Ecosystem service mapping in the Severn estuary and inner Bristol Channel

September 2014

Funded by: NERC Marine Renewable Energy Knowledge Exchange

Matthew Ashley

ashm@pml.ac.uk

Project steering group:

Mark Robins (RSPB), Lynne Osgathorpe (RSPB),Tara Hooper (PML), Esther Collis (WWT), Sean Christian (RSPB)

.

Acknowledgements

The authors and project steering group wish to thank the Natural Environment Research Council (NERC) for funding this Marine Renewable Energy Knowledge Exchange project and thank experts consulted in relation to the ES within the study region for useful discussions, which have contributed to the production of this manuscript. Thanks also to the stakeholders attending the presentation and feedback session, the dialogue and discussions resulting from the session have greatly enhanced this manuscript and identification of considerations for future work.

Suggested citation: Ashley, M.C. *Ecosystem service mapping in the Severn estuary and inner Bristol Channel.* Report for NERC Marine Renewable Energy Knowledge Exchange Project. September 2014, RSPB and Plymouth Marine Laboratory, Plymouth 100pp

Contents

List of Figures

List of Tables

List of Acronyms

AIS: *Automatic Identification System*

BAP: *Biodiversity Action Plan*

CEFAS: *Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, UK*

DEFRA: *Department for Environment, Food and Rural Affairs*

EIA: *Environmental Impact Assessment*

ES: *Ecosystem service/s*

GIS: *Geographical Information System*

HER: *Historic Environment Records*

IFCA: *Inshore Fisheries and Conservation Authority*

JNCC: *Joint Nature Conservation Committee*

MA: *The Millennium Assessment*

MESH: *Mapping European Seabed Habitats (European Commission funded project)*

MCZ: *Marine Conservation Zone*

MMO: *Marine Management Organisation*

MPA: *Marine Protected Area*

MRE: *Marine Renewable Energy*

NCC: *Natural Capital Committee*

NE: *Natural England*

NERC: *Natural Environment Research Council*

NRW: *Natural Resources Wales*

RSPB: *Royal Society for the Protection of Birds*

SCC: *Social Cost of Carbon*

SeaWiFS: *Sea-Viewing Wide Field-of-View Sensor (NASA marine phyto-plankton observation mission)*

SAC: *Special Area of Conservation*

SPA: *Special Protection Areas*

TEEB: *The Economics of Ecosystems and Biodiversity*

TEV: *Total Economic Value*

TIDE: *Tidal River Development (European Commission funded project on sustainable development in estuaries)*

UKNEA: *UK National Ecosystem Assessment*

UKNEA FO: *UK National Ecosystem Assessment Follow On*

WWT: *Wildfowl and Wetlands Trust*

VMS: *Vessel monitoring system*

Project synopsis: Ecosystem service mapping in the Severn estuary and inner Bristol Channel

Aim

This Natural Environment Research Council (NERC) Renewable Energy Knowledge Exchange funded project, conducted in partnership between Plymouth Marine Laboratory and the RSPB aimed to:

Assess and map delivery of key ecosystem services (ES) within the greater Severn estuary and Bristol Channel (Figure 1).

Ecosystem services are the benefits people obtain from the natural environment. The habitats within the Severn estuary and inner Bristol Channel provide significant resources from cycling and storage of carbon through to flood prevention, income from recreational activities and inspiration for cultural activities. The outputs of the project provide a new set of ideas and material to aid better informed decision making in the greater Severn.

Scope

The scope of the project was to utilise the three month project period to take a broad scale approach to identify priority locations for the supply of key ES. Gaps in knowledge and barriers to assessment (limitations) were highlighted to aid future projects and target future research to support ES assessment in the Severn and inner Bristol Channel region. Identification of hotspots for key ES was intended to provide developers, regulators and other stakeholders with an insight into locations and importance of these sites and begin to provide a baseline to examine future benefits and dis-benefits from developments.

Project Objectives:

1. Identify and assess five key ES and related activities provided within the greater Severn Estuary, at least one of which should be a cultural service.
2. Map ES and related activities within a Geographical Information System.
3. Explore potential valuation approaches to add scales to the benefits of the services.
4. Communicate the findings to key stakeholders.

Approach

Review of ES frameworks, data collation and mapping were conducted by the principal investigator. Guidance and discussion on which frameworks to apply and selection of key services were conducted with assistance from a steering group managed by the RSPB. The steering group consisted of members of academic bodies (PML) and non-government organisations (RSPB and the Wildfowl and Wetlands Trust, WWT). Steering group members ranged from individuals with specialist backgrounds in ES research, individuals with knowledge of the Welsh and English regions within the study area and a representative of a parallel nature focussed project in the region ('Severn Vision Project'). The findings of the project were presented to a regional stakeholder group for feedback which is reflected in this final report. The audience contained representatives of industry (energy industry, renewables, ports and shipping, IFCA), environment (NRW, Environment Agency, WWT, RSPB, IFCA) and research (Cardiff, Bristol and Gloucestershire Universities).

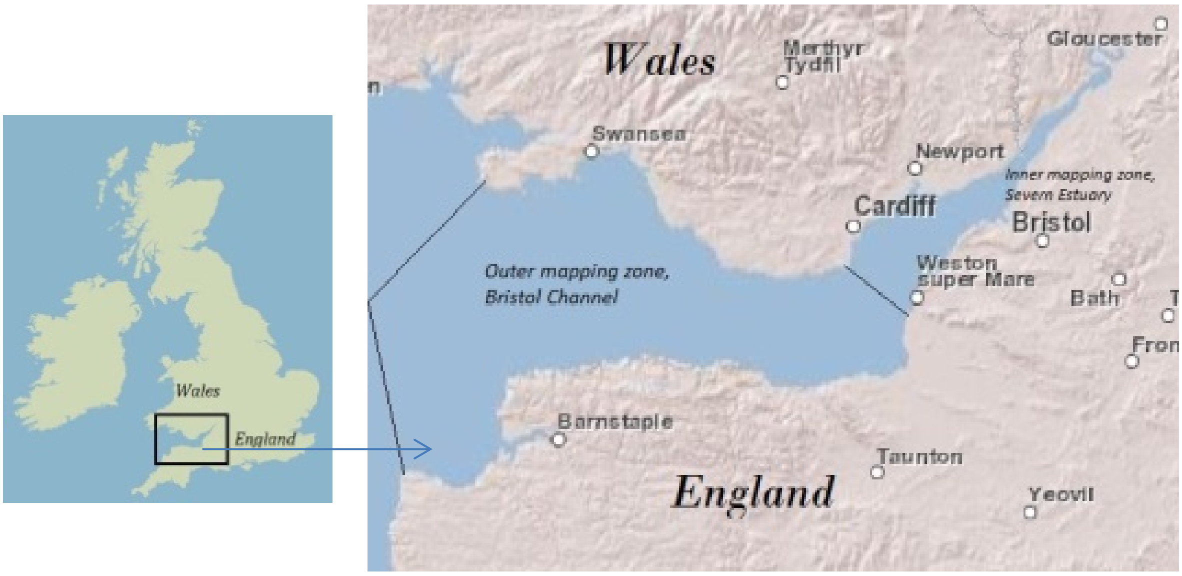

Figure 1. The Severn estuary and the inner Bristol Channel study area

Key findings

Assessment of supply, and mapping of supply, of key ES highlighted the importance of the greater Severn and inner Bristol Channel in delivering ES that provide benefits to communities, both locally and internationally.

Key benefits identified through this ES mapping exercise include:

- The presence of significant marine transport links and ports, the presence of which support regional, national and international trade and industry.
- Multiple ES benefits that flow from the regions extensive intertidal areas, particularly mud bank habitats and the intertidal saltmarsh habitats. The study highlighted their importance for:
    - flood risk management,
    - carbon sequestration and burial (storage),
    - archaeological resources and
    - wild food and fisheries.

The Severn region was also identified to be of considerable cultural importance which suggests a much more detailed assessment and interpretation of the range of cultural services is required than was possible during this project.

Next steps for ES research on the Severn were identified, in particular:

- Research priorities for more detailed understanding of each key ES in the region, and the underlying ecological, physical and hydrographic processes and functions that support them.
- Early engagement with the regions academic institutions, industries (e.g. ports, energy, etc.), statutory agencies, topic specific experts (e.g. English Heritage), and NGOs, would benefit future work in order to:
- Utilise and apply the broad range of existing regional knowledge and expertise.
- Identify best available data sources and support a joined up approach to identify areas supporting key ES delivery and then addressing mitigation and management solutions at an early stage.

Section1. Literature Review

1.1 Introduction to ecosystem services (ES) assessment

The needs of society that support human well-being, such as; energy provision, atmosphere regulation, management of waste materials and cultural richness are inextricably linked to the natural environment. Environmental impact assessments (EIAs) are now commonplace as statutory requirements to protect the natural environment from excessive impact from public and private development activities (HMSO, 2000). However, environmental impacts such as loss of biodiversity, and related social and economic impacts, continue in both the developed and developing world (Secretariat of the Convention on Biological Diversity, 2010). The ecosystem services (ES) approach has evolved as a means to emphasise the linkages between this continuing degradation of environmental resources and the associated loss of social and economic benefits, providing a tool to support policy, management and marine planning decisions.

One reason that policy and planning decisions continue to overlook social and environmental externalities is because there is no market for many of them and they are not readily quantified in terms that permit their direct comparison with the exploitation of manmade capital (Costanza et al., 1997; Barbier, 2007). The aim of the ES approach is to provide a common language and a transparent framework for quantifying the ecological, social and economic choices to aid their consideration in development decisions (Granek et al., 2009).

The ES concept is an anthropocentric approach to resource management. It applies a utilitarian philosophy, in which the value people place on ecosystems is derived from the utility (or preference satisfaction) that the natural world provides (Bateman et al., 2011). The approach attempts to better communicate the connection between ecosystem functioning and human wellbeing by linking environmental characteristics to the benefits that groups and individuals obtain from the ecosystem (Daily, 1997; Granek et al., 2009) (Fig 1.1).

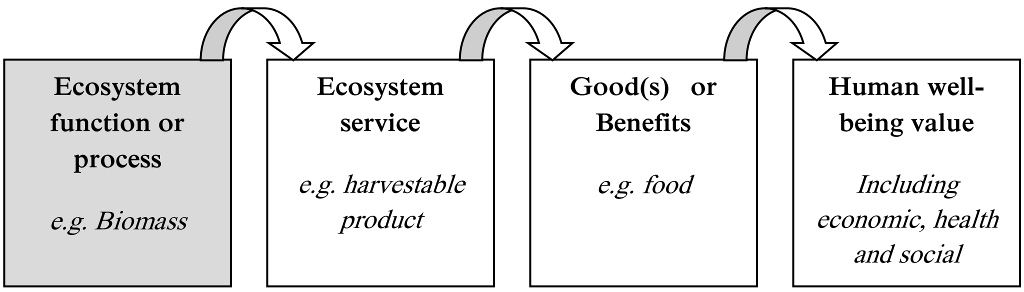

Figure 1.1 The conceptual cascade linking ecosystem functions and processes to human well-being that underlies the ecosystem service approach, adapted from Mace et al., (2012).

The ES approach can be identified to stem from philosophical foundations in the eighteenth and early nineteenth centuries (Mooney and Ehrich, 1997). More recent interest in the approach developed in the late 1990's. Daily (1997) and Costanza et al. (1997) provided significant work establishing the ES concept and its applications.

Since the re-emergence of the concept in the late 1990s the ES approach has been adopted as a means to inform policy making, as governance decisions as based on human welfare (Defra, 2007a). The Millennium Ecosystem Assessment (MA) 2001- 2005 utilised the ES approach from the outset in its aims to assess the impacts on human wellbeing of ecosystem change, and the different options for enhancing the preservation of ecosystems to secure their contribution to the fulfilment of human needs. An ES approach has also been adopted more recently in a second global initiative: The Economics of Ecosystems and Biodiversity (TEEB) aims to highlight the economic benefits of biodiversity and the costs of its loss (de Groot et al., 2010). At a national level the UK National Ecosystem Assessment (UK NEA) was conducted between 2009 and 2011, following the recognition in the MA that biodiversity loss was a significant problem across nations globally. The UK NEA identified ES were in decline within the UK and led to the government aiming to put the value of natural capital (a representation of ES) at the heart of the Government's economic thinking. The Natural Capital Committee (NCC) was formed in 2011 to provide independent expert advice to the government on valuing natural capital. The reports of the NCC were released in 2014 providing approaches to view ES and environmental benefits as natural capital which underpin all other types of a capital. Although a variety of means of categorising ES are available, these international and national projects provide widely accepted frameworks which are adapted in this study.

These guiding ecosystem service assessment programmes are summarised in the following case studies below.

Case study 1: Millennium Ecosystem Assessment (MA)

The Millennium Ecosystem Assessment (MA) was launched by UN Secretary General Kofi Annan in June 2001 as a 4 year international work programme, and involved scientists from over 100 nations. The program focused on the links between ecosystem change and human well-being, particularly how humans have altered ecosystems and how changes in ecosystems have affected human well-being. The ES framework developed was designed to meet the needs of decision makers who require scientific information on the relationships between ecosystem change and human well-being. Ultimately the framework aimed to identify policy responses that could be adopted from local to global scales to improve ecosystem management. The MA framework allocated ES into four categories:

- **Provisioning:** raw materials obtained from ecosystems: food, water, timber.
- **Regulating:** ES maintaining climate, water quality, flooding and regulation.
- **Cultural:** non-material benefits to people from ecosystems such as, recreation, spiritual, aesthetic benefits.
- **Supporting:** elements and functions on which all other ES depend such as; primary production, nutrient cycling and soil formation.

The MA linked the state and changes to these ES categories to human well-being, with a focus on poverty reduction. Human well-being was considered to rely on a range of factors, these included:

- Material minimum for a good life
- Health
- Good social relations
- Security
- Freedom and choice

In addition, the MA examined how drivers of change in ES affected services and, thus, human well-being. Drivers of change were considered as indirect drivers such as:

- Demographic
- Economic
- Socio political
- Science and technology
- Cultural or religious

Or direct drivers of change:

- Changes in local land use and land cover
- Species introductions or removals
- Technology adaptation and use
- External inputs (fertilizer, pest control)
- Harvest and resource consumption
- Climate change
- Natural physical and biological drivers (volcanoes, evolution)

The work of the MA not only demonstrated the importance of ES to human well-being, but also showed that at global scales, many key services are being degraded and lost. Actions (management responses) were considered that would be taken either to respond to negative changes or to enhance positive changes at all points in the interaction between drivers of change and ES categories and human well-being factors.

(Millennium Ecosystem Assessment 2005)

Case study 2: The Economics of Ecosystems and Biodiversity (TEEB)

The Economics of Ecosystems and Biodiversity (TEEB) programme was initiated in 2007 by the environment ministers of the G8 and five further countries. The programme aimed to assess the global economic benefit of biological diversity, considering how the costs of the loss of biodiversity and the failure to take protective measures compared to the costs of effective conservation. TEEB's approach focuses on valuation frameworks and methodologies.

Three phases of the TEEB study were conducted, **the first phase** utilised the expertise and resources of various organisations to complete a study and report that collated evidence and examples of valuation. The initial study and report also identified elements of a biodiversity/ecosystem valuation framework, and considered long standing issues such as ethics in making choices regarding future values.

TEEB approach to valuation
Three core principals guided the TEEB approach to analysing and structuring valuation to achieve conservation and sustainable use, reflecting different situations in which ES valuation may be applied:

1. Recognised value – Conservation and sustainable use can be achieved through value that is already recognised, such as a natural site being protected in its original state as it is regarded as a sacred spiritual site.
2. Demonstrated value – Economic value is demonstrated to provide evidence for policy makers or business decisions that need to consider full costs and benefits of an ecosystem in addition to just available market values (such as private goods).
3. Capturing value – The value of ecosystems can be applied to provide direct reward or incentives to enhance conservation and sustainable use of an ecosystem, through measures such as:
    - Payments for ecosystem services
    - Reforming environmentally harmful subsidies
    - Introducing tax breaks for conservation

The second phase led to further specific studies on economic valuation, these included reports on the fundamental concepts and state of the art valuation methodologies, and an introduction to approaches and recommendations for mainstreaming the economics of nature into decision-making, as well as analysis and guidance on:

i) How to value and internalize biodiversity and ecosystem values in policy decisions.
ii) Mainstreaming biodiversity and ecosystem values at regional and local levels.
iii) How business and enterprise can identify and manage their biodiversity and ecosystem risks and opportunities.

Values provided by ecosystems and their services were then examined in respect to relevant economic sectors. Costs of biodiversity loss and ecosystem degradation were assessed in this phase with an ultimate focus on integrating findings from these studies into decision–making at all levels.

The third phase implemented the program at country level, aiding governments to build national, regional and local government capacity to produce tailored economic assessments of ecosystems and biodiversity. This phase aided implementation of the ES approaches into policy making.

TEEB is an ongoing initiative, and one of its current themes is to highlight the economic benefits of oceans and coasts, and to attempt to fill some of the knowledge gaps that hamper ES assessments within the marine environment.

TEEB (2010)

Case study 3: UK National Ecosystem Assessment (UK NEA)

The UK National Ecosystem Assessment (UK NEA) was initiated in 2009 following the results of the MA, which indicated the extent, globally that ES were being lost. Conducted between 2009 and 2011 the UK NEA undertook the first analysis of the UK's natural environment in terms of the benefits it provides to society and continuing economic prosperity. The UK NEA undertook an assessment for the UK, following a similar framework to the MA to enable the identification and development of effective policy responses to ecosystem service degradation (Figure 1.2). The UK NEA framework also incorporated post-MA advances, particularly for economic valuation methodologies to avoid double counting of ecosystem services. (de Groot et al., 2010, Ring et al. 2010, Balmford et al. 2011, also Fitter et al. 2010 on ES in Europe and Fisher and Turner 2008 on enabling economic valuation of ES).

Similar feedbacks were included from direct and indirect drivers of change in ecosystems and well-being as in the MA (Figure 1.3). However, the UK NEA framework adapted classification of ecosystems (within 8 broad habitat types occurring in the UK), ecosystem services, the processes driving change and their outcomes (on ecosystems, ecosystem services and human well-being) for the UK context (UK NEA 2011).

Ecosystem processes ► Ecosystem services ► Goods ► Value to human well-being

(Well-being is assessed as an increase or decrease in economic value, increase or decrease in health and positive or negative effects on shared social benefits)

Figure 1.2 The derivation of goods and subsequent values to human well-being from ecosystems used in the UK NEA.

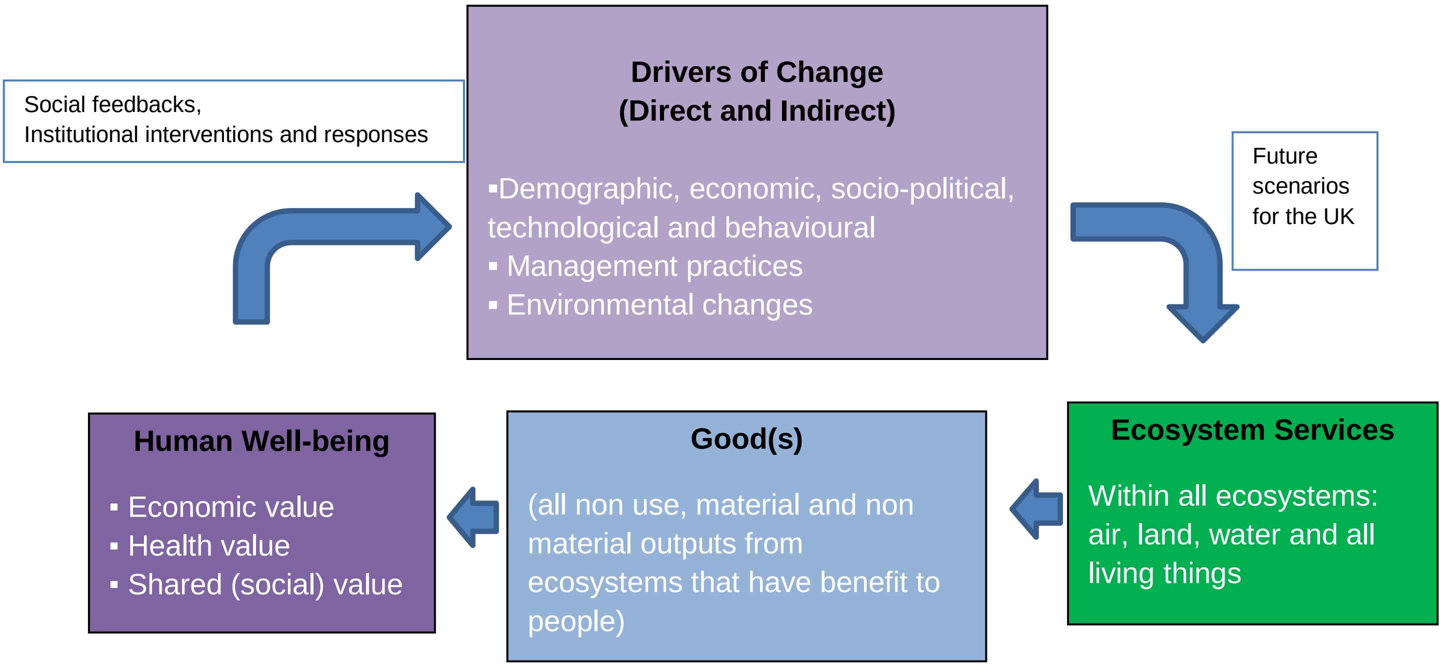

Figure 1.3. The UK NEA framework incorporating drivers of change, future scenarios and social feedbacks.

UKNEA Follow-on Phase (UK NEAFO) 2011-2014

Conducted between 2011 and 2014 the NEAFO builds on the framework of the existing NEA (figure 2), to provide new information and tools, particularly aimed to help decision-makers across all sectors understand the wider value of ecosystems and the services they offer (UK NEAFO 2014). Each advance within the NEAFO is of relevance to assessing the impacts of energy generation, particularly due to the focus on embedding ES assessment in policy and planning decision making.

Specific advances have been built into the framework in key areas: Natural capital, ESs and the macroeconomy, economic valuation of ESs, coastal and marine ESs, cultural ESs, shared and plural values, operationalising scenarios (scenarios were originally identified in the NEA), response options (to improve policy and practice for sustainable delivery of ESs), embedding ES framework into policy appraisal and the development of tools to aid decision makers to embed ES approach within policies and decisions (UK NEA FO 2014).

(UK NEA 2011, UK NEA FO 2014)

Case study 4: Natural Capital Committee (NCC)

The UK NEA revealed 30% of the essential services provided by nature are in decline. This led to UK Government statements expressing an aim to put the value of England's natural capital at the heart of the Government's economic thinking. To achieve this an independent 'Natural Capital Committee' was set up in 2011/12 for an initial 3 year period to provide independent, expert advice.

Natural capital represents the ES approach by viewing the benefits or services provided by nature as natural capital that underpins all other types of capital – manufactured capital (roads, building, machines) as well as human and social capital (health, knowledge, culture and institutions). Natural capital is, therefore viewed as the foundation on which economy, society and prosperity is built. The Committee's first State of Natural Capital report provides the following definition.

"*Natural capital refers to the elements of nature that produce value or benefits to people (directly or indirectly), such as the stock of forests, rivers, land, minerals and oceans, as well as the natural processes and functions that underpin their operation*" (NCC 2013, 2014).

The conceptual framework developed by the NCC applies this definition by:

1. Identifying ***stocks and assets*** (species, estuaries, coasts).
2. Relating the ***service or services*** (wildlife, crops, freshwater) provided by each natural capital stock as outputs or features of the stock.
3. Identifying the ***goods*** that are produced from services (***Goods*** are what people receive and use from natural capital stocks, goods can range from physically received goods such as food to those that aren't physical such as good air quality or recreation)
4. Identifying the ***benefits*** (to people) provided when goods are consumed or used. Under the NCC framework the benefits provided to people are the aspect of the natural capital and services that can be valued (often in monetary terms). It is identified however that there is substantial variation among different groups of beneficiaries, over time, place and circumstance.

The framework is illustrated in figure 1.4.

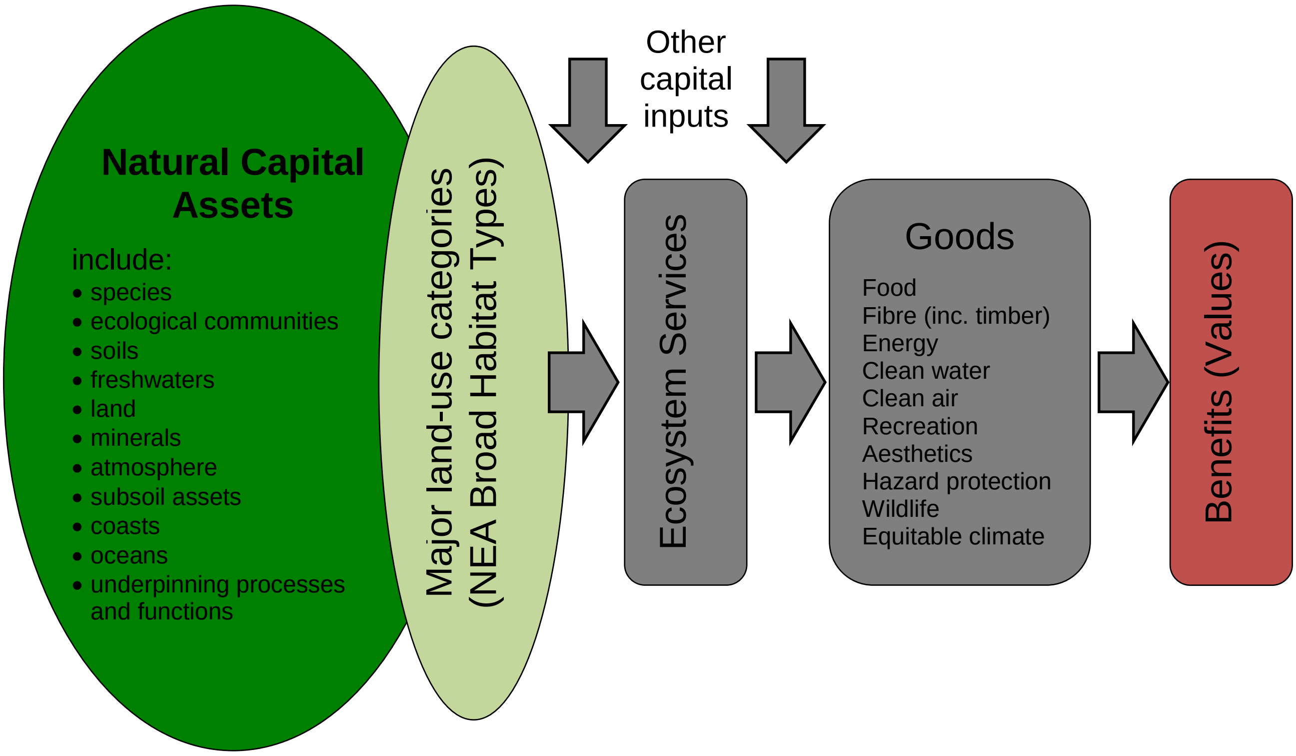

Figure 1.4 The NCC framework, reproduced from NCC (2014)

The NCC proposes the use of ***major land use categories*** as accounting units for natural capital. The eight UK broad habitat types designated by the UKNEA are adapted for this purpose:

▪Mountains, moorlands and heaths ▪Enclosed farmland ▪Semi-natural grasslands ▪Woodlands ▪Freshwaters ▪Coastal margins ▪Urban ▪Marine

These are adapted due to their presence as measurable units (with the recognition that they are not an adequate representation of natural capital and need to be disaggregated further for analytical purposes). Major land use categories are intended in practice to be areas of land and sea mapped according to their biophysical characteristics and the nature of recent human management within them (NCC 2014).

The UK broad habitat types are utilised as they can be assessed individually and, being spatially distinct units, when added as a whole can represent the total UK land and sea area.

Metrics are introduced by the NCC to measure stocks of assets with the aim of identifying how benefits might change over time. The metrics are required to be relevant to the assets themselves and to the benefits that derive from them. Relevant metrics are stated by the NCC as needing to be characteristic of each stock, major land use categories and benefits. The intention is to be able to reflect how changes might impact current and future assets, goods and benefits.

Examples of metrics are given for

1. **Natural capital stocks** – *species abundance and distribution, habitat area and condition*
2. **Major land use categories** (8 land use categories in total, those relevant to the study region are: marine, coastal margins freshwaters and urban) – metrics are suggested as any combination of *quantity, quality and spatial configuration* of natural assets such as *vegetation, species, soils / substratum,* and benefits such as *harvestable crops/species, wild species conservation, carbon storage and recreation.*
3. **Benefits –** *contribution to human wellbeing*, mostly expressed in monetary terms where possible**.**

The introduction of major land use categories provides an opportunity to link metrics between natural assets and benefits to measure status, condition or amount across the three categories of metrics (natural capital stocks, major land use categories and benefits)

1.2 Natural Capital Stocks in the Severn estuary and inner Bristol Channel region.

Assessing key ES within the study region using the NCC framework holds great potential, particularly for linking assessments to other similar environments in the UK. The assets, land use categories and goods/benefits under the NCC framework are discussed in relation to the study region below. Spatial extent of example matrices, substratum type and designated conservation areas are mapped in Figures 1.5 and 1.6.

Natural capital stocks**: (Ecological communities, species, soils, freshwaters, land, minerals, atmosphere, subsoil assets, coasts, oceans, as well as the natural processes and functions that underpin their operation).** Within the study region the estuarine and marine regions provide diverse ecological communities, species, substratum (inferred as equivalent to soils), and natural processes and functions that underpin these. Abundance and distribution of species and area of habitat/substratum provide a usable metric to measure natural capital stocks in the study region (Figure 1.5).

Major land use categories**: (The broad habitats used in the UK NEA: mountains moors and heaths, enclosed farmland, semi natural grasslands, woodlands, freshwaters, coastal margins, marine and urban).** Major land use categories such as marine, urban, freshwaters, estuarine are all represented in the study region. The natural assets such as substratum and vegetation or species presence and distribution can be measured in the study region (Figure 1.5). Benefits such as carbon storage and wild food / fisheries have functional relationships with the metrics related to estuarine and marine environments and quantity, quality or spatial extent can be assessed in relation to society's needs.

Goods/benefits: **(Food, fibre (including timber), energy, fresh water, recreation, clean air, amenity, aesthetic, wildlife conservation and equable climate)** Changes in these are noted to yield changes in human well-being that, in turn, can be valued in monetary terms in most cases (NCC 2014). A diverse array of goods/benefits, including many of those noted in the examples provided by the NCC (2014) are present in the study region such as wildlife conservation (Figure 1.6).

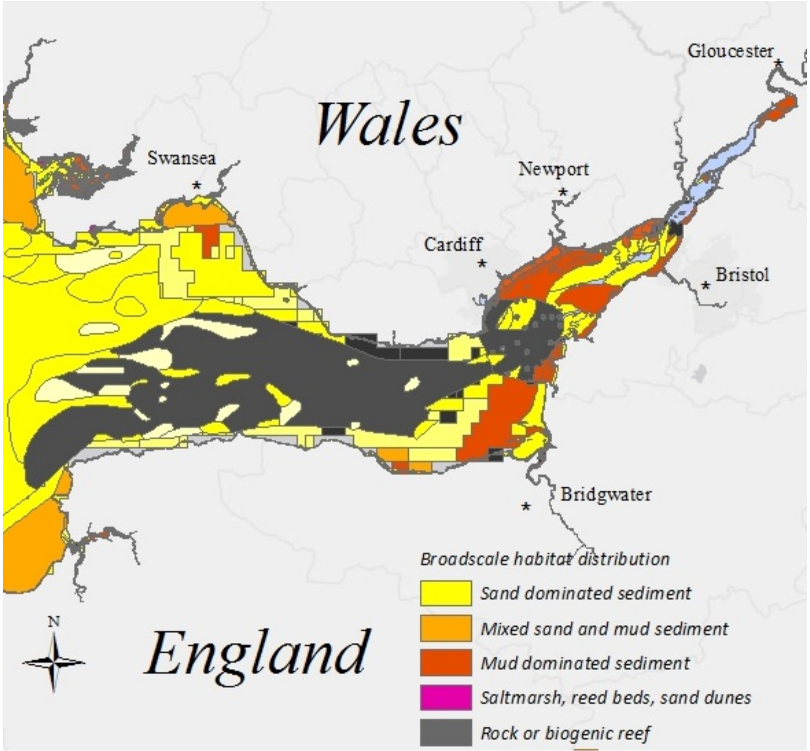

Figure 1.5 The spatial distribution and extent of broad scale substratum types in the inner Bristol Channel and Severn estuary.

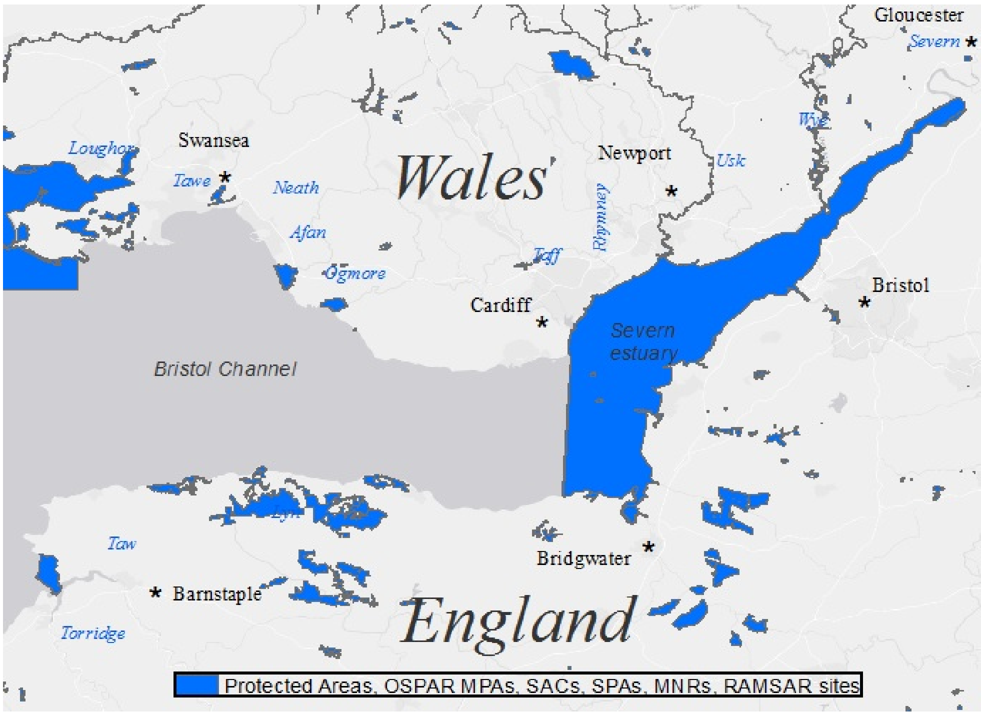

Figure 1.6 Designated conservation areas in the Severn estuary and Bristol Channel including: Ramsar sites, OSPAR MPAs, SACs, MNRs, SPAs.

1.3 Key developments in valuing Ecosystem Services

Approaches for ES assessment and valuation have continued to develop following the MA. One particular focus of TEEB, the UKNEA and other studies has been on the transition from conceptual to operational frameworks. In particular, there has been much debate on how valuation should proceed in order to reduce the risk of double counting, which can arise if the total ecosystem value is derived from aggregation of all the different ecosystem components. For example, adding the separate values for nutrient function and biodiversity risks double counting the value of the nutrient function that is 'captured' within the overall biodiversity value (Ledoux and Turner, 2002). Also, it is much simpler to value only the ecosystem endpoint, as measuring all the underlying processes is much more complex (Boyd and Banzhaf, 2007). Thus, use of the term 'ecosystem benefit' has been advocated in order to define the point at which a direct gain in human welfare provided by ES is realised, and hence identify the parameter for which valuation should be attempted (Fisher et al., 2009; Hooper et al., 2014). This view directly links benefits with 'goods' as defined in the UK National Ecosystem Assessment (UKNEA 2011) with the added, wider scope, that benefits beyond the generation of tangible objects are considered.

The key distinction in the consideration of benefits (or goods), as opposed to the services that provide them, is that no attempt is made to value supporting services. Food, raw materials, clean water, recreation, flood alleviation, an equitable climate and cultural heritage, for example, are simply reclassified, and remain amenable to valuation (Table 1.1).

Table 1.1 Examples of specific benefits considered by Hooper et al., (2014) and their relationship to ES categories.

Service type	Benefit/Value category	Examples of specific benefits
Provisioning	Food	Fish, shellfish, marine plants and algae
	Raw materials	Bait, aggregates, industrial products, biofuels
Carrier	Provision of space	Transport, mooring, energy installations
Cultural	Recreation and tourism	Nature watching, angling, watersports
	Cognitive development	Education, research
	Heritage and identity	Archaeology, cultural heritage
	Psychological wellbeing	Visual amenity, inspiration
Regulating	Contaminant control	Clean water and air
	Distrurbance prevention	Food and erosion control, climate regulation
	Existence, Bequest	Knowledge that adequate habitat is available locally and will continue to be
	Option	Availability for alternative future uses

The environmental benefit assessment methodology set forward by Hooper et al (2014) provides a practical means of applying the assessment of environmental benefits to a geographical region such as the wider Severn estuary. The environmental benefits approach is particularly useful when a transparent process is required to demonstrate how benefits were selected for mapping, quantifying intensity and finally applying valuation methodologies.

1.4 A methodology for Environmental Benefits Assessment

The environmental benefits approach utilises a systematic methodology, adapting frameworks of ecosystem service classification from MA and UK NEA and valuation methodologies from TEEB and UK NEA (Hooper et al., 2014). The systematic process begins with:

1. *Site characterisation and identification of stakeholders*

The limits of the region or site and its key environmental and social characteristics (such as protected areas, land use patterns) are defined, and the key individuals and organisations who can provide relevant information about use of the area are identified.

2. *Identification of relevant environmental benefits*

The input of these stakeholders (in addition to reference to peer-reviewed and grey literature) is essential for the second step of the process which is to compile a detailed inventory of the environmental benefits occurring within the study region.

3. *Current level of benefit delivery and importance of environmental benefits*

In parallel with the inventory compilation, the level at which each benefit is delivered and its relative importance within the study site can be determined, on qualitative or quantitative scales, depending on the resource available for the assessment. This allows prioritisation of future effort in, for example, valuing benefits or assessing changes in benefit delivery that could arise from a particular development or impact.

1.5 Valuing ecosystem services and benefits

Once benefits (goods) have been identified within a study region, there are various methodologies by which they can be valued (in both monetary and non-monetary terms). Two philosophical approaches to valuation have developed: *Intrinsic / Inherent value,* and *Instrumental / extrinsic value.*

1. *Intrinsic / Inherent value* supports a subjective view of ecosystem benefit valuation as ecosystems are considered of 'value' (and thus should be conserved), simply because they exist, regardless of whether or not people derive any benefit from them.

2. *Instrumental / extrinsic value* supports anthropogenic approaches to valuation in which the value of the ecosystem results from the human benefits it provides.

Extrinsic valuation methodologies such as those undertaken within established ES frameworks (MA, TEEB, UK NEA), utilise the concept of Total Economic Value (TEV) (Figure 1.7). TEV is divided into a series of categories and sub-categories. The primary division is between ***use values*** and ***non-use values***. The former describes benefits derived from actually using ecosystems, and can be further divided according to whether the benefit is obtained from *direct use* (e.g. food, recreation)*, indirect* use (such as flood protection) or represents the *option value* from some as yet unknown future use. Non-use values are derived just from knowing a species or habitat exists (the *existence value*) and that resources will still be available for future generations (*bequest value*).

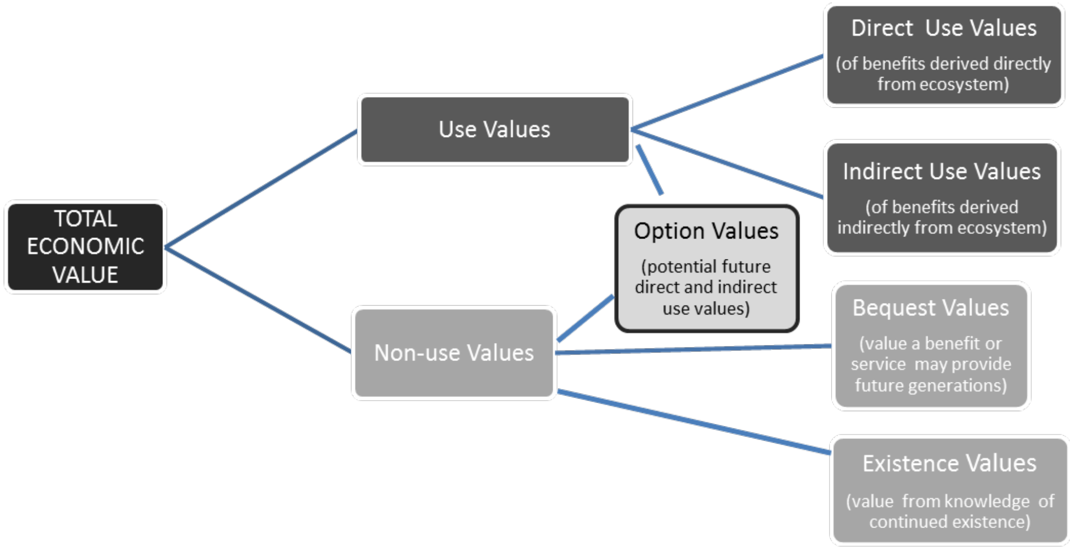

Figure 1.7. Categories and sub categories of ecosystem service values used to assess Total Economic Value (TEV) of a region or ecological system, adapted from UK NEA.

Valuation of direct and indirect uses

Market prices for direct use goods (such as food) provide the most straightforward form of ES valuation. However, market prices for resources such as fish species and individual crops change according to fluctuations in demand and availability, and so adjustments to consider these distortions are required (DEFRA 2007a, UKNEA, 2011, 2014) (Table 1.2).

Cost based approaches also utilise market prices. For indirect uses, for instance the role of a wetland for storm protection, the value can be obtained by determining the costs for construction of a man-made defence to replace the service provided by the ecosystem (*replacement cost*) or by evaluating the cost of damage that would have occurred had the ecosystem not provided the required service (*damage cost avoided*). *Production function approaches* also utilise market prices as they consider the extent to which the environment contributes to the value of a marketed good, and so may be applied to, for example, value the role of an estuary as a nursery habitat for commercial fish. *Revealed preference methods* consider how value is demonstrated through the actual choices people make, and these also consider market values. One example, *Hedonic pricing* considers how purchase values (usually property prices) vary depending on ecosystem service categories and benefits such as air and water quality, landscape attributes or presence of amenities. The *travel cost method* utilises people's financial expenditure on travel and associated costs required to reach particular site (usually for recreation) as a means of valuing the environmental attributes of that location.

Importance of recreational environmental benefits to individuals and societies can also be quantified by observing intensity of use in *random utility* and *stated preference* assessment methods. *Stated preference methods* utilise a survey and interview based approach that is practised in many *willingness to pay* assessments of value of ES or benefits (DEFRA 2007a, UKNEA 2011, 2014) (Table 1.2).

Valuation of option values, bequest values and existence values

Traditionally option values and non-use values provide the greatest challenge when valuing ES. There are no observable behaviours related to these values and so *stated preference methods* are required, in which individuals are asked for their *willingness to pay* to secure particular environmental attributes or ES. Examples of stated preference approached include *contingent valuation* in which the respondent is asked to state the amount he would be willing to pay to secure an increase in the level of an environmental good. An alternative to contingent valuation is offered by choice experiments, which present respondents with a set of alternatives, each of which is defined by a series of attributes (including cost). This mimics real market situations, in which people are faced with a choice of goods with similar attributes but different levels of those attributes. The trade-offs made by respondents between the different alternatives allow their willingness to pay for the different attributes to be determined.

Although criticised for possible bias in responses from survey respondents and difficulty in confidently assessing future economic markets and choices these methods provide insight into value of non-use categories and future option values of ES and benefits. Through rigorously designed and conducted surveys these methods provide data that can aid and inform development and policy decisions in a region (DEFRA 2007a, UKNEA 2011, 2014) (Table 2).

Table 1.2. Commonly used valuation methods in ecosystem service and benefit valuation, adapted from UK NEA.

Valuation method	**Description**	**Applicable benefits (examples)**
▪*Market prices*	Direct market prices of a benefit. In most cases however, prices would require adjustment for market distortions.	·Crop prices ·Fish prices
▪*Production function methods*	Role of ES within the production of a benefit using an adjusted market price.	·Crop prices ·Fish prices
▪*Damage costs avoided*	Calculates the costs saved through an ecosystem benefit such as flood prevention in a region from wetlands.	·Storm or flood damage costs avoided by maintinaing a wetland
▪*Revealed preference methods*	Reliant on *willingness to pay* approaches which examine the costs people will accept to utilise a benefit.	·Travel time and costs payed to utilise recreational benefits
▪*Stated preference methods*	Use of surveys to directly ask individuals to make choices regarding their willingness to pay.	·Willingness to pay higher water rates for cleaner rivers

1.6 Mapping of ecosystem services and environmental benefits

Mapping of ES and benefits is essential to aid decision making and policy aimed at achieving sustainability (Crossman et al., 2013). Goals within the EU Biodiversity Targets for 2020 include the requirement for EU Member States, with the help of the European Commission (EC), to map and assess the states of ES within their national territories by 2014 (EU Biodiversity Targets, Target 2, Action 5., Egoh et al., 2012). In respect to the marine renewable energy knowledge exchange approached in this study, the mapping of key environmental benefits allows the identification of sites providing ecosystem benefit hotspots, thus aiding the marine renewable energy industry to identify sites with reduced consenting risk.

Mapping of environmental benefits – defining presence and intensity within spatially explicit units (such as a mapped grid) – reflects the fact that both presence and demand for environmental benefits is spatially explicit and may alter geographically (Crossman et al., 2013). Mapping within a specified region such as the greater Severn estuary provides a better understanding of the benefits provided and their location. In turn maps produced can provide the basis for management decisions within marine and estuarine planning. Mapping of environmental benefits also provides the first step towards robust measurements of the stocks of natural capitol to inform further management actions in accordance with biodiversity conservation policies, such as payments for ecosystem services, biodiversity and wetland banking, carbon offsets and trading and conservation auctions (Crossman et al., 2013). Mapping of a number of habitats, ecosystems and environmental benefits within a given region also aid the examination of connections between habitats, biodiversity and final benefits (TEEB 2010).

1.7 Mapping approaches

Geographical information systems (GIS) are the most commonly used tool to assimilate and map ES data and environmental benefits. The common methodology is to create a grid or network across the study region of planning cells or planning units at the required resolution (e.g. 1 km^2 cells within a grid covering the study region) (Rees et al., 2012).

Key reviews on approaches to mapping ES have been conducted by Martinez-Harms and Belvanera (2012) and Egoh et al. (2012). Recently, Crossman et al. (2013) developed further the findings of these reviews with the aim of providing a standard ‘blueprint’ to standardise mapping of ES (and benefits). Crossman et al. (2013) provided a critical assessment of existing techniques used to model and map ES within service categories. The key techniques identified by Crossman et al. (2013) are summarised for each service (benefit) within each service category in Table 1.3.

Table 1.3. The attribute data and mapping and modelling techniques currently applied in existing studies for each ES (benefit), ES and benefits are displayed in the table within relevant ecosystem service categories, adapted from Crossman et al., (2013).

Ecosystem benefit	**Methods used to map and model service or benefit**	**Resolution / confidence**	**Reference**
Provisioning services			
Food	Land use data in combination with agricultural statistics, usually over coarse scales.	poor	multiple
	Models linking agricultural simulation process models to land use, soil and climate variables.	good	Bryan et al., 2009, 2011a
Water	Models / indicators estimating volume of water yield available for consumptive uses across river basin, lake, etc. Utilise pricipitation levels, evapotranspiration, land cover, soil water holding propoerty data etc.	dependant upon level of data availble for site	Zhnag et al., 2002 CSIRO, 2008 Mendoza et al., 2011
Raw materials	1. Spatially explicit volumes of timber and non-timber products available or spatially explicit harvest volumes. 2. Models linking spatial extraction of products to household demographic and labour data as well as location attributes and habitat types (forest) within a region	1. moderate 2. good	1.Maes et al., 2012b 2.van Jaarsveld et al., 2005
Genetic, medicinal and ornamental resources	Mapping of medicinal plants based on land cover data	poor	Chen et al., 2009 Fisher et al., 2011
Regulationg services			
Climate regulation	1. Quantify the carbon stocks in soil/sediment and vegetation system (use established relationships between land cover types and carbon stocks) 2. Estimate flows in carbon, or changes in carbon stocks, following a change in use or management of a region (use empirically-derived relationships between climate, soil and vegetation growth. 3. Remotely sensed estimates of primary productivity	1. moderate 2. good 3.moderate	1. Egoh et al., 2008 Nelson et al., 2009 2. Crossman et al., 2011c 3. Raudsepp-Hearne et al., 2010
Moderation of extreme events	1. Map proxies to estimate water retention capacaties as function of vegetation or soil/sediment type. 2. Map extent of magroves or similar habitat as a proxy for benefit from flood or storm damage. 3. Predict magnitude of flood or storm damage given data on hydrography, hydrology, topography, geology, soil, vegetation and management practices.	1. moderate 2. moderate 3.good	1. Chan et al., 2006 Ming et al., 2007 Schulp et al., 2012 2. Costanza et al., 2008 3. Posthumus et al., 2010 Ennaanay et al., 2011 Nedkov and Burkhard, 2012

Ecosystem benefit	Methods used to map and model service or benefit	Resolution / confidence	Reference
Habitat services			
Life cycle maintenance	habitat suitability for a species/biodiversity estimated through species distribution and the independent variables influencing it. 1. Map/model species distributions, soil characteristics, topographic and climatic variables, land use and land cover. 2. Indicies of species distribution and biodiversity hotspots.	1. good 2. moderate	1. Nelson et al., 2009 Rolf et al., 2012 2. Willemen et al., 2008 Posthumus et al., 2010
Maintenance of genetic diversity	Mapping biodiversity hotspots	moderate	Myers et al., 2000
Cultural and amenity services			
Opportunities for recreation and tourism	1. Location specific proxies i.e. number of waterfowl or deer, total fish catch per unit area, number of cyclists/walkers, daily or overnight stays at tourist locations, landscape naturalness and attractiveness	good	Jenkins et al., 2010 Naidoo et al., 2011 Lara et al., 2009 Willemen et al., 2008 Petz and van Oudenhoven, 2012 Gret-Regamey et al., 2008b Anderson et al., 2009 Eigenbrod et al., 2009 Maes et al., 2012b
Aesthetic information	1. Questionnaires or interviews on personal preferences. 2. Mapping landscape attractiveness based on factors such as naturalness, skyline disturbance and watershed. 3. Hedonic pricing using property values and distance metrics from features of interest	1. moderate 2.moderate 3.moderate	1.,2. de Vries et al., 2007 3. Crossman et al. 2010 Raudsepp-Hearne et al., 2010
Insiration for culture art and design	1. Qualitative maps of cultural heritage 2. Land use, land cover 3. Important artistic or literary works inspired	1. moderate 2. poor 3.moderate	1. Bryan et al., 2010 Posthumus et al., 2010 2. Willemen et al., 2008 Brenner et al., 2010 3. Hooper et al., 2014
Spiritual experience	Locations considered by local people to have high importance for social and spiritual value	moderate	Raymond et al., 2009 Bryan et al., 2010, 2011b

Section 2. Environmental benefits assessment for the greater Severn estuary and Bristol Channel

The region consists of two linked zones, the estuarine Severn estuary (the second largest estuary in the UK) and the marine inner Bristol Channel (Figure 2.1). All regions are subject to the largest tidal range in Europe, fuelling the potential for significant marine renewable energy developments (Regen SW and Marine Energy Matter 2012). Within the study region are a diverse array of habitats, landscapes and seascapes containing habitats and features of international conservation importance as well as some of the UKs largest ports and trade links (Severn Estuary Partnership 2011). Within this huge and diverse natural environment there are significant environmental benefits from climate regulation to provision of recreational space.

The first stage in selecting and mapping key ES delivered by the Severn estuary and Bristol Channel consisted of a rapid investigation of a broad inventory of the environmental benefits provided by the habitats and features within the study region. The simplified environmental benefits assessment undertaken for this project aimed to identify important benefits provided by the region to aid the selection of the key environmental benefits to be taken to the mapping stage.

2.1 Study site (geographic scope)

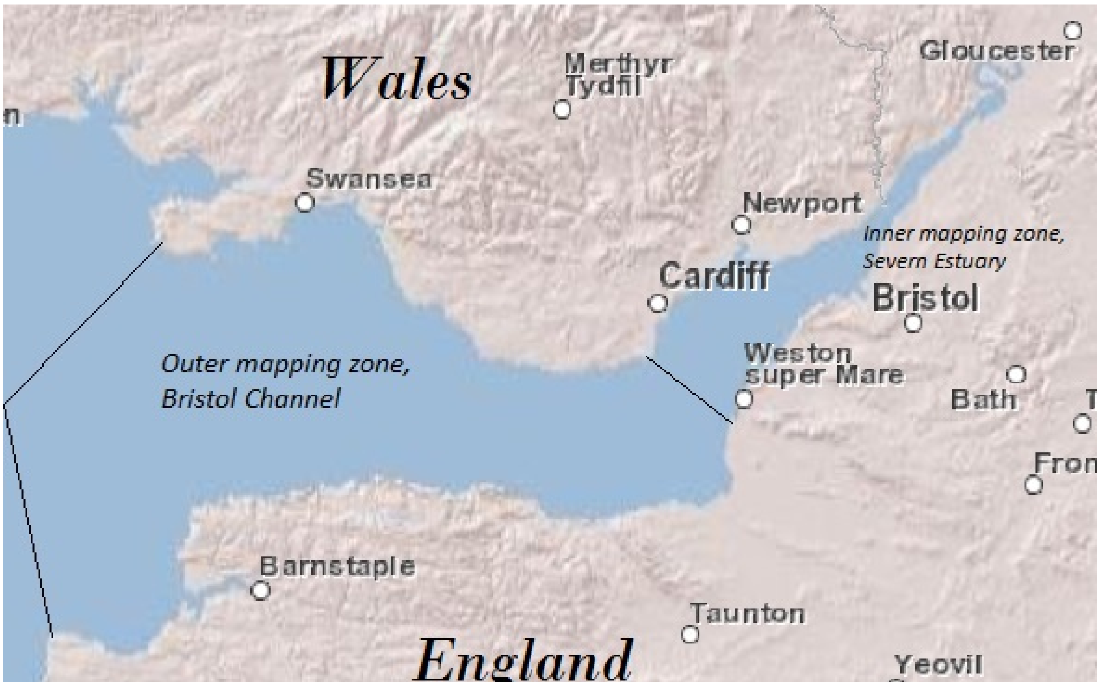

Figure 2.1. The Severn estuary and Bristol Channel study site (referred to as the greater Severn estuary), lines within the estuary denote the cut off between two separate mapping regions, the Severn estuary and the Bristol Channel.

2.2 Identifying relevant environmental benefits

A synopsis of ecosystem service categories and relevant environmental benefits within the Severn estuary and Bristol Channel study region is provided in Table 2.1. A more detailed inventory of ecosystem services and benefits delivered within the Severn estuary and Bristol Channel study site is provided in Table 2.2. The inventory in table 2.2 does not contain assessments of the impact of developments and change on each benefit and resulting effects on human wellbeing provided by Hooper et al., (2014). In this instance the construction of an inventory is aimed at summarising the benefits delivered and providing a basis for selecting key benefits for mapping within this study. Both tables (2.1 and 2.2) provided discussion documents at steering group meetings conducted to assess key benefits to be taken forward for mapping within the project.

2.3 Inventory

Table 2.1 Broad scale assessment of environmental benefits delivered within the Severn estuary and inner Bristol Channel study region.

Ecosystem service category	*Benefits supplied within the Severn estuary and inner Bristol Channel*
Provisioning services	▪Food and raw materials,
Regulatory services	▪Carbon sequestration, management of waste, management of flood risk, air quality and climate regulation benefits
Carrier services	▪Shipping and passenger ferries
Cultural services	▪Recreational benefits, inspiring artists, shipbuilding, traditional fishing, archaeological interest, educational benefits, watersports, on water recreation, tourism

Table 2.2 Ecosystem Benefits Assessment inventory for the Severn estuary and Bristol Channel study site.

Environmental benefit	Importance	Measures (types and units)
A. Direct use (consumptive)		
Food		
Shellfish - shore-based harvesting	*	Landings / harvest statistics (kg / yr)
Shellfish - sub tidal	**	"
Eels	**	"
Salmonids	**	"
Marine fish	**	"
Marine plants	*	"
Raw materials		
Bait	*	harvest statistics (kg / yr)
B. Direct use (non-consumptive)		
Provision of space		
Moorings	*	Number of moorings
Military operations	***	Frequency of exercise
Cables and pipelines	*	Number of pipes / cables
Recreation and tourism		
Sea angling	***	Number of participants
Wildfowling	*	"
Watersports	**	"
Nature watching	***	"
Swimming	**	"
Coastal margin activities	***	"
Cognitive development		
Education	**	Number of participants
Research	**	Number of published papers / reports

Environmental benefit	Importance	Measures (types and units)
B. Direct use (non-consumptive) (continued)		
Heritage and identity		
Archaeology	**	Number and importance of sites
Cultural heritage	**	Value to the community
Psychological wellbeing		
Ambience (visual amenity, tranquility)	***	Designations recognising natural beauty / Value to the community
Inspiration	**	Numbr/ frequency/ importance of art works
C. Indirect use		
Gas and nutrient cycling		
Carbon sequestration (blue carbon)	***	Habitats present and level of carbon sequestration
Contaminent control		
Water quality regulation	***	Frequency and severity of contaminent incidents compared to threshold
Air quality regulation	*	"
Disturbance prevention		
Flood control	***	Number of properties flooded and frequency of events compared to threshold
Erosion control	**	Area of land lost compared to threshold
Climate/weather regulation	*	Incidents of extreme weather compared to threshold
D. Additional componenets of total economic value		
Existence value	**	Value to the community
Bequest value		
Option value		

Level of importance expressed in terms of policy drivers / estimate of number of people affected, importance estimated between * and ***, with *** the highest.

Section 3: Mapping 5 key services within the Severn estuary and inner Bristol Channel

3.1 Selection process – five key services

Due to the time constraints of the project only key ecosystem services that were widespread across the study site and of high importance to the region were included for selection for mapping. A shortlist of environmental benefits (Table 3.1) was created from the inventory (Table 2.2). Both the shortlist and inventory as a whole were discussed at a Steering/Reference Group meeting, held on the 9th May 2014 at RSPB offices in Exeter. The shortlist contained environmental benefits (services) within each ecosystem service category. As discussed, shortlisted benefits were required to be widespread across the study site and of high importance to the region. As marine renewable energy resources had already been mapped by Regen SW and Marine Energy Matters (2012) these were omitted.

The reference group discussed the inventory and each shortlisted environmental benefit, reviewing the importance in respect to the overall ES provided by the Severn estuary and Bristol Channel and the data requirements and sources available to effectively map the benefit.

The Reference Group also provided environmental benefits that were not included in the shortlist and discussed the potential of these as key benefits (services) to be included in the mapping stage of the project.

Table 3.1 Shortlist of ES and environmental benefits.

Service category and benefit	Extent	Mapping method	Data available	Outcome (proceed with mapping)	Notes
Regulating services					
Carbon sequestration	All	Map data and quantify level of sequstration from data	EUNIS habitat maps from surveys and broadscale.	●	
Flood control	Coastal	Map haitat types, use damage cost avoidance methods	EUNIS habitat maps, JNCC, NE. Data values for flood water volume and location fo flooding and scale of defenses required.	●	
Habitat (biodiversity provision)	All	Map habitat data	EUNIS habitat maps, JNCC, NE	○	both as general habitat maps with limited quantification / valuation and support for migratory fish
Provisioning services					
Food (fish and shellfish)	Regional hotspots	Map fishing activity, landings value and shellfish producers quantify at locations and sales data	MMO fishing activity data, personal communication with harvesters		
Migratory fish (and nursery areas)	All	Map migratory routes for species, link recreation expenditure and food sales data to migration routes.	Mapped migration routes, environment agency surveys, fish in water intake for power stations, academic papers. Relate to angling, permit applications, reveue for towns and communities on Wye and othe r tributaries,	●	
Cultural services					
Nature tourism	Regional hotspots	Link vistior numbers to sites, accommodation stays and restaurant, amenity expenditure to sites			
Research and education	Regional hotspots	Link school visits and university visits to sites. Link research publications and studies to sites			
Sense of place	All	Review methods of recording importance of sites to individuals and communities basd on sense of place. Indicate examples of sense of place studies in the study region		○	
Cultural heritage	Regional hotspots / all	Map culturally important locations, traditional fishing, boatbuilding locations. Regions inspiring works of art. Historical importance through civilisations.		●	
Archaeology	Regional hotspots / all	Map archeological sites of importnace and areas with great archeaological potential. Note major finds and potentially indicate rarity and historical importance		●	
Carrier services					
Ports, shipping, recreational boating	Regional hotspots /all	Map major ports and berths, ships handled in one year. Map shipping traffic intensity from MMO data sets. Map receational boating facilities and frequency of use		●	

3.2 Outcome of selection process

Table 3.2 Key environmental benefits within the Severn estuary and inner Bristol Channel selected through the steering group for supply level mapping.

Ecosystem service category	Benefit
Regulating	Carbon sequestration
Regulating	Flood alleviation
Provisioning	Fish (migratory fish)
Cultural	Wet archaeology
Cultural	Sense of place
Carrier	Ports and shipping

3.3 Establishing supply levels for five key environmental benefits

The aim of this assessment was to relate the habitats and ecosystem features present in the inner Bristol Channel and Severn estuary to the level of supply of each key benefit. In determining the links between habitats and the benefits supplied, two main existing sources were used: the European TIDE project (Jacobs et al., 2013 and Liekens et al., 2013), and within UK marine and estuarine habitats, the Valuing Nature Network project (Potts et al., 2013, 2013a). The supply level designations from these two projects were adapted for the Severn estuary and inner Bristol Channel study region (using associated habitats and bathymetry).

TIDE – Tidal River Development project

The *TIDE – 'Tidal River Development'* project was a 3 year European level project conducted between 2010 and 2013 (Jacobs et al., 2013 and Liekens et al., 2013). TIDE gathered some of the leading European experts from universities, port authorities, waterways administrations and others from the Elbe (DE), Weser (DE), Scheldt (BE/NL) and Humber (UK) estuaries to find multi-beneficial solutions for future sustainable estuary development. Within the TIDE project, methodologies to map ES in European estuaries were developed to aid decision making. The methodology developed for ES supply used a system of 5 supply levels ranging from essential supply (level 5) to non-important supply (level 1). ES mapped in the TIDE project included key services selected for mapping in the inner Bristol Channel and Severn estuary, in particular, carbon sequestration (storage) and four estuarine factors that combined aid flood alleviation (flood water storage, water current reduction, wave reduction and drainage of river water). Supply levels in the TIDE project were developed for each ecosystem service through participation of estuarine management experts and involved scientists and categorised by broad habitat type, depth of substrate, steepness of slopes and salinity gradients. The projects results, particularly the methodologies developed for assessing supply levels are directly adaptable to the Severn estuary and inner Bristol Channel region. For the purpose of this project and due to time constraints the supply levels developed for key services in the TIDE project were broadened and the factors of steepness of slope and salinity were excluded (Table 3.3). It is acknowledged that future developments of ecosystem service assessment in the Severn estuary and inner Bristol Channel would benefit from including these factors in assessment of final supply levels. However, salinity gradient was found within the TIDE project to have very little effect on final supply levels by habitat type (Jacobs et al. 2013).

The TIDE results aimed to be of use in different fields of estuarine management:

- Improvement of knowledge on ES in general, addressing of knowledge gaps and further pooling of expertise.
- Aid the implementation of measures: which habitats should be maintained / restored in order to stimulate certain ES, or for obtaining the maximum supply of the entire bundle of ES.
- Aid decision making processes: which ES at which location are important or less important for the vision on a certain estuary or for the respective society / residents.
- Aid estuarine governance: so synergies and conflicting aims (with other processes) can be deduced.

The step by step approach of the TIDE study is summarised as:

1. *Important ES for TIDE estuaries were distinguished* from a "long list" of estuarine services,
2. *Variation in demand* ("societal importance") was assessed along estuaries, salinity zones and for historical, present and future time steps.
3. *Ecosystem service supply* results were attained. ES supply was compared for the different estuaries and basic underlying processes and structures were pointed out.
4. *Historical ES supply* evolution through habitat change was estimated.
5. *An indicator for trade-off risk* generated by differential supply of ES by habitats was discussed.
6. *The expected effect of estuarine management measures on ES supply* was estimated.
7. *Synergies in ES supplies* (which ES supplies are increasing together) were reviewed
8. *Recommendations for research, policy and practice* were provided

The investigation of ecosystem service delivery in the Severn estuary and inner Bristol Channel focuses on step *3.* '*Ecosystem service supply'*. The remaining steps undertaken in the TIDE project approach, particularly, *2. Variation in demand, 6. Effect of estuarine management measures*, *7. Synergies in ES supplies* and *8. Recommendations for research, policy and practice*, are highly relevant to the Severn estuary and inner Bristol Channel region. As with the investigation of ecosystem service delivery in the Severn estuary and inner Bristol Channel, the work within the TIDE project provides a broad overview of ecosystem service supply in the four TIDE estuaries, (with additional information on demand on each ES in the TIDE project). Similarly, as with mapping of ecosystem service delivery in the Severn estuary and inner Bristol Channel mapping is only the first step towards capturing the value of ES (Jacobs et al. 2013, TEEB 2010).

Table 3.3 Designation of supply levels of environmental benefits within the inner Bristol Channel and Severn estuary in relation to supply level categories within the *TIDE* project.

TIDE project supply level designations	Severn estuary and inner Bristol Channel designation
Essential supply	5
Important supply	4
Moderately important supply	3
Less important supply	2
No important supply	1

UK Valuing Nature Network – Marine Protected Areas and Ecosystem Services

This study focused on the relationship between ES provided by coastal ecosystems and the designation and management of Marine Protected Areas (MPAs). In doing so a peer reviewed study was produced (Potts et al. 2013a) which provided detailed associations between specific habitat types, (including species communities) and supply levels of key ES (Table 3.4). In relation to ecosystem service delivery in the Severn estuary and inner Bristol Channel, Potts et al. (2013, 2013a) provide a higher level of detail on supply levels from habitats and features in the Severn estuary and inner Bristol Channel region than those provided through the TIDE project (Jacobs et al., 2013, Liekens et al., 2013). These associations are particularly relevant for the supply levels by habitat and species communities present in relation to carbon sequestration and suitable habitat for wild food; fish and shellfish occurrence (including shellfish cultivation).

Table 3.4 Designation of supply levels of environmental benefits within the inner Bristol Channel and Severn estuary in relation to supply level categories within the *UK Valuing Nature Network – Marine Protected Areas and Ecosystem Services* project.

UK Valuing Nature Network supply level designations	Severn estuary and inner Bristol Channel designation
Significant contribution	5
Moderate contribution (lit. referenced)	4
Moderate contribution (expert opinion)	3
Low contribution (literature referenced)	2
Low contribution (expert opinion)	1

Jenks breaks

For key environmental benefits where supply levels were designated from existing numerical data, for instance the abundance of salmon in tributaries to the Severn estuary using the estuary as a migratory route, Jenks breaks were used to ascertain supply levels. Jenks breaks cluster data in a given number of categories through calculations that ensure highest statistical differences are present between each category. To designate supply levels using Jenks breaks the total data set (for instance salmon abundance in tributary rivers) was selected and using Jenks breaks calculations was separated into 5 categories from lowest abundance / value (1) to highest (5) abundance / value ranges to provide a supply level between 1 (lowest) and 5 (highest).

3.4 Spatial mapping of environmental benefit supply levels

- *Planning cells*

Geographical information system software (ESRI ARC GIS 10) was utilised to spatially represent environmental benefit supply level data across the Severn estuary and inner Bristol Channel estuary region. The mapping approach divided the study region into 10km² hexagonal planning cells (Figure 3.1) (Rees et al., 2010). For each of the 5 key environmental benefits to be mapped, supply level scores for each planning cell in the GIS were designated as discussed in section 3.3. Habitat and species presence as well as bathymetry were the key environmental features responsible for the delivery of environmental benefits. Where benefit supply level related to underlying habitat or features the highest value for habitat or features present in any portion of the planning cell was assigned as its overall value (rather than, for example, an average). It is recognised that an average would provide a closer representation of the delivery of each supply level. However, the use of the maximum supply level related closer to the aim to provide a snapshot to identify 'hotspots' of ecosystem service (ES) delivery and to enable a precautionary approach in decision making..

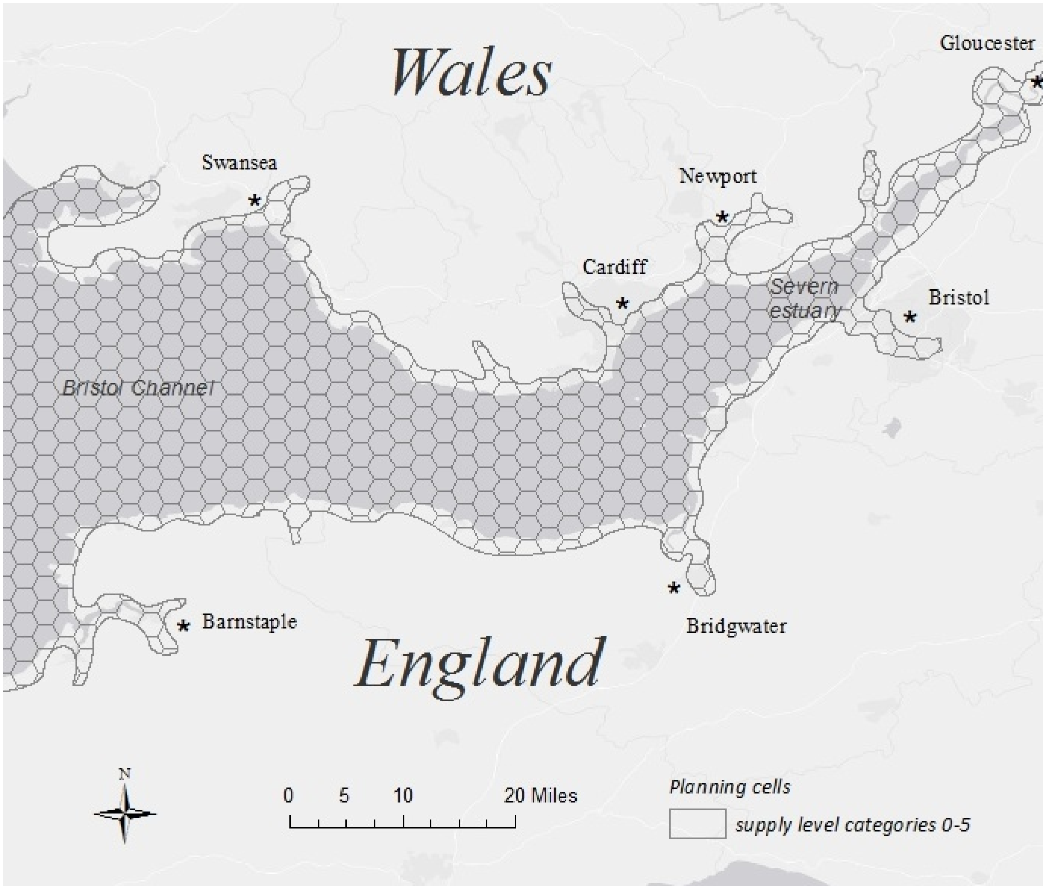

Figure 3.1 The 10km² hexagonal planning cells utilised to display spatial supply levels of key environmental benefits.

• *Habitat data*

Habitat type data for the greater Severn estuary and inner Bristol Channel region was accessed through data layers provided by the EC's INTERREG IIIB NWE Programme's Mapping European Seabed Habitats Project (MESH), which ran between 2004 and 2008. The MESH project utilised expertise and data through a consortium of twelve partners from five European countries and contains data sets in GIS format on marine habitats. Detailed data on specific habitats, such as salt marsh extents, already in GIS formats were accessed from UK's Joint Nature Conservation Committee (JNCC) and Natural England (NE) data portals. Three levels of habitat detail were available once MESH, JNCC and NE data sources were combined.

1. The least detailed level of habitat data, accessed through JNCC's UKseamap provided broad-scale predicted (modelled) substrate types derived in the absence of full surveys.
    - These data were only required for small spatial scales within the inner Bristol Channel region (Figure 3.2).
2. The next most detailed level of habitat data provided substrate type derived from surveys.
    - These data were available through the MESH project and extended through subtidal regions in the inner Bristol Channel region Figure 3.2).
3. The most detailed level provided habitat data derived from surveys, containing sediment type, tidal information (littoral / intertidal, infralittoral / shallow at low water, circallitoral / deeper at low water) and species presence.
    - These highest level data were available through the MESH project for the Severn estuary region and coastal regions of the inner Bristol Channel (Figure 3.2).

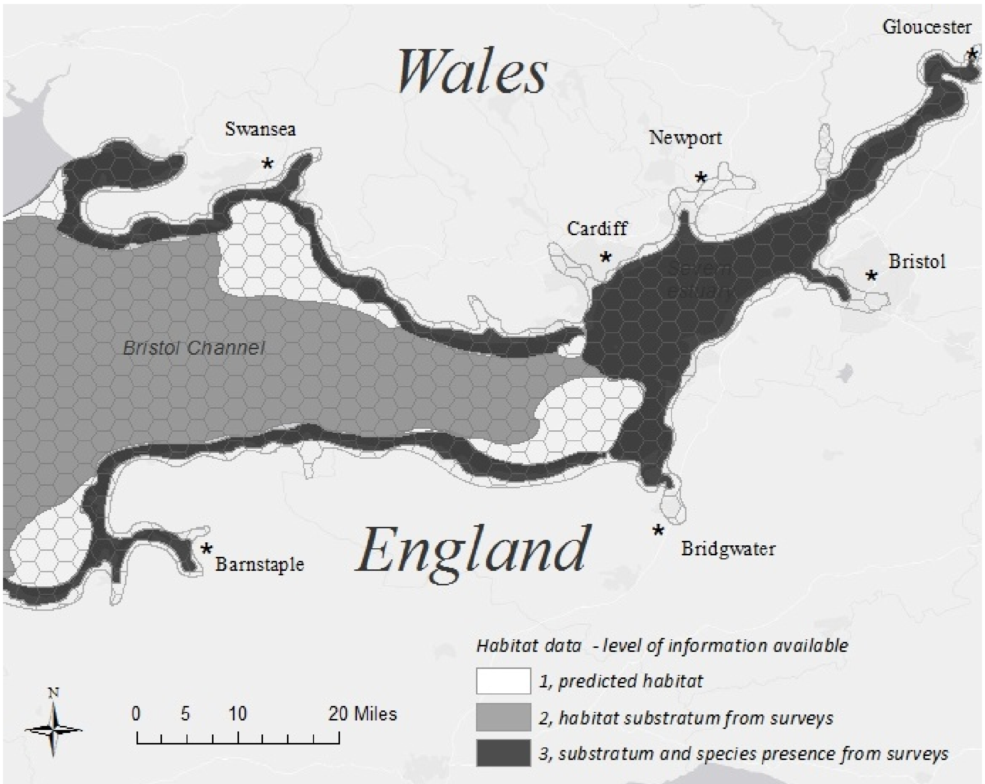

Figure 3.2 Level of habitat detail available across the study region

• *Bathymetry data*

Bathymetry information was derived from admiralty charts, downloaded in GIS format from *digimap* resources (Edina). Bathymetry contours for <2 metre depths, 5 metre depths and finally > 5 metre depths were mapped within the 10km² hexagonal planning cells (Figure 3.3).

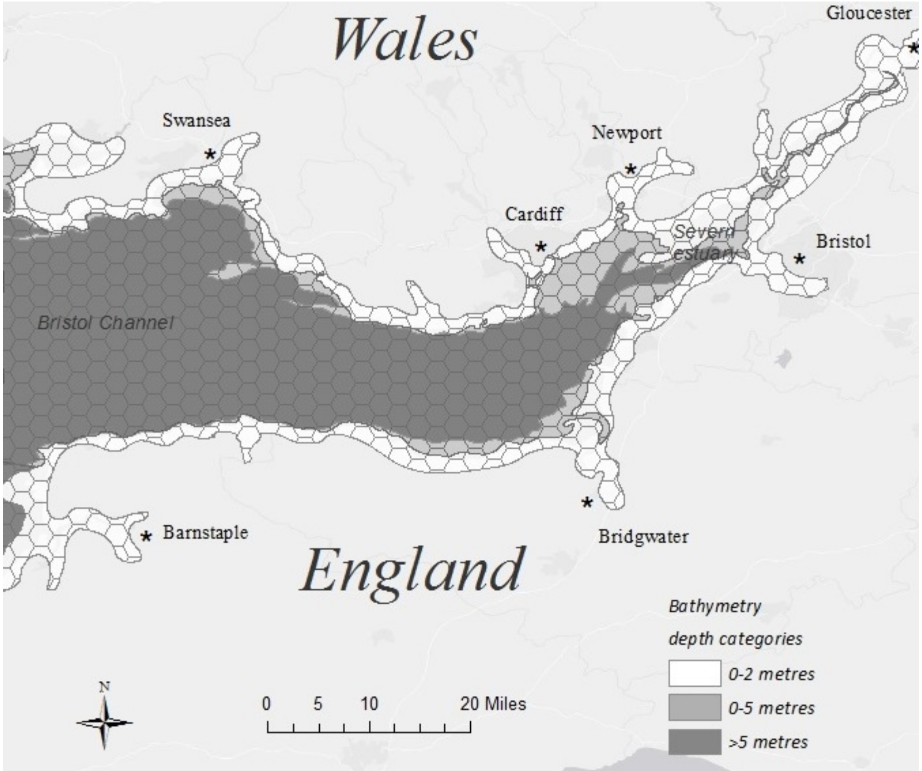

Figure 3.3 Bathymetry depth categories from charted data, accessed from *didgimap* resources *(EDINA).*

3.5 Valuation methods in relation to supply levels

The mapping of supply levels for each key environmental benefit across the Severn estuary and inner Bristol Channel region was intended to provide a base layer for application of valuation techniques. The main aim of the project was to demonstrate the presence and level of supply of each key ES benefit. Assessment of ES delivery or benefit supply is kept separate from valuation in this project unless direct marketable values (such as value of goods shipped from different ports) are used to establish supply levels. This has been done to avoid the contentious issues surrounding many valuation techniques. As multiple ES are being mapped in this project many different valuation methods are applicable. This would potentially create confusion in the interpretation of 'hotspots' or comparing the importance of one location with another. For instance, designating the importance of a location by comparing the presence of a Mesoltihic footprint with the presence of a deep channel for shipping is challenging in purely monetary terms, as the importance to humans and society are essentially very different from each. Presenting the location and level of supply (e.g. number of finds or level of shipping traffic) and relating this to the habitat and features present is intended to show where each ES benefit occurs and needs to be considered when assessing the impacts of developments or planning decisions.

The aim of the project is to highlight areas supporting greater supply of ES benefits and how different features of the study area support different benefits. Ecosystem service valuation methods are discussed in detail in Section 1. The following sections (4-9) provide the results of mapping of supply levels of each of the key environmental benefits selected within the *Ecosystem Service Delivery within the Severn Estuary and Inner Bristol Channel* project. Valuation methods applicable to each environmental benefit and associated supply levels are summarised in these individual sections with the intention they can be taken forward or developed in future work.

Section 4 Benefit: **Ports and Shipping**

Ecosystem service category

Carrier

4.1 Background

Bristol has historically been one of Britain's biggest ports of notable industrial, military importance and cultural importance. The more modern, major port facilities at Royal Portbury and Avonmouth Docks which together comprise Bristol Port, the largest port in the Severn Estuary and Bristol Channel, continue the global connections maintained by the region. Port Talbot, Swansea, Cardiff and Newport are amongst Wales' largest ports with great historical and cultural connections to the coal mining industry and present day connection to the steel industry. Smaller ports such as Sharpness, Barry, Neath, Burry Port, the Port of Bridgwater, Appledore, Bideford and Barnstaple, Ilfracombe, Lydney and Gloucester also maintain cultural links to shipping and ship building and traditional fishing industries. Recreational activities are supported by marinas providing a facility for recreational boats, such as Portishead Docks and a number of other marinas located within the Severn Estuary and Bristol Channel, including within the Cardiff Bay Barrage and Sharpness, Bristol City and Lydney Docks.

The inner Bristol Channel and Severn estuary therefore provides crucial links to export and import goods and associated economies and employment. The space and navigation routes provided by the estuary, the facilities of ports and smaller access routes such as slipways provide a substantial cultural benefit for other activities such as recreational boating and fishing.

4.2 Aims and scope

This section aimed to map benefit supply from Ports and Shipping by taking a region wide approach looking at broad characteristics (bathymetry and shipping intensity) to identify the pilotage channels (level of shipping spatially) within the study region and the level of goods (tonnage of imports and exports) passing through each port. This approach intended to highlight shipping routes to provide an indication of areas that could be impacted by development and planning decisions. The potential effect on import and export business was also intended to be demonstrated at a broad scale. Limitations are identified in relation to this broad summary approach that future assessments could address, most notably that there is data available to assess actual value and final destinations of goods.

4.2 Mapping methods

Two maps were produced, adapting approaches provided in Jacobs et al. (2013). Government trade data were utilised to map market supply levels of ports dependent upon tonnage of imports and exports. Supply levels for regions within the Severn estuary and inner Bristol Channel that provide channels for pilotage were also mapped through spatial assessment of shipping intensity data.

Individual ports were mapped with supply levels generated through Jenks breaks of data for tonnes of goods handled annually (HM Government 2012) (Figure 4.1, Table 4.1). The physical space and environmental conditions (such as deep water channels) providing beneficial access to major ports, cities and inland transportation were mapped through data on the number of ships passing annually through each planning cell (spatial shipping intensity) (Figure 4.2, Table 4.2). Shipping intensity data were derived from data sets within the Marine Management Organisation's (MMO) marine planning portal which originally utilised ship satellite positional data (AIS) (MMO 2013). A data confidence map was produced for the shipping intensity data as AIS data through the MMO's marine planning portal only extended to Newport/Bristol region at the mouth of the inner Severn estuary (Figure 4.3). Larger planning cells of 40km ² were utilised for the shipping intensity map to reflect the scale of the cells provided on the MMO marine planning portal.

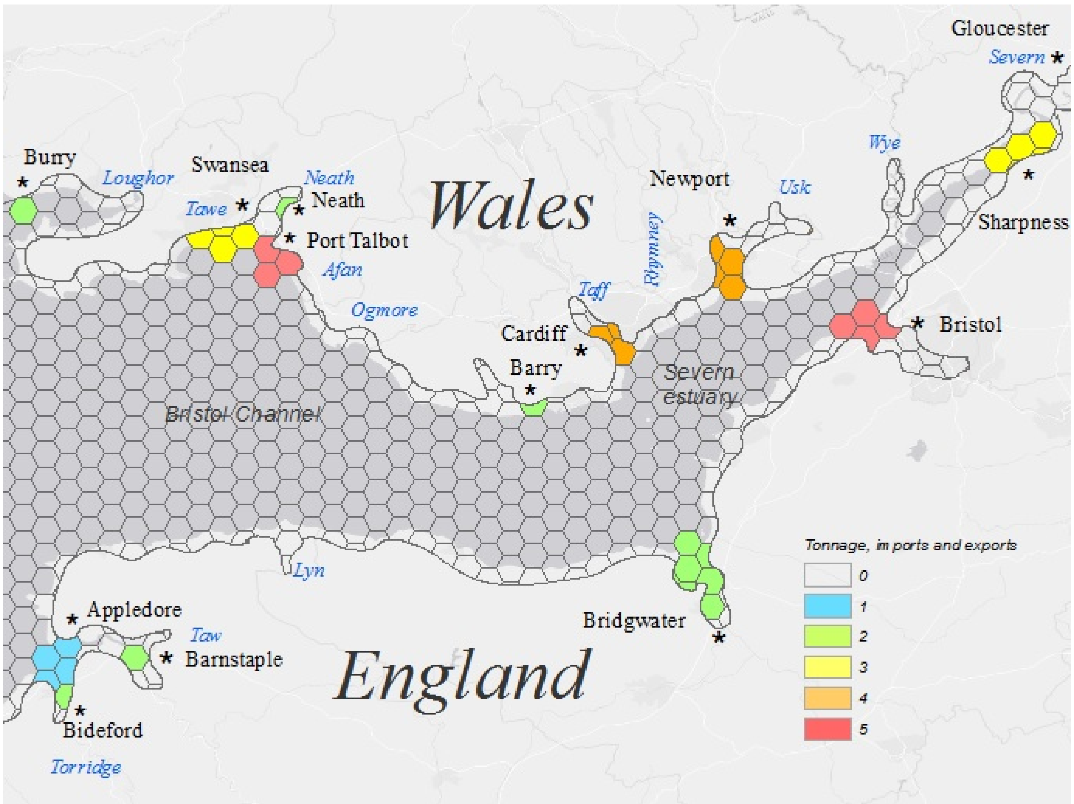

Figure 4.1 Map of ports in the study region indicating tonnage of goods handled annually (both imports and exports), tonnage ranges applicable to the supply levels 1 (lowest) to 5 (highest) are given in Table 4.1

Table 4.1 Annual Imports and exports (thousand tonnes) supply level (1-5) designations based on Jenks breaks in the original data set

Benefit supply level	Imports and exports (thousand tonnes) (Jenks breaks)
0	no data
1	0.1-40
2	40.1-412
3	412.1-604
4	604.1-2232
5	>2232

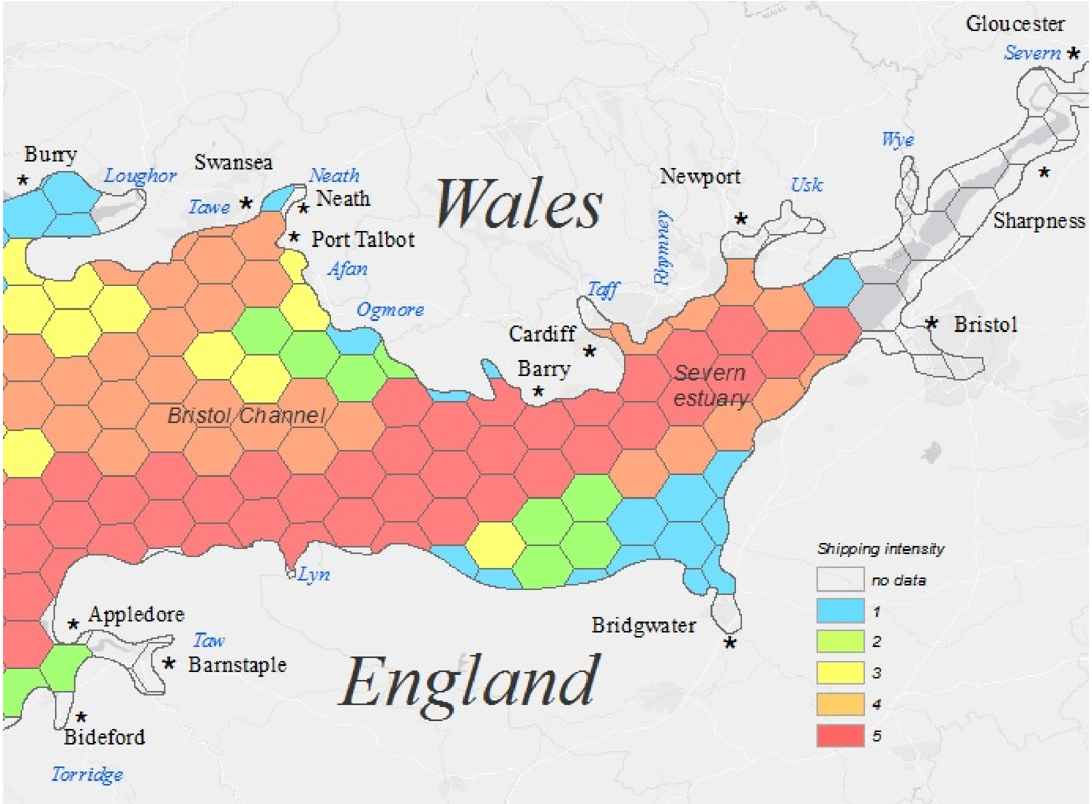

Figure 4.2 Shipping traffic intensity reproduced from MMO marine planning portal data, shipping density (No. ships) ranges applicable to the supply levels 1 (lowest) to 5 (highest) are given in Table 4.3. Data was only available for the Bristol Channel region, therefore, the Severn estuary region appears as 0 (no data). The larger scale 40km² planning cells reflect the broader scale grid provided by on MMO marine planning portal.

Table 4.2 Annual shipping intensity supply level (1-5) designations based on Jenks breaks in the original data set.

Benefit supply level	Shipping intensity (vessels per year, 2012/2013)
0	no data
1	0-40
2	40.1-160
3	160.1-1280
4	1280.1-5120
5	5120.1-10240

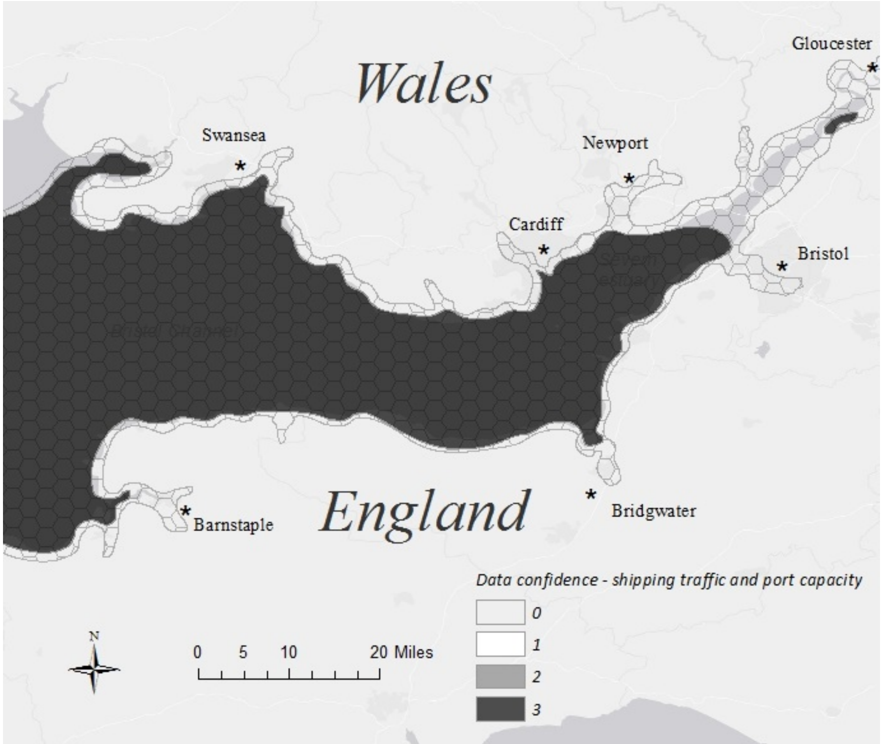

Figure 4.3 Data confidence for shipping traffic assessment

4.3 Valuation methods

Straightforward valuation techniques are possible for ports and shipping due to the presence of the large amount of marketable goods and trade involved. This provides a means to calculate transportation costs per tonne per km. The habitat and natural features of the ports, estuary and sea routes influence this value as larger deeper ports can accommodate larger ships which reduce transport costs and attract large volumes of trade and associated employment. Valuation methods associated with ports therefore cover a variety of direct market and wider social factors, such as:

- Jobs created by ports
- Value of goods and final destination in relation to ports and shipping channels
- Cultural significance

Liekens et al., (2013) provide useful guidance on valuation of ports and shipping, suggesting the value of the navigation service can be estimated by looking at the additional costs or gains for the transportation sector and for society if shipping navigation possibilities decline or improve in a given scenario.

In any given scenario the valuation of the transportation service can be determined in comparison with an alternative situation. As shipping is, on average a cheaper and cleaner mode to transport goods, alterations to ports and shipping channels will lead to additional transportation costs for the sector and society (Liekens et al., 2013). Five different types of costs which can be estimated to provide comparisons for future scenarios are reviewed by Liekens et al., (2013):

- Efficiency gains or losses, e.g. due to more or less tonnes of goods or shipping intensity.
- Time gains or losses due to faster or slower trajectories for shipping and or time required to enter the port.
- Additional costs or benefits related to longer or shorter trajectories.
- Shifts in benefits or costs, if goods are transported by other modes (such as air, road, rail) that are less or more expensive.
- Environmental benefits or costs linked to shorter or longer trajectories and / or shifts in mode of transport for goods.
- Costs of additional measures (e.g. dredging) to prevent any of the cost categories previously mentioned.

4.4 Interpretation

- *Sheltered, deep, navigable channels, lead to natural harbours and man-made ports at the heart of major cities, road and rail networks serving national and international trade.*

In addition to the environmental benefits (regulating services such as carbon sequestration and provisioning services, such as migratory corridors and suitable habitat for fish of conservation importance) the geographic and bathymetric features of the Severn estuary and inner Bristol Channel provide significant links to English, Welsh and global trade and industry. The presence of large ports, handling the largest ships within a deep, sheltered sea way and in close proximity to major road and rail networks provides a vital benefit. Together major and minor ports in the Bristol Channel handled almost 25 Million tonnes of freight in 2013 (24,982 M t) which amounts to 4.9% of the total freight traffic in all UK ports. The majority of this trade passes through Bristol Port, over 10.5 million tonnes, and Port Talbot, almost 8.5 million tonnes (UK, Department for Transport 2014).

Mapping results clearly show the links between the largest ports such as Port Talbot, Newport and Bristol and international shipping, with a clear shipping lane visible through the deepest water channel. Although from the initial data provided in the MMO marine planning portal limitations are identified below in the GIS method used to transfer the data to a smaller spatial scale as this over estimates the area covered by the shipping lane. Next steps to assess the environmental benefit supply provided by this feature include calculating transportation costs per tonnes per km within the major shipping channel to provide a baseline to compare with future scenarios.

4.5 Limitations

It is acknowledged the current maps could be improved with inclusion of data (available through regional Ports (such as Bristol Port) on the individual goods imported and exported through each port. This would provide more detailed market valuation on the goods that tonnage may miss due to the value of smaller items. The individual value of goods type and data on the final destination of each imported and exported good type would provide the data needed for assessing costs of alternate transport methods. Providing final destination would also be important in identifying the role of Severn estuary and inner Bristol Channel within international and global trade (also available through certain ports, such as Bristol Port). Such data could also be used to improve detail of mapping of shipping intensity. The MMO data set interpreted utilised AIS data and did not provide data for the

Severn estuary. Where data is missing expert judgement could be employed on the basis of Government shipping statistics. For instance, Gloucester Harbour Trustees report that there were 178 ship visits in 2013 (and much more if you include channel movements of aggregate dredgers and recreational craft) – this is the equivalent of Benefit supply level 3. A further data layer utilising expert judgement and shipping statistics would improve the evidence provided by the broad scale maps displayed in this report.

Transferring AIS data from the broader scale information provided by the MMO marine planning portal to the smaller scale planning cell resulted in overestimating the extent of the shipping lane. Planning cells with only very small portions of the cell receiving higher levels of shipping still reflect this high level across the whole cell. Using a larger spatial scale planning cell for shipping activity data was required to more accurately reflect the original data. Original shipping trajectory data alongside maps utilising expert judgement and shipping statistics would provide further evidence at a more accurate scale and on a port specific basis.

Section 5. Benefit: Carbon Storage (sequestration and burial)

Service category

Regulating

5.1 Background

Coastal and marine ecosystems play a particularly valuable role in the capture and storage of atmospheric carbon dioxide CO_2 . Termed blue carbon, vegetated coastal ecosystems such as seagrass beds, salt marshes and mangrove forests contribute much greater to long-term carbon storage per unit area of habitat than terrestrial forests (Mcleod et al., 2011). In part this is due to the ability of marine and tidal habitats efficacy in trapping suspended matter and associated organic carbon during tidal cycles (Mcleod et al., 2011).

Carbon storage within marine, coastal and estuarine habitats is likely to be of particular relevance to efforts to avoid damaging climate change and could be particularly relevant to marine renewable energy (MRE) development in the greater Severn. Maintaining hotspots in the greater Severn – those with high carbon storage properties- could be key to environmentally responsible development..

5.2 Aims and scope

Assessing storage of carbon by terrestrial and marine habitats and species has received increasing attention in recent literature. Existing methods for elucidating carbon storage benefit supply levels for marine and estuarine habitat types are adapted for mapping this key ES within the study region. This approach aims to provide a tool for identifying the locations of particular importance to carbon storage in the region. It is recognised in the limitations section that ground-truthing the actual levels of carbon storage in habitats within the estuary would increase confidence in assessments of carbon storage benefit supply. The mapping approach also assigns the highest benefit supply level relating to the various habitat and species present in a given planning cell. This precautionary approach aids identification of the locations of the highest benefit supply levels. However, the approach will potentially over assess the actual benefit supply level and consultation with more detailed habitat maps and in field sampling are recommended for impact assessments in relation to development and planning decisions.

5.3 Mapping methods

Existing studies provide detailed values on carbon sequestration (storage) of individual marine and estuarine habitats (Romero et al., 1994, Chmura et al., 2003, Andrews et al., 2006, Jones et al., 2008, Painting et al., 2010, Alonso et al., 2012). Reviews by Alonso et al. (2012) have utilised these individual studies to summarise data on carbon sequestration for each habitat type in grams of carbon per square metre, per year (Table 5.1). The European TIDE project (Jacobs et al. 2013) and Liekens et al. (2013, 2013a) and the UK, Valuing Nature Network project (Potts et al. 2013, 2013a) provide further resources and guidance on identifying relationships between specific European estuarine and marine habitat types and carbon sequestration levels. These studies provided criteria for identifying carbon sequestration supply levels in accordance with habitat maps for the greater Severn estuary and inner Bristol Channel region. Mapping within the GIS applied the methods reviewed by Crossman et al. (2013), utilising the spatially explicit planning cells (10km² planning units) within the GIS to express carbon sequestration dependent upon habitat type within each cell (Rees et al 2010). Supply levels identified for each planning cell were dependent upon the habitat with the highest supply level present in each cell (Table 5.2).

Habitat data from surveys and predicted broad-scale habitat data within the Severn estuary and inner Bristol Channel (Section 3.4) were used in conjunction with the data sets on carbon sequestration values complied by Alonso et al. (2012) and supply levels designated by Liekens et al. (2013), Jacobs et al. (2013) and Potts et al. (2013, 2013a) to identify habitat specific supply levels between 1 and 5 (1: negligible supply, 2: low contribution, 3: moderate contribution, 4: significant contribution, 5: essential contribution (Table 5.2).

Table 5.1. Carbon sequestration values in g C m^{-2} yr^{-1} for common habitats in the greater Severn estuary, adapted from Alonso et al., 2012.

Habitat	C sequestration g C m^{-2} yr^{-1}	Reference
▪Saltmarsh	210	Chmura et al., 2003
▪Intertidal mud	16	Andrews et al., 2006
▪Sand dunes	58-73	Jones et al., 2008
▪Subtidal coarse sandy sediments	>10	Painting et al., 2010
▪Sea grass meadow	20-200	Romero et al., 1994
▪Kelp forest	~400	Gevaert et al., 2008

Table 5.2. Environmental benefit supply level derived from existing studies for a) broad scale habitat only and, b) broad scale habitat and species presence, adapted from Alonso et al., (2012).

Supply level	**Broad scale habitat** (adapted from Liekens et al. (2013), Jaobs et al. (2013), Alonso et al. (2012))	**Detailed habitats** (adapted from Potts et al. (2013) in addition to, Liekens et al. (2013), Jaobs et al. (2013), Alonso et al. (2012))
5, essential supply	salt marsh and reed beds	▪ salt marsh ▪ reed beds ▪ kelp (*Laminaria spp*.) communities
4, important supply	mud dominated habitat	▪ mud dominated habitat, ▪ seaweed communities (e.g. fuccoid communities) ▪ mussell beds
3, moderate supply	sand dominated habitat	▪ sand dominated habitat with burrowing fauna communities ▪ biogenic reefs (e.g. *Sabellaria*) ▪ oyster beds
2, low supply	gravel dominated habitat	▪ gravel dominated habitat with burrowing fauna communities
1, negligible supply	rock dominated habitat	▪ rock dominated habitat with no fauna or flora species identified
0, no data available	_	_

Following analyses of the habitat present in the study region and associated supply levels according to existing literature two maps were produced,

1. The first displayed carbon sequestration supply levels dependent upon broad scale habitat type only (Table 5.2, Figure 5.1).

This method utilised the carbon sequestration by habitat type data compiled by Alonso et al. (2012) (Table 5.1) and relevant broad scale habitat supply level designation provided by Jacobs et al (2013) (Table 5.2, Figure 5.1).

2. The second map displayed carbon sequestration supply levels using more detailed habitat information, dependent upon flora species present in addition to broad habitat type (Table 5.2, Figure 5.2)

This method utilised the species presence, identified in the highest level survey data (Figure 5.2). Carbon sequestration by habitat type data compiled by Alonso et al. (2012) was combined with supply levels of carbon sequestration by UK marine habitats identified by Potts et al. (2013, 2013a) in addition to those identified by Jacobs et al. (2013). Potts et al. (2013, 2013a) provide supply levels dependent upon species presence (such as seaweeds, in particular kelps) as well as substratum to provide a more detailed assessment, especially for rock substrate (Figure 5.2).

Confidence maps relating to mapped results were created to indicate the level of detail provided by data resources:

1: Limited confidence (data providing predicted habitat only),

2: Moderate confidence (survey data indicating substrate only)

3: Good confidence (survey data indicating substrate and species presence) (Figure 5.3).

5.4 Mapped results

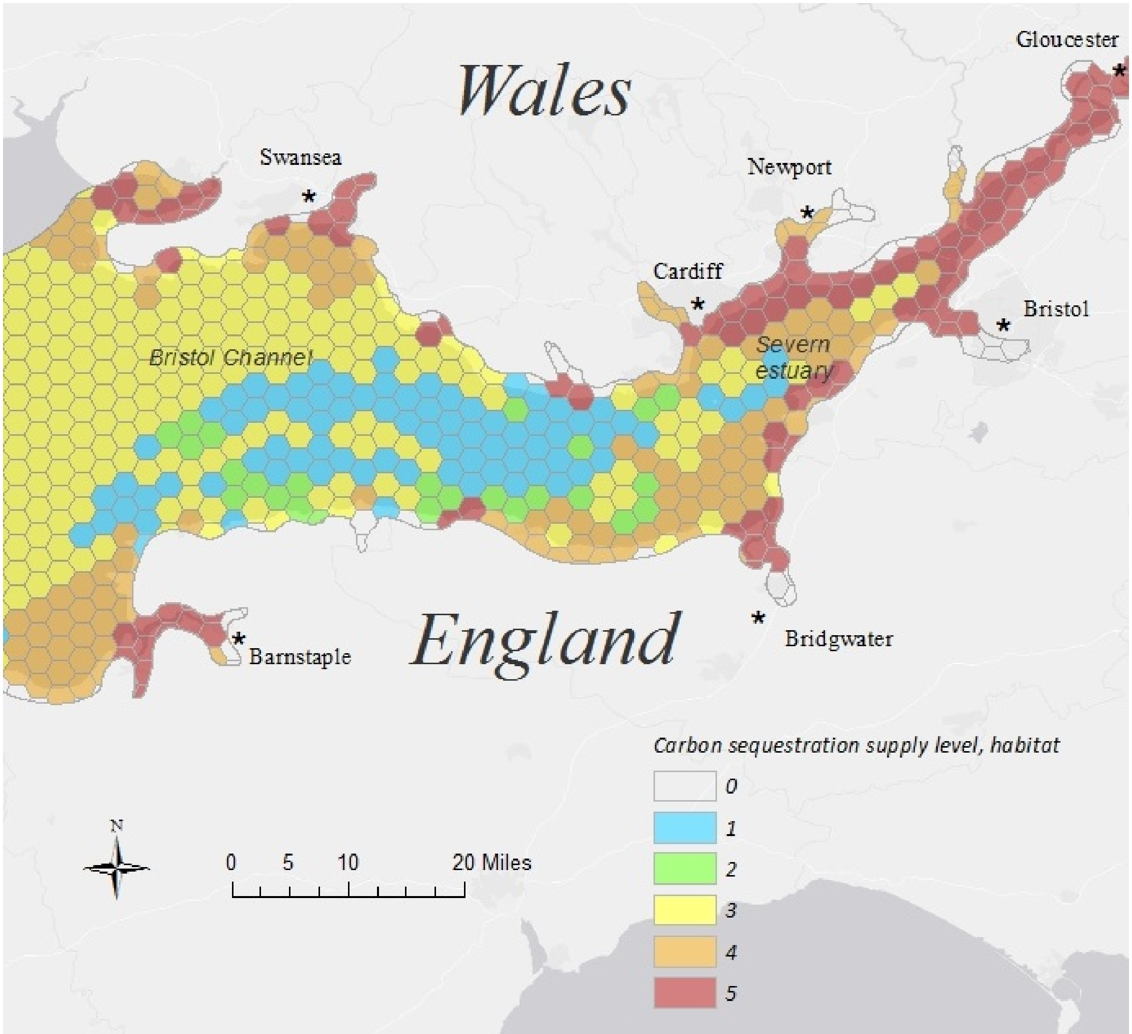

Figure 5.1 Carbon sequestration supply levels for broad habitat type based on substratum type only, using supply levels from data compiled by Alonso et al., (2012) and categories designated by Jacobs et al., (2013).

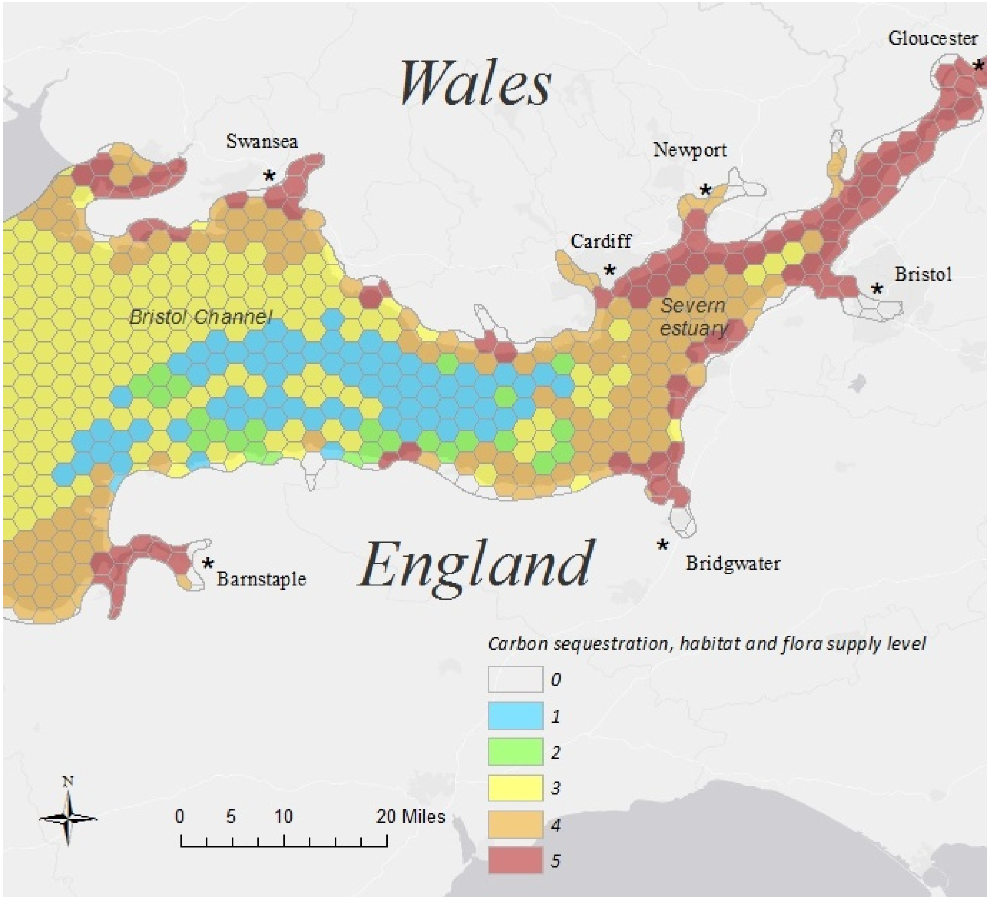

Figure 5.2 Carbon sequestration supply levels based on detailed habitat type (substratum and species) using supply level categories designated by Potts et al., (2013, 2013a) and Jacobs et al., (2013).

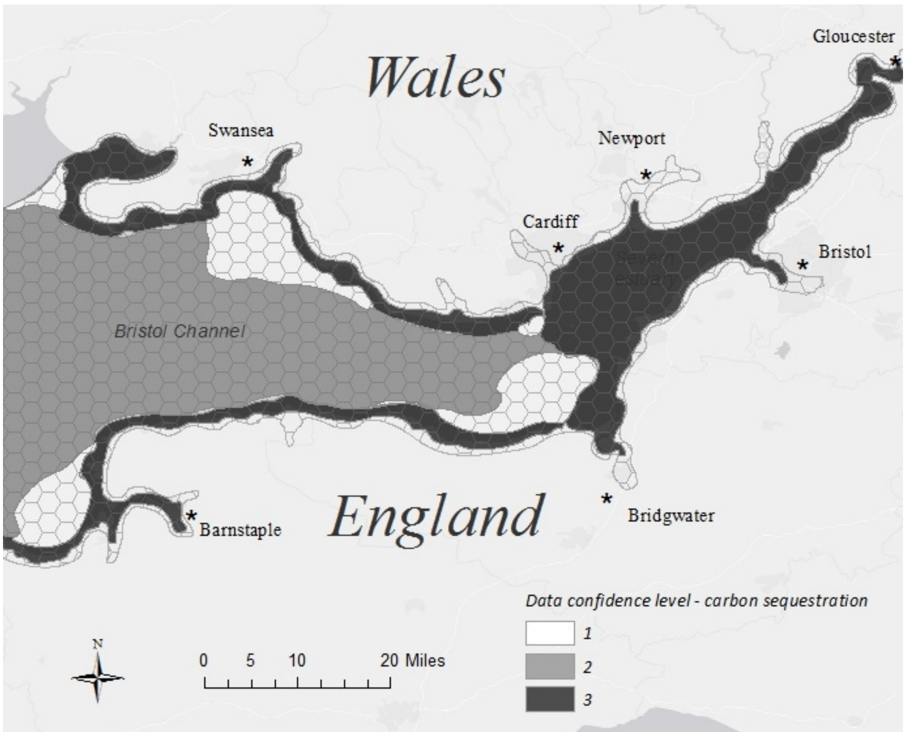

Figure 5.3 Data confidence levels (predicted habitat only =1, substratum only provided by surveys =2, substratum and species provided by surveys =3).

5.5 Valuation methods

Social Cost of Carbon (SCC) is the most commonly used approach to value the sequestering of carbon stock in living vegetation and burial of organic matter in soils, and thereby the reduction in the amount of greenhouse gases in the environment. SCC refers to the value of climate change impacts over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. (i.e. the marginal global damage costs of carbon emissions) (Liekens et al., 2013). The benefits of carbon sequestration are noted to rise in the future because the damage by climate change will increase in the future due to growing populations, and infrastructure and energy demands of future societies (Liekens et al., 2013).

A recent study using samples from estuarine saltmarsh and estuarine mudflats valued sequestration within saltmarsh to be £94/ha.year and intertidal mudflats at £52.2/ha.year (Adams et al. 2012). To provide an indicative indication of the potential value, a simple multiplication of this value suggests that just one 10km² planning cell within the study region, values of £94000/planning cell.year are produced for saltmarsh habitat and £52200/planning cell.year for intertidal mudflats. It is important to note that saltmarsh habitat does not extend throughout the entirety of many of the planning cells due to their large area, however intertidal mud flats encompass many of the shore-wards planning cells. Regarding saltmarsh specifically the Severn estuary alone contains 1400 ha (Severn Estuary Partnership 2011). The calculations provided by Adams et al., (2012) (reproduced in Liekens et al., (2013)) suggest that these saltmarshes alone provide a value of £131600 within the Severn estuary per year, although a formal benefits transfer process should be applied to more accurately determine how these published values might related to the Severn estuary.

5.6 Interpretation

- *Intertidal habitats provide significant carbon storage benefits*

- Saltmarsh habitats within the Severn estuary and estuarine regions within the inner Bristol Channel are of national and European importance due to the large extent of the habitat type (Severn Estuary Partnership 2006). The huge tidal range also reveals large extents of mudflats between tides. The social value of carbon sequestered by these habitats, calculated by Adams et al., (2012) and extent of these habitats (with highest benefit supply levels of 4 and 5) reveals the importance of these habitats within the region and their importance in ensuring the rate of climate change and associated risks is reduced for future societies.
- Whilst saltmarsh habitat may provide carbon storage capabilities beyond those of terrestrial forests (Mcleod et al., 2011) the spatial extent of intertidal mudflats in the study may provide important benefits to the supply of this ES. The contribution of intertidal mud flats requires further research to establish the actual benefits to carbon storage, research at a site specific level would provide valuable evidence on the contribution of these habitats.
- Impact assessments would benefit from examining the implications of developments to existing carbon storage properties.

5.7 Limitations

- Assigning the highest benefit supply level in relation to habitat present within a planning cell across the entire planning cell may over assess carbon storage across the cell.
- In field sampling of actual carbon storage levels and CO^2 equivalent flux levels present within the regions habitats would reduce the uncertainty of applying data from studies from other localities.
- Levels of primary production (photosynthetic plankton) are also identified by Jacobs et al. (2013) and Potts et al. (2013, 2013a) as aiding wider climate regulation as an ES. This factor can be assessed through satellite derived primary productivity from SeaWifs chlorophyll a data for the Severn estuary and inner Bristol Channel region. However, the role of primary productivity in carbon storage as an ES is debated and would require further research to establish confidence for utilisation in ES assessment.
- Although intertidal mud habitats are reported as being of high importance in relating literature (Jacobs et al., 2013, Liekens et al., 2013, Alonso et al., 2012., Andrews et al., 2006) in field data studies are scarce for this region. Factors such as erosion of sediment may affect actual values of carbon storage levels and CO^2 equivalent flux levels. Further analyses of actual in field levels of carbon storage, alongside modelling of erosion over calculation periods are required for these habitats to make a full assessment of supply levels.

Section 6. ***Benefit: Flood risk management***

Ecosystem service category

Regulating service

6.1 Background

Managing flood risk around the greater Severn is key with roles for both man made defences and .the protection provided by habitats such as salt marshes. These natural systems can reduce the need for some built developments, and so avoid both the cost of construction and loss of natural landscape associated with them (Figure 6.1). Alteration of these habitats could also potentially lead to extensive costs from flood damage to homes and businesses, thereby requiring significant man-made flood defences to be constructed if habitats are removed.

Figure 6.1 Estuarine saltmarsh, (image reproduced from Linda Hartley, flickr creative commons).

Environmental benefits from habitats that reduce flood risk are therefore provided by natural features which can be mapped and assessed. The damage prevented and the avoidance of the construction of extensive flood defences due to these features can be counted and valued as costs avoided.

Habitats in the study region have traditionally provided natural flood protection through the intertidal zones, rocky shores, salt marshes and sand dunes providing barrier zones between habited land and the estuarine / marine environment. These physical properties of the inner Bristol Channel and Severn estuary provide significant natural flood defences in a region that contains many habited regions considered at risk from flooding (Figure 6.2). Existing protection from the environment includes the natural bathymetry to aid water drainage and intertidal features to provide a buffer zone to rising waters. As towns have extended onto previous flood plains the flood protection benefits of various habitats have become increasingly valuable.

.

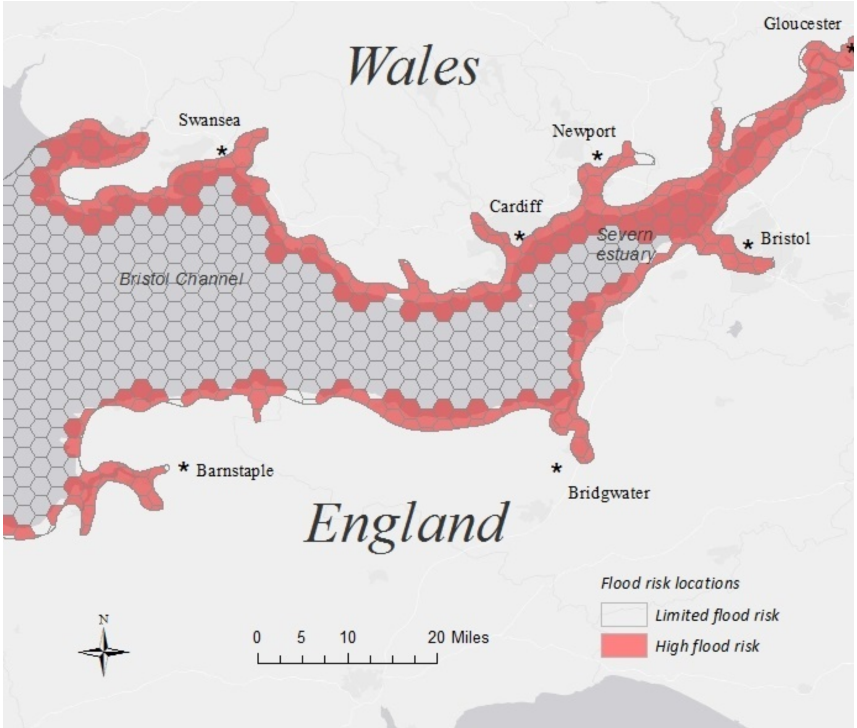

Figure 6.2 Environment agency flood alert and flood warning regions (shaded planning cells)

Intertidal habitats within the inner Bristol Channel and Severn estuary, in particular salt marsh, provide significant natural flood prevention. The Estuary's salt marshes are also of international importance, due to their dependence upon a narrow range of environmental conditions, and as such are designated as an Annex 1 Habitat and a Biodiversity Action Plan (BAP) Priority Habitat. The Severn estuary's saltmarshes provide the largest aggregation of saltmarsh habitat in the south and southwest of the UK, covering about 1,400 ha, representing 4% of the total area of saltmarsh in the UK (Severn Estuary Partnership 2011).

6.2 Aims and Scope

Flood risk management within the study region involves whole tributary catchment systems. To fully assess this ES benefit, models providing information on drainage, topography and soil properties amongst other factors would be needed. This section looks at the estuarine and marine Severn estuary and inner Bristol Channel only and applies existing habitat supply level criteria for estuarine and marine habitats developed by two key existing studies (the TIDE project, Liekens et al., 2013, Jacobs et al., 2013 and the Valuing Nature Network project , Potts et al., 2013, 2013a). The aim of this section was to identify the location and supply level of habitats and features reducing flood risk within the estuary and marine habitats. The limitations section highlights that inclusion of the entire terrestrial catchment is required for full assessment of flood risk management by the environmental features in the region. It is also acknowledged that flood protection is only one element, and the different habitat's role in mitigating coastal erosion is also of great importance.

6.3 Mapping methods

Habitat data maps and bathymetry data were utilised to establish supply levels for flood risk management within the Severn estuary and inner Bristol Channel study region (Figures 3.2, 3.3).

Existing methods provided by Jacobs et al., (2013) and Liekens et al., (2013) for evaluating flood prevention environmental benefits from estuaries were applied to assess flood risk management by habitats and bathymetry features in the study region. Four factors (provided by natural features) are considered by Jacobs et al (2013) (adapted from Liekens et al., 2013) which together act to limit damage from storms or extreme spring tides:

1. *Flood water storage based on physical properties of estuary*
2. *Water current reduction*
3. *Wave reduction*
4. *Drainage of river water*

Mapped results were produced for each of these four factors within the study region with confidence assessment maps for the data used to ascertain supply level scores (Figures 6.4, to 6.8, confidence assessment map, Figure 6.9). A final map was also produced combining total supply levels, summing supply levels for all four factors within planning cells across the study region (Figure 6.8).

1. Flood water storage based on physical properties of an estuary

The excess water that threatens to cause flooding is stored by intertidal habitats and habitats directly beyond intertidal habitats, particularly marshes (such as salt marshes). Jacobs et al. (2013) and Liekens et al. (2013) provide marsh habitats with the highest score in the narrower, upper reaches of an estuary. In the broader lower reaches of estuaries sub-tidal habitats and bathymetry play a greater role and are scored accordingly. This is because sub tidal habitats and bathymetry determine the amount of water coming into the estuarine funnel. In the case study examples provided by Jacobs et al (2013) scores (1-5) referring to the level of supply of flood prevention environmental benefits were decided by expert assessment, levels were spatially mapped relevant to distribution of features. Due to the projects broad approach and as the Severn estuary and inner Bristol Channel study region encompasses a number of tributary estuaries saltmarsh and bathymetry supply levels were kept consistent across the region. More detailed studies of individual sites within the study region would benefit from adopting the full approach detailed by Jacobs et al. (2013).

The methods provided by Jacobs et al (2013) identify flood water storage for four European estuaries based on average habitat-specific supply scores. The five point supply score scale indicates an essential supply from the habitat in a location through to a non-important supply from the habitat in a given location (Figure 6.3)

5. Essential supply
4. Important supply
3. Moderately important supply
2. Less important supply
1. No important supply

Decreasing importance of supply

Figure 6.3. The five point supply score scale applied to level of flood prevention provided by habitats within a given location (Jacobs et al., 2013).

The habitat features of importance to the supply of flood prevention benefits within a given location are summarised as:

- Shape and volume of the estuary: determines the volume and speed of the tidal wave (of greater importance in lower estuary).

- Extent of intertidal and mainly marsh habitat (which is close to critical elevation for flooding): determines the amount of water potentially stored (of greater importance as the estuary narrows).

In respect to criteria provided by Jacobs et al., (2013) supply levels for flood water storage saltmarsh received the highest benefit supply level (level 3), intertidal habitat received the next highest supply level (level 2) and all sub-tidal habitat received the lowest supply level score (level 1). As only three habitat factors were present the supply level scale does not include level 4 and 5 for the benefit of flood water storage by habitat.

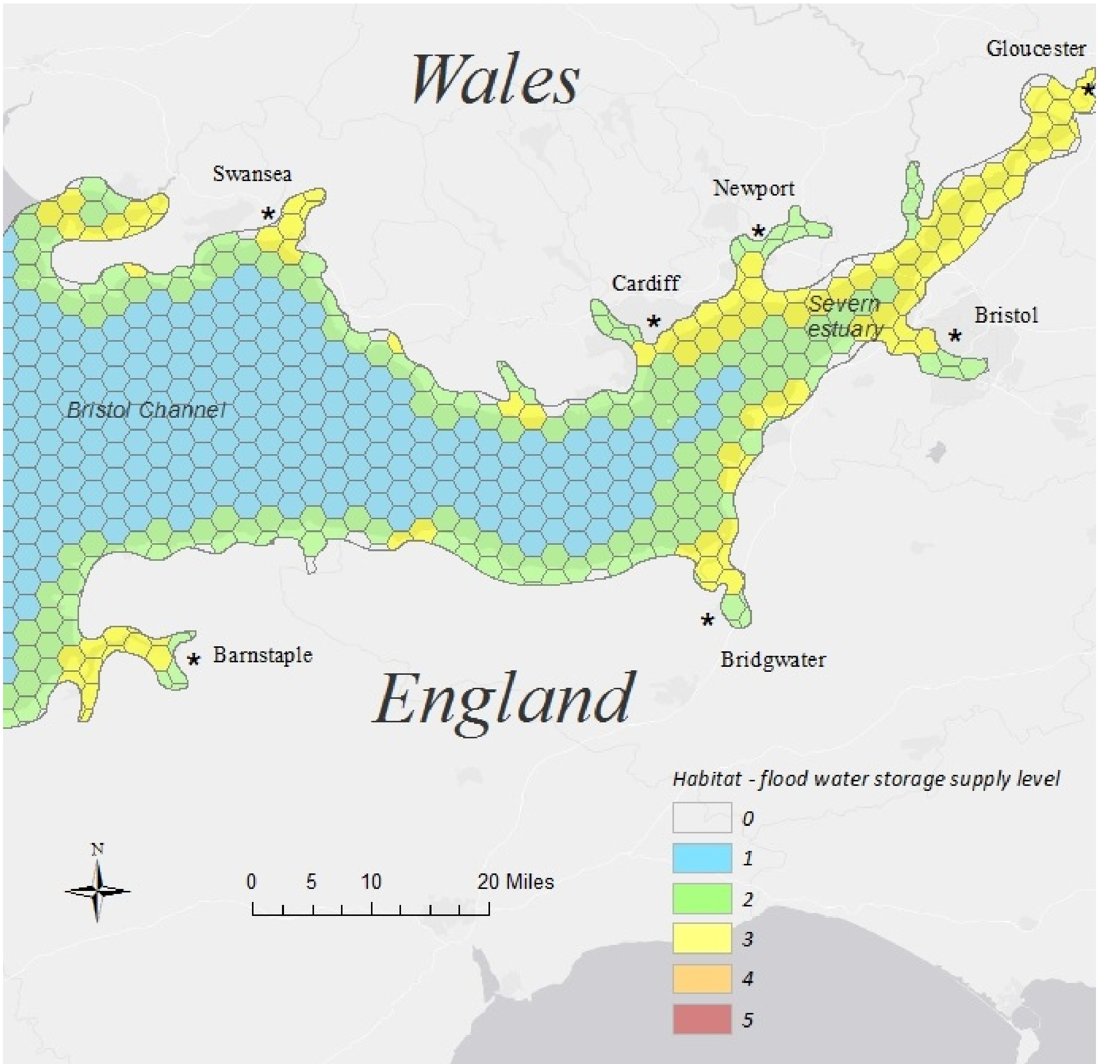

Figure 6.4 Habitat supply levels for the environmental benefit from flood water storage

2. Water current reduction

Jacobs et al (2013) identified water current reduction by physical features or vegetation as a key factor influencing the level of benefit available within estuaries for regulation of extreme events or disturbance. Reduction of water current reduces erosion of natural and technical infrastructures (by reducing shear stress) and reducing incoming tidal volume. The benefit level assessment by habitat categories applied to flood water storage benefits were applied to water current reduction. Sub-tidal rock was included as it is noted as providing a moderate beneficial supply level due to the physical structure slowing water currents (Jacobs et al., 2013, Potts et al., 2013, 2013a) (Figure 6.5).

The habitat features of importance to the supply of water current reduction benefits within a given location are summarised below:

- In intertidal habitats, particularly marshes, organism structures (vegetation) strongly reduce water currents and received the highest supply level (level 4).
- Intertidal habitats and shallow zones are more important for reducing water currents than other remaining habitat types and received a moderate supply level score (level 3).
- In sub-tidal regions morphological structures reduce water current (but less important in inter-tidal regions), sub tidal rock received the next highest supply level score (level 2).
- Remaining sub-tidal regions receive the lowest habitat supply level score (level 1).

As with flood water storage the highest supply level (level 5) is not utilised as there are only 4 factors present in the literature.

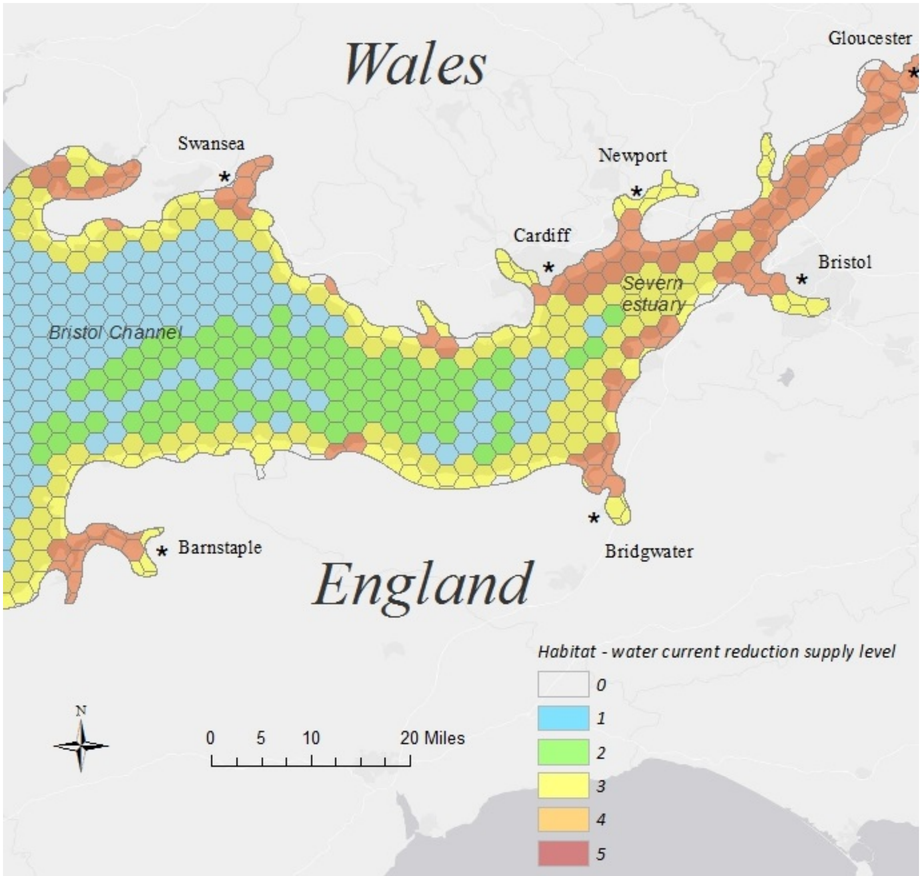

Figure 6.5 Habitat supply levels for provision of the benefit of water current reduction

3. Wave reduction

Reduction of wave heights by physical features or vegetation provides a further important factor in providing flood prevention benefits (Jacobs et al., 2013). As well as direct damage to infrastructures, excessive waves can cause increased erosion. Physical structures or organisms, particularly vegetation, reduce damage from waves caused by wind, tide and passing ship traffic (Jacobs et al., 2013). The scale used to assess supply scores was also applied to wave reduction (Figure 6.6).

- Intertidal areas and shallow zones received the higher supply levels with saltmarsh habitats receiving the highest level benefit supply (level 3), intertidal habitat the next highest (level 2) and all sub-tidal habitat receiving the lowest benefit supply level (level 1).

As with other previous factors only three benefit supply levels are available for habitat supply level for wave reduction.

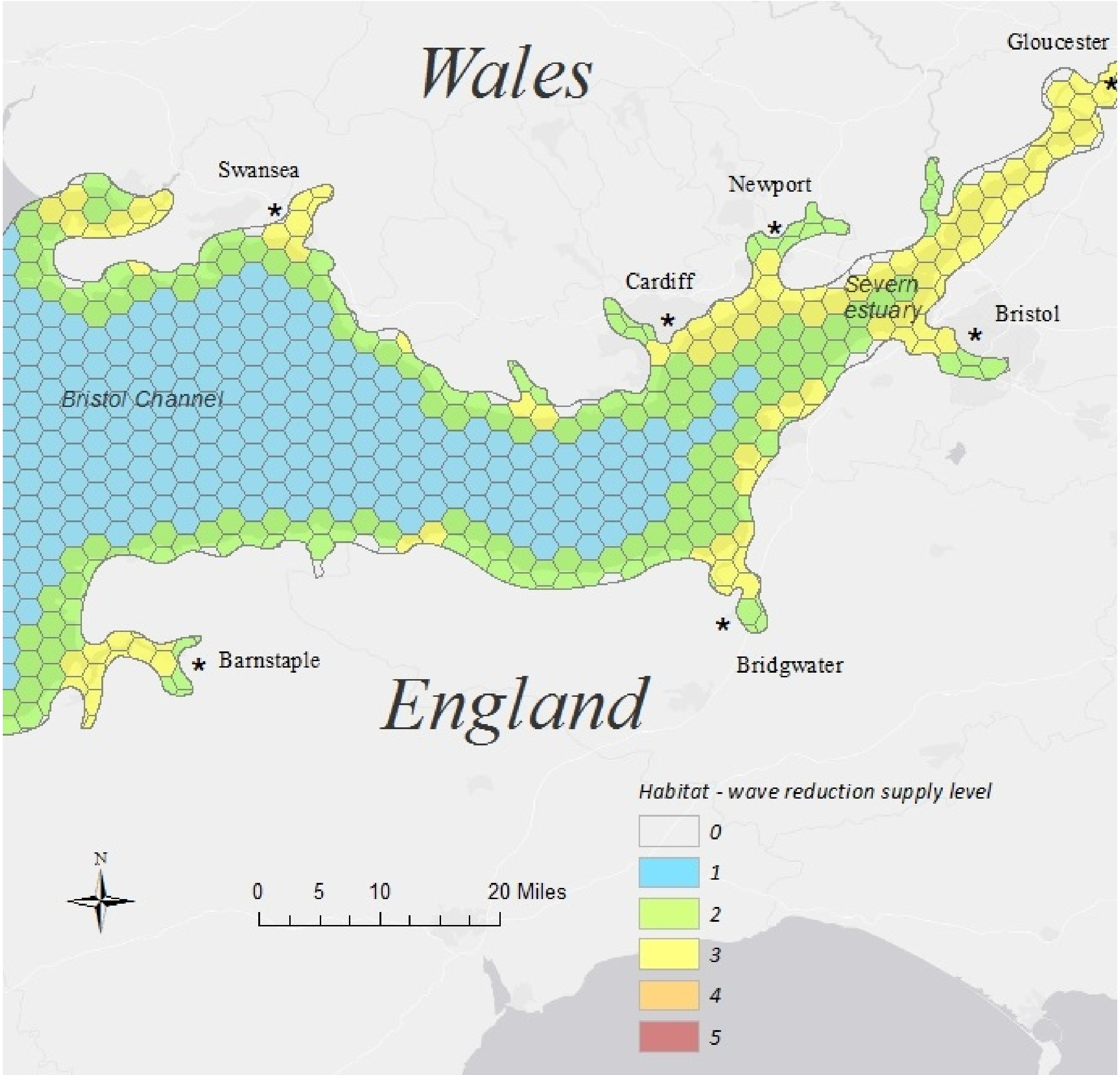

Figure 6.6 Habitat supply levels for the environmental benefit from wave reduction.

4. *Drainage of river water*

Drainage of catchments by river and estuarine systems is primarily dependent upon depth and, therefore, deep sub-tidal habitat. Drainage is also influenced by the topography and soil properties of surrounding shore based habitats. For the purpose of this preliminary study the estuarine features influencing drainage only are considered.

Drainage within an estuary such as the Severn is noted by Jacobs et al (2013) to be of high importance to evacuation of river / estuarine water after a storm tide as storm tides are often coinciding with heavy rainfall (and potential high discharges from the catchment), and emptying the estuary is essential to prevent flooding by consequent surges.

To map spatial extent of environmental benefit supply levels bathymetry contours (Figure 3.3) were utilised. Bathymetry deeper than 5m received the highest supply level (level 5), depths between 2-5m received the next highest supply level (level 4) and regions between 0-2m depths received the lowest supply level (level 1) (Figure 6.7). Due to only three supply levels, supply levels 4 and 5 are not present for this factor.

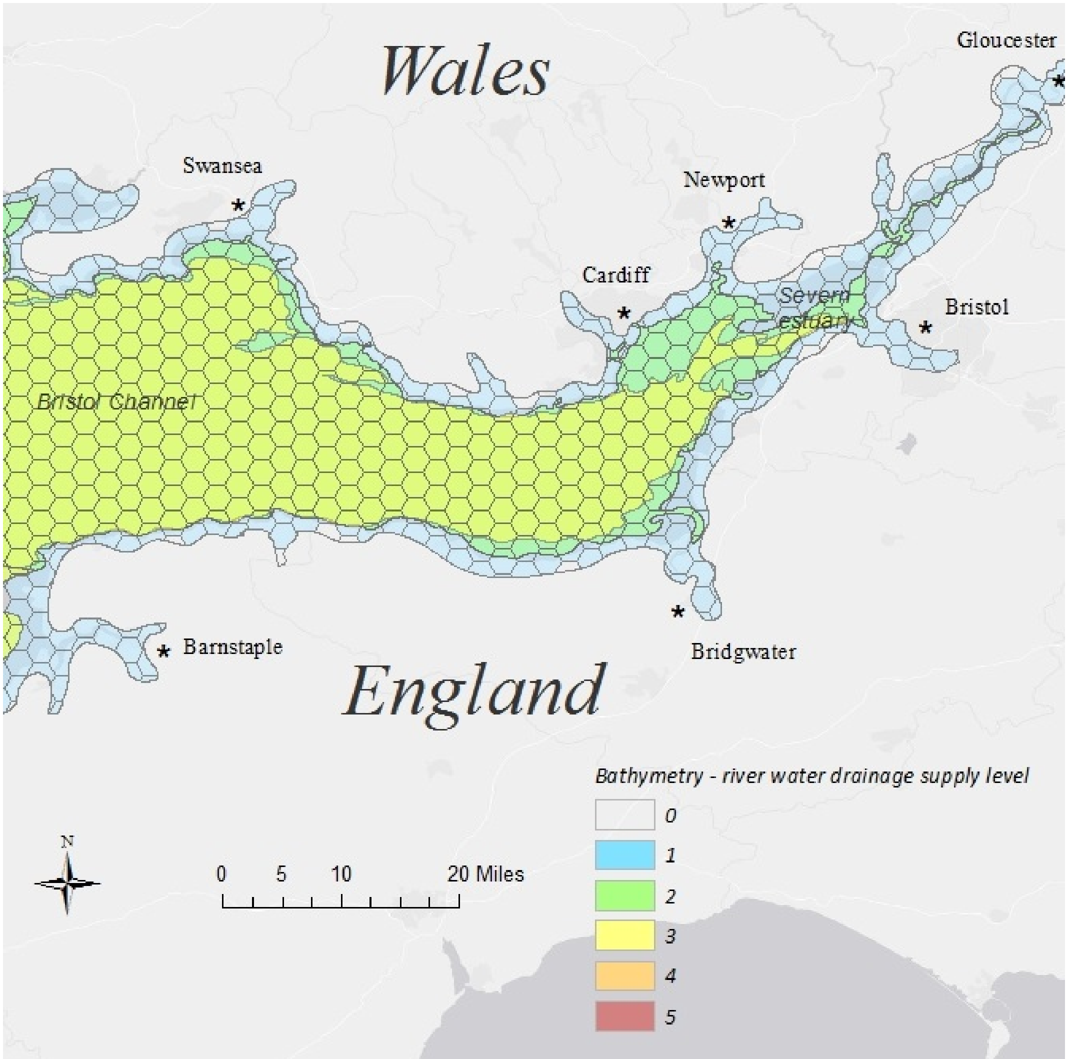

Figure 6.7 Habitat supply levels for the environmental benefit from drainage of river water dependent upon bathymetry

6.4 Combined mapped results

Combining all four factors in estuarine and marine habitats identified by Jacobs et al., (2013) that provide the environmental benefit of flood risk management produced summed scores for each planning cell. Although the interaction of flood and erosion reduction provided by habitats is more complex than this combination may suggest, the purpose of combining each factor is intended to provide a synopsis of hotspots in the study region where combined flood risk management features occur. The sum within each planning cell provided 5 benefit supply levels.

Level 5. Combined scores of >11 provided the highest benefit supply level (intertidal saltmarsh).

Level 4. Combined scores of 8-11 received the next highest benefit supply level (deeper intertidal mud and sand banks).

Level 3. Combined scores of 7-8 received the next highest supply level (shallow intertidal mud and sand banks),

Level 2. Combined scores of 7 received the next highest supply level (sub-tidal rock substratum),

Level 1. Combined scores of 6 received the lowest benefit supply level (sub tidal mud and sand banks).

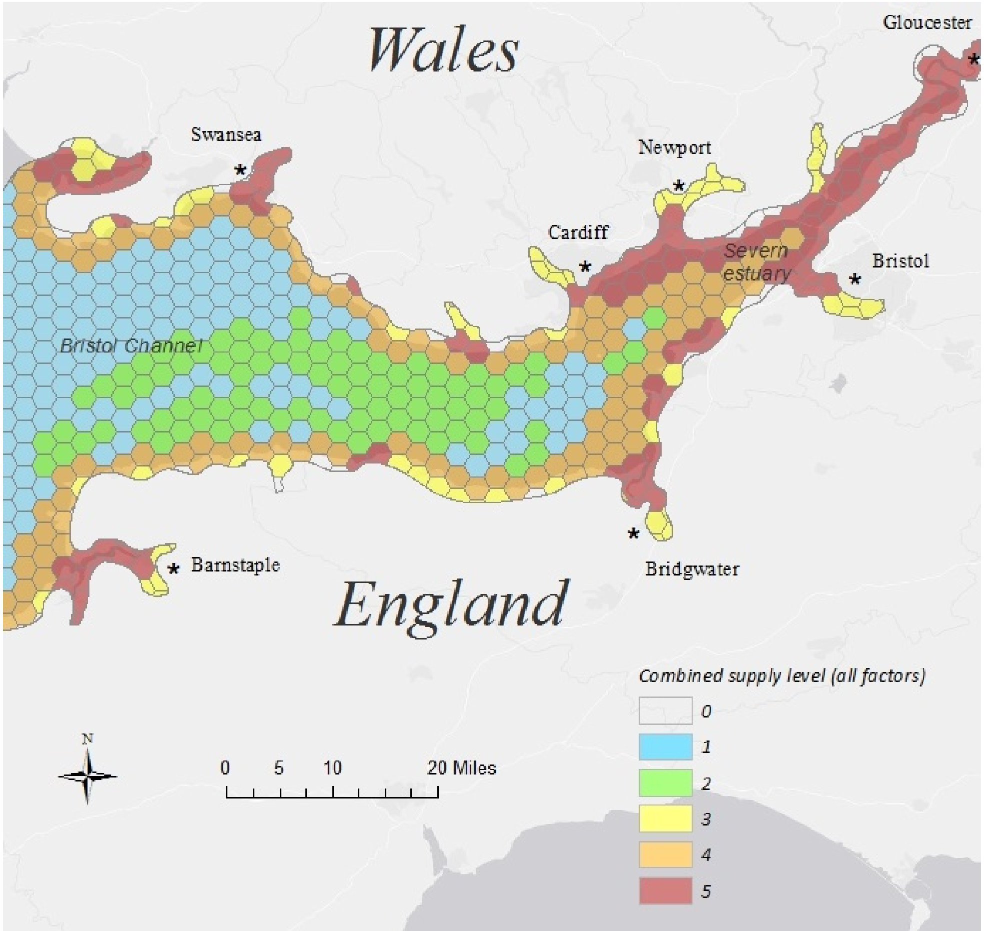

Figure 6.8 Combined habitat and bathymetry benefit supply levels for the environmental benefit of flood risk management

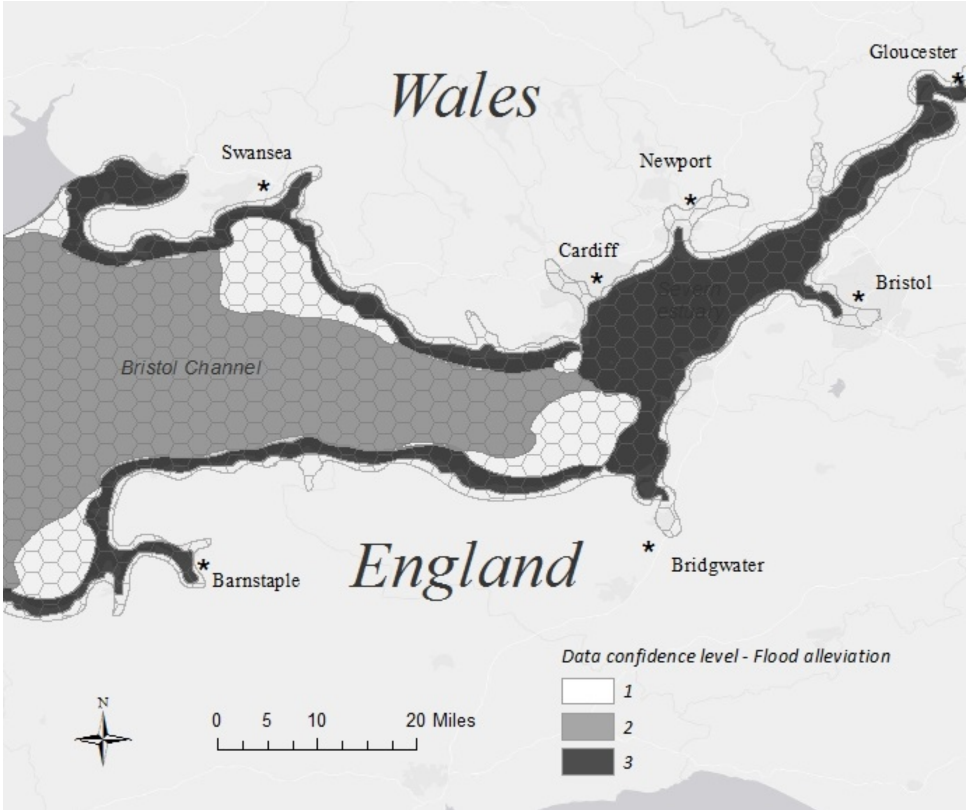

Figure 6.9 Data confidence levels for habitat data relating to flood risk management (1= lowest confidence, 3 = highest confidence)

6.5 Valuation

Damage costs avoided

Valuation of flood prevention typically relies on 1: Quantifying the value of flood damage that would be suffered if the habitat type was not present, or 2: Quantifying the cost of constructing defences equal to the flood prevention of the habitat (or a combination of both of these costs that are avoided).

Jacobs et al. (2013) relate an example of a flood risk assessment and risk valuation tool, developed For Flanders (Belgium/Netherlands), *the LATIS method.* Hydrological models are utilised in this approach to develop flood maps under different circumstances and severity of flooding. Land use is taken into account to value costs under flooding circumstances. Values are derived from replacement costs given worst case, maximum damage calculations and also less critical, actual damage calculations.

The benefit of estuarine ecosystems is calculated in the model by calculating flooding extent and replacement costs with and without estuarine ecosystems. Jacobs et al., (2013) iterate that it is not possible to provide easily applicable indicators to apply the same model across all European estuaries. However, data from the Severn estuary and inner Bristol Channel region could be utilised in a separate model using the same design principles to use mapped habitat to examine damage costs with or without habitat types present in the region (or for a smaller case study region).

6.6 Interpretation

- *The extent of intertidal habitats provides flood risk management benefits throughout the study region.*

As with carbon sequestration the environmental benefits provided by saltmarsh habitats and extensive intertidal mud and sand banks in the Severn estuary and inner Bristol Channel region are clearly evident in relation to natural provision of flood risk management. The present mapping study however, does not provide valuation to relate the presence of these habitats to financial and quality of life benefits for local communities.

An example of damage calculations for the Scheldt river in the Flemish region of Belgium and the Netherlands (Broekx et al. 2011), provided by Jacobs et al., (2013) displays the potentially very high costs avoided due to the presence of similar beneficial habitats. In the proposed management plan for the Scheldt River an optimal scenario, to reduce flood risk by 78%, would require combining 24km dyke heightening with the construction of 1325ha of additional floodplains. The resulting cost of this proposal is considerable, at an estimated 737 million euro or approximately 30 million a year. Although these figures are not directly comparable to the Severn estuary and inner Bristol Channel, reviewing the environmental features of the Severn estuary and inner Bristol Channel identified in this section through a model applying the *LATIS method* would provide a vital valuation method to assess the full importance of these habitat features to welfare in the region.

6.7 Limitations

- The mapping of habitat and bathymetry related flood risk management provides a means of identifying locations of importance to the supply of this feature. Models providing full interactions of terrestrial habitats and features would provide the means of examining the full effect of developments and future scenarios.
- Rocky coastline and cliffs also occur in the study region, the habitat related assessment methods applied from Liekens et al (2013, 2013a) did not account for this feature. Future assessments or adaptations of this approach would benefit from adapting the marine and coastal features as well as estuarine features present in the study region (Potts et al 2013, 2013a).
- Many man made defences exist in the study region, the region will also be heavily impacted from future sea level rise, potentially reducing the effectiveness of current defences. Further assessment of future scenarios and the ability of existing environmental and man-made features to alleviate risks are discussed in the English Environment Agency's *Severn Estuary Flood Risk Management Strategy* (EA 2011).

Section 7. Benefit: **Fisheries, Wild Food and Migratory Fish**

Ecosystem service category:

Provisioning

7.1 Background

Whilst commercial fishing is limited in the estuary its self, the rich nursery grounds and species diversity support valuable fishing grounds in the Bristol Channel and further afield. For instance, landings data for the whole of the Bristol Channel in 2010 showed the combined landings across fisheries utilising the region to be worth £11 000 000 (Channel Energy Ltd 2013).

Recreational fishing is very popular across the study region with associated importance to local businesses and tourism but also to the human health and relaxation benefits provided. Recreational fishing in the region is provided by the extensive shoreline and many tributary rivers. Anglers target the diverse array of marine, estuarine and freshwater species. Amongst these species is the iconic Atlantic salmon with nationally renown salmon fishing in tributary rivers such as the Wye and Usk. The Severn estuary and inner Bristol Channel supports migratory pathways for both the Atlantic salmon and European eel. Both species are of international conservation importance and also support traditional trap fisheries which provide a cultural link to 1000's of years of trap fishing practices within the study region.

This section focuses on three aspects of fisheries, wild food and migratory fish. Firstly habitat based supply levels for fisheries (marine and estuarine fish) and wild food are mapped, secondly migratory fish are considered with importance of tributary rivers to Atlantic salmon and European eel mapped using abundance data of these species presence at different life stages in each tributary.

Marine and estuarine fish:

The waters of the Severn estuary and inner Bristol Channel support one of the most diverse and rich fish communities in the UK. Sampling of fish species presence at Hinkley point power station in Bridgwater Bay (inner Bristol Channel) recorded 83 species within one year (Henderson and Bird 2010, DECC and Parsons Brinckerhoff Ltd 2008).The ten most abundant species within one year of sampling were sprat, whiting, sand goby, poor cod, dover sole, pout, sea snail, bass, flounder and dab (Henderson and Bird 2010, Severn Estuary Partnership 2011). With juvenile fish predominant, particularly into the Severn estuary, the region is considered one of the richest nursery areas in the UK (Severn Estuary Partnership 2011).

Migratory fish:

Atlantic Salmon (Salmo salar).

The inner Bristol Channel, Severn estuary and tributary rivers such as the Wye provide migration pathways, spawning grounds and nursery areas for one of the North Atlantic's most iconic species, the Atlantic salmon (*Salmo salar*). A salmon's lifecycle begins in the freshwater river where eggs are layed. In a juvenile stage as Alevins, then Fry, Parr and finally Smolts salmon will utilise tributary rivers. As a Smolt the salmon will leave the river and estuary system, migrating to the open ocean waters of the North East Atlantic through the Severn estuary and inner Bristol Channel. After 1 – 6 years as an adult in the open ocean the salmon will return through the study region to the estuaries and rivers of its birth to spawn (Figure 7.1).

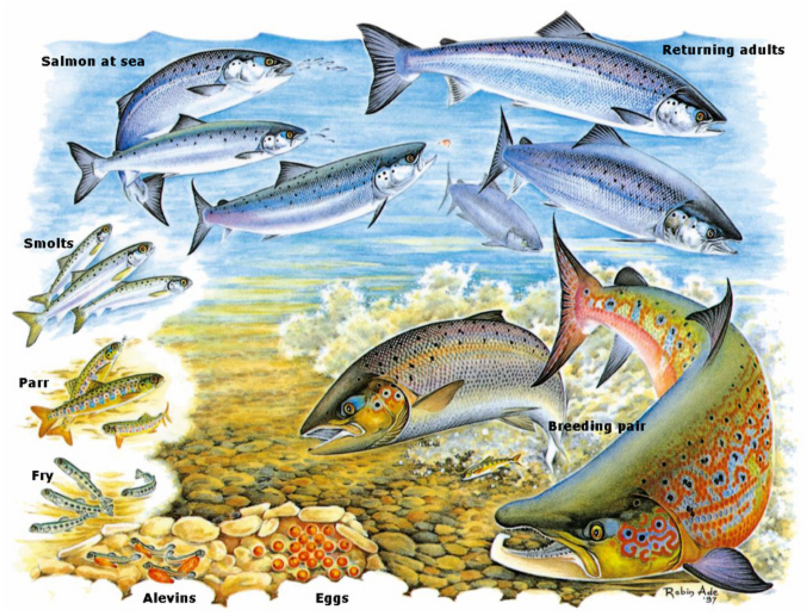

Figure 7.1. The salmon life cycle including the river, estuarine and at sea life cycle stages, Illustration by Robin Ade reproduced with permission from the Atlantic Salmon Trust.

The Severn estuary provides the major migration pathway for salmon populations utilising the estuaries tributaries during their estuarine and freshwater life stages (Figure 7.1). As a result the estuary is both a site of Special Scientific Interest (SSSI) and along with the Rivers Usk and Wye, also a Special Area of Conservation (SAC).

The presence of salmon within the Severn estuary and its tributaries provides a range of cultural and financial benefits to local communities to the extent that an individual salmon has been estimated to be worth £4,000 or greater to rural communities from the food, tourism and recreational activities the species supports (Wye and Usk Foundation 2014).

European eel (Anguilla Anguilla)

The eel fishery is the most valuable commercial inland fishery in England and Wales, providing sufficient benefits to the rural economy. Global catches of European adult eel have dropped from a peak of around 20,000 tonnes per year in the late 1960s to just around 5,000 tonnes in 2010 (Defra 2010). The high price obtained due to market demands have led to farming of eels growing globally.

As eels do not breed in captivity this only increases pressure on stocks as every farmed eel originates as an eel taken from the wild.

Management of the European eel is a Europe-wide issue because the fish forms a single stock that is distributed across the European continent. Floating glass eels migrate across the Atlantic from areas thought to be in the Sargasso Sea region on ocean currents, returning at random to separate European waterways (Defra 2010) (Figure 7.2). The European Commission has initiated an Eel Recovery Plan (Council Regulation No 1100/2007) to try to return the European eel stock to more sustainable levels of adult abundance and glass eel recruitment. Each Member State has been required to establish and implement national Eel Management Plans. These plans aim to allow at least 40% of silver eel to escape to the sea to spawn (Defra 2010).

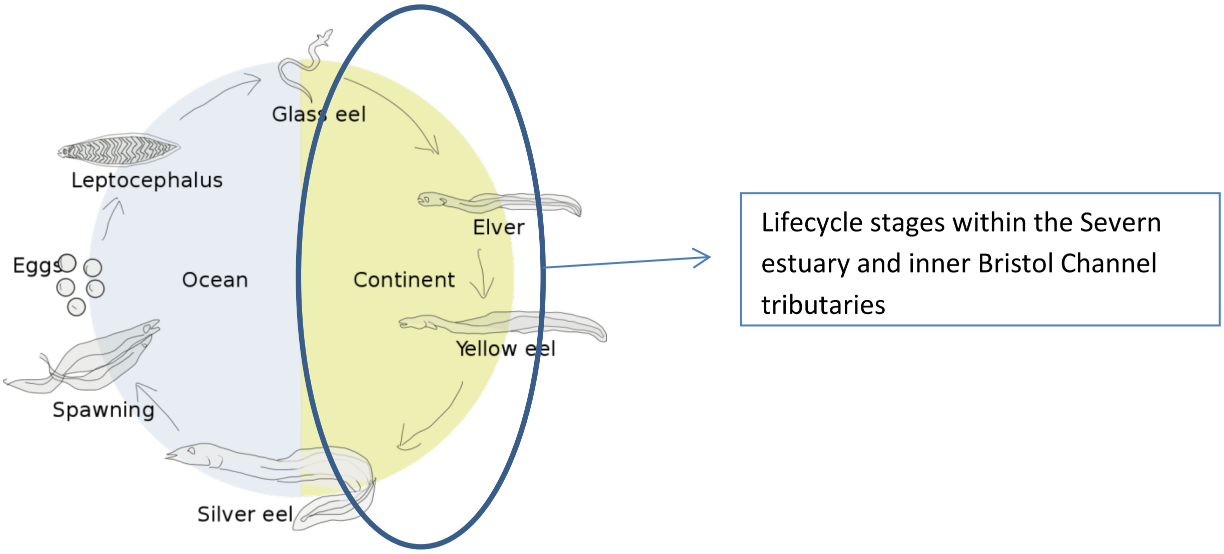

Figure 7.2 Eel lifecycle displaying *glass eel* to *silver eel* life stages within Severn estuary and inner Bristol Channel tributaries, reproduced from wediving.com

In the Severn estuary and inner Bristol Channel region there is benefit provided by the species and the habitats that support it to the rural economy and also to aiding global conservation efforts, so maintaining the stocks for future generations. For example 500 licences are issued to catch elvers in artisan hand nets on the Severn estuary. These licenses equate to 3-4 million in revenue or 35 million individuals (in 2014) whilst 60-70% of those captured in the fishery go to re-stocking European populations (Andrew Kerr, Chairman of the Sustainable Eel Group (SEG), pers comm.). The presence and abundance and of eels in tributary rivers to the Severn estuary and inner Bristol Channel, in addition to the migration pathway provided by the region are evidently of significant market and conservation value. Ensuring these pathways are clear to enable eel migration is a priority to aid conservation of the species.

7.2 Aims and Scope

This section aimed to identify the locations within the estuary where environmental habitats and features supply the benefits from fisheries and wild food under three different mapping categories:

1. Specific habitats related to supporting marine and estuarine fish and crustacean species as well as wild food, particularly edible plants, including certain seaweeds and *Salicornia* (marsh samphire)

which grow in shoreline and coastal habitats. Habitat supply levels for fish and wild food were adapted from existing studies (Potts et al., 2013, 2013a)

2. Atlantic salmon: Data were collated on the abundance of returning adults and the presence and abundance of juveniles in each tributary river to indicate the current and future importance of the region to supporting stocks of this species.

3. European eel: Data were mapped on eel abundance in tributary rivers for the Severn estuary (data was not obtained for the inner Bristol Channel tributaries).
Although the approach for migratory fish species does not relate specifically to habitat features within the study region this section aimed to provide information on the locations of importance to the supply of this benefit. The information is intended to assist with identification of locations that would require developments or planning decisions to consider migration pathways in impact assessment.

7.3 Mapping

Wild food and fisheries habitat supply level

Potts et al., (2013, 2013a) provide information on the importance of habitats , species and marine and estuarine features to fisheries and wild food ES services. Confidence in associated data sources to apply those importance levels are also given. These were adapted to provide 5 benefit supply levels to summarise the benefit supply levels in association with the study region (Table 7.1).

Benefit supply levels were mapped within planning cells based on habitat data accessed through MESH (combined data from surveys and predicted habitat type data, displayed in Figure 3.3) (Figure 7.3). The highest habitat/feature related supply score within a planning cell was attributed across the whole cell (Figure 7.4). As discussed this provides a precautionary approach but risks overestimating the benefit supply level within a location if considering more detailed spatial scales.

Table 7.1. Benefit supply levels (1-5 with 5 the highest) adapted from Potts et al. (2013, 2013a).

Supply level, wild food (and fisheries)	Habitat (adapted from Potts et al., 2013, 2013a)
1	▪ Intertidal coarse sediment.
2	▪ Intertidal boulders.
3	▪ Offshore subtidal gravel, intertidal sand.
4	▪ Intertidal rock, intertidal biogenic reefs, intertidal mud, subtidal sand, subtidal mud, blue mussell beds.
5	▪ Saltmarsh, subtidal rock, biogenic reefs, tidal swept algal communities, subtidal macrophyte communities.

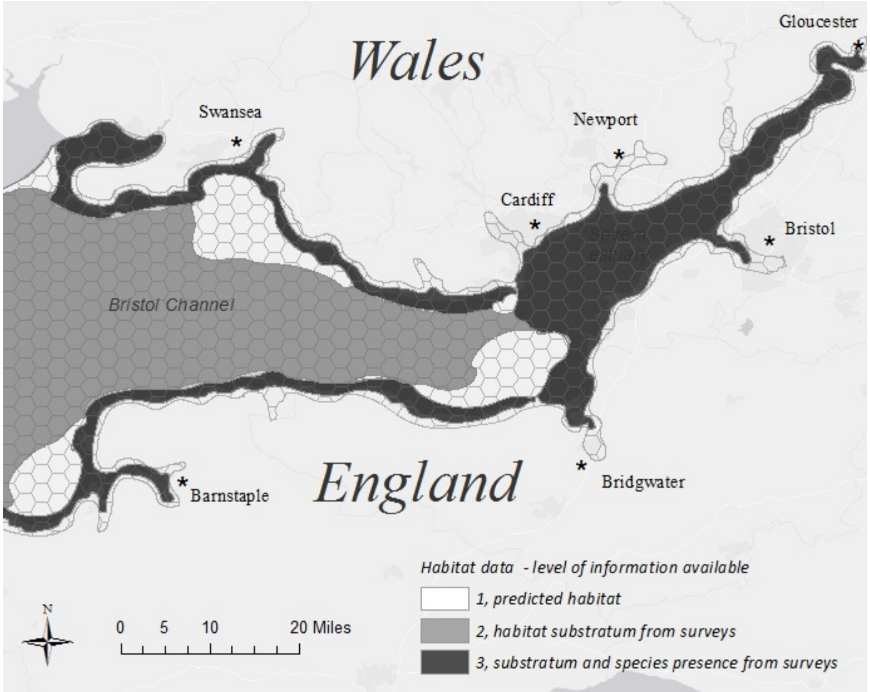

Figure 7.3 Habitat data utilised in ES supply assessment for fisheries and wild food.

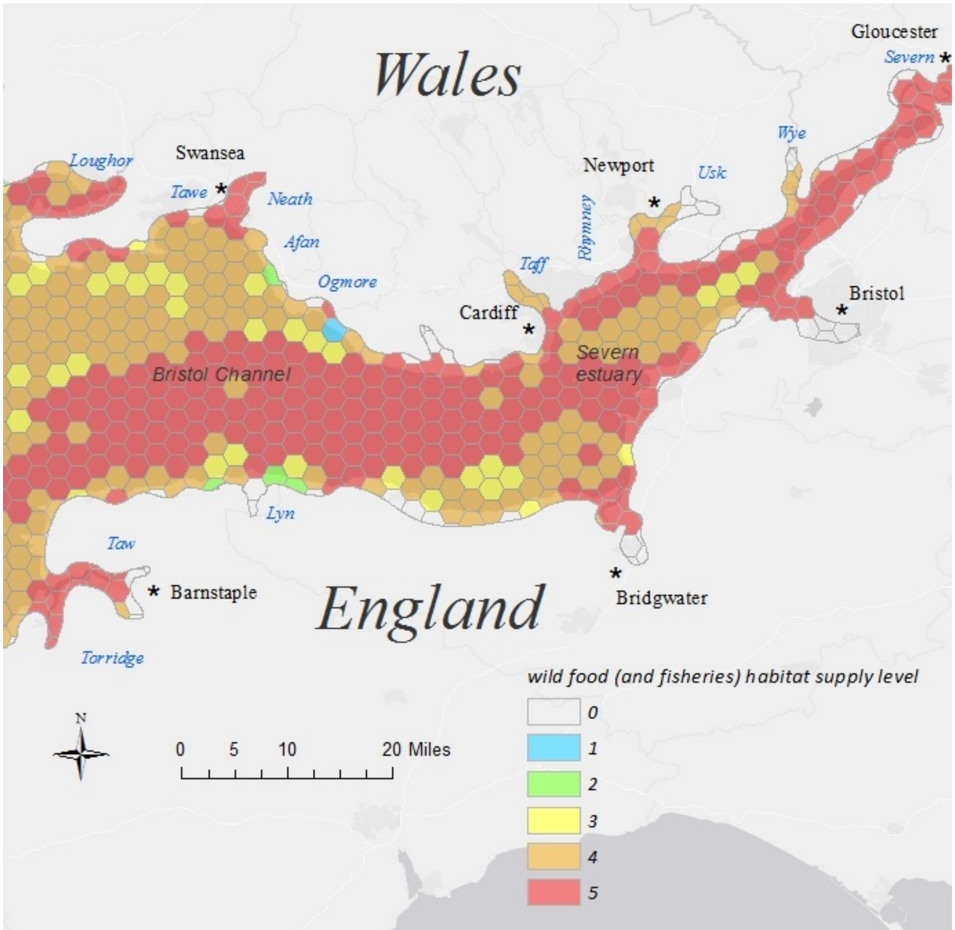

Figure 7.4 Habitat related benefit supply levels for fisheries and wild food, benefit levels extend between 1 – 5, with level 5 the highest.

Migratory fish

Atlantic Salmon (Salmo salar).

Abundance of returning adult salmon and populations of juvenile salmon using tributaries as nursery areas were used as proxies for supply level of habitats (habitats refer in this instance to whole individual tributary rivers and estuaries). The total population was viewed as using the Severn estuary and inner Bristol Channel as a migration pathway.

Three separate maps were produced with associated confidence maps for juvenile salmon only as national statistics used for other maps provided similar levels of confidence across all tributary rivers:

1. Returning adult salmon (rod caught) abundance within tributary rivers (Figure 7.5)
2. Returning adult salmon (net caught) abundance within tributary rivers (Figure 7.6)
3. Juvenile population abundance within tributary rivers (Figure 7.7).
4. Confidence maps, juvenile salmon survey data (Figures 7.8)

Abundance of returning adult salmon supply levels were assessed as salmon catch per unit effort (CPUE) for rod fishing and net fishing from national statistics for 2012 catches, held by the UK government (Environment Agency 2012) (Figure 7.5, 7.6). Jenks breaks were used on the CPUE data to establish 5 supply levels from 1 (lowest CPUE class) to 5 (highest CPUE class) to apply to CPUE values for each tributary river (Table 7.2, 7.3). These values provide a supply level of abundance and also a direct relationship to valuation based on the value of a single salmon to rural economies in each location.

Juvenile population abundance for year 1 salmon was compiled from survey data from salmon runs on each tributary river in 2012, provided by Natural Resources Wales (for Welsh tributaries) and the Environment Agency (for English tributaries). Total salmon numbers caught in each tributary were divided by survey effort (number of runs in each river where surveys were undertaken and number of samples in each run) to provide values for mean number of juvenile salmon caught, per survey, on each river (Figure 7.7). Associated supply levels were calculated as with adult salmon data, applying Jenks breaks to ascertain supply levels between 1 (lowest) and 5 (highest) (Table 7.4).

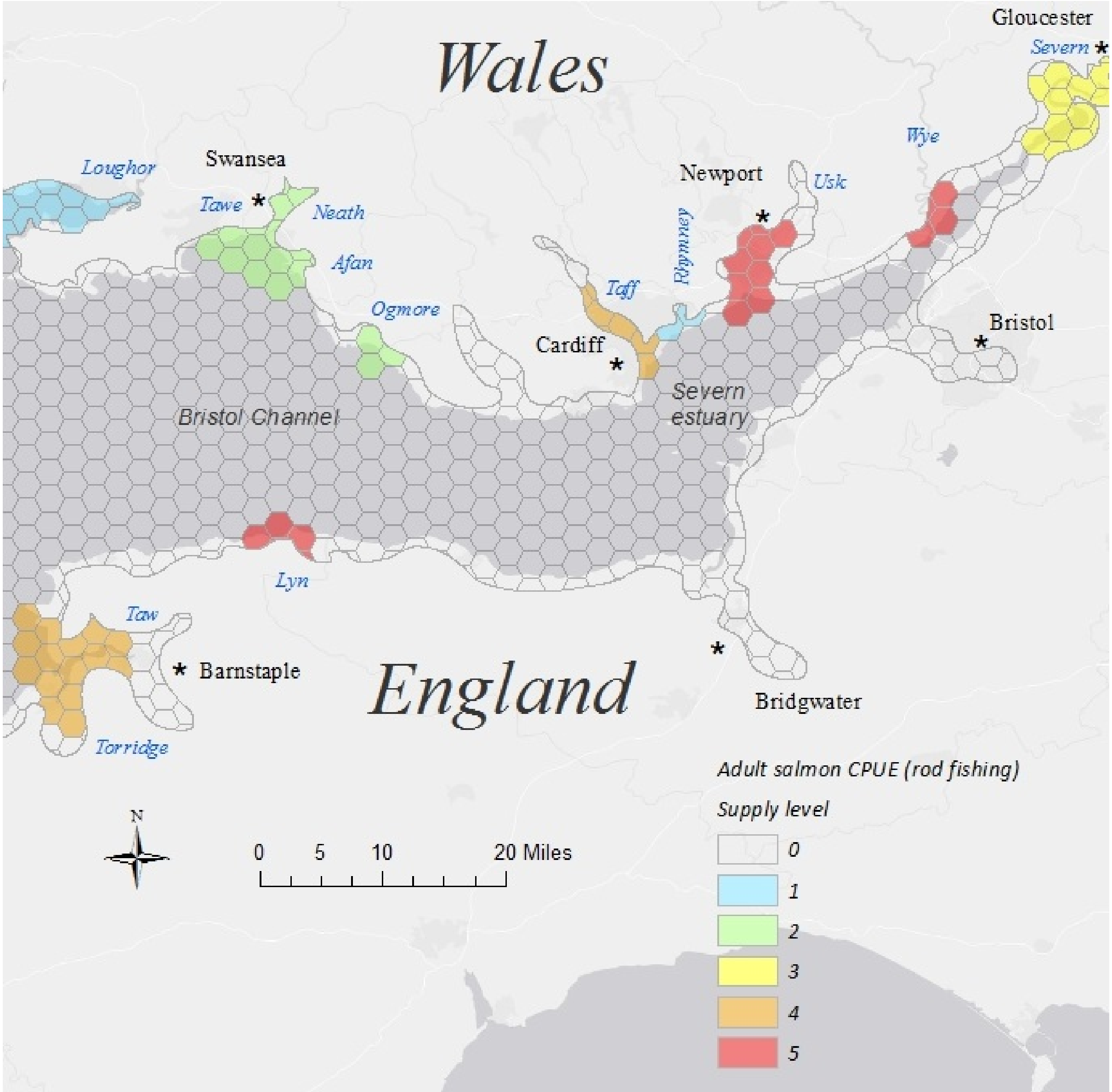

Figure 7.5 Returning adult salmon benefit supply level by tributary rivers for rod and line catch per unit effort (CPUE values associated with each supply level are provided in Table 7.2)

Table 7.2 CPUE values for rod and line caught adult salmon associated with each supply level, calculated through Jenks breaks in ARC GIS 10 (ESRI).

Benefit supply level	Salmon CPUE (Jenks breaks)
1	0 - 0.019
2	0.0191 - 0.047
3	0.0471 - 0.072
4	0.0721 - 0.122
5	0.1221 - 0.223

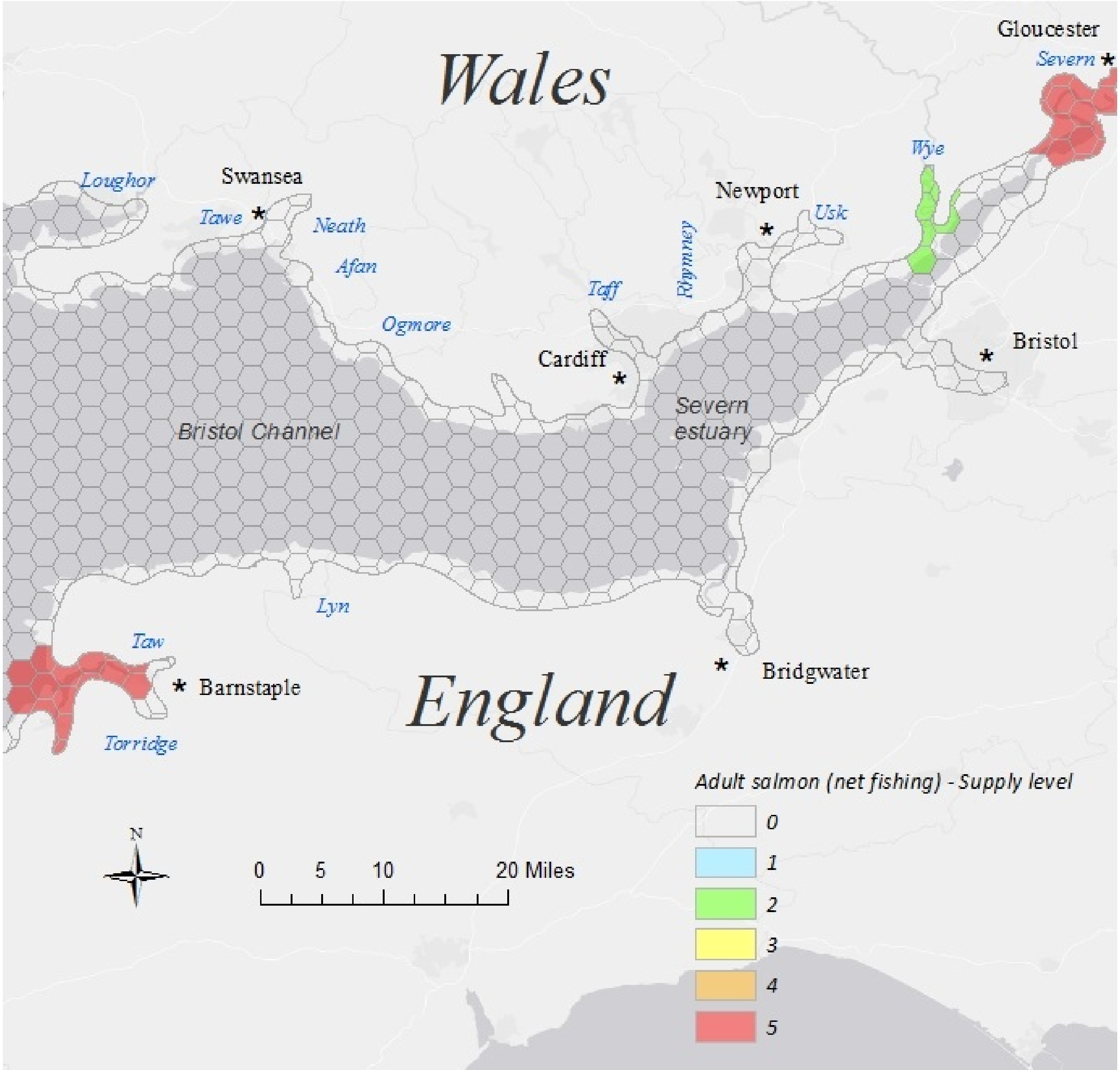

Figure 7.6 Returning adult salmon benefit supply level by tributary rivers for net catch per unit effort (CPUE values associated with each supply level are provided in Table 7.3)

Table 7.3 CPUE values for rod and line caught adult salmon associated with each supply level, calculated through Jenks breaks in ARC GIS 10 (ESRI).

Benefit supply level	Salmon CPUE (Jenks breaks)
1	0
2	0 - 0.078
3	0.0781 - 0.218
4	0.2181 - 0.365
5	0.365 - 0.81

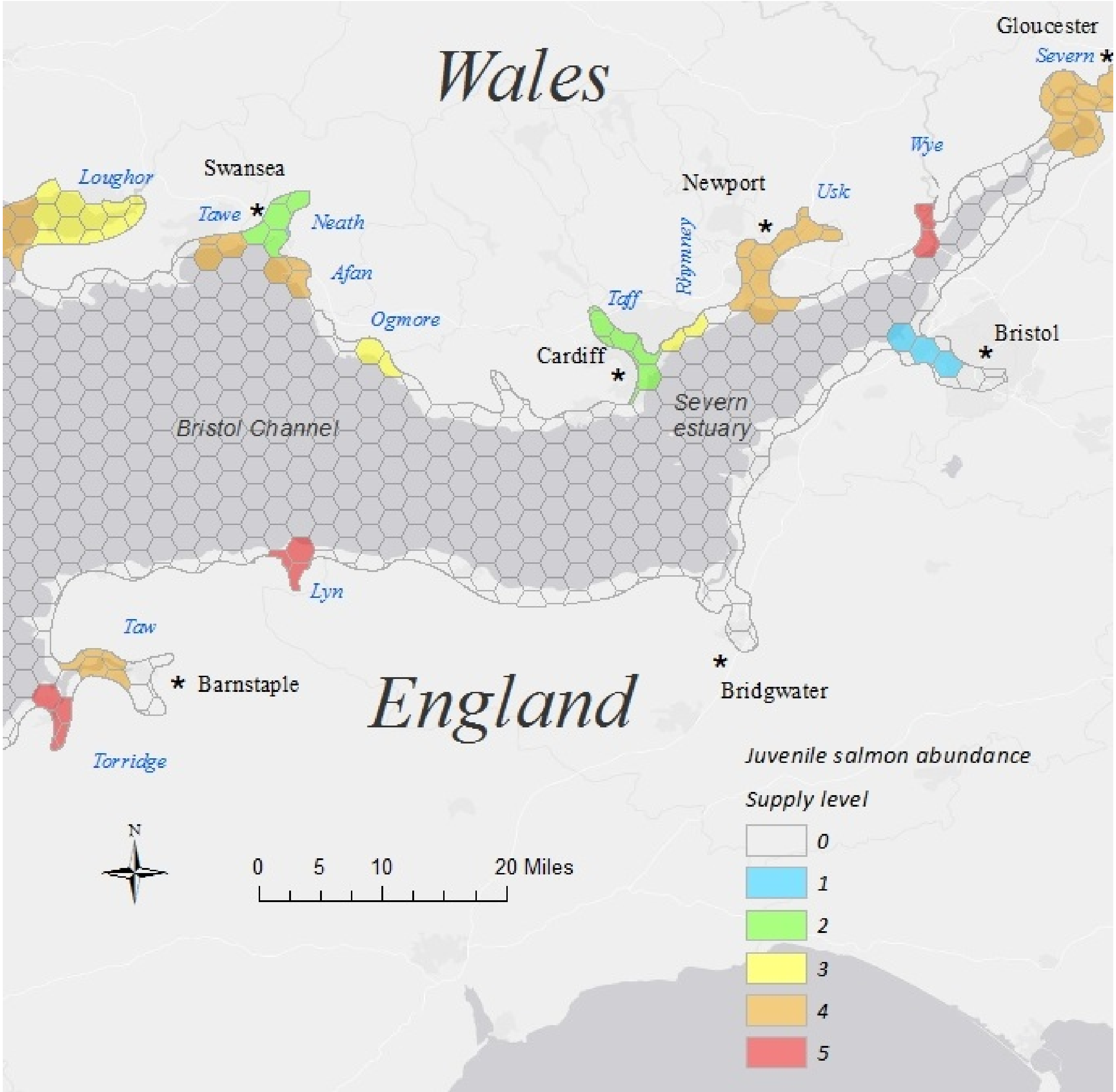

Figure 7.7 Juvenile (year one) salmon benefit supply level by tributary rivers from surveys (mean no. salmon, per survey effort values associated with each supply level are provided in Table 7.4)

Table 7.4 Juvenile salmon per survey effort values for juvenile salmon populations surveyed by Natural Resources wales and the Environment Agency associated with each supply level, calculated through Jenks breaks in ARC GIS 10 (ESRI).

Benefit supply level	Salmon, mean No. juveniles from surveys (Jenks breaks)
1	0 - 1
2	0.01 - 6.8
3	6.81 - 20.6
4	20.61 - 49.2
5	49.21 - 74.4

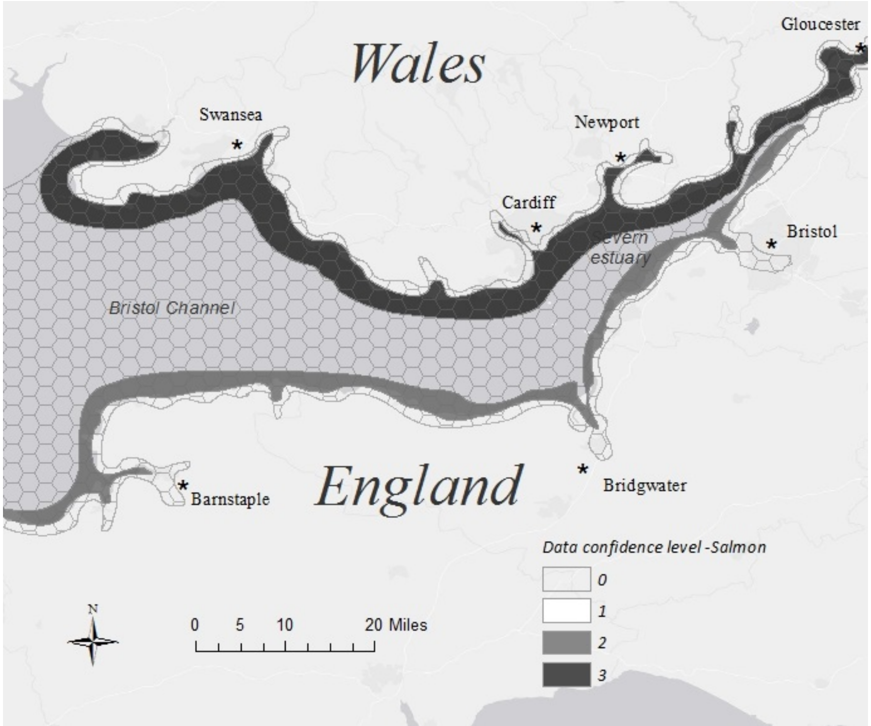

Figure 7.8. Data confidence levels for juvenile salmon abundance data (based on survey data returned from Natural Resources Wales and Environment Agency, 1=low, 3=high)

European eel (Anguilla Anguilla)

One map was produced for supply levels of European eels, based on survey data compiled by Defra (2010a) for tributaries to the Severn estuary. Similar data for the inner Bristol Channel was not ascertained in the timescale of the project.

Distribution of eel in the Severn estuary catchment had been surveyed between 2001 - 2005 and combined results were available through Defra (Defra 2010a). For mapping benefit supply levels the maximum density of eel (no. individuals) provided at a survey site was totalled for each catchment river. Jenks breaks were calculated on the resulting data set to provide supply levels between 1 (lowest) and 5 (highest) for tributary rivers to the Severn estuary (Table 7.5, Figure 7.9). Associated confidence maps displaying the spatial extent that data extracted from Defra (2010a) covered were included (Figure 7.10).

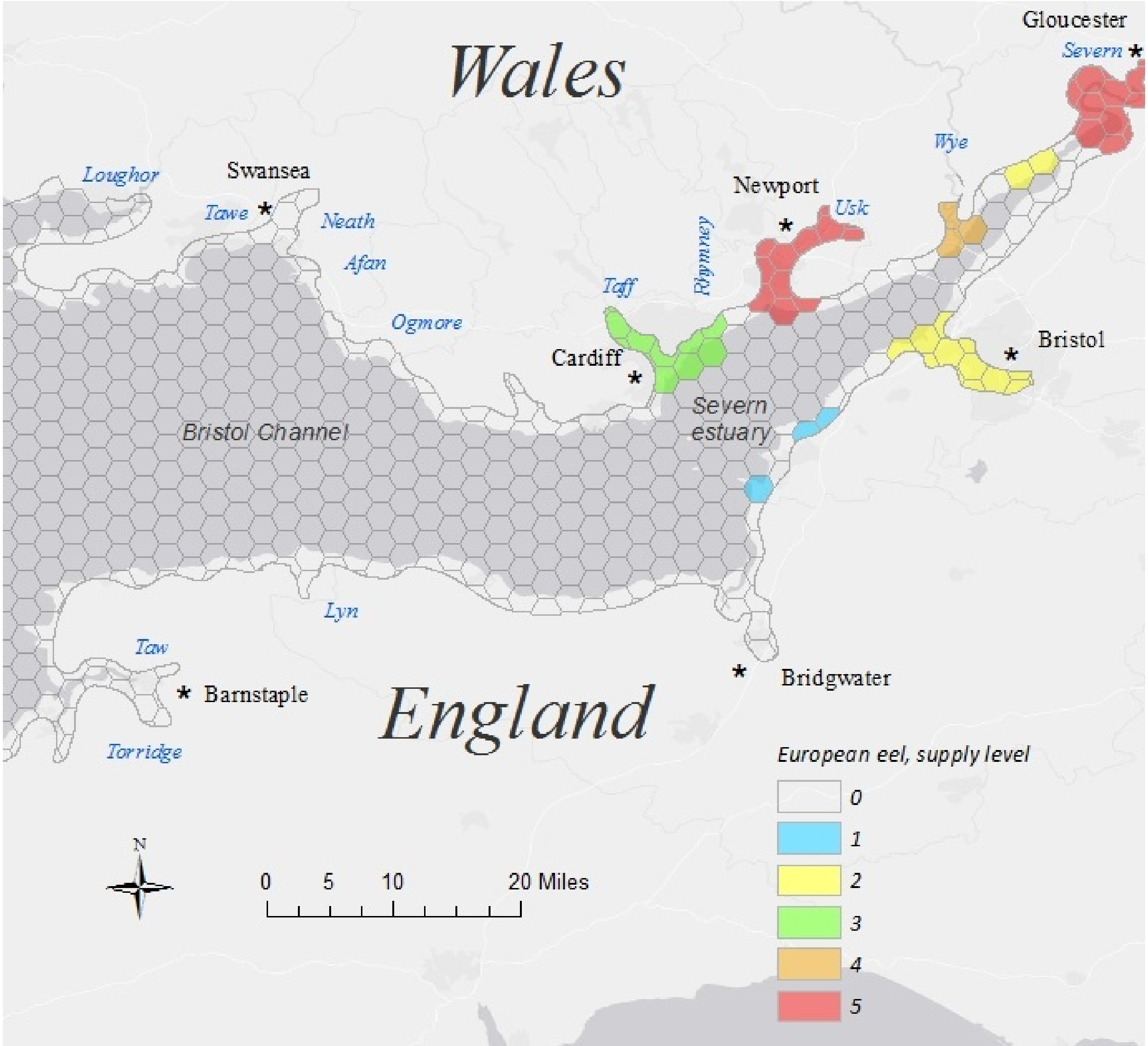

Figure 7.9 European Eel benefit supply level by tributary rivers for surveys (total no. Eels per tributary from DEFRA surveys 2001-2005, values associated with each supply level are provided in Table 7.5)

Table 7.5 Eel abundance values (sum of individual samples of eel density per 100m², within each river catchment) associated with each supply level, calculated through Jenks breaks in ARC GIS 10 (ESRI).

Benefit supply level	Eel abundance (Jenks breaks)
1	0 - 13
2	13.1- 38
3	38.1 - 102
4	102.1 - 147
5	147.1 - 549

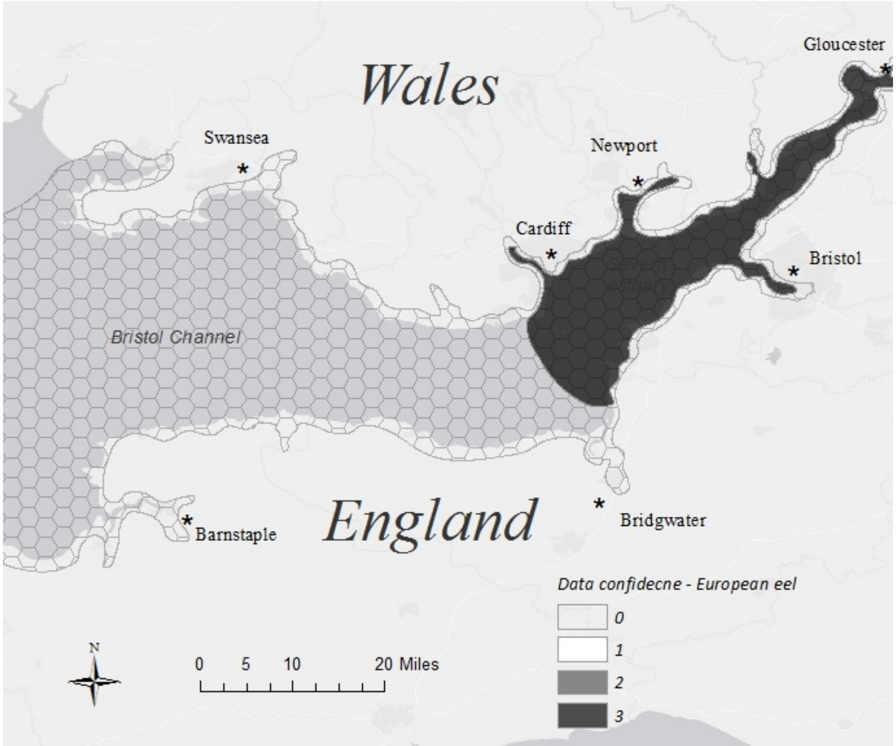

Figure 7.10 Data confidence levels for eel abundance data (based on survey data compiled by Defra (2010a), (0 no data, 1=low, 3=high)

7.4 Valuation methods

- Market values for commercial fisheries
- Expenditure in local communities for recreational fisheries
- Bequest value (value of conserving species) for future generations
- Bequest value for the international importance of stocks

Value per salmon to rural communities for the Wye and Usk is discussed in non-peer reviewed resources (Wye and Usk foundation 2014). Similar valuation estimates are provided in literature from North America. Market values for salmon and eel are also available to allow benefits transfer across tributaries and sum for the region as a whole.

Market values for commercial fisheries present the most straightforward approach to valuation, given past present or future abundance or health of a stock, dependent upon habitat presence in the region. Liekens et al. 2013 present a valuation example from the Ijzer estuary in Belgium (although for a shrimp fishery).

Flooding of 27ha of agricultural land in the estuary created a positive effect on the nursery habitat available for the shrimp catch in the North Sea. This benefit was assessed through developing a population model incorporating shrimp production, and recruitment (assumptions) shrimp growth and mortality (from literature) with habitat availability. The model displayed between 0.5 and 0.9 tonnes of adult shrimp are recruited to the shrimp fishery. Using market price valuation the total value of the habitat service provided by the additional habitat was estimated to be up to 0.46 million Euro per year, depending on the scenario modelled (Liekens et al., 2013).

7.5 Interpretation

- *Nationally important nursery area habitats and internationally important migratory fish benefits.*

The Severn estuary and Bristol Channel provide important habitat for marine fish, particularly nursery areas within the estuarine and inshore coastal regions. The region is also evidently vital in providing breeding and nursery grounds for Atlantic salmon and habitat for European eel through juvenile to adult life stages, thereby, aiding stocks of international importance. The importance of tributary rivers within the catchment of the survey region and the requirement for clear migration pathways (and conservation of habitat quality in those pathways) is of importance to these species.

As well as supporting commercial and recreational fisheries the presence of the species and related fisheries provide significant cultural associations, for instance the traditional trap fisheries link to millennia of history within the region, or the relaxation and health benefits provided by recreational fishing. Although these aspects are beyond market valuation the attraction of the region to visitors and the importance of associated tourism to rural communities is important to recognise in planning and development decisions.

The maintenance of migration pathways and quality of habitat is of consideration to planning and development decisions due to the international conservation status related to migratory species and importance of the region as a nursery area for many species. This issue is addressed in more detail by Marine Scotland (Malcolm et al., 2010).

7.6 Limitations

- Although the current maps of benefit supply provide an indication of current abundance and so supply levels of these species, supply level designation could be improved through use of multiple year data, particularly monitoring from surveys.
- Further maps on habitat supply levels for nursery areas for all species and specialised, detailed spatial scale maps for Atlantic salmon and European eel (from returning glass eel life stages to migrating silver eel life stages) would benefit interpretation of the importance of the region to fish species.
- Supply levels associated with estuarine habitat types and river habitats would provide baseline data to inform models such as the example provided by Liekens et al., (2013). Potential effects of habitat removal or creation could then be assessed to aid future management of stocks and inform decision making.
- Valuation of recreational fisheries would be aided by use of sources such as Devon and Severn Inshore Fisheries and Conservation Authorities work on studying and valuing recreational angling in collaboration with the National Sea Angling Survey (Armstrong et al., 2012).

Section 8 *Benefit: Archaeology*

Ecosystem service category

Cultural

8.1 Background

The Severn estuary, inner Bristol Channel and the surrounding valleys and waterside landscapes provide some of the richest links through human history available in Europe, and potentially globally. The shifting mudflats in particular contain links to our earliest roots, literally allowing people in the present day to walk in the footsteps of ancestors from 8000 years ago. The 'Goldcliff footprints' and surrounding archaeological sites provide a visceral link to the day to day lives of European hunter gatherer people. Moving through the ages, extensive Roman forts, transport, pottery and even evidence of Roman land reclamation exist in the region. Medieval fish traps remain in areas where local residents continue to practice traditional fishing methods in a similar manner to those millennia before. Into modern times the importance of defending the estuary during the Second World War is remembered through sentry posts, machine gun posts and anti-aircraft defences found along the shores in the region. Finally the importance of the transport link provided by the estuary and Bristol Channel (both locally and globally) is evident in the well preserved port facilities and shipwrecks from Roman, medieval and Tudor times through to the present day (Figure 8.1).

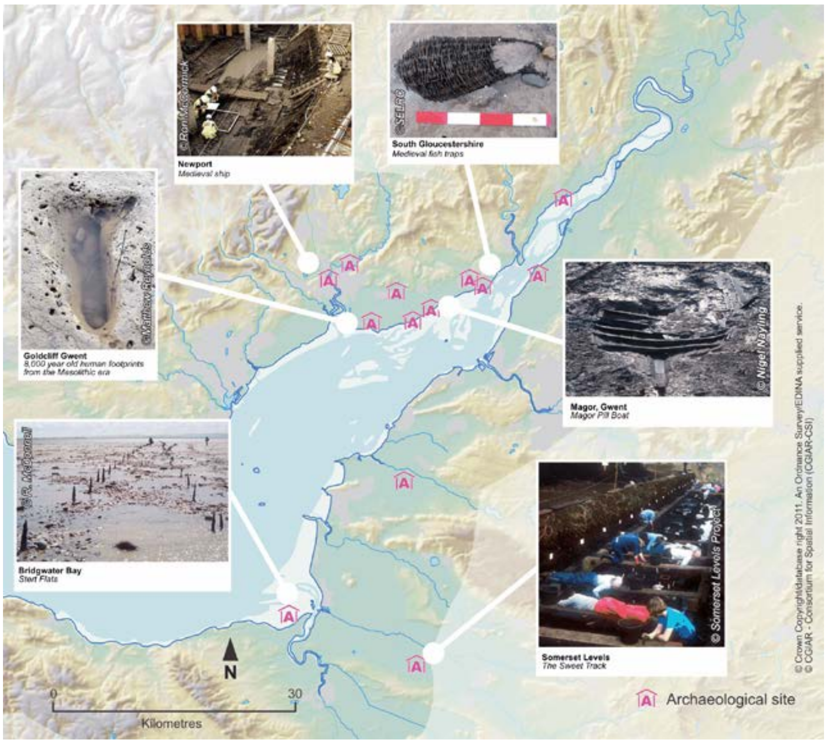

Figure 8.1.Map of archaeological sites of interest in the Severn Estuary and inner Bristol Channel (reproduced from Severn Estuary Partnership 2011).

8.2 Aims and Scope

Three separate mapping approaches were taken to demonstrate the benefit supply in relation to archaeological sites. An initial broad scale approach mapped the historical environment records for all archaeological sites within the study region. This approach aimed to display the huge variety of archaeological interest in the study region. Mapping all records for the coastline in the region, including towns and cities presented a huge array of different archaeological sites and records throughout all historical periods. As this initial mapped result of benefit supply does not relate to environmental habitats and features and crosses between the marine and terrestrial environment it only aims to provide an introduction to the areas rich archaeological importance.

To map archaeological benefit supply levels within the intertidal zone and shoreline Mesolithic to Bronze Age sites extending between the Cardiff region of the inner Bristol Channel in the west, and east into the Severn estuary on both shores to Gloucester were presented as a case study. This case study aimed to present spatial benefit supply of Mesolithic to Bronze Age sites as they are of international importance and potentially impacted by planning and developments that affect the inter tidal zone. The approach applied was intended to be applicable to other historical eras.

The intertidal mud and specifically intertidal peat habitats are of importance to the preservation and accessibility of these sites. Natural erosion within the estuary, especially following storm events reveals well preserved archaeological remains throughout historical periods. To provide a broad scale map of habitat types and features of importance to providing / supporting archaeological finds the final approach mapped benefit supply related to habitat type within all study region planning cells. Habitat data from surveys (where available) was combined with broad-scale modelled habitat within the GIS. The highest habitat benefit supply score present was attributed across the entire planning cell to provide a broad view of habitat related hotspots, taking a precautionary approach to identifying region of high importance to this benefit.

If developments or planning decisions are undertaken in a region the maps are limited to providing an indication of the presence of habitat and features that relate to archaeological importance. Due to the high diversity of sites within the region, the irreplaceable nature of archaeological finds, the importance to understanding human history and the cultural link to past societies it is strongly advised that archaeology specialists are consulted from the earliest stages to provide site specific advice.

8.3 Mapping delivery of archaeology as an environmental benefit

The methods undertaken to deliver the three approaches are summarised below (1: Mapping all historical environment records, 2: Case study: Mapping Mesolithic to Bronze Age finds in the Cardiff/ north Somerset to Gloucester region, 3: Relating habitat types and environment features to archaeological benefit supply):

1. Mapping all Historical Environment Records in the region:

The total number of historical environment records within 10 km² planning units were mapped individually for all archaeological records available throughout the study region through the Heritage Gateway (English region) and The Glamorgan-Gwent Archaeological Trust Ltd (GGAT) (Welsh region). Principal data sources within these records were regional Historic Environment Records (HER) and English Heritage's PastScape data (HERs aim to provide a comprehensive catalogue of known archaeological and historical sites) (Figure 8.2).

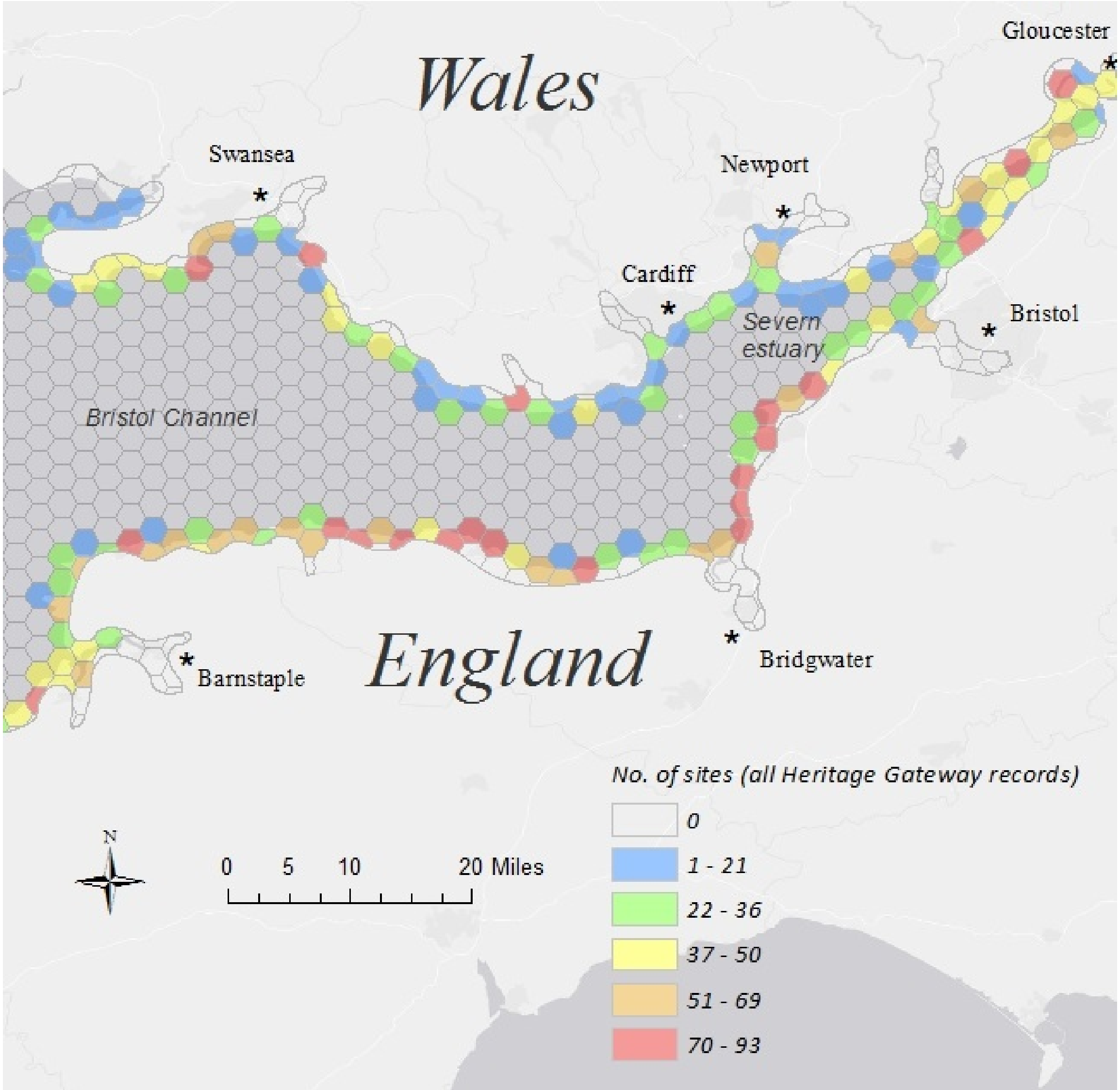

Figure 8.2. Map displaying the total number of archaeological sites from pre-historic to modern periods, recorded for the inner Bristol Channel and Severn estuary region (records taken from Historic Environment Records and EH PastScape data).

2. *Case study: Mapping Mesolithic to Bronze Age finds in the Cardiff/ north Somerset to Gloucester region.*

A case study for the Severn estuary out to Cardiff and Weston Super Mare (outer Severn estuary) was completed identifying Mesolithic to Bronze Age sites (Figure 8.3)

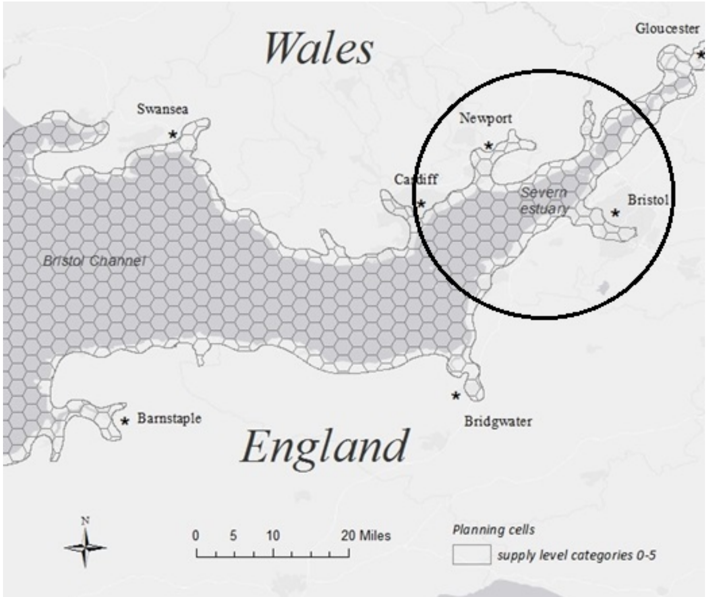

Figure 8.3 The case study region, identified by the black circle.

This case study utilised detailed archaeological survey finds reported in peer reviewed and professional literature sources (Bell et al., 2010, Chadwick et al., 2013). The abundance of sites occurring within a planning cell was used to quantify level of supply (Figure 8.4), confidence in the data used to map finds was also mapped (Figure 8.5).

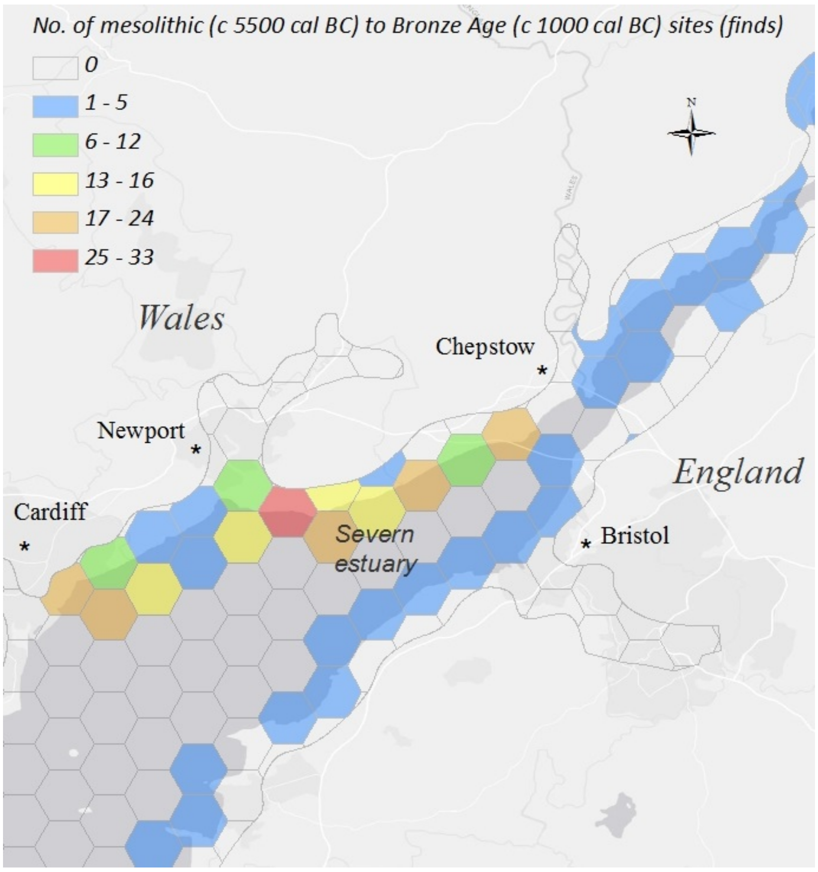

Figure 8.4. Map displaying Mesolithic to Bronze Age sites identified within the outer Severn estuary by Bell et al., (2010), and Chadwick et al., (2013).

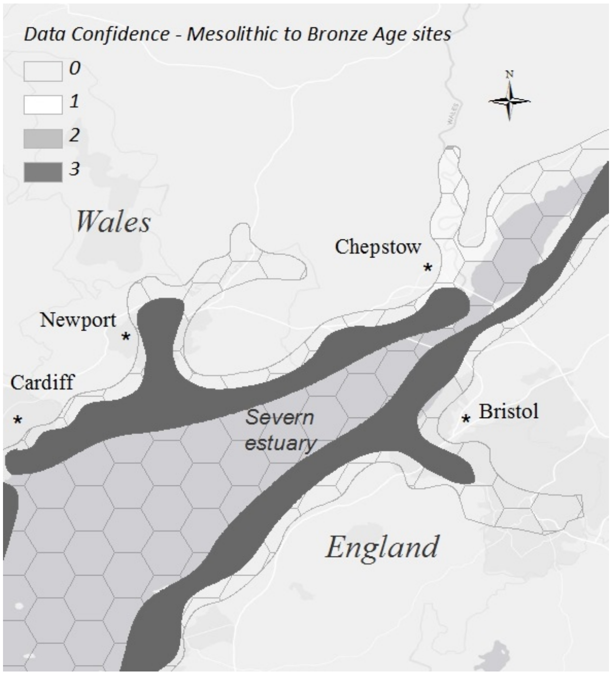

Figure 8.5 Level of confidence in detail of data supporting supply level of archaeological finds (0=no data, 1=low confidence, limited to reports and popular literature, 2=moderate confidence, some reports and grey literature, 3=high confidence, in field surveys and published literature retrieved)

3. Relating habitat types and environment features to archaeological benefit supply.

To link the environmental conditions present in the Severn estuary and inner Bristol Channel region to the presence and delivery of archaeological benefits a combined data layer of habitat survey data and broad-scale habitat data was used (data layers available through the European MESH project and JNCC, Figure 3.3). Existing literature sources relating estuarine sediments links to archaeological finds from Mesolithic through to Bronze Age time periods were used to develop a basic 5 point scale of importance of habitat type to delivery of archaeological finds (archaeological benefits) (Bell et al., 2010, Chadwick et al., 2013).

Following review of habitat links (categories were also sent for review to experts in Severn estuary archaeology) the following scale of 'benefit supply level' (5 providing the greatest benefit) was applied to the habitat data:

0. Insufficient habitat data
1. Rock
2. Gravel dominated sediment
3. Sand dominated sediment
4. Mud dominated sediment
5. Intertidal peat deposits

A value from 0-5 was assigned to each planning unit in the study region based on the level of the habitat type with the highest benefit supply level value within that planning cell (Figure 8.3). Confidence in data resources were also mapped (Figure 8.4).

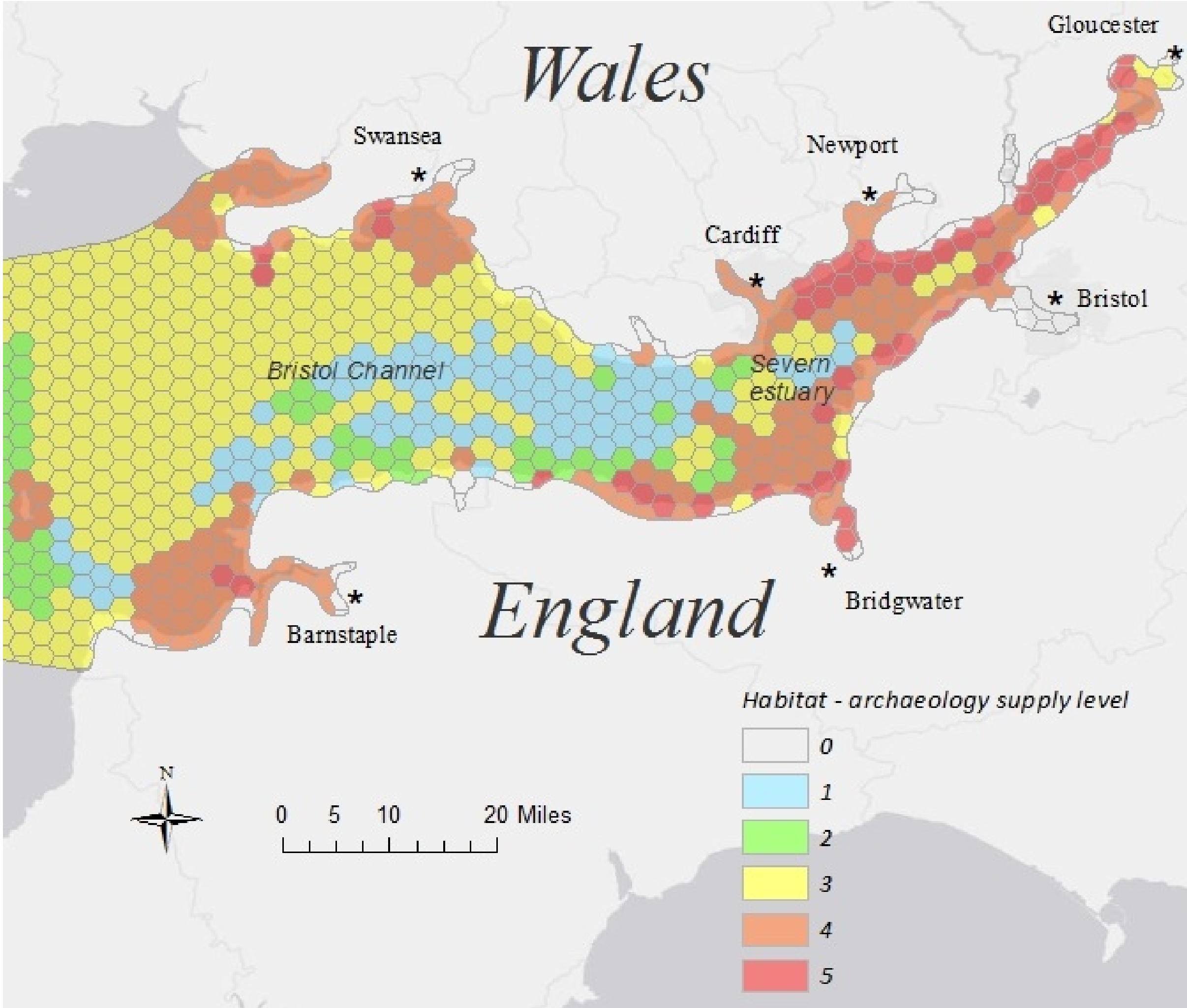

Figure 8.6. Map of archaeological benefit supply scores based on habitat type

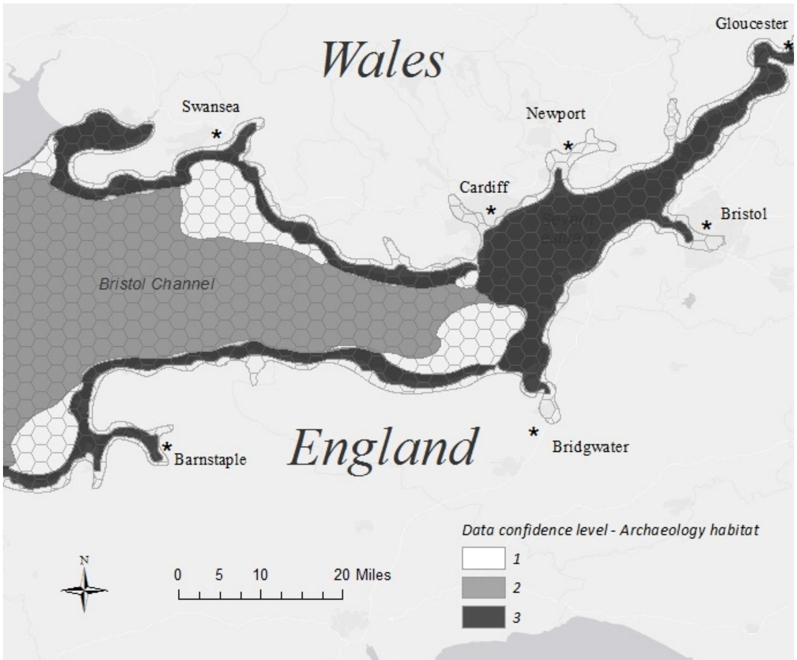

Figure 8.7 Level of confidence in habitat data (0=low, 2=moderate and 3 =high)

8.4 Valuation

Valuation of archaeological sites and finds is a very contentious area due to the importance to understanding human history and human links to past cultures. Sites and finds are by their nature irreplaceable and valuation is possibly most relevant when treated as bequest values or existence values. Whereby, the preservation of archaeological sites is important due to their existence and the present generation's responsibility is to ensure sites remain preserved for their benefit to future generations.

Direct valuation methods do exist that can be applied to specific sites or regions of archaeological interest, however it is important to be aware of the potentially greater existence or bequest value when considering the methods summarised below.

- It is possible to provide direct valuation through associated tourism (visitor numbers and hotel and B&B bookings) and established methods such as *travel cost* which utilises the principle of *willingness to pay* through assessing measures such as distance travelled and expenditure undertaken to visit a specific site.
- Education and learning value can be similarly assessed through research interest such as total value of research grants linked to a site or value to learning through numbers of school and university field trips taken to sites.
- Surveys of public and local communities are of use in establishing not only *willingness to pay* but also *bequest values* (value of evidence of the past and past cultures to future generations).

8.5 Interpretation

- *Huge variety of historic environment records across the region and internationally important archaeological resources within intertidal peat habitats.*

The available valuation methods have limited practical examples in the literature reviewed for this study. It is also recognised that does not represent the full value of many of the important archaeological sites and potential sites within the Severn estuary and inner Bristol Channel. The presence of visual evidence of 8000 years of habitation and cultures in the region is recognised to be more likely to cross into less quantifiable values such as sense of place, cultural identity and the value for knowing the sites are preserved for future generations (bequest values). These recording and valuation approaches will be approached in the following section on *sense of place*. Timescales for this initial project may prevent a full application of these methodologies unless possibilities arise for work to be taken forward in future projects.

As with other benefit supply level maps the presence of extensive saltmarsh, and in this instance intertidal peat deposits reveals the importance of these habitats not just to the region but internationally (international importance of Mesolithic finds). The unique combination of a huge tidal range and the presence of these habitat features provide environmental conditions that accentuate these benefits. The large tides experienced in the region, combined with erosion due to flooding and storm erosion will continue to reveal new finds and archaeological evidence as time goes on.

Spatial mapping of Mesolithic to Bronze Age finds revealed distinct hotspots. Extending this approach at similar, smaller spatial scales across the study area and for the full range of historical periods would aid identification of similar archaeological resource hotspots.

8.6 Limitations

- Mapping all Historical Environment Records provides an indication of the huge number and diversity of archaeological sites but without identifying sub sets of periods can only display that all regions have archaeological considerations.
- Consulting Historical Environment Records in specific regions under consideration for planning and development at more detailed spatial scales would be required to aid planning and development decisions (and is required in impact assessments).
- Historical Environment Records may be collated differently within each county or region, thereby, it is vital to consult archaeological experts within the earliest stages of development.
- The case study within the outer Severn estuary displays the large number of internationally important sites within a small area, this demonstrates the need for detailed small scale regional assessment of archaeological benefit supply, with input from experts from the outset.
- The relationship to habitat types and environmental features (Figure 8.6) would be enhanced with greater evidence of how marine / estuarine habitats may aid delivery of cultural services from archaeology. Further consultation with the archaeological research community would benefit further developments of this approach.

Section 9: Benefit: Sense of place

(connection with place / place attachment)

Ecosystem service category

Cultural

9.1 Background

The means and representation of people's connection with place has been debated in social research literature but the underlying theme of sense of place is repeated place interactions and experiences which create strong emotional ties. Whilst the landscape and events discussed in the literature can be very different, from individual's associations with a country fair to people's relationships with specific cities or regions the process of emotional attachments occurs in relation to each of the landscapes (Kyle and Chick 2007). This provides a unique personal association with places, the landscapes, and the historical and cultural properties.

9.2 Aim and Scope

Assessing the ES benefits from cultural services and sense of place (also referred to as place attachment) is one of the most challenging but possibly also most important areas in ES assessment. Mapping the relationships between local environments and attributes of sense of place (related to the local environment) experienced by individuals living and working in the study region was beyond the resources of this study. Instead, methods for identifying and mapping sense of place attributes for locations within the study area are summarised to indicate how a project could be taken forward to engage local communities and collate sense of place attributes in relation to the various localities within the Severn estuary and inner Bristol Channel.

People's sense of place, and their motivations around these can hugely important for wellbeing, health and relaxation. Changes in an environment, and most obviously new large scale developments can affect the attributes that have important links to people's sense of place. This can have negative effects on the community or provoke public opposition. The premise behind identifying attributes from the environment linked to sense of place across localities in the study region is to guide developers and planners on issues or attributes to consider at the outset of projects. The methods detailed below (such as the community voice method) also provide approaches to involve individuals and communities in planning or development decisions which will affect sense of place. The cultural mapping approaches which have become applied in country specific examples by UNESCO to safeguard cultural assets and knowledge in regions facing war or political turmoil are also acknowledged to be adaptable to recording attributes of sense of place (Clark et al., 1995, Poole 2003, UNESCOBK 2014).

Cultural mapping is recognized by UNESCO as a crucial tool and technique in preserving the world's intangible and tangible cultural assets. The approach encompasses a wide range of techniques and activities including community-based participatory data collection and management as well as recorded accounts of cultural assets. Collated resources are then mapped, often using GIS software.

Review and design of a full cultural mapping programme's application to the Severn estuary and inner Bristol Channel is beyond the current scope of this project, however, its applicability to the region and mapping sense of place as an ES benefit are recognised. Clark et al., (1995), Poole (2003), and UNESCOBK (2014) provide guidance on the techniques involved.

The individual techniques introduced in the following methods section could be used within a larger cultural mapping programme for the region. The techniques introduced are: 1. Interview approaches, 2. Photo voice method, 3. Community voice method and 4. Analytical approaches to measuring peoples sense of place attributes.

9.3 Mapping methods

1. Interview approaches: '*Why is the estuary important to you?*'

Data collection would be led by open ended interviews on the aspects of the landscape and local region that are important to people (for instance asking individuals, 'Why is the estuary important to you?'). Analyses of often repeated responses provide the most simplistic form of data interpretation and responses can be linked to the region or locality interviews referred to (Figure 1).

Figure 9.1 Wordle, representing the responses of 40 members of the UK public when asked for; *'a description of the British seaside.'* The larger the word the greater number of times it was mentioned. Reproduced from the Geographical Association's document available at
http://resources.collins.co.uk/free/Wedoliketobebesidetheseasidecompressed.pdf

2. Photo voice method

To further link individuals responses and perceptions to localities the photo voice method can be applied where interviewees would also be asked to provide a photographic record of the aspects of the landscape that are important to them, and comment on the photos (photo voice method).

The resulting data set to be mapped would be obtained by identifying key themes in interview responses for each locality and key themes in photographic records for each locality or region. When individual study site localities are mapped across the whole estuary and inner Bristol Channel study site, a vocal and pictorial pattern of key sense of place themes across the region would be identifiable.

The examples in Figure 9.2 (a) and 9.2 (b) display two responses of a photo voice project for a similar coastal and estuarine geographic region. The photo voice project was initiated as a community project to record how the youth in the community view their neighbourhood. Cameras were provided and instructions given to 20 participants to take a photo and provide a description of why the scene was important to them. The project aimed to give local school students the chance to open the public's eyes to how they feel about their local community (North Kitsap Herald, June 2008)

Charles Lawrence Memorial Boat Ramp … may not look like much but this dock was important to the area because it was a place to swim, used to be a ferry dock for the mosquito fleet, and a fishing place. As a child I would jump off and swim to shore.

The memories that rush through your head, describing the thoughts that could never be forgotten. Each piece of wood has a place in your past. Soon to be torn down, the memories will always remain. Even though this personally historic land mark will be gone, the new land mark to take its place will make new memories, to full-fill the lives of the youth to come.

Figure 9.2 Photo voice responses of two students involved in the photo voice exercise undertaken in North Kitsap, Washigton, USA 2008.

The constraints with this method would be the level of participation in interviews and photo voice fieldwork, the number of localities and the sample sizes returned for each locality. However, although valuation methodologies are limited for this approach results would indicate sense of place attributes that could inform planning and decision making, particularly regarding maintaining key cultural ties.

3. Community voice method

The community voice method developed at Duke University, North Carolina, USA builds on the practice of interviews and photo voice methods to gather community perceptions of a given region. The method can be used to address particular landscape or conservation management issues or simply record individual's experience of and attachment to a region.

A multi stage process is practised, stages 3 and 4 below include elements that are included if the community voice project is centred on a development or management issue such as fisheries management or coastal development such as renewable energy.

1. Initial sample surveys gather opinions and perceptions of a sub sample of the population.
2. The second phase consists of interviews with a large number of residents, identified through *snowball sampling* (peer referral) and self-referral of survey respondents. The interviews are then analysed to identify prevalent viewpoints. Representative interview segments are also included in a short documentary film (Figure 9.3).
3. Public meetings are conducted where survey results (prevalent viewpoints) are presented and the documentary film is shown. Where development and management issues are the focus of the community voice project structured, small-group discussion followed the presentation, giving participants an opportunity to share their own visions for the area.
4. Participants' visions from all public meetings are then compiled and ranked. At a follow-up meeting participants identify priority issues from the ranked vision list and structured discussions are undertaken on how those issues could be tackled.
   (Community Voice Method 2011)

Figure 9.3. Community voice interview and documentary film making in South Caicos, British West Indies. Image reproduced from Duke University community voice method resources

5. Measuring Cultural Ecosystem Benefits: Sense of Place

Hattam (2014) provides a multidisciplinary approach for measuring cultural ecosystem benefits, in particular sense of place. Where previous reviewed methods provide open ended interviews and let themes emerge for community discussion at a later stage the approach outlined by Hattam (2014) identifies the attitude context of sense of place. This provides a more analytical methodology that allows features of sense of place to be measured.

This method adopts an attitudinal approach developed by Jorgensen and Stedman (2001, 2006), in which *sense of place* is viewed as being unobservable but constructed of 5 key factors:

- Place meaning
- Place attachment
- Place dependence
- Family importance
- Community importance

As these factors are also potentially unobservable Hattam (2014) applied '*Confirmatory factor analysis'* model techniques. Confirmatory factor analysis requires the investigator to come up with hypothesised responses, or indicators, that (they hypothesise / predict) will be of repeated importance in interviewee or survey respondents replies to a question such as '*What does the estuary mean to you?,*' (for instance selecting hypothesised responses such as '*wildlife'* or '*open space*,'). The confirmatory factor analysis model then statistically tests the actual responses to investigate if they conform to the hypothesised responses or not.

The approach provides the opportunity to test hypothesised theories in relation to the attributes or factors linking to sense of place for individuals or communities at specific sites. This allows specific responses or factors to be accepted or rejected on an analytical basis (using objective statistical techniques). The effects of 'moderators' such as age or income bracket can also be explored if these have been collected in interviews or surveys.

This approach can feasibly be applied to different sites within the Severn estuary or inner Bristol Channel.

9.4 Valuation methods

These methods do not provide straightforward economic valuation data. The different interpretation of value between individuals relating to the environment around them may be inappropriate for monetary valuation. However, the human perspective and community opinion and perceptions can be recorded through qualitative analysis such as identifying prevalent viewpoints (oft repeated topics and themes). The perceptions provided by individuals can be brought to group discussions and provide a means of opening discussion. This data and information can directly inform management and planning decisions as well as indicating the factors relating to the landscape or region of highest importance to the local community.

9.5 Interpretation

- *Diverse natural and cultural environments in the study region provide many unique 'sense of place' elements. These require existing recording and investigation methods to be adapted to inform development and planning.*

All methods reviewed provide a means to approach sense of place for individuals and communities, or the factors constructing an overall sense of place within a given environment. For the Severn estuary and inner Bristol Channel region this provides the opportunity to build up information on the key factors influencing sense of place amongst communities living and working in close proximity to the estuary or other groups such as tourists and visitors. Building awareness of these factors can aid decision making by providing a baseline of the key factors of importance to people living in or visiting a site, and therefore the key factors, particularly in relation to the natural environment to be considered and maintained to maximise human welfare. Methods aiding community involvement in decision making and mitigation such as the Community Voice Method are potentially useful tools to engage the public and reach mitigation or management solutions.

9.6 Limitations

- Deriving sense of place, particularly as an ES benefit, is still a developing area. Cultural mapping approaches and the individual methods to assess sense of place introduced in this section are constantly developing. Alternative techniques and methodologies are also present.
- To document sense of place attributes throughout the study region would require significant effort and resources, particularly to get involvement from all actors across multiple communities.
- The approaches would suit a number of smaller projects to present overviews of areas but the methods would still need to be applied as targeted projects to aid location specific planning or development decisions.

Section 10. Summary

This study has highlighted the importance of the greater Severn and inner Bristol Channel, in delivering ecosystem services (ES) that provide benefits to communities both locally and internationally.

Key benefits identified through this ES mapping exercise include:

- The presence of internationally significant marine transport links and ports, the presence of which support regional, national and international trade and industry.
- Multiple ES benefits that flow from the regions intertidal areas, particularly mud bank habitats and the intertidal saltmarsh habitats. This study highlights their importance for:
    - flood risk management,
    - carbon sequestration and burial (storage),
    - archaeological resources and
    - wild food and fisheries.

The Severn region is also of considerable cultural importance which suggests a much more detailed assessment and interpretation of the range of cultural services than was possible during this project.

The study was undertaken over a very short time frame (three months) and so was deliberately limited to a small number of ES, which were selected to provide an example from each service 'category' and these were assessed necessarily at a broad scale. Nonetheless, this exploratory work demonstrated the value of conducting spatially explicit assessments of ES. Mapping allows the delivery of ES to be visualised in an accessible way: the GIS outputs were well received by stakeholders at a meeting convened to seek their input on the draft products of this study. The use of GIS also provides the potential for the ES data to be overlaid onto other spatial data (e.g. location of energy resources & coastal developments), and thus support planning and decision making.

Considerations for future work.

Future research should utilise the strengths and address the weaknesses identified in this study, in particular considering the full range of ES provided by the estuary system and developing greater precision and confidence to each.

Detailed ES assessment requires multidisciplinary ecological, social and economic research, expertise and associated data resources. Next steps on the Severn would benefit from early engagement with the regions academic institutions, industries (e.g. ports, energy, etc.), statutory agencies, experts, and NGOs, in order to utilise their knowledge. There remain many unknowns in ES assessments, with expert approaches key to filling gaps. For example, on the Severn, more will need to be done on the significance of different habitats and environmental features to individual ES delivery.

Understanding the benefits present in any location and the relationship to community wellbeing absolutely requires the engagement of stakeholders through the assessment processes. This project included steering group sessions, a stakeholder presentation and feedback session that brought many key parties together for this kind of dialogue. Strong, well designed, stakeholder liaison will be critical to future studies.

In summary, considerations for future ES assessment linked research are identified as;

- Building information resources is central to underpinning greater confidence (precision) in assessment of supply of many ES in the Severn complex. Level of detail in habitat, species and species community data is not uniform throughout the study region. Although extending full habitat and species surveys across the study region is a complex undertaking, the resulting data would provide greater confidence (and precision) in results of ES assessment and modelling exercises.
- A focus on better interpreting the contribution of habitats and species present in the region to ecosystem functions (and so provision of ES that relate to those functions). Again this is central to increasing confidence in assessment of supply of ES in the study region. For instance, role of sedimentary habitats in carbon cycling and storage is poorly understood compared to vegetated habitats.
- Indicators, as in species or factors which can be measured to reflect the provision of an ES and how that ES changes over time provide a means of simplifying assessment of ES supply. However, more work is needed on identification of indicators for ES delivery.
- Research is required to identify and build knowledge around quantitative measures for specific ES to aid assessment and application of ES assessment and mapping to development and environmental management decisions.
- Building knowledge on cultural ES within the study region, including development of methods and tools to assess these.
- Developing a shared knowledge development framework, roadmap, and capacity across the considerable regional academic, environmental and industry expertise. This will provide a greater rigour and depth of knowledge around factors relating to each ES within the region.
- An outreach approach that generates significant engagement across sectors, for example, from; planners, decision makers, industry representatives, research community and civil society, to create a rich understanding for development choices in the greater Severn.

Section 11. References

ABPmer 2014. ABPmer's 'Blue Carbon Calculator' webpage accessed July 2014 from http://www.abpmer.co.uk/About_Us/Publications/Buzz/ABPmers_Blue_Carbon_Calculator/

Adams, C. A., Andrews, J. E., Jickells T. 2012. Nitrous oxide and methane fluxes vs. carbon, nitrogen and phosphorous burial in new intertidal and saltmarsh sediments. Science of the Total Environment 434: 240-251.

Alonso, I., Weston, K., Gregg, R., Morecroft, M. 2012. *Carbon storage by habitat -Review of the evidence of the impacts of management decisions and condition on carbon stores and sources*. Natural England Research Reports, Number NERR043.

Anderson, B.J., Armsworth, P.R., Eigenbrod, F., Thomas, C.D., Gillings, S., Heinemeyer, A., Roy, D.B., Gaston, K.J., 2009. Spatial covariance between biodiversity and other ecosystem service priorities. Journal of Applied Ecology 46, 888–896.

Andrews, J.E., Burgess, D., Cave R.R., Coombes E.G., Jickells, T.D., Parkes D.J., Turner. R.K., 2006. Biogeochemical value of managed realignment, Humber estuary, UK. Science of the Total Environment, 371, 19-30.

Armstrong et al., 2012. Sea Angling 2012 – a survey of recreational sea angling activity and economic value in England. Defra 2012 accessed July 2014 from: http://webarchive.nationalarchives.gov.uk/20140108121958/http://www.marinemanagement.org.uk/seaangling/documents/finalreport.pdf

Atkins, J., Banks, E., Burdon, D., Greenhill, L., Hastings, E., Potts, T. *An analysis of methodologies for defining ecosystem services in the marine environment* JNCC Report No. 491 2013

Barbier E.B. 2007. Valuing ecosystem services as productive inputs. Economic Policy 22 (49): 177-229

Bateman I.J., Mace G.M., Fezzi C., Atkinson G., Turner K. 2011. Economic Analysis for Ecosystem Service Assessments. Environmental and Resource Economics 48 (2): 177-218

Bateman I. and Sen A. (Eds). 2010. *UK National Ecosystem Assessment (NEA). Economic analysis for the NEA: Interim (Phase 1) Report.* 16 February 2010. 222pp

Bell, M., Caseldine, A., Neumann, H. *Prehistoric intertidal archaeology in the Welsh Severn estuary, Council for British Archaeology Research Report 120*, Council for British Archaeology 2000.

BirdLife International (2012) Spotlight on Ecosystem Services. Presented as part of the BirdLife State of the world's birds website. Available from: http://www.birdlife.org/datazone

Boyd J. and Banzhaf S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63: 616-626.

Brenner, J., Jime´nez, J.A., Sarda´, R., Garola,A., 2010.An assessment of the non- market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53, 27–38.

Broekx, S., Smets, S., Liekens, I., Bulckaen, D., De Nocker, L. (2011). Designing a long-term flood risk management plan for the Scheldt estuary using a risk-based approach Natural Hazards 57(2): 245-266.

Bryan, B.A., Barry,S.,Marvanek,S.,2009.Agricultural commodity mapping for land use change assessment and environmental management: an application in the Murray and Darling Basin, Australia Journal of Land use Science 4, 131–155.

Bryan, B.A., Kandulu, J.M., 2009. Cost-effective alternatives for mitigating Cryptos - poridium risk in drinking water and enhancing ecosystem services. Water Resources Research 45

Bryan, B.A., Raymond, C.M., Crossman, N.D., Macdonald, D.H., 2010. Targeting the management of ecosystem services based on social values: Where, what, and how? Landscape and Urban Planning 97, 111–122.

Bryan, B.A., King, D., Ward, J.R., 2011a. Modelling and mapping agricultural opportunity costs to guide landscape planning for natural resource management. Ecological Indicators 11, 199–208.

Calloway, R., Lock, J., Bishop, E., Blazey, T., A Tidal Energy Lagoon in Swansea Bay: Optimising its Value for Biodiversity by Creating and Artificial Reef. Poster presented at the 2nd International Environmental Interactions of Marine Renewable Energy Technologies Conference, Stornoway, Isle of Lewis UK 28th April – 2nd May 2014.

Chadwick, A., Catchpole T., Brunning, R., Nayling, N. *Severn Estuary Rapid Coastal Zone Assessment Survey Phase 2 Fieldwork report Volume 1: Text and Figures*, a report for English Heritage (NHPCP project 3885) Version 3.2 final, February 2013.

Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C., Daily, G.C., 2006. Conservation planning for ecosystem services. Plos Biology 4, 2138–2152.

Channel Energy Ltd 2013 *Atlantic Array Offshore Wind Farm Environmental Statement. Volume 3: Offshore Annexes. Annex 13.1: Commercial Fisheries Technical Report* June 2013, Revision A. Document Reference: 6.3.13.1, accessed May 2014 from http://infrastructure.planningportal.gov.uk/

Chen, N., Li, H., Wang, L., 2009. A GIS-based approach for mapping direct use value of ecosystem services at a county scale: Management implications. Ecological Economics 68, 2768–2776.

Chmura, G.L., Anisfeld, S.C., Cahoon, D.R., Lynch, J.C. 2003 Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochemical Cycles*. 17, 1111.

Clark, I., Sutherland, J., and Young, G. (1995) *Mapping Culture - A Guide for Cultural and Economic Development in Communities*. AGPS: Canberra.

Community Voice Method (2011) *The Method* published online 2011, accessed from http://communityvoicemethod.org/the-method/ May 2014, further resources available at http://communityvoicemethod.org/turks-caicos/; http://communityvoicemethod.org/change-in-coastal-communities/

Crossman et al., 2013 A blueprint for mapping ecosystem services. Ecosystem Services 4, 4-14

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R.V, Paruela J, Raskin R.G, Sutton P and van den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260

CSIRO, 2008. *Water availability in the Murray–Darling Basin. A report to the Australian Government from the CSIRO Murray–Darling sustainable yields project*. CSIRO, Australia.

Daily G.C. (Ed) 1997. *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press, Washington. 392pp

Daily G. and Matson P. 2008. Ecosystem services: From theory to implementation. *Proceedings of the National Academy of Science* 105: 9455-9456

DECC (prepared by Parsons Brinckerhoff, Black & Veatch Ltd.) *Severn Tidal Power – Scoping Topic Paper: Migratory & Estuarine Fish* DECC 2008.

Defra 2010 *Eel Management plans for the United Kingdom*, accessed May 2014 from Defra online archives, http://archive.defra.gov.uk/foodfarm/fisheries/documents/fisheries/emp/overview.pdf

Defra 2010a *Eel Management plans for the United Kingdom Severn River Basin District*, accessed May 2014 from Defra online archives, http://archive.defra.gov.uk/foodfarm/fisheries/documents/fisheries/emp/overview.pdf

DEFRA. 2007a. *An introductory guide to valuing ecosystem services*. Department for the Environment, Food and Rural Affairs, London. 68pp

de Groot R., Fisher B., Christie M., Aronson J., Braat L., Gowdy J., Haines-Young R., Maltby E., Neuville A., Polasky S., Portela R. and Ring I. 2010. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation**.** In: Kumar, P. (Ed). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Earthscan

de Vries, S., Lankhorst, J.R.-K., Buijs, A.E., 2007. Mapping the attractiveness of the Dutch countryside: a GIS-based landscape appreciation model. Forest Snow and Landscape Research 81, 43–58

EA (2011*) Severn Estuary Flood Risk Management Strategy: Strategic Environmental Assessment Report* Environment Agency January 2011

Eigenbrod, F., Anderson, B.J., Armsworth, P.R., Heinemeyer, A., Jackson, S.F., Parnell, M., Thomas, C.D., Gaston, K.J., 2009. Ecosystem service benefits of contrasting conservation strategies in a human-dominated region. Proceedings of the Royal Society B - Biological Sciences 276, 2903–2911.

English Heritage 2013 *Historical Environment Guidance for Wave and Tidal Energy English Heritage 2013* accessed July 2014 from http://www.historic-scotland.gov.uk/wave-tidal-energy-guidance-nov-13.pdf

Environment Agency 2013 *Salmonid & Freshwater Fisheries Statistics for England & Wales, 2012, including declared catches for salmon, sea trout, eels, smelt and lamprey by rods, nets and other instruments* Version 1 November 2013

Ennaanay, D., Conte, M., Brooks, K., Nieber, J., Sharma, M., Wolny, S., Mendoza, G., 2011. Valuing land cover impact on storm peak mitigation. Pages 73-88. In: Kareiva, P., Tallis, H., Ricketts, T.H., Daily, G.C., Polasky, S. (Eds.), *Natural Capital: Theory and Practice of Mapping Ecosystem Services*. Oxford University Press, Oxford.

FHRC 2010, *The benefits of flood and coastal risk management: a handbook of assessment techniques* 2010.

Fisher B, Turner R.K and Morling P. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68: 643-653.

Fisher, B., Turner, R.K., Burgess, N.D., Swetnam, R.D., Green, J., Green, R.E., Kajembe, G., Kulindwa, K., Lewis, S.L., Marchant, R., Marshall, A.R., Madoffe, S., Munishi, P.K.T., Morse-Jones, S., Mwakalila, S., Paavola, J., Naidoo, R., Ricketts, T., Rouget, M., Willcock, S., White, S., Balmford, A., 2011. Measuring, modelling and mapping ecosystem services in the Eastern Arc Mountains of Tanzania. Progress in Physical Geography 35, 595–611.

Egoh, B., Reyers, B., Rouget, M., Richardson, D.M., Le Maitre, D.C., van Jaarsveld, A.S., 2008. Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment 127, 135–140.

Gevaert, F., Janquin, M.-A., Davoult. D. 2008. Biometrics in *Laminaria digitata*: A useful tool to assess biomass, carbon and nitrogen contents. Journal of Sea Research, 60, 215–219.

Granek E.F., Polasky S, Kappel C.V., Reed D.J., Stoms D.M., Koch E.W., Kennedy C.J., Cramer L.A., Hacker S.D., Barbier E.B., Aswani S, Ruckelshaus M, Perillo G.M.E, Silliman B.R., Muthinga N., Bael D and Wolanski E. 2010. Ecosystem Services as a Common Language for Coastal Ecosystem-Based Management. Conservation Biology 24: 207-216

Gret-Regamey, A.,Walz, A., Bebi,P., 2008b.Valuingecosystemservicesfor sustainable landscape planning in Alpine Regions. Mountain Research and Development 28, 156–165.
Hartiq, T., Korpela, K., Evans G.W., Garling, T., A measure of restorative quality in environments. SHPR 14: 175-194.

Hattam C., *Exploring cultural ecosystem services from the marine environment*, presentation at the 2nd Marine and Coastal Policy Forum, Plymouth, June 2014

Henderson, P.A. and D. J. Bird, 2010. Fish and macro-crustacean communities and their dynamics in the Severn Estuary. Marine Pollution Bulletin 61 (2010) 100-114

HM Government 2012, *Port freight statistics: provisional annual 2012*, accessed from https://www.gov.uk/government/publications/port-freight-statistics-provisional-annual-2012 May 2014

HMSO. 2000. Environmental impact assessment: guide to procedures. Department of Communities and Local Government. 67pp

Hooper, T., Cooper, P., Hunt, A. and Austen, M., 2014. A methodology for the assessment of local-scale changes in marine environmental benefits and its application. *Ecosystem Services (in print)*

Jacobs, S.W., Vandenbruwaene, D., Vrebos, O., Beauchard, A., Boerema, K., Wolfstein, T., Maris, S., Saathoff, S., Meire. P. 2013. *Ecosystem service assessment of TIDE estuaries*. Study report in the framework of the Interreg IVB project TIDE. ECOBE, UA, Antwerp, Belgium. Accessed May 2014 through http://www.tide-toolbox.eu/reports/

JNCC (2012) *EUSeaMap Predicted habitats Celtic Sea* accessed from http://jncc.defra.gov.uk/default.aspx?page=6266 April 2014, data downloaded April 2014, data last updated by JNCC July 2012

Jenkins, W.A., Murray, B.C., Kramer, R.A., Faulkner, S.P., 2010. Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. Ecological Economics 69, 1051–1061.

Jones M. L. M., Sowerby, A., Williams, D.L., Jones. R. E. 2008. Factors controlling soil development in sand dunes: evidence from a coastal dune soil chronosequence. Plant Soil, 307, 219–234.

Jorgensen, B.S., Stedman, R., 2001. Sense of place as an attitude: lakeshore property owners' attitudes toward their properties. Journal of Environmental Psychology 21, 233–248.

Jorgensen, B.S., Stedman R.C. A comparative analysis of predictors of sense of place dimensions: Attachment to, dependence on, and identification with lakeshore properties. Journal of Environmental Management 79 (2006) 316–327

Kyle G. and Chick G., 2007. The Social Construction of a Sense of Place, Leisure Sciences, 29: 209–225, 2007

Lara, A., Little, C., Urrutia, R., McPhee, J., Alvarez - Garreton, C., Oyarzun, C., Soto, D., Donoso, P., Nahuelhual, L., Pino, M., Arismendi, I., 2009. Assessment of ecosystem services as an opportunity for the conservation and management of native forests in Chile. Forest Ecology and Management 258, 415–424.

Ledoux L. and Turner R.K. 2002. Valuing ocean and coastal resources: a review of practical examples and issues for further action. Ocean and Coastal Management 45: 583-616.

Liekens I., Broekx S., De Nocker L., 2013 *Manual for the valuation of ecosystem services in estuaries*, a study commissioned by Antwerp Port Authority (APA), accessed May 2014 through http://www.tide-toolbox.eu/reports/

Liekens I., De Nocker L., Broekx S., Aertsens J. (2013a) Ecosystem services and their monetary value in: Jacobs, S.; Dendoncker N. & Keune, H. (Ed.), Ecosystem service debates – reflections from the community of science and practice in Belgium. Ecosystem Services, Edition: 1st, Publisher: Elsevier, Editors: Sander Jacobs, Nicolas Dendoncker, Hans Keune, 2013 pp.13-28,

Mace, G., Norris, K., Fitter, A.H., 2012. Biodiversity and ecosystem services: a multi layered relationship. Trends in Ecology & Evolution 27, 19–26.

Maes, J., Paracchini, M.L., Zulian, G., Dunbar, M.B., Alkemade, R., 2012b. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. Biological Conservation 155, 1–12.

Malcolm I.A., Godfrey J. and. Youngson A.F. Review of migratory routes and behaviour of Atlantic salmon, sea trout and European eel in Scotland's coastal environment: implications for the development of marine renewables Scottish Marine and Freshwater Science Vol 1 No 14 2010

Mapping European Seabed Habitats (MESH) *EUNIS habitat maps from surveys*, data downloaded from MESH http://www.searchmesh.net/download data last updated by MESH 9th December 2013, data downloaded April 2014

Marine Management Organisation (MMO), 2013. Marine Planning Portal accessed through http://planningportal.marinemanagement.org.uk/# May 2014, last updated June 2013

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schagner, J.P., Grizzetti, B., Drakou, E.G., Notte, A.L., Zulian, G., Bouraoui, F., Luisa Paracchini, M., Braat, L., Bidoglio, G., 2012a. Mapping ecosystem services for policy support and decision making in the European Union. Ecosystem Services 1, 31–39.

Maes, J.,Paracchini, M.L., Zulian, G., Dunbar, M.B., Alkemade, R., 2012b. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. Biological Conservation 155, 1–12.

Mendoza, G., Ennaanay, D., Conte, M., Walter, M.T., Freyberg, D., Wolny, S., Hay, L., White, S., Nelson, E., Solorzano, L., 2011. Water supply as an ecosystem services for hydropower and irrigation. Pages 53-72. In: Kareiva, P., Tallis, H., Ricketts, T.H., Daily, G.C., Polasky, S. (Eds.), *Natural Capital: Theory and Practice of Mapping Ecosystem Services*. Oxford University Press, Oxford, UK.

McLeod E, Chmura GL, Bouillon S, Salm R, Bjork M, et al. (2011) A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Frontiers in Ecology and the Environment 9: 552–560.

Ming, J., Xian-guo, L., Lin-shu, X., Li-juan, C., Shouzheng, T., 2007. Flood mitigation benefit of wetland soil - A case study in Momoge National Nature Reserve in China. Ecological Economics 61, 217–223.

Mooney H.A. and Ehrlich P.R. 1997. Ecosystem Services: A Fragmentary History. In: Daily G.C. (Ed). *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press, Washington. p11-19.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Naidoo, R., Weaver, L.C., Stuart-Hill, G., Tagg, J., 2011. Effect of biodiversity on economic benefits from communal lands in Namibia. Journal of Applied Ecology 48, 310–316.

NCC 2013. The State of Natural Capital: Towards a framework for measurement and valuation A report from the Natural Capital Committee April 2013 Accessed May 2014 from: https://www.naturalcapitalcommittee.org/working-papers.html

NCC 2014. Towards a Framework for Defining and Measuring Changes in Natural Capital Working Paper 1 March 2014 Natural Capital Committee March 2014. Accessed May 2014 from: https://www.naturalcapitalcommittee.org/working-papers.html

North Kitsap Herald, June 2008, accessed May 2014 from: http://www.northkitsapherald.com/news/18283404.html

Millennium Ecosystem Assessment (MA) 2003 *Ecosystems and Human Well-being. A Framework for Assessment*, MA and Island Press Washington D.C. accessed May 2014 from http://www.unep.org/maweb/en/index.aspx

Millennium Ecosystem Assessment (MA) 2005. *Ecosystems and human well-being: synthesis*. Island Press. Washington, D.C.

Nedkov, S., Burkhard, B., 2012. Flood regulating ecosystem services - Mapping supply and demand in the Etropole municipality, Bulgaria. Ecological Indicators 21, 67–79.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D.R., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M.R., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7, 4–11.

Painting et al., 2010. Defra report MEC3205. *Results of fieldwork to quantify key process affecting the flow of C, N, O and Si at key sites in the North Sea*. 65pp.

Petz, K., van Oudenhoven, A.P.E., 2012. Modelling land management effect on ecosystem functions and services: a study in the Netherlands. International Journal of Biodiversity Science, Ecosystem Services & Management 8 (1-21).

Poole, P. (2003) *Cultural Mapping and Indigenous Peoples*. A report for UNESCO, March 2003

Posthumus, H., Rouquette, J.R., Morris, J., Cowing, D.J.G., Hess, T.M., 2010. A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. Ecological Economics 69, 1510–1523.

Potts, T., Jackson, E., Burdon, D., Saunders, J., Atkins, J., Hastings, E. & Langmead, O. 2013. *Marine Protected Areas and Ecosystem Services – Linking Conservation and Human Welfare?* Unpublished report of the NERC-funded Valuing Nature Network, January 2013, UEA, Norwich.29pp.

Potts, T., Burdon, D., Jackson, E., Atkins, J., Saunders, J., Hastings, E., Langmead, O., 2013a. Do marine protected areas deliver flows of ecosystem services to support human welfare? Marine Policy 2013.

Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., 2010. Ecosystem service bundles for analyzing trade-offs in diverse landscapes. Proceedings of the National Academy of Sciences 107, 5242–5247.

Raymond, C.M., Bryan, B.A., MacDonald, D.H., Cast, A., Strathearn, S., Grandgirard, A., Kalivas, T., 2009. Mapping community values for natural capital and ecosystem services. Ecological Economics 68, 1301–1315.

Regen SW and Marine Energy Matters 2012 *Bristol Channel Energy – A Balanced Technology Approach Discussion Document* November 2012, last accessed from http://regensw.s3.amazonaws.com/bristol_channel_energy_balanced_technology_approach_20121127_c541010d0b3719f8.pdf May 2014

Rees, S. E., Rodwell, L. D., Attrill, M. J., Austen, M. C., Mangi, S. C. 2010 The value of marine biodiversity to the leisure and recreation industry and its application to marine spatial planning, Marine Policy, 34 (5), pp. 868-875.

Romero, J., Pérez, M., Mateo, M.A., Sala, E. 1994. The below ground organs of the Mediterranean seagrass *Posidonia oceanica* as a biogeochemical sink. Aquatic Botany, 47, 13-19.

Rolf, W., Lenz, R., Peters, D., 2012. Development of a quantitative 'bioassay' approach for ecosystem mapping. International Journal of Biodiversity Science, Ecosystem Services & Management 8, 71–79.

Schulp, C.J.E., Alkemade, R., Klein Goldewijk, K., Petz, K., 2012. Mapping ecosystem functions and services in Eastern Europe using global-scale data sets. Inter- national Journal of Biodiversity Science, Ecosystem Services & Management 8, 1–13.

Secretariat of the Convention on Biological Diversity. 2010. *Global Biodiversity Outlook 3*. Montréal, 94pp

Severn Estuary Partnership, *The Archaeology of the Severn Estuary: A guide for planners, developers, decision makers and local communities.* Published by the Severn Estuary Partnership, Cardiff University, accessed May 2014 from: http://www.severnestuary.net/sep/pdfs/severnarchaeodesignguidefinal06.pdf

TEEB (2010) The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Kumar, P. (Ed), Earthscan, London and Washington.

TEEB (2010a), *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB.*

The Severn Estuary Partnership 2011 State of the Severn Estuary Report: An initial overview of the Estuary's use and features, The Severn Estuary Partnership, c/o School of Earth and Ocean Sciences, Cardiff University, Cardiff, Wales, accessed from http://www.severnestuary.net/sep/publications/soser.html April 2014

UNESCOBK 2014 (UNESCO Bangkok) Cultural mapping information page, accessed July 2014 from http://www.unescobkk.org/culture/tools-and-resources/tools-for-safeguarding-culture/culturalmapping/

UK, Department for Transport, (2014), UK ports and traffic statistics tables, produced by the Department for Transport. Accessed from https://www.gov.uk/government/statistical-data-sets/port01-uk-ports-and-traffic September 2014.

UK National Ecosystem Assessment (NEA) 2011. The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge.

UK NEA FO 2014. UK National Ecosystem Assessment (2014) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK.

van Jaarsveld, A.S., Biggs, R., Scholes, R.J., Bohensky, E., Reyers, B., Lynam, T., Musvoto, C., Fabricius, C., 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience. Philosophical Transactions of the Royal Society B: Biological Sciences 360, 425–441.

Webster, C.J., *South West Archaeological Research Framework The Archaeology of South West England Resource Assessment and Research Agenda.* Published by Somerset Heritage Service Somerset County Council, County Hall, Taunton, TA1 4DY, 2007

Willemen, L., Verburg, P.H., Hein, L., van Mensvoort, M.E.F., 2008. Spatial characterization of landscape functions. Landscape and Urban Planning 88, 34–43.

Wye and Usk Foundation 2014. *Salmon Conservation*, unpublished website page, accessed May 2014 from http://www.wyeuskfoundation.org/projects/salmonconservation.php

Zhang, L., Dawes, W.R., Walker, G.R., 2001. Response of Mean Annual Evapotranspiration to Vegetation changes at Catchment Scale. Water Resources Research: 37.