. Slope is one of the main key underlying factors used in the SENCE approach to ecosystem service mapping, as it relates to the functioning of a wide variety of ecosystem services. For example it affects how the land can be used agriculturally, as well as being strongly correlated to the movement of water through the landscape. For detailed information on which maps used landform as a proxy, refer to the indicator documents provided alongside the report / in Appendix L.

The resulting, seamless slope layer was re-classified to form groups based on cut-off values used for agricultural land classification (MAFF, 1988) (Figure 28).

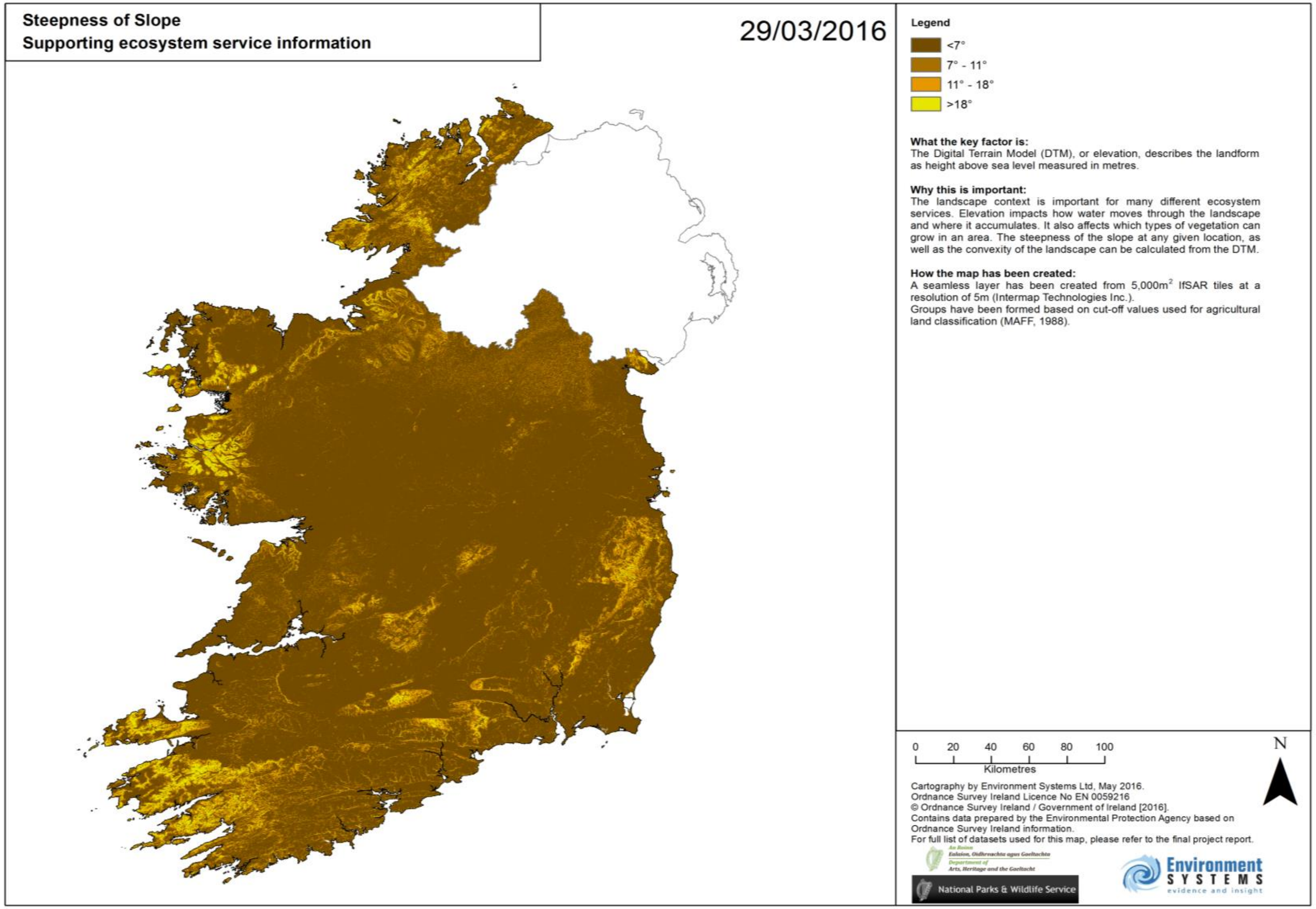


Figure 28: Slope

5.5 Rule-Base Development

The project utilised a rule-base approach to map and combine individual elements of ecosystem services, i.e. different data layers. This provides a stepped approach to building a representation of the whole or part of a complex ecosystem interaction.

The rule-base assessment is based on indicators which interact in different ways for the services under consideration. These indicators, for each parcel of land, are predominantly based on:

- The type of land cover (e.g. woodland or heathland)
- The soil and geology underlying the site
- The position of the land parcel in the landscape (e.g. on a steep slope or valley bottom next to a river or distance from an urban area)
- The management regime or designation applying to the site (e.g. intensive, extensive, little active management or designation, such as SAC or NHA).

These are considered as major indicators of ecosystem services. For some ecosystem service maps supporting data is also used which provides an additional indicator of ecosystem services provision. They provide information about, but are not direct measurements of, the service of interest. For example, due to its inherent biophysical properties, woodland slows down water flow through the landscape and provides a natural flood control measure. Thus, despite not containing direct measures of retention time, a woodland would be scored as being of higher importance to natural flood control than, for example, amenity grassland. Based on habitat data, the mapped output from the GIS model for *'Land temporarily storing water'* would, therefore, consider service provision in wooded areas to be higher than in other areas. In this way, all attributes contained in the datasets chosen for mapping of a service are treated as indicators of service provision and are jointly considered by the GIS model to produce a final map based on all available indicators (see section '5.6 Creation of ecosystem service maps').

The rule-base is designed to be transparent and transferable. It uses scientific knowledge to score each ecosystem indicator using expert interpretation of the datasets used. The weightings are retained in a tabular format and the same approach can be applied to model and map other ecosystem services or for application at a different scale. The approach is iterative in nature which can be applied using standardised parameters or can be adapted using local knowledge.

For each ecosystem service, a rule-base was developed to determine:

- the specific attribute information of each dataset considered important for mapping that service;
- the relative value to be assigned to the different classes of each element to enable mapping;
- if applicable, weightings required when different datasets are to be combined.

Appendix L outlines the technical, scientific understanding underpinning each of the indicators mapped. Table 14 illustrates how the rule-base describes the scoring of the datasets pertaining to potential soil carbon storage, demonstrating how these data attributes can be used to build up a representation of the ecosystem service being analysed. Expert knowledge on soil carbon richness was used to construct the rule-base.

In order to account for the fact that mapping is based on indicators, rather than direct measurements, certainty tables are created to illustrate our understanding of the indicator in relation to the service of interest. To do so, three primary questions are addressed:

- How much do is known about the contribution of the indicator towards the ecosystem service provision?
- How much does the indicator influence the ecosystem service?
- How good is the data available to map the indicator?

In response to these questions, all indicators were scored for certainty into three levels; high, medium and low. This was completed for each respective dataset with the following descriptions:

- **High** - meaning a lot is known about the indicator and knowledge is well-documented, for example, in many books and textbooks; the data has good coverage at a suitable scale for the project, and/or the indicator has a high amount of influence on the service being mapped.
- **Moderate -** meaning something is known about the indicator, there is some scientific literature (e.g. within journals), but there might not be a general consensus; the data may have really high resolution data of discrete features but is only available for part of the area to be mapped, and/or the indicator, although specific, does not actually, as far as is understood at present, contribute a huge amount to the goods and benefits received from the service.
- **Low -** meaning the indicator is not well-understood as it has not been researched in detail and there is not a great deal of scientific literature available to help us understand the contribution of the indicator to the ecosystem service, and/or the spatial data available is old, has very little coverage or is at a scale which requires manipulation and could lose detail (i.e. it is not a good fit, but is all that is available at the time).

Table 14: Rule-base scoring example (Soil carbon)

Data name	Attribute heading 1	Attribute 1	Soil Carbon Score
BasemapIE_IG _Q1_08 (OSI Prime 2)	HAR: L1 - L2	Built environment - Built environment	Minor negative
Connolly Derived Peatland Map	HAR: L1 - L2	Blanket bog - Low-level	Very high
Slope Classes	Slope	>18°	Major negative
Saltmarsh Monitoring Project	HAR: L1 - L2	Semi-natural grassland - Coastal grassland mosaic	Moderate
Article17 - 21A0	HAR: L1 - L2	Machair - Machair	High-very high

Legend (generic)*
Major negative
Moderate negative
Minor-moderate negative
Minor negative
Very low negative
Negligible negative
No effect on service
Negligible
Very low
Low
Low-Moderate
Moderate
Moderate-High
High
High-very high
Very high

*Generic legend on left most column illustrating the full range of potential classes for outputs (ie not specific to Soil carbon attribute scorings).

5.5.1 *Steering Group Consultation on Rule-Bases*

Following the second stakeholder workshop in November 2015, the second iteration of rule-bases for each ecosystem service to be mapped was prepared and sent out to members of the Steering Group for comment. The consultation package included a set of maps of the ecosystems service provision together with information on:

- The CICES class represented by the map;
- The position of the service being mapped within the ES Cascade;
- Information on what the ecosystem service being mapped is;
- The indicators generated from GIS attribute data to map the service;
- Information on how the map was created;
- How the map was scored or weighted based on the influence of each indicator for that service;
- A proxies and limitations spreadsheet for each ecosystem service.

On review of the consultation package, comments were prepared by the steering group members. The comments were collated to identify specific messages and to adapt the scoring and use of data based on the more local and expert knowledge of ecosystems from the steering group members. Using the collated comments, the GIS models for each service were adapted to create a revision of each map.

5.6 Creation of ecosystem service maps

After scoring the key factors and supporting indicators, including any intermediate layers (see section '5.4 Primary Intermediate Layers'), they are then combined in an overlay analysis (Figure 29). For example: woodland may have a positive influence on the regulation of water quality, as can organic soil (in good condition) – they have been scored highly. However, steeply sloping land promotes overland flow and is not good for natural control of water quality – this attribute was given a low score. In combination, the area would have a medium to high rank for its contribution to water quality control, based on the exact steepness of the slope and the type of woodland. Negative scores assigned to attributes that reduce provision of a service, e.g. intensively managed arable land reducing water quality, will appropriately reduce the overall value during the overlay analysis.

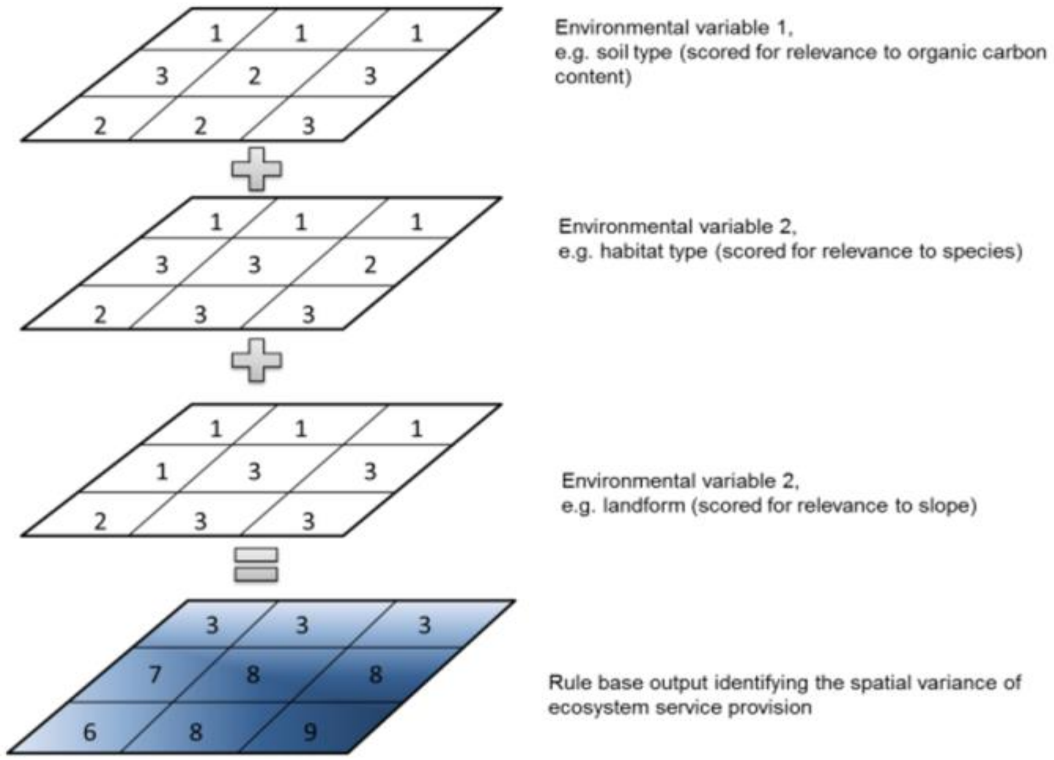


Figure 29: Schematic representation of the overlay analysis used in the SENCE approach to ecosystem service mapping; this process describes how the information from different key factor layers is combined to obtain information on ecosystem service delivery within each parcel of land.

6. Mapping outputs

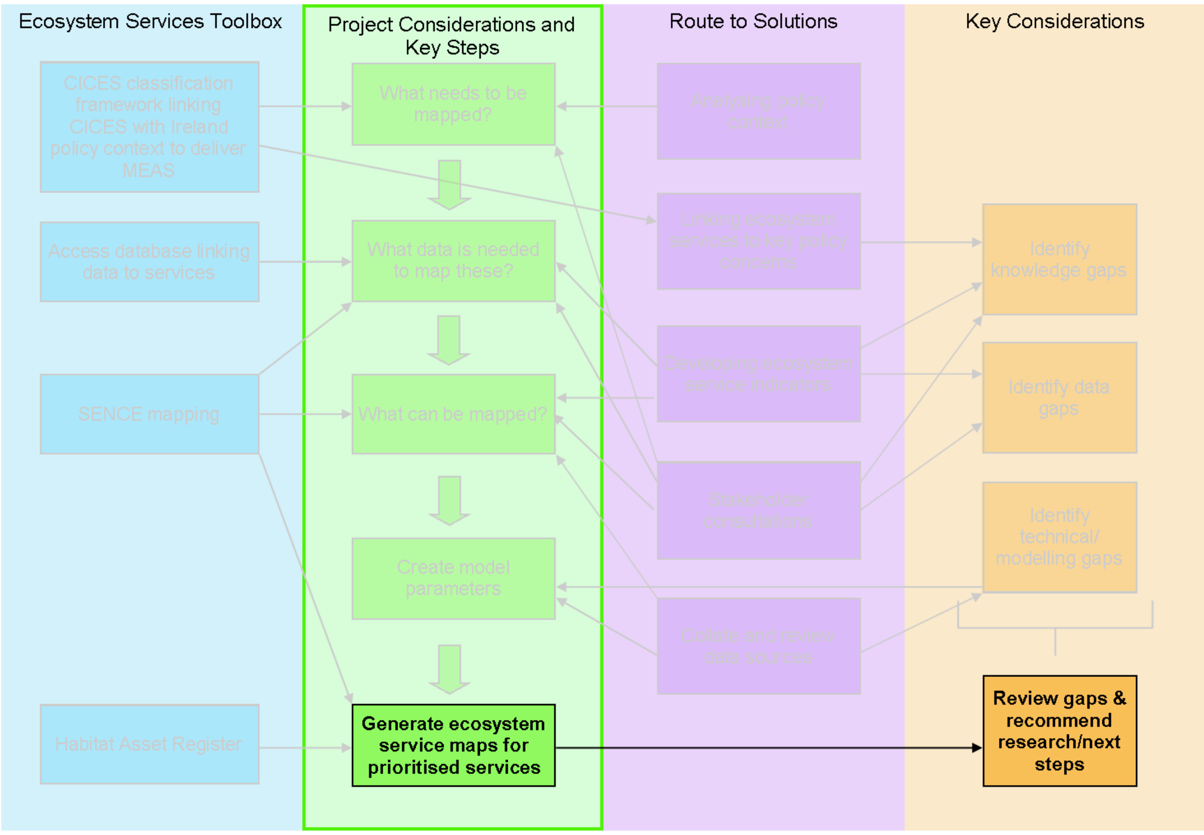


Figure 30: Project approach – tools, considerations and steps detailed in this section.

The maps are modelled approximations of our best estimates of the situation at the current time with the data available. The maps have been created from available data at strategic scales (as opposed to local scale mapped with detailed input data). Therefore, any proposed action on individual sites will need to be assessed at a site level, using available or creating more detailed information appropriate for supporting decisions at that scale. If individual site surveys are undertaken, the results should be fed back into a regional or localised model to help enhance the spatial understanding of ecosystem services in that area.

Ecosystem services are primarily based on natural, biophysical characteristics, which generally do not align with administrative and management units, which may determine the distribution of beneficiaries. Approaches to mapping ecosystem services and the data from which to create maps are constantly evolving. Where further research and data becomes available, the mapping models can be revisited and updated utilising new knowledge and data.

As per prioritisation during stakeholder consultation, selected ecosystem services were modelled using the SENCE tool to create maps of:

- **Land temporarily storing water** (Ecosystem service: Regulation of flows (Regulating))
- **Areas of land promoting good water quality** (Ecosystem service: Regulation of water quality)
- **Terrestrial food** (Ecosystem service: Nutrition from crops, livestock and wild foods)
- **Terrestrial biodiversity: Habitats, management, ecological networks, and species** (Function: Naturalness, support of systems and species, and resilience)
- **Marine areas that provide food** (Ecosystem service: Marine food (Provision))
- **Marine biodiversity: Habitats and management** (Function: Naturalness, support of systems and species, and resilience)
- **Carbon storage maps**

Carbon storage as an ecosystem service is of high interest due to its impact on climate change. Carbon sequestration describes the process of gaseous carbon being removed from the atmosphere, by, for example, being incorporated into the biomass of fresh vegetation growth. The carbon retained within the currently existing vegetation biomass is the carbon stored in this vegetation. With vegetation die-off, carbon stored in plants is incorporated into the soil profile; the carbon is thus stored in the soil, as well as in the vegetation. Similarly, carbon is stored in marine sediments, which, if at sufficient depth, can form areas of long-term carbon storage, i.e., the carbon stored in this manner is unlikely to be released for a long time. Generally, carbon sequestration refers to the process of carbon being removed from the atmosphere and being incorporated into another medium. Carbon storage refers to the carbon currently present within said medium. Maps produced during this project model the latter of the two.

- **Soil carbon** (Ecosystem service: Regulation of greenhouse gases (carbon))
- **Vegetation carbon** (Ecosystem service: Regulation of greenhouse gases (carbon))
- **Marine carbon** (Ecosystem service: Regulation of greenhouse gases (carbon))

Each of these maps is created based on relative comparison, rather than showing ecosystem service provision in an absolute sense. The scoring system (see Section 'Rule-Base Development') says, for example, that one habitat contributes much more to the provision of the service than another habitat does. In that sense, the final outputs are meant to be interpreted as showing relative ecosystem service provision. The areas shown as being of the highest value on the maps have been modelled as contributing the most to the provision of this service within Ireland and are, therefore, Irish hotspots of ecosystem service provision for the service in question. This means that without further quantification, no direct comparison between different maps for carbon storage can be made; each map will be highlighting where in Ireland provision of the three types of carbon storage is highest / lowest, but how much carbon 'highest' means in tonnes is, at this stage, unquantified.

Due to the strong impact urban areas have on ecosystem service provision, two small areas of compromised data in the OSi buildings layer showed distinctly on the ecosystem service maps produced. To avoid these areas showing as sites of disbenefit to the service, the areas of compromised data are shown in black on all maps affected.

Note – Whilst the Habitat Asset Register (HAR) is based on the best data currently available, it does contain some inherent limitations due to the manner in which LPIS categorises permanent pasture. This may lead to an underestimation of semi-natural grassland and heaths. For details, please refer to the section on data gaps and the section on the preparation of LPIS data for usage in the HAR.

While the scorings assigned in the Rules-base are qualitative, as these are related to spatial distributions it is possible to quantify the areas assigned each of the qualitative classes. Therefore, in addition to the maps, charts are supplied that help the reader to see the overall contribution of various areas to each service within Ireland. In order to create these charts, the continuous data on ecosystem service provision shown on the map is grouped into classes, such as 'neutral' (= modelling showed the service to not be provided, but there is also no disbenefit), 'ES provision' (= modelling showed an average amount of provision), or 'ES provision hotspot' (= exceptionally high ecosystem service provision was modelled, within the range of values obtained for this service).

The area coverage (as % of terrestrial or marine area) for each class is calculated. In combination with the maps, the charts help to see both how the provision of one service is in Ireland overall, but also how provision is distributed. For example, for one service, 80% of the area might be falling into the class 'ES provision', 10% into 'Disbenefit', and 10% into 'Some ES provision'. This would show that this service is provided consistently throughout Ireland, with some sites that are negative for this service. For another service, 20% might be falling into the class 'Strong disbenefit', 20% into 'Neutral', 40% into 'ES provision', and 20% into 'ES provision hotspot'. This would indicate a much patchier distribution of the service, with some areas being very valuable (and possibly of importance for the provision of this service on a national level), whilst other areas have a strong detrimental effect on the provision of the service in question.

For information regarding attributes of input layers having been scored as disbenefits for a service, please refer to the excel Rule-bases provided as part of the supplementary material for this project as described in the introductory chapter, Table 1.

6.1 Land Temporarily Storing Water

6.1.1 Summary

The map (Figure 31) indicates the spatial variation in the capacity of land to regulate the flow of water, through interception of rainfall through the vegetation canopy (CICES Ireland sub-Classes Mitigation of Peak Flows) and through the absorption of rainfall into the soil (CICES Ireland sub-Class Water Storage). The capacity of land to regulate the flow of water will become increasingly important with greater climate variability and associated risk of flooding and drought (as indicated in the policy & pressure matrix, Appendix F).

The main factors determining this capacity are topography, geology, soil, vegetation and land use. Steeper topography results in faster movement of water overland, whilst on gently sloping and flat land, the speed of water flow slows. Porous rocks allow water to be absorbed, helping retain water below-ground rather than the rainfall remaining on the surface and contributing to run–off. Similarly, deep soils with a moderate to high organic matter content also absorb water, reducing the amount that can form overland flows. The more complex the structure of the vegetation, the higher the interception of rainfall and the more the energy in the water is dissipated and slowed before it reaches the ground. Land without vegetation cover, for example arable areas before or after cropping, or sealed surfaces, provide a very rapid pathway for water to move.

In terms of the spatial distribution of this service, approximately 90% of the country has been classified as either providing, providing strongly, or forming hotspots of service provision (Figure 32). Areas of lower provision for water regulation (classified as Disbenefit (1.25 %) or Some Disbenefit (1.69 %)).are mostly associated with areas of bare ground and sealed surfaces

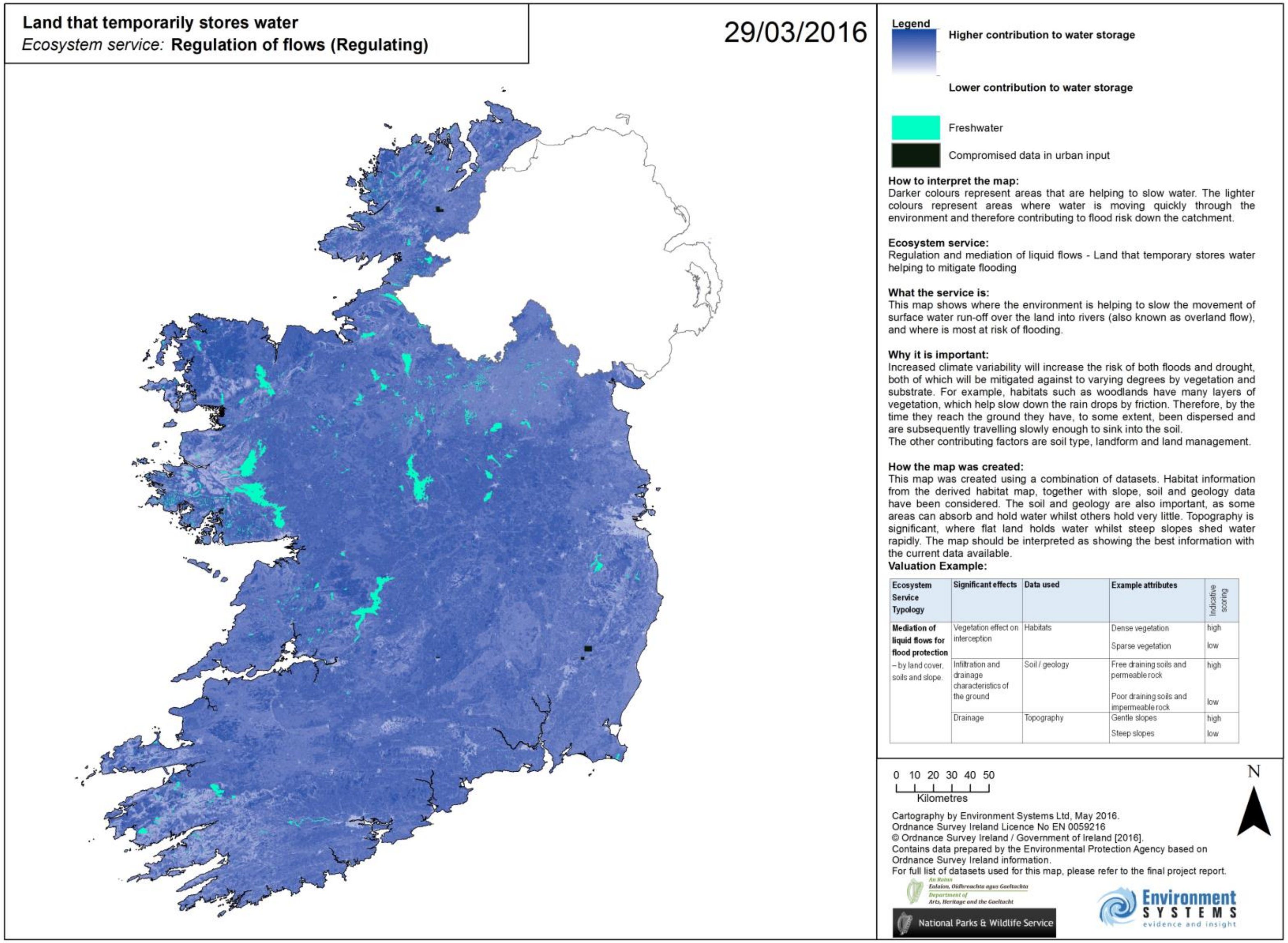


Figure 31: Map: Land Temporarily Storing Water

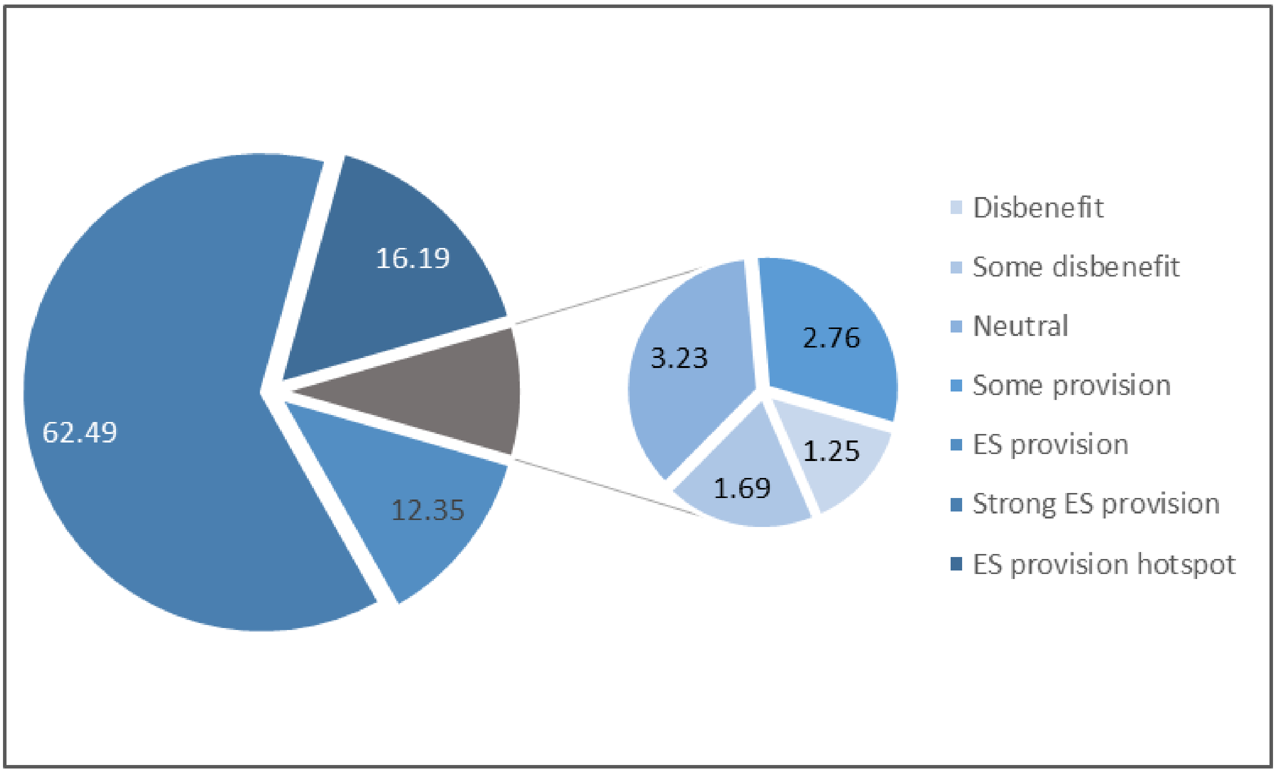


Figure 32: Contribution of Ireland's terrestrial areas to temporary water storage (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.1.2 How the input data relates to these results

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further explanation for the rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

Above ground vegetation coverage and structure influence the transit of precipitation, and scores reflect the complexity of the structure of the vegetation. Soil moisture retention is influenced by multiple biological, physical and chemical properties of the soil; its organic matter content, depth, aspect, and slope as well as its management history. The score in the 'Rules-base' reflects these features. Underlying geology influences both soil characteristics, structure and topography and will determine the capacity of the rock itself to hold water, these features are reflected in the scores given. For topography, the lowest scores are given on highly sloping and poorly vegetated areas and the highest scores in areas with gentle slopes and full vegetation cover. The highest scores for habitats are awarded to native woodland with understorey, a shrub layer and tall canopy trees, as these provide the highest level of interception. Aquifers also have a strong role in water retention and are scored highly as a result.

The map illustrates the spatial variation in the combination of these factors, with potential service provision being lowest in non-vegetated sealed areas (urban areas) and for land with very steep slopes with little vegetation cover in the uplands. The raised bog areas and the wooded valleys show as the areas of highest provision. Floodplains are also areas of high provision, especially where there are complex vegetation structures (e.g. woodland or a high density of hedges) because they can hold water in storm events. Although these areas may themselves flood at times, they slow the flow of water, avoiding or delaying the speed at which water reaches downstream areas. This can be an important service for towns and cities near the outflow of rivers where the impact of flooding can be severe.

6.1.3 How the map relates to other maps produced

The degree that water is intercepted or continues as overland flow will have an influence on the removal or contribution of pollutants in solution or suspension in water. Therefore, there is a relationship between the potential 'Regulation of Flows' service with that of ***'Regulation of Water Quality'***. This due to the fact that areas with a high rate of overland flow (generally sealed areas or steep areas) have a greater chance of encountering pollutants on the surface when the water is in a high state of energy. These pollutants can then become suspended in the water and can be transported into the river systems. On shallower slopes with vegetation cover, rainfall is more easily absorbed into the soil which aids the purification of the water through interactions with soil chemistry and biological action of the roots.

Areas of steeply sloping land or where there are areas of sealed surfaces show that there is correspondence between low Mediation of Water Flow and low '***Regulation of Greenhouse Gases: Soil Carbon Storage'***. Steep slopes do not store water well and provide little opportunity for soils to form carbon stores.

6.1.4 Data and knowledge gaps associated with this map

The data used includes habitat cover, soils, geology and topography as these provide a good indication of factors that determine how water is naturally stored by different ecosystems. The 'Rules-base' could be improved by considering the following data gaps:

- The 'Rules-base' does not incorporate the effects of precipitation. Rainfall data could be incorporated to identify which catchments have a both a high precipitation and low flow regulation potential relative to residential areas to model flood risk.
- The map does not model where the potential flow of water will occur. Inclusion of data such as catchment boundaries and drainage networks (e.g. non-river channels that water flows through after heavy rainfall events) could be incorporated to determine exactly where water will travel through the landscape.

- The depth of soils including knowledge of soil profiles could add a greater level of detail to the mapping of this service.
- See also section on mapping limitations inputs.

6.2 Water Quality (of Freshwater)

6.2.1 Summary

The map (Figure 33) indicates the spatial variation in the potential for areas of land to influence water quality (CICES sub-class Ireland 'Terrestrial & freshwater habitats which provide nutrient retention and pH buffering').

Water quality regulation (including sedimentation) varies relative to the combined spatial variation in substrates, slope, vegetation type and land use. Some soil types filter water as it percolates through (e.g. alkaline clay-loams), whilst others (e.g. peat) add to the suspended particulate matter and mineral burden of the water. In addition, slope is a key influencing factor, as steep slopes shed water more rapidly than shallow slopes. Faster flowing water has higher energy and is able to carry more particulate matter (picked up from the land surface) within it.

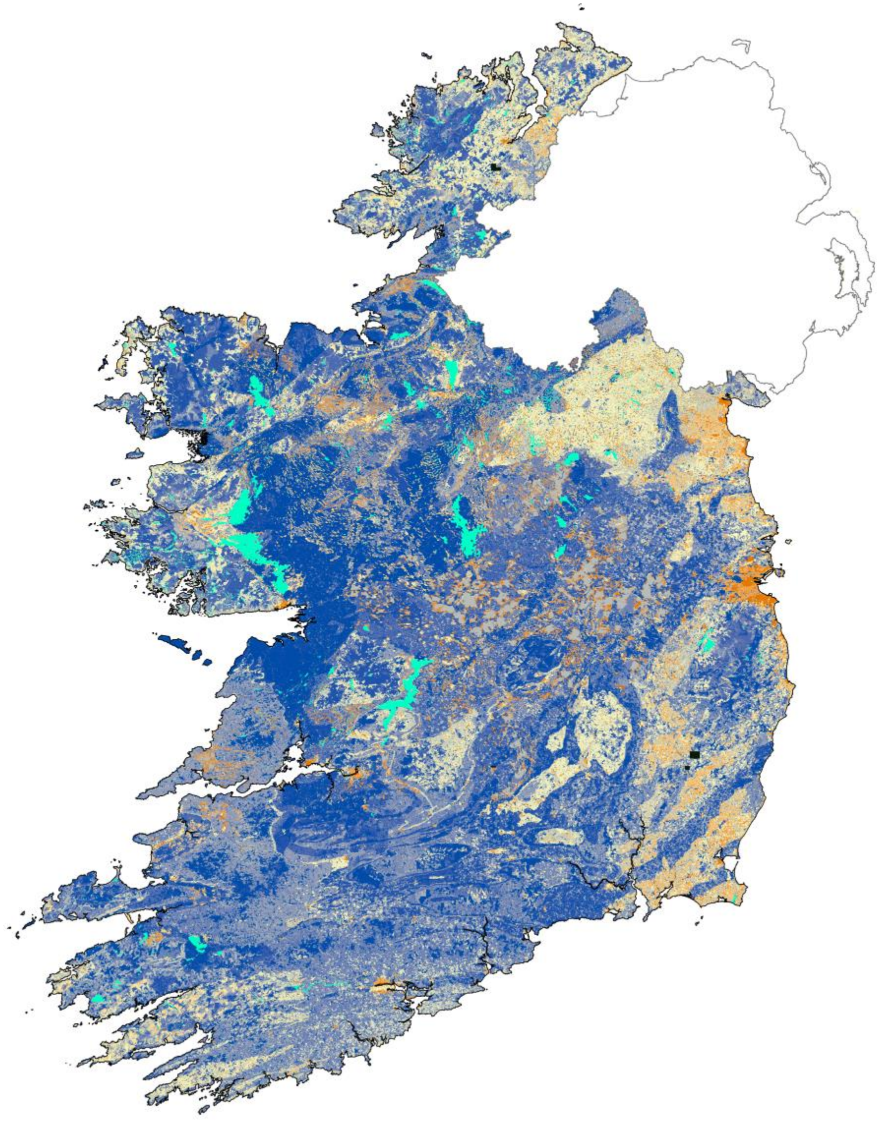
Some plant species (e.g. reeds) assist with water purification, taking-up ions selectively and reducing chemical pollution. In addition, plant roots trap and prevent particulate matter reaching water courses. Intensive arable cropping can increase the pollution burden; areas of bare soil are more susceptible to erosion and also have the potential for high inputs of inorganic fertilizers, pesticides and herbicides. In addition, areas which are grazed by livestock, and in particular areas where livestock have free access to the water courses add to contamination through poaching of the land and input of faecal coliforms.

This map considered particulate matter and general buffering capacity. The lowest provision is associated with arable land, urban areas and unvegetated peat, which erodes easily (with organic material being carried in the water giving it a brownish colour without extensive treatment). Sites with calcareous, porous rock and extensive aquifers generally have good filtration as the chemistry of the rocks helps purify the water as it is stored underground.

The breakdown of service provision by area shows that almost half of the country (49.87%) has been classified as having ES Provision for this service, and a further 16% Strong ES Provision, while only 0.42% were classified as being hotspots for provision (Figure 34). Areas classified as either Disbenefit or Some Disbenefit amount to c9%, with these areas potentially contributing to the pollution burden of freshwater to some degree.

Areas of land promoting good water quality
Ecosystem service: **Regulation of water quality**

29/03/2016



Legend

Higher contribution to promoting good water quality

Some disbenefit to promoting good water quality

Freshwater

Compromised data in urban input

How to interpret the map:
The darkest colours represent land that contributes most to filtering sediment from the water and, therefore, 'better' water quality. Lighter colours represent land that may be inputting impurities into the water environment.

Ecosystem service:
Regulating and maintaining chemical condition of freshwater – Water Quality Regulation

What the service is:
Contribution of the land to the filtration and supply of fresh water.

Why it is important:
Pure clean water is essential for human health and underpins the whole environment.

How the map was created:
The map has been created using information on soil type from the Teagasc national soils and subsoils datasets, landform in terms of slope angle and habitats from the compiled habitat map. It uses scientific knowledge to model which areas of land are likely to be filtrating water and which areas of land are potentially having an adverse effect by inputting impurities. The map should be interpreted as showing the best information with the current data available. The map is intended for use at a strategic scale. If information is needed about current site specific water quality a detailed field survey should be undertaken.

Valuation Example:

Ecosystem Service Typology	Significant effects	Data used	Example attributes	Indicative scoring
Water Quality Regulation	Land cover effect on	Habitat	Woodland Hedge Heathland Bog Arable	med/high med med med/low low/neg
	Filtration effect of the soils	Soils	Brown earths Peaty soils	med/high low
	Slope is linked to flow rate	Elevation – slope based on DTM	Steep slopes	Negative

0 20 40 60 80 100
Kilometres

N

Cartography by Environment Systems Ltd, May 2016.
Ordnance Survey Ireland Licence No EN 0059216

Contains data prepared by the Environmental Protection Agency based on Ordnance Survey Ireland information.
For full list of datasets used for this map, please refer to the final project report.

An Roinn Ealaíon, Oidhreachta agus Gaeltachta
Department of Arts, Heritage and the Gaeltacht
National Parks & Wildlife Service
Environment SYSTEMS evidence and insight

Figure 33; Map: Water Quality (of Freshwater)

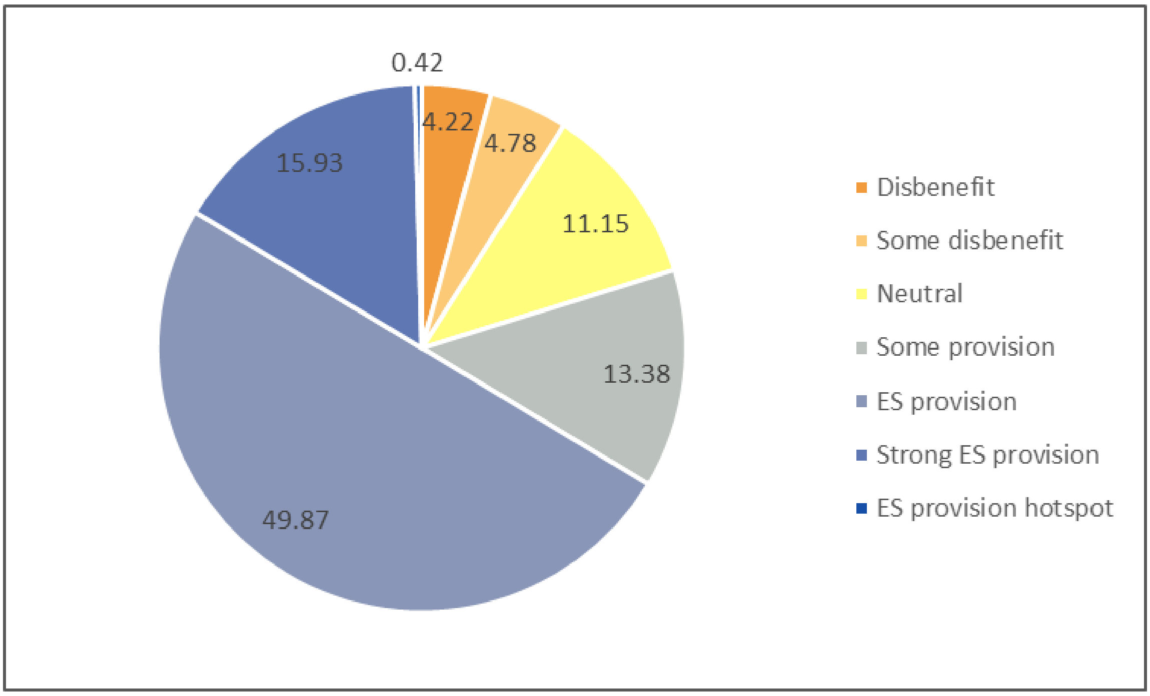


Figure 34: Contribution of Ireland's terrestrial areas to water quality regulation (%) regarding sedimentation; note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.2.2 How the input data relates to these results

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

National spatial data representing the key factors influencing water quality have been combined to develop a qualitative potential distribution of the service. The key factors in the 'Rules-base' broadly include vegetation (modelled through the Habitat Asset Register). Vegetation with deep root systems or vegetation where the dominant species has a strong role in nutrient cleaning (e.g. reeds) are scored as high potential provision. The substrate (incorporated through a combination of soils, sub soils, geology and aquifer data) are scored; with alkaline, porous soils on extensive aquifers having the highest scores as the soil and rock chemistry in these areas will facilitate the removal of particulate matter and other pollutants from the system. Shallower slopes are scored with a high level of provision as water moving slowly has less energy and is therefore less likely to carry sediment and pollutants. For the influence of grazing land, the Habitat Asset Register and designations network data were used; with the lowest scores being on improved grassland likely to be carrying high numbers of livestock. More precise data on land management would greatly assist the accuracy of this proxy score (see data gaps below).

The areas of highest provision for this service are most strongly concentrated in a band along the west of the country (Figure 33). The areas of disbenefit are located in major cities and in the more intensive / arable farming areas in the east of the country. Areas where peat is likely to be unvegetated and therefore eroding can also been seen on the map in the centre of Ireland. In areas scored similarly for all other supporting input data, outlines of some of extensive aquifers can be distinguished on the map given their additional impact in storing water allowing pollutants to be deposited in rocks.

6.2.3 How the map relates to other maps produced

There is a relationship between the 'Regulation of Water Quality' and the service '***Regulation of Flows***'. This is due to the interaction between slope and vegetation/soil type on steep or non-porous areas with little vegetation. Here water generally moves faster giving a low value for flow regulation and with the potential energy to pick up more particulate matter giving a low value for Regulation of Water Quality.

There is also some correlation of areas of high provision on this map with the '***Regulation of Greenhouse Gases (Vegetation Carbon)***. This is due to the fact that the habitats storing the most carbon are generally those with the deepest rooting systems which trap more water and remove more pollutants.

6.2.4 Data and knowledge gaps associated with this map

This map aims to model the national spatial variation in the potential for regulating and maintaining water quality. The data used includes habitat cover, soils, geology and topography and proxies for management information. It does not model the complexities of the different pathways and vectors for individual pollutants such as nitrogen or phosphorus. More detailed modelling work at catchment level is being undertaken by EPA for the Water Framework Directive examining these specific pathways. The model could be improved by considering the following data gaps:

- Incorporation of stocking density data, linked to LPIS parcels would considerably enhance the output by providing an indication of risk of pollution from livestock rearing. However, this was not feasible with the data available and the time constraints of the project. Mapping stocking density, where stock has access to the river system would further refine the model.
- Point sources of pollution have not been considered and would help complete the picture to identify disbenefit hotspots.
- See also section on mapping limitations.

6.3 Soil Carbon

6.3.1 Summary

The map (Figure 35) illustrates the spatial variation in potential soil carbon storage service (CICES sub-class for Ireland 'Areas Important for Emissions Reduction'). Carbon storage is of importance due to its potential to mitigate climate change impacts (see Appendix F). Carbon sequestration describes the process of gaseous carbon being removed from the atmosphere and stored in the soil. Carbon storage refers to the carbon currently present within the soil. This map models the potential for carbon storage in the soil.

The amount of carbon stored in a system is primarily influenced by the physical and chemical properties of soil, which determine its capacity to store carbon. Habitats, through the vegetation present, also play a role in soil carbon storage in that vegetation provides the main source of carbon input into the soil system. Slope and management have a small effect, this is because soil on very steep slopes retains less carbon and because land which is cropped each year (where the above ground vegetation is removed from the system), especially where managed with inorganic fertilisers, will lose carbon from year to year.

Roughly 25% of the terrestrial area of Ireland is classed as being of highest potential provision and are associated with peatlands or semi-natural woodland (Figure 36, classes Strong ES Provision, ES Provision Hotspot). 62% of the country potentially provides a moderate level of carbon storage (class ES Provision) due to the soils being rich in organic compounds and stabilised year round through permanent vegetation cover, i.e. areas of permanent grassland. These factors facilitate a stable soil profile with a generally medium to high organic component, as roots and dead litter material from the vegetation provide a constant input of carbon to the system which is broken down by the soil fauna and stored as soil organic carbon. Areas of lower provision (classes Neutral, Some Disbenefit and Disbenefit) are associated with urban areas, bare ground, bare rock, clear-felled forests or ploughed sites.

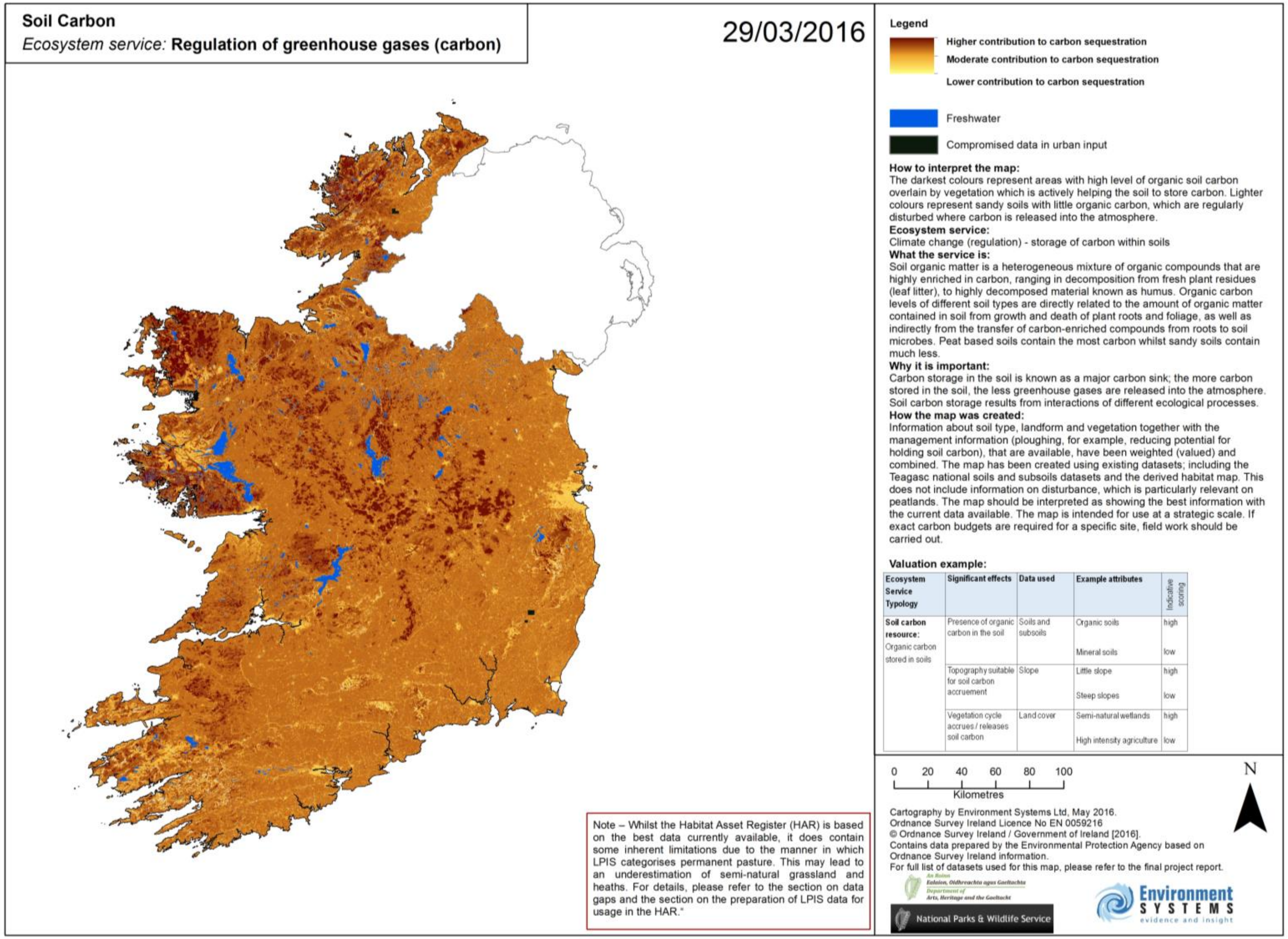


Figure 35: Map: Soil Carbon

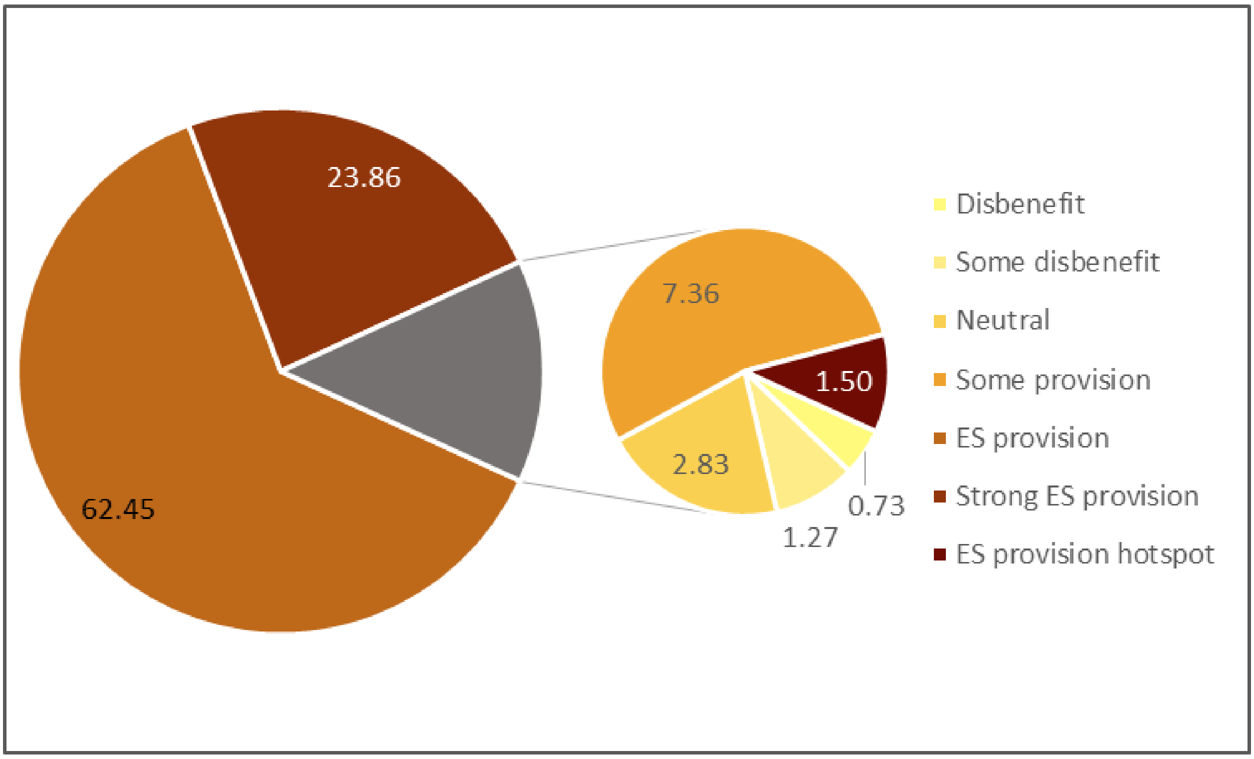


Figure 36: Contribution of Ireland's terrestrial areas to soil carbon sequestration (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.3.2 How the input data relates to these results

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

The soil data has a very strong influence on the model for soil carbon storage, with organic soils having the highest provision. Where these soils are coincident with semi-natural habitats with a high potential for additional vegetation carbon entering the system, hotspots of ecosystem service supply occur. These areas have been scored as high provision in the 'Rules-base'. Conversely, paved or sealed surfaces have no potential to accumulate carbon by sequestration from the atmosphere or through decomposition of organic matter and are scored as neutral as they do not have an impact on the service. Areas of cropping where carbon is frequently removed from the system are shown as a disbenefit, as are areas of potential eroding peat where organic material is being removed from the system. Where bare ground exists, soil erosion is a potential risk, which can, in some cases, cause the release of carbon back into the atmosphere. Steep slopes have a strong influence and can be identified on the map, as in these areas there is an increased erosion risk leading to loss of carbon from the eroded soils.

The map (Figure 35) shows a variation on a north west- south east axis. The north and west of Ireland generally has a much stronger role in carbon sequestration in the soil than the south east where arable farming and less organic rich soils are present which store less carbon.

6.3.3 How the map relates to other maps produced

Regulation of greenhouse gases (Vegetation Carbon): The amount of carbon stored in vegetation has some correspondence with that stored in soil, as vegetation is the primary mechanism by which carbon enters the soil system. However, there are certain differences; the soil carbon map shows the highest scoring in areas where anaerobic conditions together with semi-natural bog and mire habitats are growing peat. By contrast, in the vegetation carbon map the largest concentration of vegetative carbon occurs on an aerobic medium such as deep brown soils which support broadleaved woodlands.

Regulation of greenhouse gasses (Marine Carbon): Despite the fact that the marine and terrestrial maps both record potential carbon sequestration, they are difficult to compare as the carbon cycle in each environment is very different, with separate drivers and pathways based on the difference of the main medium of delivery (air and water). The mechanism for carbon sequestration is distinctly different in air and water as each medium has very different chemical and physical properties. The land supports a higher carbon accumulation than the ocean as much primary productivity in the terrestrial environment is undigested and therefore enters the decomposer cycle and is stored. In the marine environment the major proportion of primary productivity is consumed, digested, and assimilated into higher trophic levels and comparatively little enters the decomposition phase of the cycle to be stored (Chapin et.al., 2011).

'***Nutrition for crops, livestock and wild foods':*** Areas with higher amounts of soil carbon storage capacity are often associated with sites with little soil disturbance. These areas are mostly extensively managed for grazing, and are therefore areas of lower agricultural production. These areas are of higher importance for regulating carbon through soils.

Biodiversity: Regulation of carbon through soils shows a degree of correspondence with areas of higher biodiversity. This is likely to be a consequence of the accumulation of higher amounts of organic matter in undisturbed systems which are also those most likely to be more natural, with many different niches developing over time which support a high degree of structure, species diversity and resilience.

6.3.4 Data and knowledge gaps associated with this map

As outlined above, this map aims to model the national spatial variation in the potential for carbon storage in the soil. The data used includes soil; geology and habitat cover together with topographic information.

The maps currently indicate storage of carbon in the soil system rather than the sequestration potential. The model could be improved by considering the following data gaps:

- Information on the depth of the soil layer (in particular for organic soils) which influences how much carbon is stored is not incorporated into the current model due to lack of data; this would greatly enhance the model.
- Information on peatland condition. Disturbance of peatlands is particularly important for terrestrial soil carbon, as peat forms probably the most abundant source of the carbon in the terrestrial environment, however when disturbed it turns from a carbon sink into a carbon source. This lack of data on peatland condition may be addressed through EPA STRIVE funded SCAMPI project.
- Land use, and in particular permanence of grasslands, are important factors. However, there are limitations with the use of LPIS as a proxy in this regard (see section on mapping limitations and data gaps).
- Soil and habitat condition also determine the capacity of soil to store carbon but this was not available nationally.
- Erosion is a major factor determining how stable the soil profile is. Slope and habitat in conjunction form an additional indicator (soil erosion) which could be modelled to increase the overall accuracy.
- See also section on mapping limitations and data gaps.

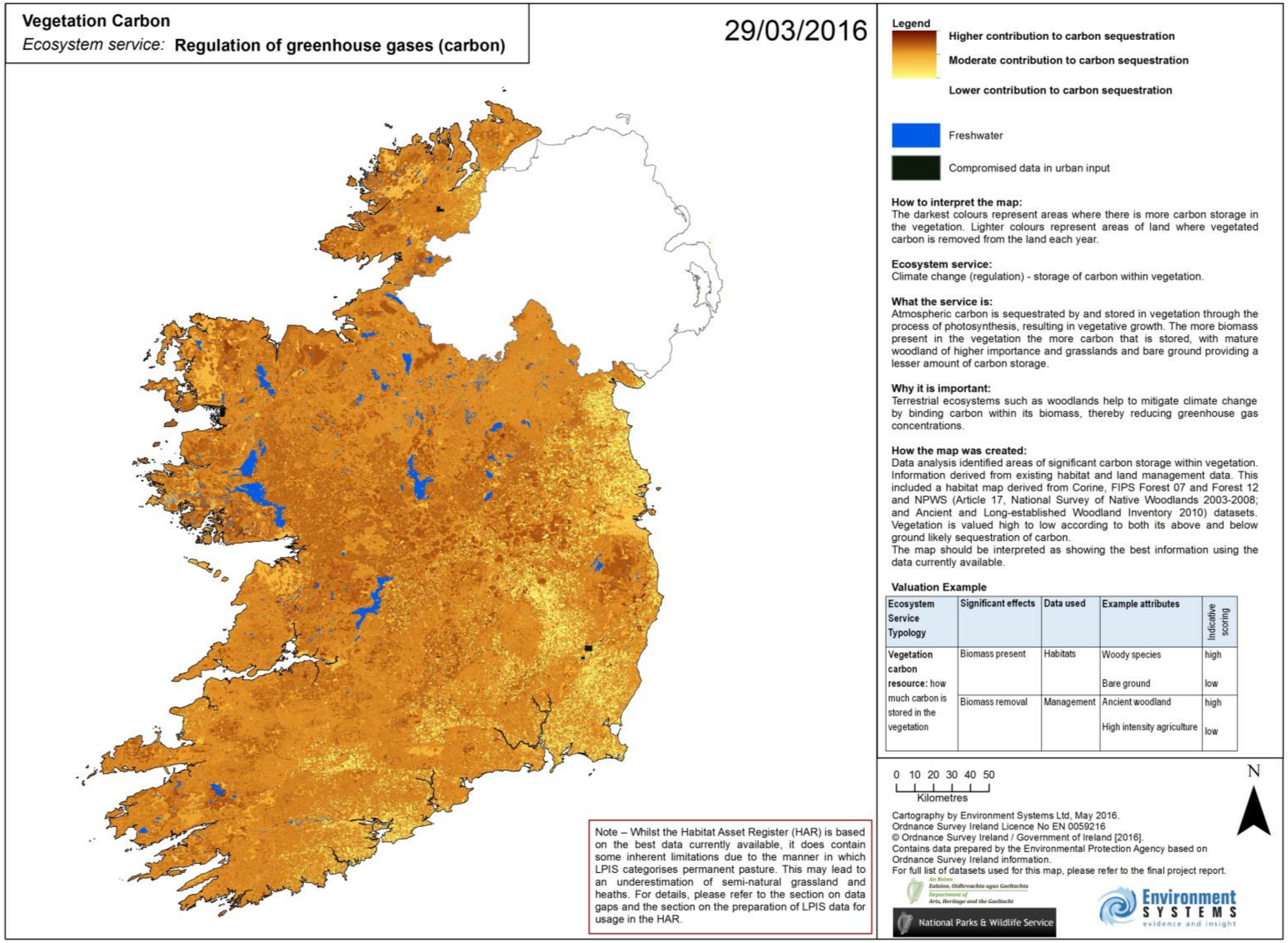
6.4 Vegetation Carbon

6.4.1 Summary

The map (Figure 37) illustrates the spatial variation in potential carbon storage in vegetation across Ireland. This comprises part of the CICES sub-class for Ireland 'Areas important for emissions reduction'. Carbon storage in vegetation is of importance due to its potential to mitigate climate change impacts (see Appendix F). Carbon sequestration describes the process of gaseous carbon being removed from the atmosphere. Carbon storage refers to the carbon currently present and stored within the vegetation. Maps produced during this project model carbon storage in vegetation.

Naturally, habitats, and the dominant species present in each, have the strongest link to this service. However soil, topography and management also have an impact on the vegetation, and influence the model to some degree. The highest regulation of carbon in vegetation is associated with permanent, high-biomass habitats, particularly broadleaved woodland. A large proportion of Ireland's terrestrial area is covered by permanent vegetation cover, including land used for grazing. This permanent grazing land provides a relatively high potential for vegetation carbon storage, particularly through storage in the extensive network of plant roots which develops under such conditions.

Figure 38 shows c. 88% of Ireland's terrestrial area is classified as ES Provision (82%) or Some ES Provision (6.32%) of carbon stored in vegetation, however only c.2% is classified as the strongest provision (Strong ES Provision) and is mostly associated with ancient woodland on deep brown soils with multiple layers of vegetation and large mature trees several centuries old. Approximately 10% of areas are classified as Neutral provision, Some Disbenefit or Disbenefit. These are associated with sealed surfaces and land under arable rotation. In these areas, fertiliser input facilitates fast removal of carbon from the atmosphere through photosynthesis, but the vegetative biomass created is removed frequently, therefore carbon vegetation storage is relatively low or negative.



Ecosystem Service Typology	Significant effects	Data used	Example attributes	Indicative scoring
Vegetation carbon resource: how much carbon is stored in the vegetation	Biomass present	Habitats	Woody species	high
			Bare ground	low
	Biomass removal	Management	Ancient woodland	high
			High intensity agriculture	low

Figure 37: Map, Vegetation Carbon

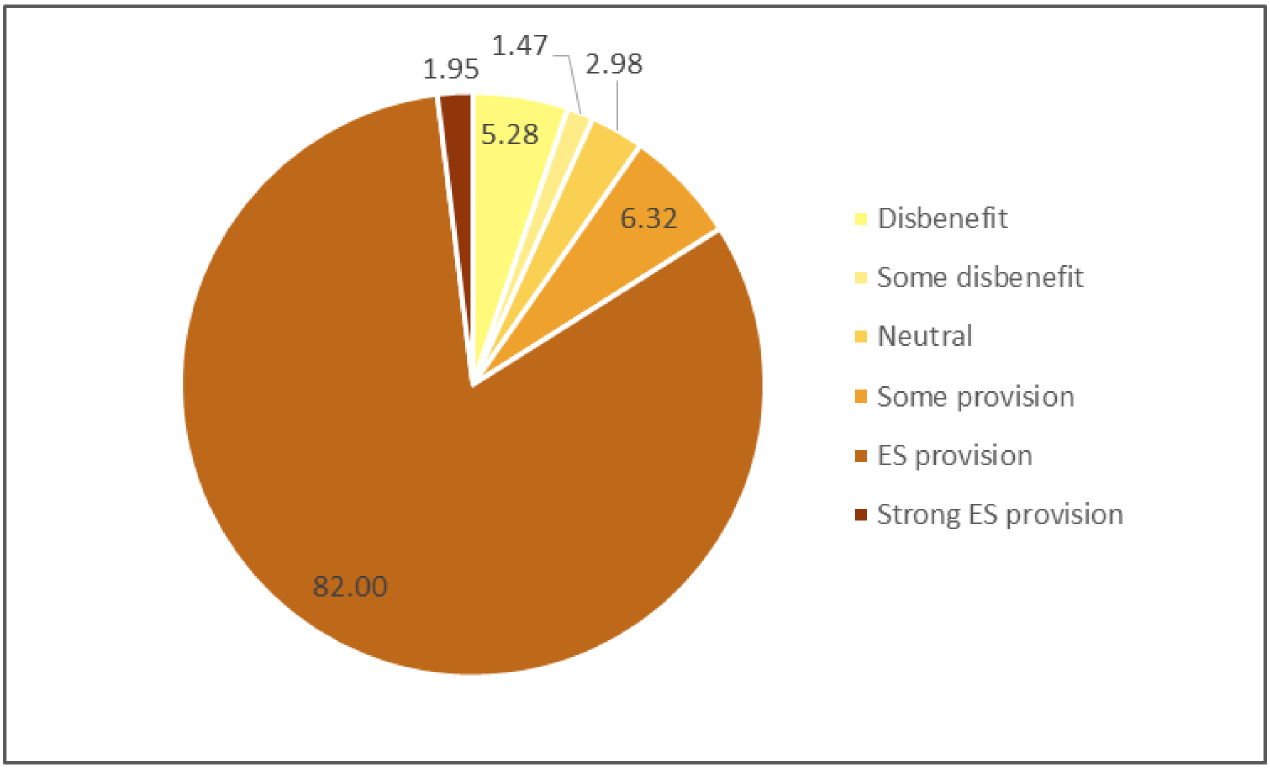


Figure 38: Contribution of Ireland's terrestrial areas to vegetation carbon sequestration (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.4.2 *How the input data relates to these results*

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

The primary data source for this output is the Habitat Asset Register, with highest provision in semi-natural woodland habitats, which are given the highest score. Areas of land designated under conservation policy are likely to contain higher vegetation biomass and less impacted soil than the same habitat without protection, as they are likely to be subjected to less anthropogenic disturbance. They therefore indicate areas likely to store higher amounts of carbon within vegetation than unprotected areas of the same type.

Arable land shows clearly as low provision areas on the map, as this is one of the only land cover types where vegetation, and the associated carbon, are removed frequently. These therefore have the lowest score in the model. The distribution of more natural habitat in the north-west contrasts on the map with the more arable areas in the south-east of the area.

6.4.3 How the map relates to other maps produced

The relationship between the 3 modelled outputs relating to carbon sequestration; ***'Regulation of greenhouse gases*** (***Soil Carbon)'***, 'Regulation of greenhouse gases (Vegetation Carbon)' and '***Regulation of greenhouse gases*** (***Marine Carbon)'*** maps is explained in the section on soil carbon relationships. The key difference between soil and vegetation carbon is due to the fact that the highest storage of carbon in vegetation is found in woodland, whereas for soil carbon the highest storage is found in peat.

Food Provision *&* **Regulation of Water Quality***:* Areas contributing strongly to food provision show as disbenefits to vegetation carbon, as the harvesting of crops also removes the carbon. In addition to the removal of crops, the use of fertilisers and herbicides to increase yields also affects water quality in areas of arable production. There is therefore a negative relationship between these maps and vegetation carbon.

Biodiversity*:* Regulation of vegetation carbon shows a degree of correspondence with areas of higher biodiversity. This similarity can be expected given the accumulation of higher amounts of organic matter in undisturbed systems which are also those most likely to be more diverse with many different niches developing over time that support a high degree of structure, species diversity and resilience.

6.4.4 Data and knowledge gaps associated with this map

This map aims to model the national spatial variation in the potential for carbon storage in vegetation. The data used includes the Habitat Asset Register, soils, geology and topographic information. The maps currently indicate storage of carbon in the vegetation system rather than the sequestration potential. The model could be improved by considering the following data gaps:

- Habitat cover as an indicator for vegetation carbon storage could be enhanced with nationwide data on the condition of semi-natural habitats. Direct measurements of biomass cover and density, for example, for ancient woodlands with understorey and ground flora will contain more vegetation carbon than semi-mature plantation woodland with no understorey.
- Data on the extent of hedgerows throughout the agricultural matrix of Ireland could further enhance modelling of vegetation carbon, as the woody vegetation of the hedgerows is one of the main contributors to vegetation carbon storage within an agricultural landscape.
- See also section on mapping limitations.

6.5 Terrestrial Food

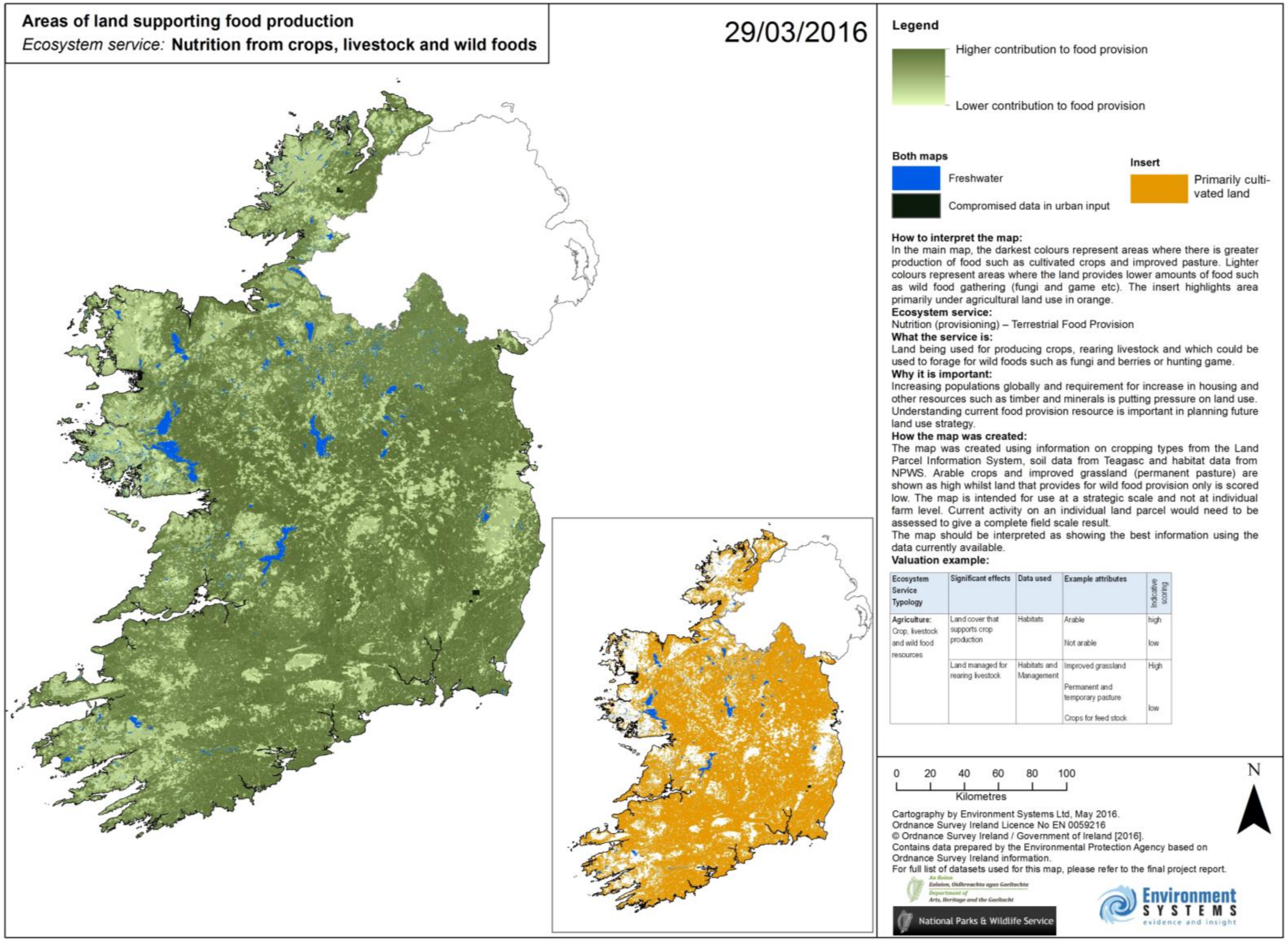
6.5.1 Summary

The map (Figure 39) shows the contribution the land of Ireland makes to food production considering crops, livestock and wild foods. This map models a combination of CICES sub-classes for Ireland under the Provisioning class ‘Nutrition from crops, livestock and wild foods’. These are: grain crops, pollinated crops, market vegetables, dairy and beef cattle, sheep, wild plants, fruits and fungi, wildfowl, terrestrial game birds and deer.

Nutrition is a key service, but is part of a bundle of services, all of which need to be considered in decision making when considering competing land use interests.

The map is largely modelled from the information on habitats using the Habitat Asset Register using the association between habitats and the agriculture and wild animals they are likely to support. Topography and management information are also pertinent and are included in the model as they affect the type and intensity of the agricultural enterprises.

As Ireland’s predominant land use is agriculture, 71% of the terrestrial area can be categorised as potentially providing “Ecosystem Service provision” or “Strong Ecosystem Service provision” (Figure 40). Areas of strong food provision (approximately 9%) correspond primarily to land being cultivated for cropping, with land with improved grasslands used for dairying or more intensive livestock rearing having a moderately high value. Other areas, in particular semi natural areas, have a higher potential for provision of wild foods (wild plants, fruits and fungi, wildfowl, game birds, deer) but at a lower output than farmed areas.



Ecosystem Service Typology	Significant effects	Data used	Example attributes	Indicative scoring
Agriculture: Crop, livestock and wild food resources	Land cover that supports crop production	Habitats	Arable	high
			Not arable	low
	Land managed for rearing livestock	Habitats and Management	Improved grassland	High
			Permanent and temporary pasture	
			Crops for feed stock	low

Figure 39: Map: Terrestrial Food

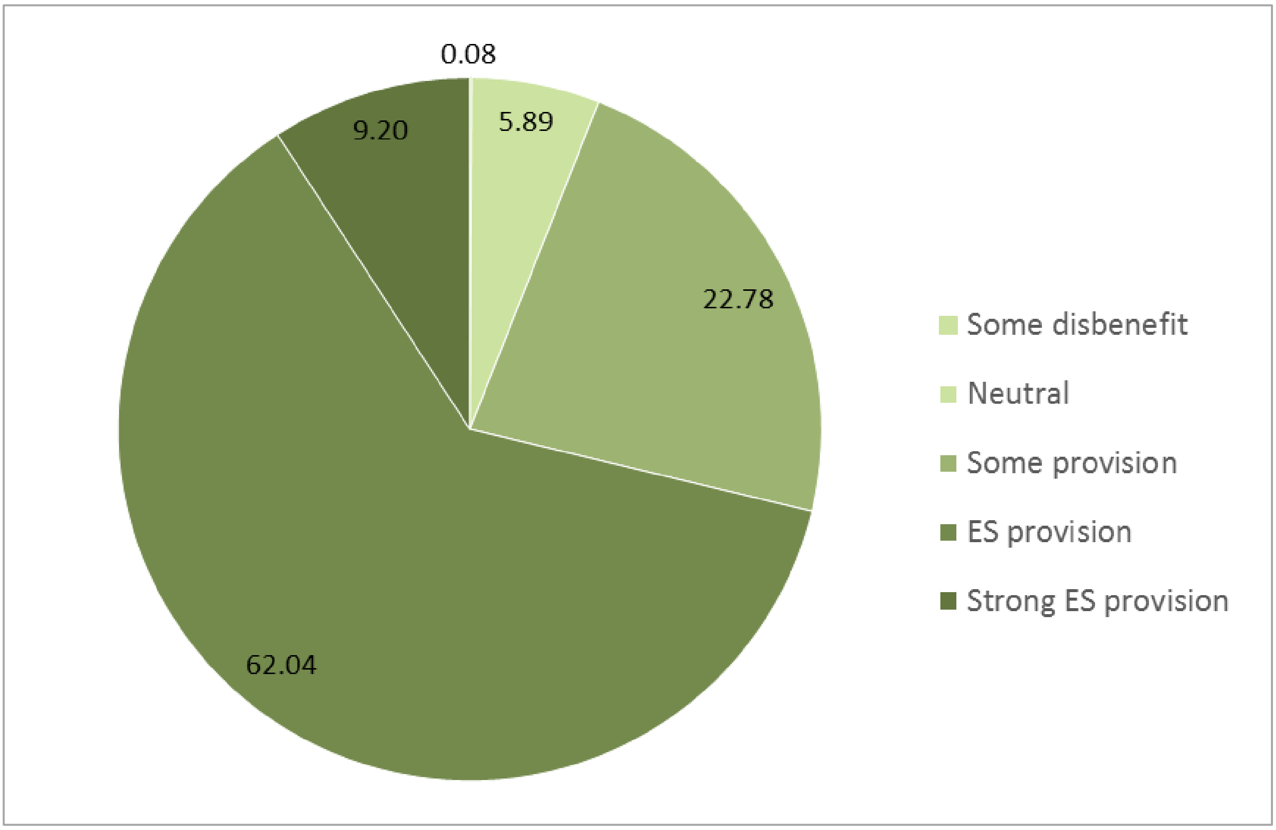


Figure 40: Contribution of Ireland's terrestrial areas to food provision (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.5.2 *How the input data relates to these results*

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

The data is strongly influenced by the Habitat Asset Register and, specifically, the LPIS data contained therein. Areas that have been identified as arable land using LPIS show as the highest provisioning areas with the highest scores. Semi-natural habitats and conservation designation sites show as having a lower contribution to the supply of this ecosystem service as these areas are likely to either have lower intensity grazing regimes or may be limited to wild food provision only.

6.5.3 *How the map relates to other maps produced*

There is a broad inverse relationship between food provision and '***Regulation of Water Quality***'. This is because high intensity agriculture has a greater risk of causing negative impacts on water quality through the input of pesticides, inorganic fertilisers and herbicides. The areas in the high scoring for food provision show a similar pattern to areas of lower potential service provision for water quality regulation.

There is a broadly inverse relationship between the spatial distribution of areas of higher food provisioning and those areas of higher '***Biodiversity'*** potential, modified to a degree by the potential for wild food yield from semi natural areas. Intensively managed areas tend to contain monocultures and are therefore intrinsically less biodiverse supporting far fewer species, genetic diversity and being less resilient than natural complex systems.

6.5.4 Data and knowledge gaps associated with this map

This map aims to model the national spatial variation in the potential for food provision based on the likely agricultural and wild food provision associated with different habitats and land use types. The model could be improved by considering the following data gaps:

- The model relies heavily on LPIS to distinguish arable areas from other farmed grasslands. However there can be considerable variation in the management and yield amongst these categories, more exact data on farming systems would greatly enhance the model.
- The outputs would also be improved through inclusion of stocking density and type at farm or parcel level, and also by inclusion of data on crop type, crop and yield (and which may vary within a single year for the same area).
- Spatial information on hunting bags and seaweed harvesting would improve the modelling of the wild food elements if available.
- Note that this map has been prepared at a strategic level and is not suitable at localised detailed scales showing individual holdings or fields.
- See also section on mapping limitations.

6.6 Terrestrial Biodiversity

6.6.1 Summary

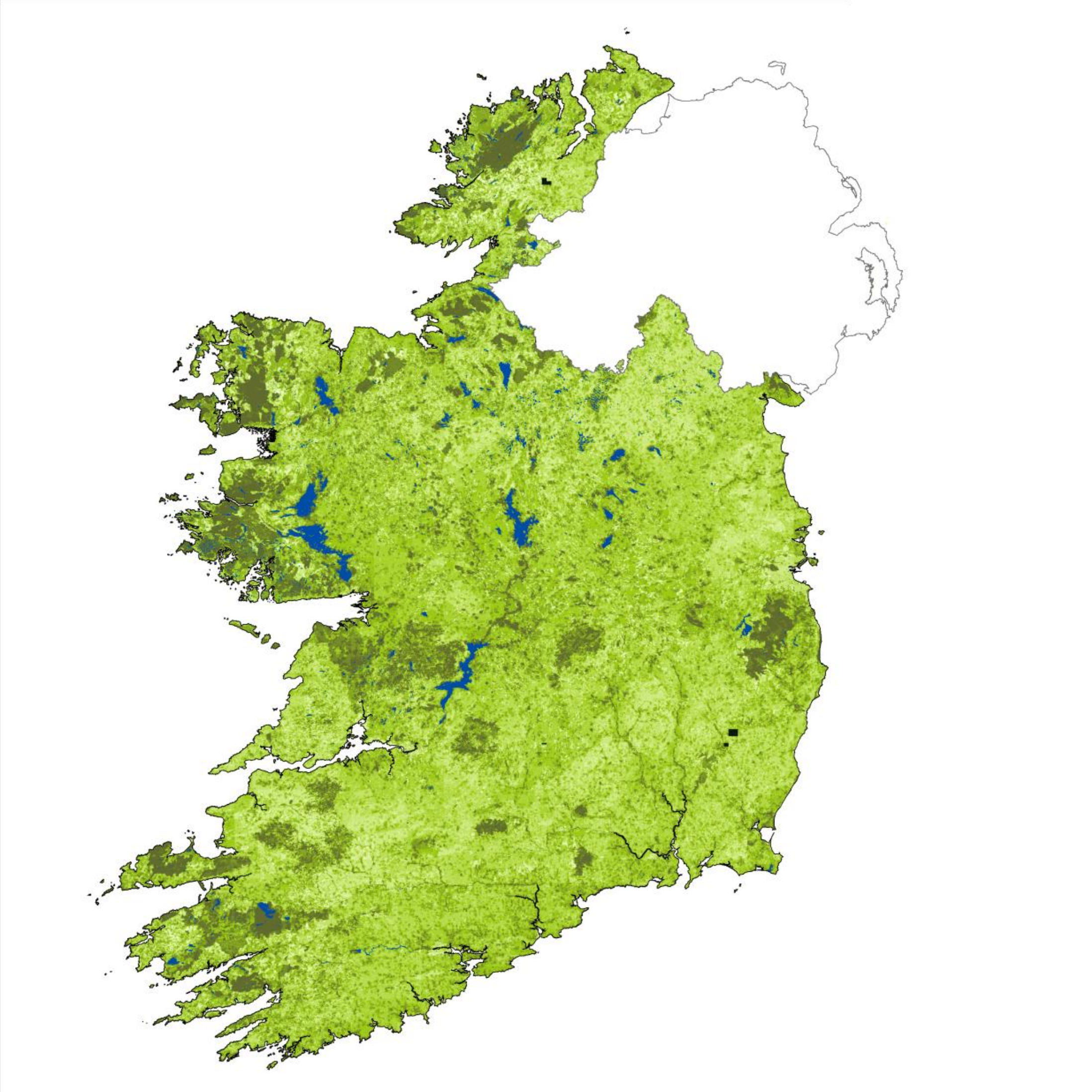
Figure 41: Map, Terrestrial biodiversity, shows the contribution the land of Ireland makes to terrestrial biodiversity considering habitats, networks, management and species information. It is a map of CICES Function rather than an ecosystem service. This function has been modelled as it provides valuable information for decision making, as biodiversity underpins the functioning of the environment. Natural and semi-natural communities provide resilient ecosystems, regulating the functions of the environment (such as carbon and water cycling) and contain both genetic and often, but not always, species diversity; both above and below ground. The map also provides an opportunity to identify sites where this function could be enhanced by specific management or restoration action, by, for example joining two areas of high biodiversity to from a larger, more resilient patch.

The map has been modelled considering information of the Habitat Asset Register for habitat information. It is underpinned by models of functional ecological networks, as these are considered important factors to model and map. This is due to the fact that they have the potential to provide useful spatial information on the biophysical characteristics within these networks, and also the fact that the resilience of habitats within the networks is enhanced as genetic diversity through species movement is facilitated within them (see 'Habitat Network Section' under 'Primary Intermediate Layers'). Biological networks for Ireland were calculated for broadleaved woodlands, non-acid and non-improved grasslands, heathlands and acid-grasslands and fen, marsh & swamp. Areas where management is undertaken to preserve the biodiversity were considered. The coincidence of species of conservation interest (see section 'Species Coincidence Layer' under 'Primary Intermediate Layers') has been incorporated as a proxy indicator of well-functioning systems.

Areas that are assigned the highest value for biodiversity functions are those areas where there is a coincidence of relevant factors, such as the presence of semi-natural habitats falling within ecological networks (where genetic movement is supported) and are associated with high species diversity or include species of importance (i.e. protected or priority species). Based on the combination of factors, the area has been categorised into a set of 4 classes ranging from some provision to 'ES' provision hotspot. Just under 1% of the landmass has been classified into the highest class (ES Provision hotspot) while 95% of the remaining area has been categorised as Strong (24%) or ES Provision (71%). Built areas, including which sealed or artificial surfaces, make the lowest potential contribution to biodiversity.

Terrestrial biodiversity: Habitats, management, ecological networks, and species
Function: **Naturalness, support of systems and species, and resilience**

11/05/2016



Legend

Freshwater
Compromised data in urban input
Land of higher biodiversity value
Land of lower biodiversity value

How to interpret the map:
The darkest colours represent areas with biophysical properties likely to support high levels of biodiversity, areas with good habitat connectivity, and/or many observations of species of conservation concern. Light colours represent areas not contributing as strongly to biodiversity.

Ecosystem function:
Biodiversity - Naturalness, support of systems and species, and resilience.

What the ecosystem function is:
Biodiversity includes not just the number of species, but how well the systems function, cycle nutrients and support species. Areas with higher structural diversity, that is areas where there are many different types of habitat or different layers to a habitat, such as ancient species rich woodland and wetland complex's, usually support the highest diversity as there are more ecological niches available for different species to thrive

Why it is important:
Biodiversity as a function underpins many ecosystem services; therefore, it is useful to show where the hotspots occur.

How the map was created:
Terrestrial biodiversity was mapped using habitat, management, connectivity of semi-natural habitats in ecological networks, and records of species of conservation concern as proxies.

Valuation table

Ecosystem Function	Significant effects	Data used	Example attributes	Indicative scoring
Biodiversity	Habitat effect (complexity, niche availability)	Habitat asset register	Broadleaved woodland Arable / Urban	High Low
	Ecological networks	Combined ecological networks for Ireland	Part of network Not part of network	High Low
	Management	Protected Sites	SAC and nature reserve Nature reserve	High Medium
	Species records	Combined records of species of conservation concern	Many records Few records	High Low

0 20 40 60 80 100
Kilometres

N

Cartography by Environment Systems Ltd, May 2016.
Ordnance Survey Ireland Licence No EN 0059216

Contains data prepared by the Environmental Protection Agency based on Ordnance Survey Ireland information.
For full list of datasets used for this map, please refer to the final project report.

An Roinn Ealaíon, Oidhreachta agus Gaeltachta
Department of Arts, Heritage and the Gaeltacht
National Parks & Wildlife Service
Environment Systems evidence and insight

Figure 41: Map, Terrestrial biodiversity

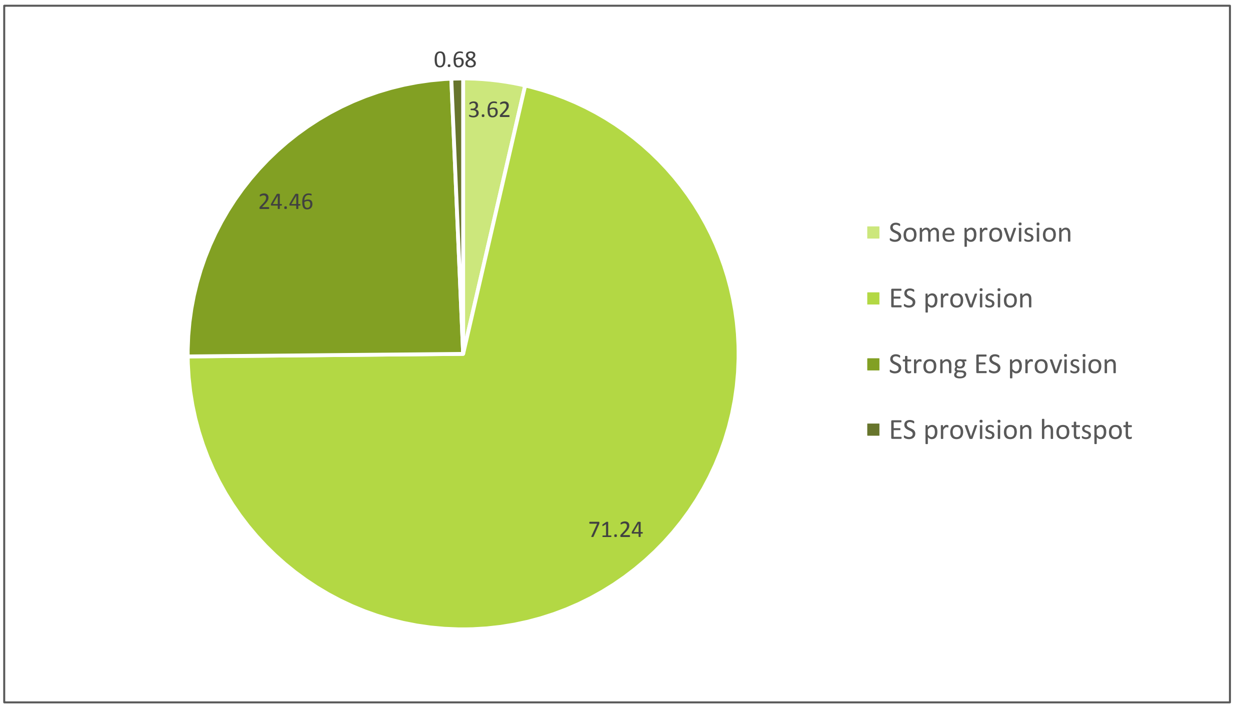


Figure 42: Contribution of Ireland's terrestrial areas to biodiversity (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.6.2 How the input data relates to these results

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

Management and land cover have a strong influence on the resulting map, with areas of semi-natural habitat showing as being of high biodiversity value, and arable land and intensively managed grassland showing as lower biodiversity value. The results are also influenced by records of species of conservation interest and areas of land that contribute to one or more ecological networks; this causes a range of contribution to biodiversity value being modelled for land within the same habitat type. The effect of soil type had a small impact as the potential below ground diversity of soils can be significant. The greatest biodiversity provision is found in semi-natural habitats that contribute to several networks, co-occurring in areas managed for biodiversity enhancement, and which are associated with selected species

The map shows the strongest scores in the most semi-natural habitats towards the west of the country and in the raised bogs in the central areas. The urban areas show as lower scored areas (Figure 41: Map, Terrestrial biodiversity).

6.6.3 How the map relates to other maps produced

This map is related to the other services as it shows a key function of the environment of Ireland. However, the function has strongest affinity with the following services:

'Nutrition from crops, livestock and wild foods': Areas of high biodiversity interest correspond to areas of lower food provision. However, within the agricultural matrix, biodiversity value can vary greatly based on the intensity of the farming system in place.

'Regulation of greenhouse gases (***Soil Carbon)'***: Areas of high soil carbon for the most part fall within sites of high biodiversity value. Exceptions are semi-natural habitats that are not associated with organic and/or thick layers of soil.

'Regulation of greenhouse gases (***Vegetation Carbon)'***,: Areas which store much carbon in vegetation coincide with high biodiversity areas, as they tend to be formed on well-established natural systems with long lived plants, such as ancient woodland.

6.6.4 Data and knowledge gaps associated with this map

This map aims to model the national spatial variation in biodiversity. With the data available, this map is focused on looking at the diversity of the entire landscape, considering habitats in the context of their function in networks. It also built on the concept of using biodiversity conservation/ management as a proxy for ecosystem health/ condition, looking at position in relation to networks and presence of indicator species as a proxy for resilience. The model could be improved by considering the following data gaps:

- Habitat condition is significant in the functioning and resilience of the natural communities as it influences how well the ecosystem services are performed. Although a considerable amount of data on condition of habitats from NPWS surveys was available to the project, such biodiversity monitoring data is only available for a small sample nationally, and generally only for those habitats protected under the EU Habitats Directive. Consequently, such data could only be included in a very few cases as it did not have comprehensive coverage. Given the importance of condition in assessment of services this is a key data gap.
- Data for species of conservation interest (i.e. legally protected and/or policy relevant species only) has been included by mapping the coincidence of different species but not their abundance. This distribution will suffer from the usual limitations in terms of recorder bias (there is a tendency to record species where they are already known to be present, where there is high likelihood of presence, or where there is a need (such as pre-construction surveys) to survey. Areas outside of these zones are therefore, likely to be under recorded, and this caused an apparent bias around the coast and urban centres for the species coincidence layer. Furthermore the distribution only

incorporates species of conservation interest, therefore species of importance for ecosystem functioning and resilience may be missing.

- See also section on mapping limitations.

6.7 Marine Areas that Provide Food

6.7.1 Summary

The map (Figure 43) shows marine areas potentially contributing to food provision through the provision of algae, fish, and shellfish. This map models a combination of multiple CICES classes for Ireland under the provisioning classes 'Wild animals and their outputs' and 'Animals from in-situ aquaculture' including Coastal aquaculture - finfish (Salmonids), Coastal mariculture – oysters and Red / Green / Yellow / Brown algae (splash zone to lower shore), each of which are of policy relevance in Ireland (see Appendices D and F).

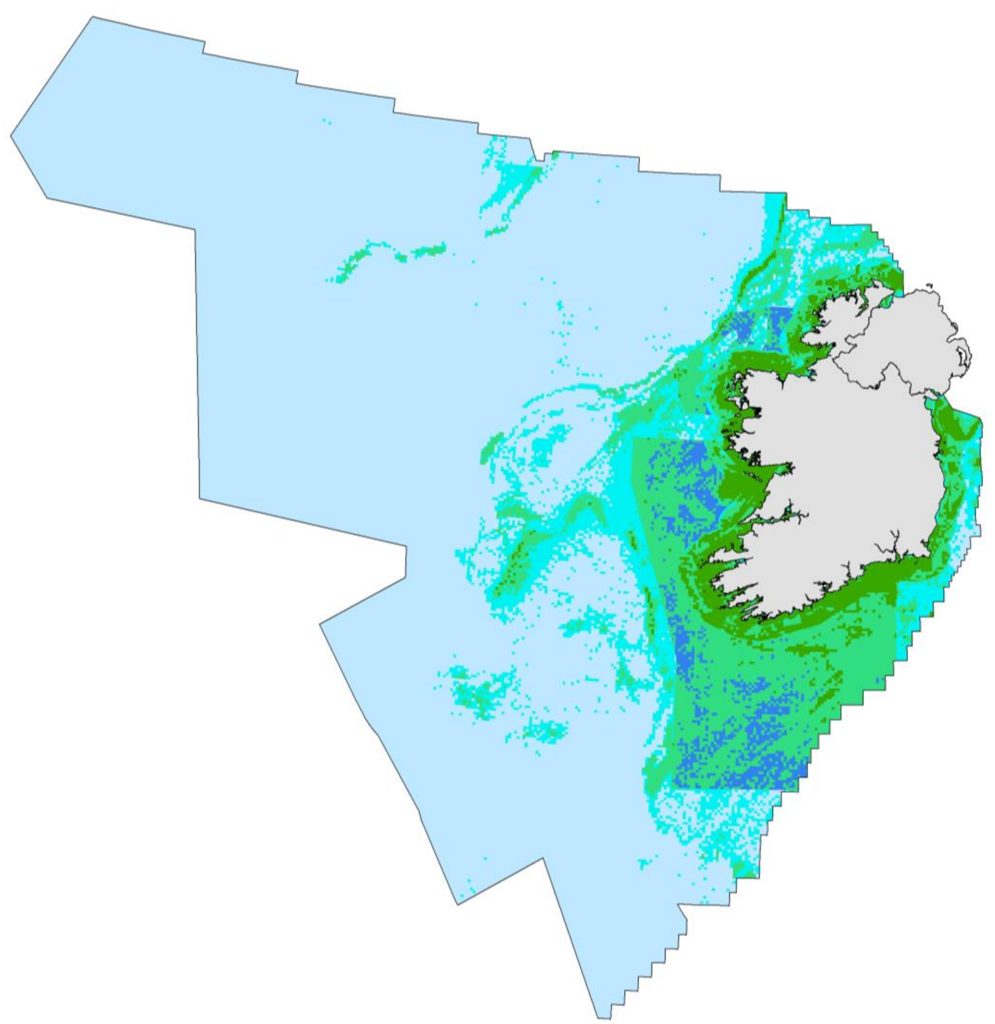
Ireland's marine area consists of an area approximately ten times that of its land area. The map provides an overview of the main spatial locations important for food species within this area. Most of the activity recorded is concentrated in the shallower waters around the coast. Shallower water tends to support more species, as benthic communities are present as well as those which form in the part of the water column with sufficient light to provide energy. The map uses the best data that there is available, but much less is known about the marine environment and it should be regarded as indicating potential contribution. The map could be used in combination with other marine maps to consider multi-functionality of selected areas.

Known ecosystem service provision, e.g. with fisheries effort as indicator, is low in the majority of the marine area (73%) see Figure 44, particularly further offshore. The small patches of the strongest known food provision, e.g. the highest fishing effort, are located along the coastline, with particular hotspots in near shore areas, especially along the south-east coast. Approximately 16% of the waters of Ireland are shown as strong provision or as Ecosystem Service provisioning hotspots.

Marine areas that provide food

Ecosystem service: **Marine food (Provision)**

29/03/2016



Legend

- ES provision hotspot
- Strong ES provision
- ES provision
- Some provision
- Neutral

How to interpret the map:
Green colours represent areas with a high contribution to marine food provision, based on data on fisheries effort; turquoise and blue areas have a lower direct contribution to marine food provision.

Ecosystem service:
Food (provision) – Marine areas that provide food

What the service is:
This service includes everything taken from the sea for human consumption. This includes fish (marine and diadromous), shellfish, crustaceans, and algae, both from wild harvest and from aquaculture.

Why it is important:
Increasing populations globally create increasing demand for food provision and are putting pressure on the marine ecosystem. Understanding current food provision, particularly in the coastal zone, is important in future marine spatial planning.

How the map was created:
The most important datasets for mapping of this service are direct measures relating to fisheries. Protected areas are included in the scoring, as they can help protect fish stock and juvenile life stages. Terrestrial habitats have been included in the mapping where they are of direct relevance, such as saltmarshes, which form nursery areas and support marine fisheries. Anthropogenic structures can impact marine food provision, if they are associated with fisheries restrictions.
This map does not consider how different substratum types support marine fisheries.

Valuation example:

Ecosystem Service Typology	Significant effects	Data used	Example attributes	Indicative scoring
Marine Food Provision	Fisheries management	Fisheries data	High intensity Low intensity	High Low
	Fisheries closures	Protected areas	None Closed for fisheries	Neutral Low
	Unharvestable areas	Dumping at sea / Windfarms	Area can be harvested Area cannot be harvested	Neutral Low

0 50 100 150 200 250
Kilometres

N

Cartography by Environment Systems Ltd, May 2016.
Ordnance Survey Ireland Licence No EN 0059216

Contains data prepared by the Environmental Protection Agency based on Ordnance Survey Ireland information.
For full list of datasets used for this map, please refer to the final project report.

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Department of Arts, Heritage and the Gaeltacht
National Parks & Wildlife Service
Environment SYSTEMS evidence and insight

Figure 43: Map, Marine areas that provide food

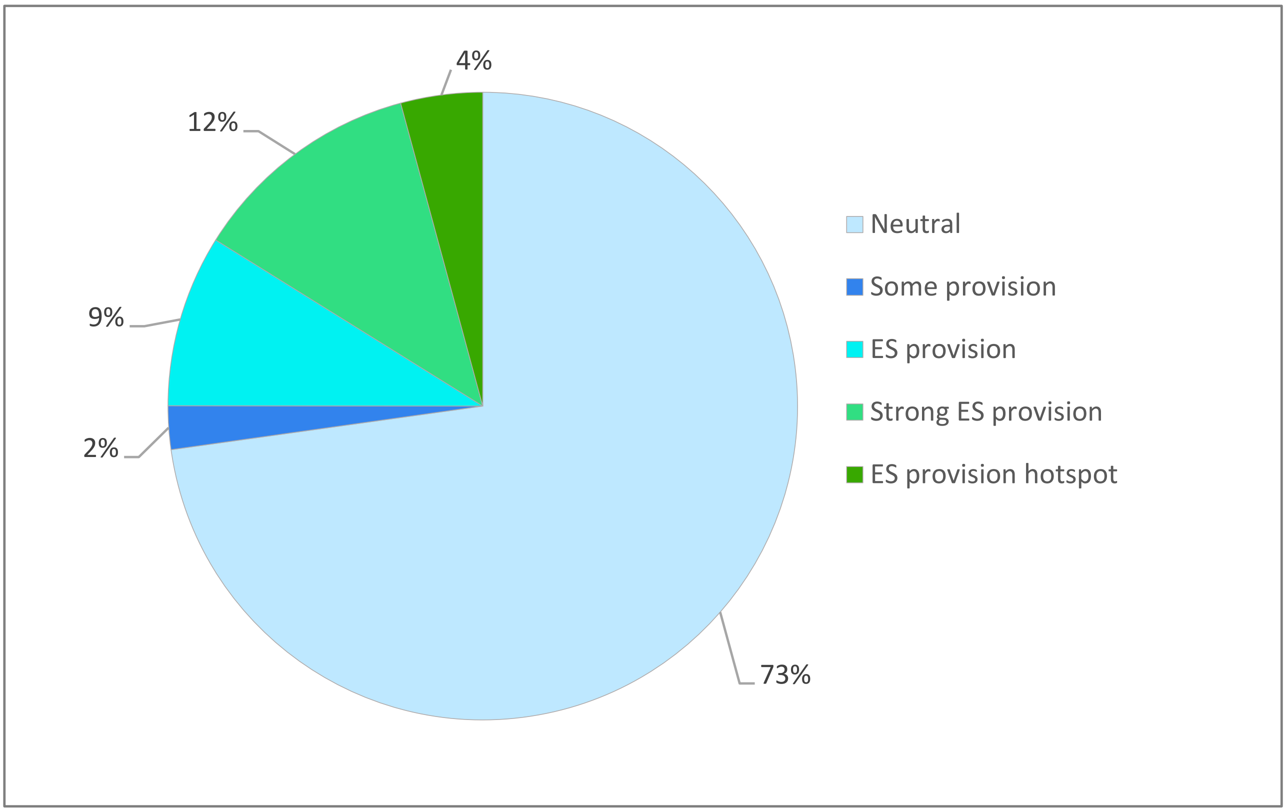

Figure 44: Contribution of Ireland's marine areas to food provision (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.7.2 *How the input data relates to these results*

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

The creation of this map relied heavily on fisheries data, both gear data and quantitative data on fisheries effort. Areas where numerous types of fishing activity occur at high levels of intensity are taken as the best available indicator of hotspots of ecosystem service provision. This does not, however, mean that the area may not be at a risk of overexploitation.

Additional factors are the various fisheries restriction zones, such as the biologically sensitive area to the south of Ireland. These zones have been given a positive score, as they promote healthy fish stocks. As these management areas are defined by straight lines, they show very clearly on the mapped output.

6.7.3 How the map relates to other maps produced

Fisheries practices can, in some cases, reduce marine biodiversity through active removal of species and through habitat disturbance. Therefore, areas with many overlapping types of fisheries effort are also visible on the stock map for *Marine Biodiversity*, where they show as areas of slight disbenefit.

There is a tentative relationship between marine food and *Marine Carbon*. Techniques such as dredging for shellfish and bottom trawling were considered as negative factors for the ability of the seabed sediment and substrate to store carbon. For example, when the dredging machinery scrapes the seabed it disturbs the sediment and distributes particles throughout the water column, meaning the carbon storage potential of the seabed is drastically reduced. As deep water sites are of higher value for marine carbon, whilst fisheries effort is centred along the coast, the interaction between these services is minor.

6.7.4 Data and knowledge gaps associated with this map

This map aims to model the national spatial variation in the potential for food provision in the marine environment. The map relies heavily on data available on fisheries but it is uncertain how representative this is of actual effort, intensity or yield. It is possible that recording bias causes the high food provision modelled for coastal areas, whilst neutral values further offshore could be caused by less data being recorded and available. The model could be improved by considering the following data gaps:

- To improve understanding of the fisheries resource, i.e. the supply of algae, fish, and shellfish, it would be beneficial to understand the relationship between different habitats utilised over their whole lifecycle to maintain healthy stocks. Furthermore the relationship between habitat types and individual target fish species is not well enough understood
- Data on species-specific fishing areas was not available, or does not currently exist to enable spatially explicit mapping to incorporate this concept at this time.
- The relationship between habitat types, resilience and individual target fish species is not well enough understood.

6.8 Marine Carbon

6.8.1 Summary

The map (Figure 45) shows marine areas potentially contributing to carbon storage. This map models the CICES sub-class for Ireland 'Areas important for emissions reduction'. Carbon storage in the marine environment is of importance due to its potential to mitigate climate change impacts (see Appendix F). Carbon sequestration describes the process of gaseous carbon being removed from the atmosphere. Carbon storage refers to the carbon currently present and stored within the marine environment. Maps produced during this project model carbon storage rather than sequestration. Carbon stored in the marine environment by primary productivity is utilised by other organisms higher up the food chain in a much more extensive way than in terrestrial environments and less enters the decomposition phase of the cycle and is stored. However, although carbon storage may be relatively lower in the marine environment by unit area, as Ireland's marine area is much more extensive than the terrestrial area, marine carbon contributes a significant fraction of Ireland's overall carbon storage. This map is created using the best available data. It can therefore be regarded as a proxy for marine carbon and a first step towards mapping its distribution.

Atmospheric carbon is sequestrated by, and stored in, the marine environment through two main processes. The first is photosynthesis where CO_2 is used by phytoplankton and oxygen is released. The resulting microbes that grow from the process pass into the food chain. The other main method is via dissolution and chemical reaction of carbon dioxide and water forming bicarbonate which is mainly stored in marine sediments.

The type, depth and disturbance of the substrate were considered, together with activities likely to provide more disruption of the benthic environment, as the main indicators for this ecosystem service. The role of substrate in marine carbon storage is related to the particle size distribution of the sediment. Coarse sandy sediments have large particles which allow water to flow freely through the upper part of the sediment, flushing the region with oxygen. Finer, tightly-packed sediments such as mud and clay allow less water penetration and so are less oxygenated. Higher levels of oxygenation promote greater microbial activity, leading to faster carbon cycling and lower levels of carbon retention within the sediment. The greater the depth, the more likely the carbon is to be stored, as it will be less prone to disturbance and further oxidation. Of the marine area in Ireland 42% provides a moderate level of this service (Class ES Provision), but less than 1% of the area was classified as Strong ES Provision (Figure 46).

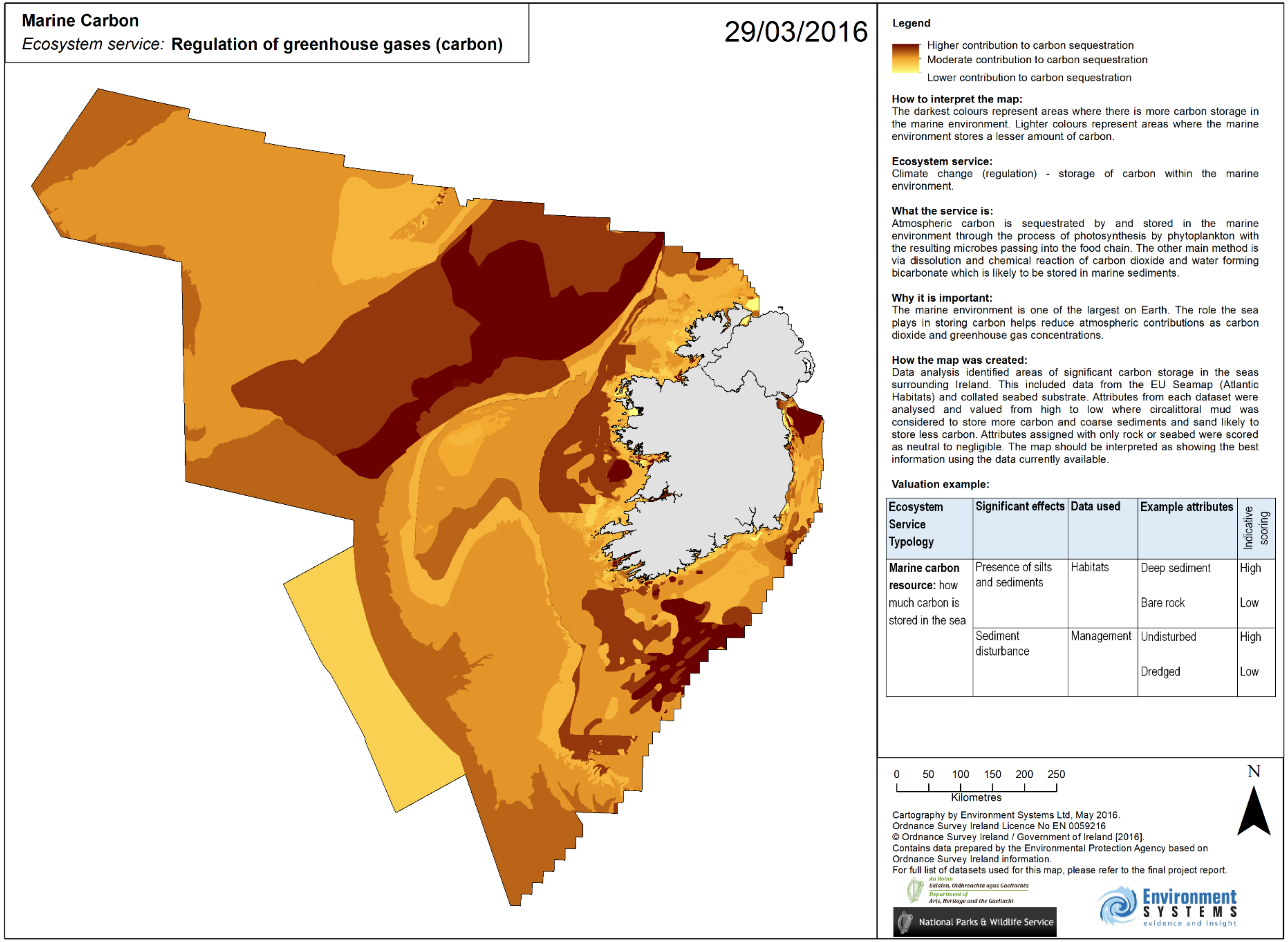

Figure 45: Map, Marine carbon

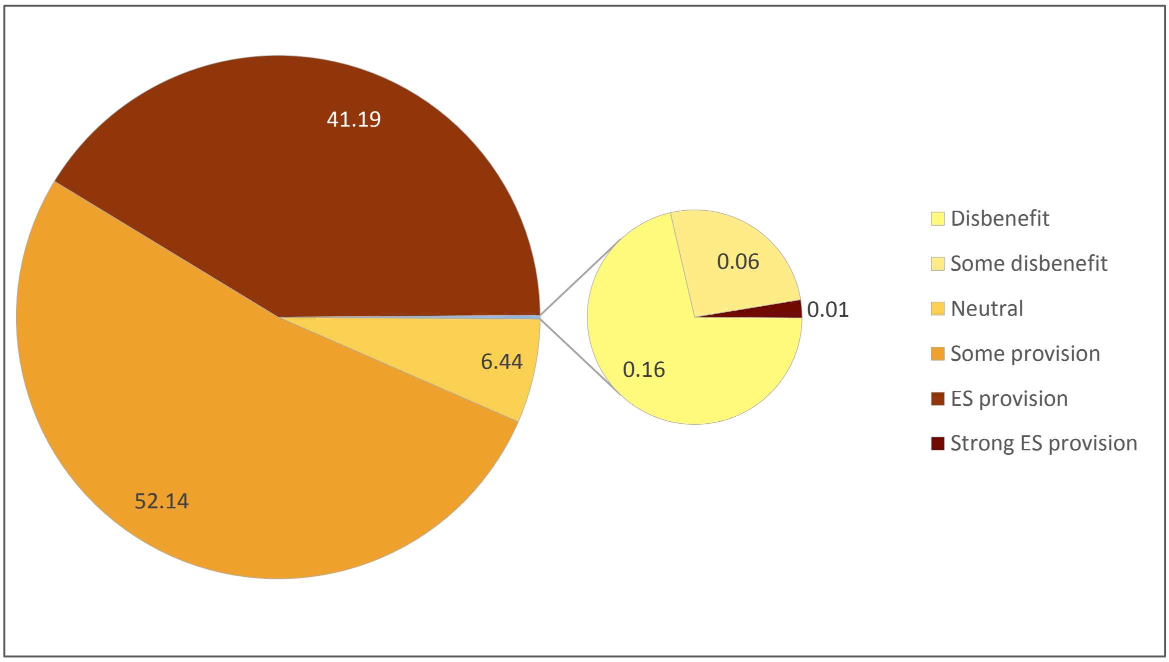

Figure 46: Contribution of Ireland's marine areas to marine carbon storage (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.8.2 How the input data relates to these results

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

Indicators of marine carbon storage rely on substrate and depth information; depth is important, as carbon stored in deep sediment is more likely to be stored long-term as it is subjected to less frequent natural disturbance. Data was taken from both the EU Sea map and the map of collated seabed substrate.

Highest scores for marine carbon storage are located to the north west and to the south of Ireland's territorial waters. Deeper areas, such as the deep-water channel to the North West of Ireland, show as high value areas. Sites with coarse sediment and high disturbance (i.e. high current or wave energy environments) show as areas with lesser value, as it is more difficult for carbon to be sequestered into the seabed. Fisheries data on dredging influences the map, lowering the scores at sites were fisheries activity disturbs the sediment (e.g. dredging and trawling). This has only a minor effect on the overall map, as, within the whole of Ireland's marine area, dredging activity has only been recorded for few sites.

6.8.3 How the map relates to other maps produced

As both maps rely heavily on substrate/depth (recorded in one dataset), similar patterns appear on the map for marine carbon and ***Marine Biodiversity***. However, similarity between the maps is limited to patterns, as the high value areas do not correspond.

Compared to the maps for ***Regulation of Greenhouse Gases (Soil Carbon)***, the overall area indicating particularly high regulation of carbon in the marine environment is lower. However, there is a large area which has moderate importance for marine carbon. This is due to the potential for long-term storage in low energy environments in the deeper areas off shore. These areas are extensive in the marine environment.

6.8.4 Data and knowledge gaps associated with this map

This map aims to model the national spatial variation of areas with the potential for carbon storage in the marine environment. The data used includes depth and substrate as partial indicators for marine carbon storage. The model could be improved by addressing the following data gaps:

- Biomass within the sediment will differ based on how well oxygenated the area is, which could form an additional indicator.
- Similarly, removal of carbon from the sediment back into the water column will be higher in high energy/high disturbance environments and a combination of fetch and/or average wave height maps, as well as measures of benthic currents could form additional indicators.
- The map does not incorporate processes occurring within the water column, where factors such as depth of light penetration, presence of fronts, currents or eddies, as well as the depth of thermocline and halocline can affect the overall productivity of the marine carbon pump.
- It does not consider the efficiency of chemical exchange of carbon at the air-water interface.
- See also section on mapping limitations.

6.9 Marine Biodiversity

6.9.1 Summary

Figure 47 shows the areas with biophysical properties that support marine biodiversity based on habitats, sediment and management information. It is a map of CICES 'Function' rather than an ecosystem service (see Figure 4). The map function has been modelled and mapped as it provides valuable information for decision making, as biodiversity underpins the functioning of the environment. Marine communities help regulate functions of the environment such as carbon and nutrient cycling. The map also provides an opportunity to highlight areas where biodiversity is important. However, species data has not been incorporated in the model due to the difficulty of mapping such mobile species with incomplete data. In addition marine biodiversity can be split into pelagic (relating to the open sea) and benthic (relating to, or occurring at, the bottom of a body of water) organisms. Amongst the latter, estimates suggest that only a very small percentage is known as of yet, which adds uncertainty to using substrates as indicators for biodiversity. This map should therefore be regarded as a first step, based on currently available mapping rather than a definitive map, and is developed to indicate areas of potential multiple functions.

The main indicator is the substrate type found in an area; the highest values being where biogenic (formed by living organisms, e.g. corals or mussels) habitats have been recorded. High energy environments with a lot of tide, current and wave action have quite a low value, as movement of currents in these areas can cause crushing of benthic organisms, with exposure also being an influencing factor. Other indicators include anthropogenic structures, as these offer additional habitat complexity, and which therefore potentially increase biodiversity in the immediate vicinity by creating additional ecological niches. Fisheries, depending on the type of fishing gear used and intensity, can have a negative effect on marine biodiversity. The strongest negative impact would be expected from bottom trawling in areas that are naturally low in disturbance, such as stable sediments or biogenic reefs, whilst the impact on mobile sediment (i.e. high energy environments) in areas of higher exposure would be quite low.

Shallow areas, where sunlight penetrates, will generally contain greater biodiversity than deeper areas, where there is less readily usable energy. Deeper areas, on the other hand, contain some of the most specialised and rarest species. However, due to the vast expanse of deep and dark ocean bed, biodiversity hotspots do not develop in the same way as in shallow, sun-lit areas.

Protected areas are considered to have a positive effect on biodiversity, even though the lack of physical boundaries in the marine environment makes this effect difficult to quantify.

Overall values for marine biodiversity vary most around the coast, with high value occurring to the south of Ireland, within an area designated as biologically sensitive. This area, together with coastal SACs and shallow water bays, are the main contributors to the approximately 26% of areas falling into the classes "ES provision", "Strong ES provision", or "ES provision hotspot" (Figure 48). Disbenefit areas occur in small patches around the coastline primarily due to known areas of dumping at sea.

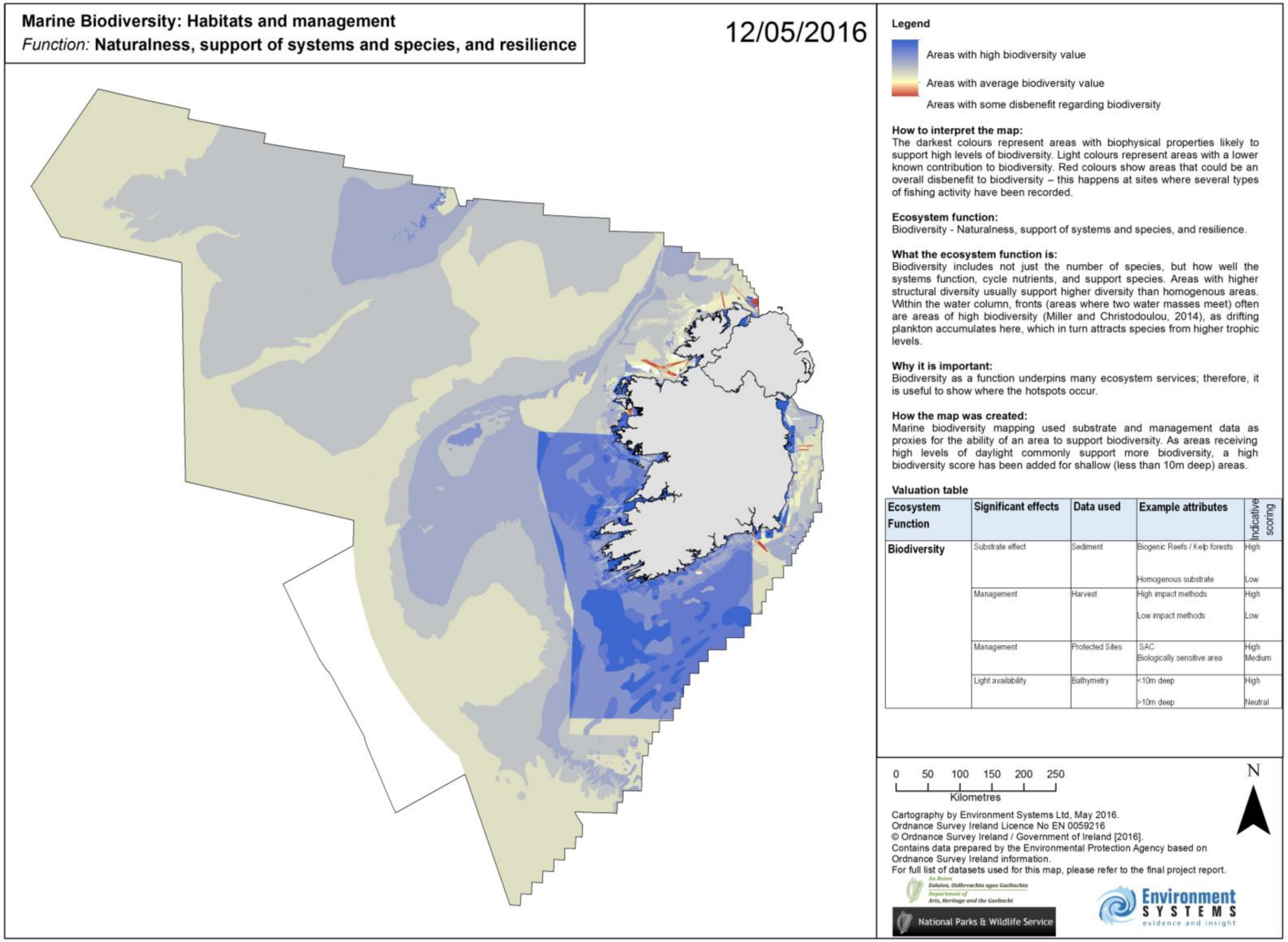

Figure 47 Map, Marine biodiversity: Habitats and management

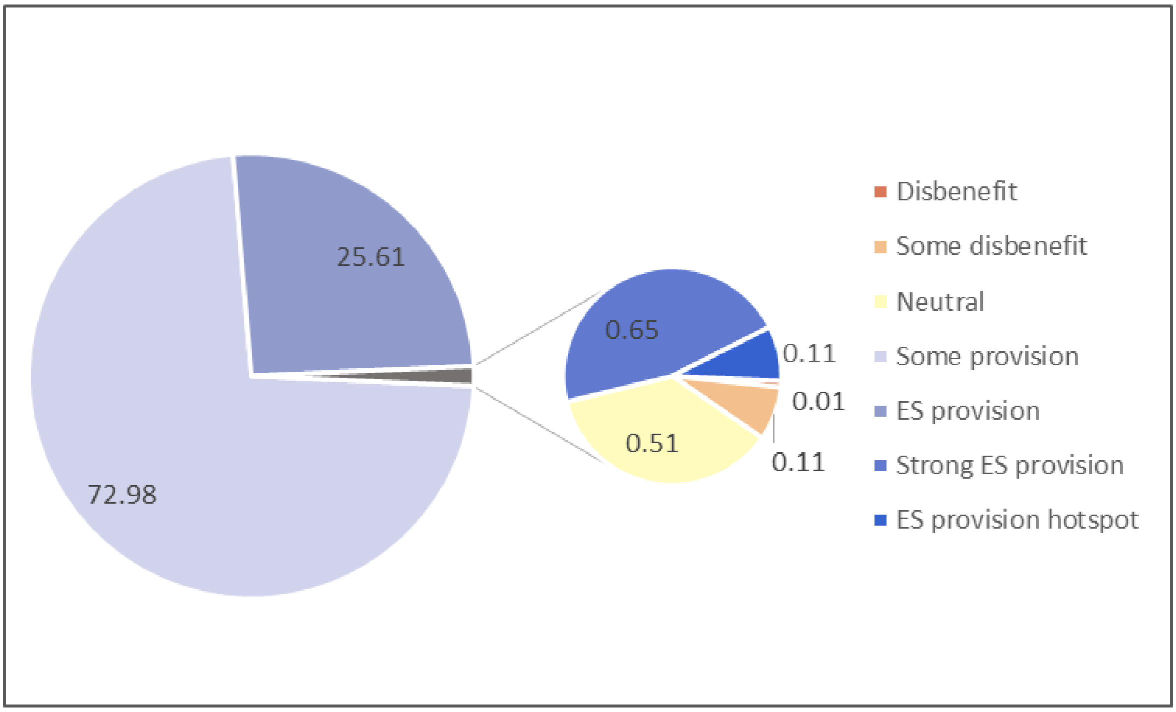

Figure 48: Contribution of Ireland's marine areas to marine biodiversity (%); note that, as the map is coloured across a colour gradient, whilst values have been grouped for the graph, colours do not exactly correspond between the two.

6.9.2 How the input data relates to these results

The project 'Rules-base' (MS Excel file) details the model inputs and qualitative weightings for the service. Further rationale behind the scientific reasoning for the scoring system can be found in the indicator documents (Appendix L).

Despite substrate data forming the basis for demonstrating biodiversity value, the areas of highest and lowest overall value are primarily determined by management data. Overall values for marine biodiversity vary most around the coast, with high values occurring to the South of Ireland, within an area designated as biologically sensitive. This area, together with coastal SACs and shallow water bays, are the main contributors to marine biodiversity.

Protected sites are considered to benefit marine biodiversity and show clearly on the map. Similarly, fisheries activities, for practices affecting the habitat (such as dredging), can have a negative effect on biodiversity. Areas with high fisheries effort, therefore, show as disbenefit.

Additionally, coastal areas have been modified based on a high, positive score for areas <10m deep, which receive lots of light, as the light facilitates higher plant biomass due to potential for photosynthesis, which in turn creates additional niches for other species. This particularly shows in bays, coastal lagoons, and estuaries around Ireland.

6.9.3 How the map relates to other maps produced

As both maps include substrate data and no further datasets with full coverage of the area of interest, similar patterns appear on the map for ***Marine Biodiversity*** and ***'Regulation of Greenhouse Gases (Marine Carbon)'***. However, as deep areas are of particularly high value for carbon sequestration, the maps are similar only with regards to patterns, whilst high and low provision areas are in different locations.

High value areas for *Marine Food Provision* based on fisheries effort and marine biodiversity overlap in several locations, as sites with high biological productivity also attract greater fish stocks resulting in greater fishing effort.

6.9.4 Data and knowledge gaps associated with this map

This map aims to model the national spatial variation in marine biodiversity in Irish waters. With the data available this map focused on looking at the diversity of the entire seascape. It also built on the concepts of biodiversity conservation/management as a proxy for ecosystem health/condition. Much less is known about functions in the marine environment and therefore this map is preliminary. The model could be improved by considering the following data gaps:

- The map for marine biodiversity does not include species data. This is because many marine species are highly mobile, so that point observations included in the map could easily misrepresent the overall results. Additionally, recording is often biased to large marine species, in particular marine mammals. Therefore, incorporating species data is likely to attribute higher biodiversity value to those areas known for marine mammals, instead of mapping marine biodiversity as a whole.
- NPWS marine community mapping was not incorporated into this map, as this data does not cover the whole extent of the marine mapping and incorporating it into the habitat data with less details would create an inconsistent data set.
- Further research and data on the role and distribution of benthic communities is needed.
- See also section on mapping limitations.

7. Limitations and Next Steps

This section deals with limitations and data gaps that were identified in the course of the project and which steps could be taken in the future to further advance the incorporation of ecosystem services into policy and decision making in Ireland.

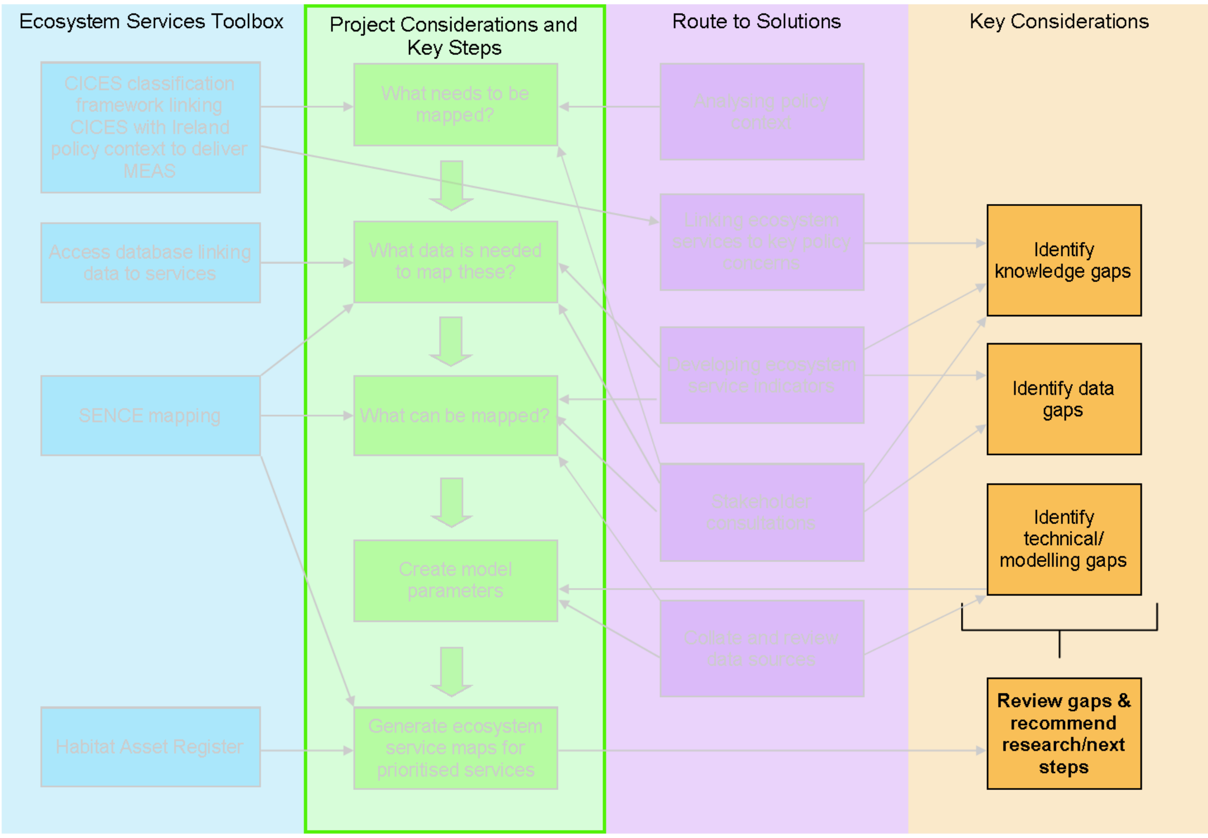

Figure 49: Project approach – tools, considerations and steps detailed in this section.

7.1 Mapping limitations

All ecosystem service maps created during this project are based on proxies and indicators, which has some inherent limitations. All outputs rely on the quality of the input data, both with regards to spatial resolution and to the quality of the classes assigned within the source data. In addition, the map data depends on sufficient knowledge of how the data recorded in the input data affects the provision of any of the ecosystem services and on a comprehensive set of indicators (e.g., no data on a proxy of major importance is missing). In addition to these general limitations associated with the use of proxy data, specific limitations to the output maps are listed in Table 15.

Table 15: Map specific, data associated limitations to the accuracy of maps produced during this project

Dataset / map	Data gap
Habitat Asset Register	• Fen data: Fens are important wetland habitats. However, currently no national dataset on the extent of fens is available. NPWS investigation of possible use of relevant soil classes from different national soils datasets as proxies found none were suitable as they had poor correlation with known fen distributions. This is a limitation in the study and a data gap that's needs to be addressed • Turlough data: Only 22 turloughs are covered by spatially explicit data. The remainder is covered by data points that have been buffered based on area coverage of the turlough in question, which does not create accurate boundaries • Hedgerows: The hedgerow data for Ireland was derived through remote sensing and could not be used without quality assurance effort, which was not part of this project. The map included woodlands, which are, in this project, covered in part through more accurate NPWS data on woodlands. Additionally, tile boundaries of input imagery are clearly visible. Were the hedgerows to be included at the bottom of the habitat conflation, they would be mostly overwritten, but if they were included at the top, they would partly overwrite potentially more accurate data on woodlands. • Information on hedgerows would be particularly important for mapping of the woodland network and, therefore, influence the biodiversity stock map.
LPIS data	• Grassland: The manner in which the LPIS system categorises Permanent Pasture may lead to an overestimation of the amount of grassland that is actually heavily improved. The Guide to Land Eligibility Direct Payment Schemes 2015 (http://www.agriculture.gov.ie/media/migration/farmingschemesandpayments/basicpaymentscheme/LandEligibility2015Booklet010515.pdf) states that: "Permanent grassland includes productive ryegrass dominated swards, less productive swards that include rush and other non-grass herbaceous species and grassland that includes heather which is grazable and where grass and herbaceous species are not predominant". This may lead to areas that are not overlain by better resolution habitat data being categorised as Permanent Pasture when it may contain other habitats such as Heaths or Blanket Bogs. This is a particularly significant issue with soil carbon resources and a national project is underway to try and map these features. • Additionally, as the data does not record percentage cover of the individual classes, the classes used are conservative best estimates. In the case of a mix of an arable class and a grassland, the area will appear as arable, even though in reality 90% of the area could be grassland. However, in the final HAR only c1.5% of Ireland's terrestrial extent are covered by mosaic classes from LPIS, making this a minor issue with regards to overall accuracy for ecosystem service mapping.
Species data	• Resolution: Species data was recorded at varying resolutions (from points to 10km squares), hence low resolution data will be given a disproportionate influence (this was offset to a degree through the lower scoring based on resolution). • Recording bias (spatial): There is the potential for recording bias within the species dataset, with values generally being higher around the coast and urban centres. This could be because of high interest in the marine-terrestrial interface and because of surveying need for development projects occurring around urban centres. • Recording bias (species): There is the potential for recording bias towards species that are, for example, protected under designations that require reporting, or towards species monitored for development projects. Species or regions with a reporting need are likely to be represented through more exhaustive data.
Habitat Condition	• Coverage: The majority of condition data was not available nationally.

Dataset / map	Data gap
Land use – Stocking density	• Stocking density data was not available for ES mapping, but is very important for ES delivery, particularly for regulation of water quality
Crop types and yield	• Knowing crop type and yield would help quantify the food resource more accurately. Whilst crop types are recorded in LPIS, this data was not used, due to yield not being recorded and many mixed value fields, which could not be scored accurately.
Soil depth	• Data regarding the depth of the soil layer can improve mapping accuracy for soil carbon and water related ES, in particular for peat soils.
Peat disturbance/ condition	• Peatlands: Condition data has to some extent been included (to distinguish between cut-over and active raised bog). However, a project (EPA STRIVE funded SCAMPI – Status and Condition Assessment and Mapping of the Peatlands of Ireland) is currently in progress, which will facilitate more accurate modelling of ecosystem service provision from peatlands.
Location and flow direction of drains (including tile drains)	• This is necessary to assess the flow rate for reducing flooding risk and for calculating pathways of pollutants, such as seepage from septic tanks, to show water quality.
Point source pollution features	• Adding point source pollution risk features to the water quality map would enhance its accuracy. This was not undertaken at the all-Ireland scale as the data becomes very detailed. It could however be considered for local scale mapping.
Erosion risk	• Calculating erosion risk across Ireland would also significantly enhance the models for water quality.
Marine food provision	• Fisheries data (wild harvest): Only limited information (e.g. metadata) available regarding what was measured and how • Aquaculture: No data was available on marine food provision through aquaculture • Further indicators (habitat): It is difficult to find indicators to use that go beyond direct measures of fisheries effort or fishing gear. It would be interesting to map the contribution of each area to this service based on how individual habitats contribute to healthy fish stocks for important target species. However, establishing this link between habitats and fish stocks would require an extensive desk review of literature regarding the ecology of the species of interest.
Bathymetry	• The bathymetry raster layers had some gaps in coastal areas. These were filled in through interpolation from the CTD depth measures (point file), which can create some inaccuracies.
Marine ecosystem services	• The marine environment is very much three dimensional, with processes occurring in the water column being just as relevant as pelagic or benthic ones. Therefore, incorporating processes occurring in the water column could further improve modelling accuracy.

7.1.1 Projects addressing current mapping limitations

A range of Irish research and mapping projects are either currently underway or planned for the near future. The results of these projects will address some of the data and mapping limitations noted during this project and allow for updates on the outputs. These projects and how they could be incorporated into mapping are listed in Table 16.

Table 16: Future and underway projects addressing data and mapping limitations noted during this project

Project	Project purpose	Limitations addressed
Hedgerow mapping by Bluesky (Pilot project)	Detailed hedgerow mapping in Cork	Lack of accurate hedgerow data addressed for one county
Flooding / Water quality by OPW (www.cfram.ie/pfra/interactive-mapping/ and EPA (Catchments.ie)) Flood Studies Update Programme	Newer maps on flooding and water quality were created this year (2016) The development of new or recalibrated flood estimation	Maps in this project precede the release of these newer datasets; relevant maps could be updated or interpreted using this information Detailed data on flooding.
CforRep by University College of Dublin	Obtaining information for better carbon reporting in Ireland	Lack of accurate data on soil carbon particularly in relation to that found under Permanent Pasture
SEAI Bioenergy Mapping	Land suitability mapping for bio-energy crops: Short rotation willow, Miscanthus and oilseed rape	Potential in Ireland for growth of energy crops
Valuing the significant ecosystem services provided by Irish coastal, marine and estuarine habitats (NUIG)	To obtain more information on coastal and marine ecosystem services	Lack of spatial data in marine and coastal environments.
SAT4Grass	Mapping grassland intensification (using field spectroscopy measurements and satellite to measure grassland yield and paddock management)	More accurate proxy for fertilizer input
Drainmap	Mapping drained farmland	More accurate proxy of temporary water storage and contribution to water quality in farmland
SCAMPI (EPA STRIVE funded)	UCC/Teagasc Mapping condition of Irish peatlands	Peatland condition important for a number of ecosystem services, particularly relating the hydrological cycle and climate change mitigation

Project	Project purpose	Limitations addressed
TaLAMH, Teagasc	Delineation of upland habitats using semi automated methods	Additional data to improve upland mapping and arable and pasture mapping in lowlands in addition to LPIS
NPWS ongoing habitat and species surveying	Mapping of habitats and species	More detailed and up-to-date information
LIFE Active Raised Bogs Restoration Project	Improve the conservation status in Ireland of active raised bogs	Monitoring restoration works on designated raised bog sites under National Raised Bog Special Area of Conservation Management Plan 2016-2021 including 12 raised bogs which are part of Irish Raised Bog LIFE Project
EPA-funded project: A framework for the restoration of degraded peatlands	EPA / Trinity College	UCD and TCD are carrying out this 3-year research project (2015-2018))
KerryLIFE project	Restore populations of freshwater pearl mussels in Caragh and Kerry	Additional information on distribution of a species of conservation concern (at a local level)
Tellus Project (Geological Survey of Ireland)	Provide additional geoscience information	Additional information regarding geology and associated features

7.2 Cultural Ecosystem Services

The on-going discussions concerning the revision of CICES have been prompted in part by the difficulty of defining and measuring cultural ecosystem services. Many of the difficulties arise because it is often hard to distinguish the particular ecological characteristics of species and places that give rise to cultural services and the associated benefits that people enjoy. The way cultural services are conceptualised is undergoing scrutiny in the international literature (Chan and Satterfield, 2016). Thinking about how different measures of cultural services can be generated across all elements of the ecosystem service cascade can help to overcome some of these difficulties, but there is also often a more fundamental problem arising from the simple lack of data (Tratalos et al., 2016). Data on cultural services is often difficult and costly to generate, because it involves survey information in most cases. The *Monitoring of Engagement with the Natural Environment* [24] (MENE), undertaken in the UK illustrates the value of longitudinal survey data in the context of ecosystem services and the scale of resource commitment required in order to develop a clear picture at national scales. In the future, it may well be that relevant data can be generated in a more rapid and cost effective way. For example, recent work has shown how, by analysing photos placed on social media by the public, the qualities and characteristics of different environmental settings that are used for various kinds of activities (Tenerelli et al., 2016) can potentially be understood. In order to take work on cultural ecosystem services further in Ireland, it would be useful for any future study to review the range of material that relates to cultural ecosystem services that are available, and to document how this can be used to characterise cultural services at different spatial scales. The work could also look at strategies for overcoming data gaps.

7.3 Further ES Framework Methodology Development

7.3.1 CICES

At the time of the preparation of this report, the current version of CICES (V4.3) is being reviewed in order to determine whether any revisions are necessary. This process is drawing heavily on the experience of users, and so in this context the results from Ireland will be especially valuable in taking this discussion forward. Potential 'modifications' to CICES have previously been explored in Ireland (see our earlier discussion in section'3.4 Developing CICES in the Irish Context').

[24] https://www.gov.uk/government/statistics/monitor-of-engagement-with-the-natural-environment-2015-to-2016

On the basis of the outcomes of these discussions, and the experience gained in this project, our recommendation is that while the overall structure of CICES seems appropriate, it is useful in an operational context to break down the class level (the most detailed within the current CICES structure) to more specific sub-classes. These sub-classes are at the level of ecosystem goods and services that can actually be measured 'on the ground' and which have particular policy or management relevance in Ireland. When CICES was designed it was anticipated that this kind of customisation at the sub-class level would provide users with the kinds of flexibility they would need to develop geographically specific applications, and the experience in Ireland is valuable in showing how this can be done.

7.3.2 Developing Policy or Sector Relevant Reporting Categories

In quantifying ecosystem services, it is clearly important to be as specific as possible, so that indicators are easy to interpret and meaningful. This report has shown how this can be done by expanding the range of metrics used to quantify ecosystem service classes by creating policy relevant 'sub-classes' that are then nested into the overall structure. Clearly for higher level policy work more aggregated indicators would be useful; this might be especially useful in the context of the MAES Process and any associated reporting commitments. Thus an area that might be looked at in any future work would be how to develop suitable, more aggregated indicators, at the CICES Group and Division levels. An approach used elsewhere involved identifying a 'basket of indicators' that can be used to characterise these more general reporting categories with some kind of weighting system used to generate an overall score.

A further aspect of this work would be to look at user-needs more generally, and explore how, in an Irish context, policy or sector relevant reporting categories can be constructed using CICES classes, groups and divisions.

7.3.3 Ecosystem Service Indicators

The work described in this report on indicators (Section '4.2 Developing Ecosystem Service Indicators') demonstrates how CICES at the class and sub-class levels can provide a framework for indicator development. By looking at these indicators in the context of the SENCE tool, the work has demonstrated how these indicators can be cross-referenced to the different elements of the 'ecosystem service cascade' so that users can see how service outputs can be quantified using different direct and proxy measures. This approach is particularly important because it enables the role of 'biodiversity' in service output to be more clearly demonstrated and potentially monitored.

In order to take this work further a number of elements could be further developed:

- At present the material in Appendix F is based on a review of key policy areas that are relevant in the Irish context. This work was used to identify *potential* service sub-classes and metrics that could be used to assess the status and trends of these ecosystem service outputs. In order to continue the dialogue with stakeholders that has been started by this project, the appropriateness of these indicators could be reviewed, and others added where gaps are felt to exist.
- Only a subset of the potential policy relevant indicators at sub-class level identified have been used in this study for quantification and mapping. The selection was made on the basis of data availability and where policy priorities were thought to lie. In order to continue the dialogue with stakeholders which has begun through this project, it would now be valuable to identify the next set of indicators that can be quantified and mapped, given current data resources, and where data gaps exist, what kinds of monitoring and measurement strategy might be put in place to overcome these deficiencies.
- During this project, no quantitative assessment was carried out. However, the work done on this project can be regarded as the precursor to economic evaluation. However, taking this step was beyond the scope of this project. The creation of the Habitat Asset Register and the qualitative ecosystem service maps provide a set of data layers and initial outputs that could be reused to develop ecosystem service modelling and economic valuation further and leave room to incorporate additional data.
- As the focus was on the development of national indicators, it was not possible to utilise data sources which were only available for specific locations. The application of the framework to a local pilot would provide the opportunity to verify the appropriateness of the indicators approach while enhancing them using available local data. This would also provide greater opportunity to examine links between specific structures, processes and functions with individual and multiple services and benefits. Furthermore, a local pilot would give greater opportunity for outputs to be customised to the needs of local decision making. The transparency of the valuations provided by the spatial framework approach can provide a valuable mechanism for consultation with local stakeholders and incorporation of their values.
- The Rules-base provides a transparent way for weighting datasets. As new data becomes available from new research projects, these can be used to update the indicators and the map outputs. The data base should also be maintained so that newer data sources are incorporated.
- The species coincidence layer was comprised of legally protected and policy relevant species. It was beyond the scope of the current pilot to analyse the data in terms of functional groupings and their role with respect to specific ecosystem services, but this could be done using the data gathered to create the species coincidence layer as a starting point.

7.3.4 Opportunities mapping

Stock maps are only one type of ecosystem service maps that can be produced through the SENCE methodology. They provide information on the current distribution of ecosystem service provision. There are additional map types that can be produced, one of which are opportunities maps. These show areas where the provision of a specific ecosystem service could feasibly be enhanced. This considers which areas are unsuitable for modification, or only allow for certain types of management, such as the implementation of agri-environment options on agricultural land.

As a next step the outputs created as part of the national pilot to date can be combined to develop such opportunities maps to enable the evaluation of multiple benefits and trade- off analysis at the national scale.

Once opportunities and stock maps exist, they can be combined to show areas with trade-offs, interactions, and synergies between services and opportunities. Areas with multiple opportunities can be highlighted, to indicate areas where management action has the potential to enhance the provision of more than one ecosystem service.

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Appendices

All appendices are provided in a separate document.

- Appendix A: Findings of the Review of Mapping and Assessment Tools
- Appendix B: Workshop 1 Outcomes
- Appendix C: Workshop 2 Feedback Report
- Appendix D: Ecosystem Theme, Pressure and Policy Matrix
- Appendix E: Waterford Symposium Ecosystem Service Grouping
- Appendix F: CICES Sub-classes for Ireland
- Appendix G: Example Outputs "All Ireland Matrix"
- Appendix H: Data Audit for Mapping Ecosystem Indicators
- Appendix I: Data Audit for the Habitat Asset Register
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- Appendix K: Description of LPIS-derived Habitat Classes in Terms of Ecosystem Service Provision
- Appendix L, Indicator documents providing the technical background to each service mapped.