Ecological Indicators 49 (2015) 61–75

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Marine ecosystem services: Linking indicators to their classification

Caroline Hattam[a,*], Jonathan P. Atkins[b], Nicola Beaumont[a], Tobias Börger[a], Anne Böhnke-Henrichs[c], Daryl Burdon[d], Rudolf de Groot[c], Ellen Hoefnagel[e], Paulo A.L.D. Nunes[f], Joanna Piwowarczyk[g], Sergio Sastre[h], Melanie C. Austen[a]

[a] Plymouth Marine Laboratory, The Hoe Plymouth, Prospect Place, Devon, PL1 3DH, UK
[b] Hull University Business School, University of Hull, Hull HU6 7RX, UK
[c] Environmental Systems Analysis Group, Wageningen University, PO Box 47, Wageningen 6700 AA, the Netherlands
[d] Institute of Estuarine & Coastal Studies, University of Hull, Hull HU6 7RX, UK
[e] DLO Agricultural Economics Research Institute, Wageningen University, PO Box 29703, Alexandevueld 5, The Hague 2502LS, the Netherlands
[f] Global Partnership for Wealth Accounting and Valuation of Ecosystem Services (WAVES), Agriculture and Environmental Services Department, The World Bank, 1818H St., Washington, D.C. 20433, United States
[g] IOPASN, Powstańców Warszawy 55, P.O. Box 148, Sopot 81-712, Poland
[h] ICM-CSIC Passeig Marítim de la Barceloneta, 37-49, Barcelona E-08003, Spain

ARTICLE INFO

Article history:
Received 6 November 2013
Received in revised form 3 September 2014
Accepted 8 September 2014

Keywords:
Marine ecosystem services
Classification
Indicators
Functions
Benefits
Dogger Bank

ABSTRACT

There is a multitude of ecosystem service classifications available within the literature, each with its own advantages and drawbacks. Elements of them have been used to tailor a generic ecosystem service classification for the marine environment and then for a case study site within the North Sea: the Dogger Bank. Indicators for each of the ecosystem services, deemed relevant to the case study site, were identified. Each indicator was then assessed against a set of agreed criteria to ensure its relevance and applicability to environmental management. This paper identifies the need to distinguish between indicators of ecosystem services that are entirely ecological in nature (and largely reveal the potential of an ecosystem to provide ecosystem services), indicators for the ecological processes contributing to the delivery of these services, and indicators of benefits that reveal the realized human use or enjoyment of an ecosystem service. It highlights some of the difficulties faced in selecting meaningful indicators, such as problems of specificity, spatial disconnect and the considerable uncertainty about marine species, habitats and the processes, functions and services they contribute to.

1. Introduction

Human activities in the marine environment are extensive and few areas are now untouched by them. Competition between these activities for space and resources is increasing, especially in coastal zones, leading to growing calls for more effective management of marine ecosystems. Since the 1990s, there has been a shift in marine management thinking from a single activity ('sectoral') approach toward management focused on ecosystems, acknowledging the interactions between components of ecosystems and the position of humans within these systems (Atkins et al., 2011). This ecosystem approach to management necessitates a deeper understanding of the linkages and dynamic relationships between ecological, social and economic systems (Borja et al., 2010).

Central to the ecosystem approach is an understanding of ecosystem services, the direct and indirect contributions that ecosystems make to human well-being (de Groot et al., 2010a). By assessing the impacts of human activities on ecosystem services, a clearer understanding can be gained of the trade-offs between these activities and ecosystem services. The overall effect of human activities on human well-being, as well as on the environment, can be explored (Millennium Ecosystem Assessment, 2005). The more detailed understanding that arises can contribute to the development of more informed management plans and a more transparent decision-making process.

The interactions between natural systems and human society are complex and their analysis calls for the establishment of a systematic assessment framework (Atkins et al., 2011). This requires a clear understanding of what is meant by ecosystem services along with a comprehensive approach for their categorization. Many ecosystem service classifications have been defined and support the identification of aspects of ecosystems that require further exploration in an ecosystem service assessment. Little

* Corresponding author. Tel.: +44 0 1752 633100.
E-mail address: caro4@pml.ac.uk (C. Hattam).

http://dx.doi.org/10.1016/j.ecolind.2014.09.026
1470-160X/

guidance is offered, however, in how to undertake this assessment. The identification and quantification of indicators of changes in ecosystem services and the benefits they provide for humans is one way of bridging this gap. What is considered an ecosystem service, and hence what makes a relevant and useful ecosystem service indicator is likely to be context specific.

This paper first reviews the state of the art of ecosystem service classifications and in the selection of their associated indicators. From this a series of research questions are derived. Building on this literature an ecosystem service classification for marine systems is proposed and distinct indicators are selected for each service. As a part of the VECTORS project (www.marine-vectors.eu), this classification is then applied and relevant indicators are specified for a case study site in the North Sea the Dogger Bank. Indicators of ecosystem functions and ecosystem benefits are also identified. The process leading to the identification of the indicators is then discussed.

2. State of the art

2.1. Ecosystem service classifications

The Millennium Ecosystem Assessment (MA) classification of ecosystem services is perhaps the most cited. It defined ecosystem services as “the benefits people obtain from ecosystems” (Millennium Ecosystem Assessment, 2005, p.v), and divided them into four ecosystem service categories: supporting, provisioning, regulating and cultural services. Although it has been widely applied, it is not without criticism. The loose definition of ecosystem services by the MA undermines the application of accounting systems to ecosystem services (Boyd and Banzhaf, 2007). As the value of supporting services is considered inherent in the value of all other services (Fisher et al., 2009), the absence of hierarchy within the classification makes it inappropriate for use with ecosystem service valuation (Wallace, 2007; Fisher and Turner, 2008) as it leads to considerable double counting (Boyd and Banzhaf, 2007). This makes it problematic to apply in a decision-making context (Fig. 1).

A number of ecosystem service classifications have subsequently been developed (e.g., Fisher et al., 2009; de Groot et al., 2010a; Balmford et al., 2011; Mace et al., 2011; EEA, 2013), some of which have been tailored specifically for the marine environment (e.g., Atkins et al., 2011; Böhnke-Henrichs et al., 2013; Liquete et al., 2013; Turner et al., 2014). Each strives for a clear distinction between ecosystem services (also known as final services), the functions that generate those services (also called intermediate services) and the benefits derived from the services. Where the boundaries are placed between services, functions and benefits varies with classification.

The inclusion of abiotic components of ecosystems into ecosystem services classifications has been disputed. Abiotic components are integral to ecosystems, determining ecological functions, and hence ecosystem services. Some classifications explicitly include water and abiotic raw materials, as well as human activities such as aggregates, energy generation, and shipping (e.g., Atkins et al., 2011; Cooper et al., 2013). Their inclusion, however, is problematic. Ecosystem services are considered to be ecological in nature (Fisher et al., 2009) and delivered by the living components of the ecosystem. The quantity and quality of abiotic components (e.g., aggregates, oil and gas) is not generally determined by the living parts of the ecosystem. Where they are (e.g., water quality), this is already captured by

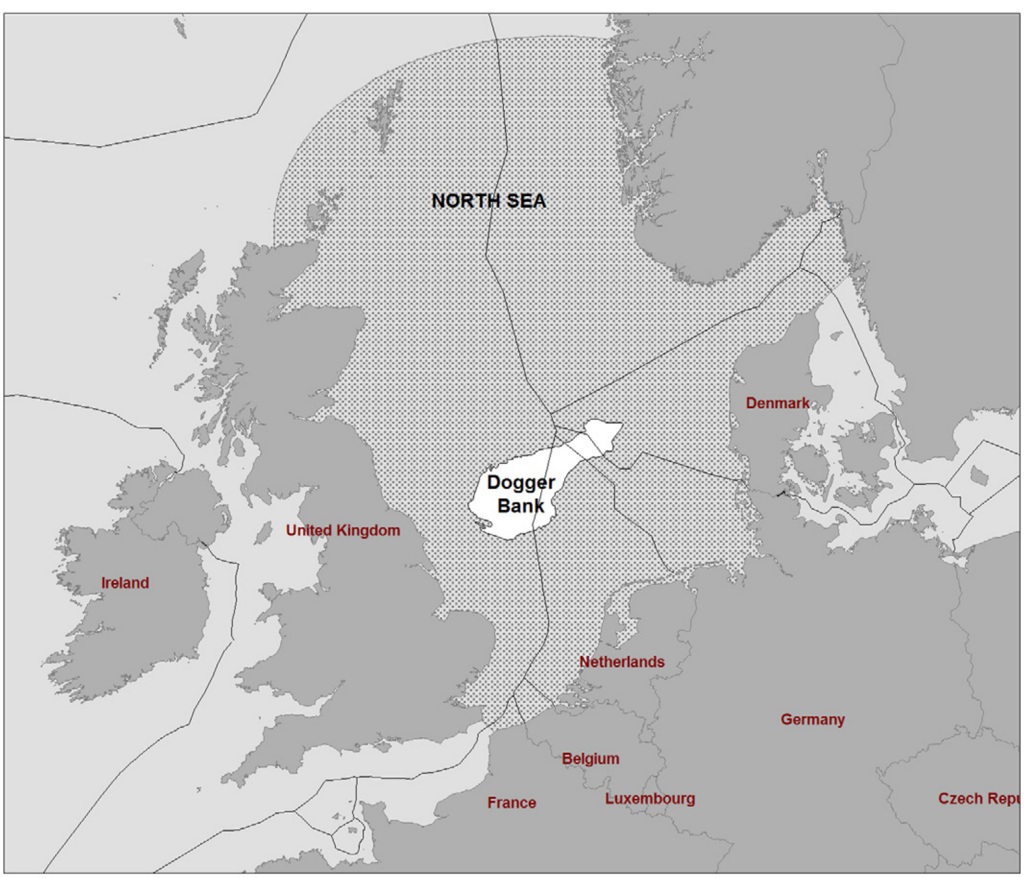

Fig. 1. Location of the Dogger Bank (the white area) in the North Sea.

other services (e.g., waste treatment and assimilation). To overcome this difference, the Common International Classification of Ecosystem Services (CICES) consultation recommends the development of a complementary classification for abiotic outputs from ecosystems (Haines-Young and Potschin 2013).

de Groot et al. (2010a) suggest that "perhaps we should accept that no final classification can capture the myriad of ways in which ecosystems support human life and contribute to human well-being" and "that no fundamental categories or completely unambiguous definitions exist for such complex systems" (p. 17). Classification systems need to be suited to the policy and management problem at hand, and different interpretations may be needed depending on the context (Fisher et al., 2009; de Groot et al., 2010a).

To assess the ecosystem services identified by a classification system, the capacity of the ecosystem to deliver ecosystem services in biophysical terms and their ability to maintain this over time must be determined (TEEB, 2010). Ecosystem services result from a bundle of ecosystem functions (e.g., the provision of seafood results from a combination of primary and secondary production, biogeochemical cycling, food web dynamics etc.) and may contribute to a range of ecosystem benefits (e.g., the regulation of climate helps provide a habitable environment, allows the production of food and facilitates multiple ecosystem functions important for other services) (Austen et al., 2011). Assessing and quantifying every aspect of ecosystem services is a challenging task, especially when the relationship between services, functions and underlying biodiversity remains poorly understood (Kremen, 2005; Barbier, 2007). The use of indicators can facilitate this process.

2.2. Ecosystem service indicators

Indicators are proxies for complex phenomena and can be used to reflect the provision of a service and how it is changing over time. Indicators, where measureable, are useful for supporting management activities as well as contributing to studies aiming to model and value changes in ecosystem service provision (Niemeijer and de Groot, 2008). Practical guidelines for selecting indicators relevant to ecosystem services, however, are still missing (van Oudenhoven et al., 2012; UNEP-WCMC, 2011), especially for the marine environment. There is no unified approach to indicator selection or agreed indicators for each ecosystem service. Consequently, indicator selection is often inconsistent with a focus on arbitrary categorical indicators and monetary values (Seppelt et al., 2011). Without a coherent approach there is a danger that the information contained in the indicators cannot be validated and is not relevant to management (Dale and Beyeler, 2001).

Many of the indicators already developed within the literature are not specific to ecosystem services. They often focus on taxonomic identities of communities and species, or structural and functional aspects (Feld et al., 2009). They tend to be selected for a limited number of ecosystem services (e.g., Haines-Young et al., 2012) or for more wide ranging environmental features such as landscape structure (e.g., Syrbe and Walz, 2012). This is often due to insufficient data to characterize them (Reyers et al., 2010). Those that are supported by data tend to be associated with provisioning and regulating services (Feld et al., 2009; Layke, 2009; UNEP-WCMC, 2011; Egoh et al., 2012).

Food provision indicators are well established and relatively easy to quantify. Agricultural production, or land area given to production, are common proxies for food provision (Egoh et al., 2012). Extensive efforts are also made to measure some fish stocks (e.g., ICES stock assessment database) and fish catch is recorded globally (e.g., FAO, 2012).

Although indicators for regulating services are also numerous, they are not all measured equally. In a review of 78 terrestrial papers, Egoh et al. (2012) found that climate regulation (primarily focusing on carbon storage and sequestration) and water flow regulation were most commonly assessed. Feld et al. (2009) identified a bias toward indicators of water retention. In the marine and coastal environment, Liquete et al. (2013) found that most studies focus on water purification, coastal protection and climate regulation.

Typically indicators for regulating services are used to track negative change or degradation of the service (e.g., changes in habitat area track loss of carbon storage capacity). They are often lagging indicators that demonstrate damage that has already occurred. They cannot anticipate change and provide little information about future degradation (Layke, 2009). How to use these indicators to demonstrate avoided change, such as the avoided impacts of a pollution incident as a result of bioremediation, remains a challenge.

Fewer indicators for cultural services have been identified and quantified, although this situation is changing. Hernández-Morcillo et al. (2013) found that most cultural ecosystem service studies focus on indicators of recreation and tourism (a bias also evident in studies of the marine environment, Liquete et al., 2013). Furthermore, most indicators for cultural ecosystem services were unclear in their definitions, purpose and understanding of the processes to be measured. Similar findings were reported by Milcu et al. (2013). Both report that indicators of ecosystem benefits were most widely cited and the link to the state of the ecosystem was rarely mentioned. This is problematic as benefit indicators may not indicate what, if anything, in the ecosystem requires management or intervention if the indicator moves in a particular direction. Movement of the indicator may simply reflect changes in human preferences.

To generate a better understanding of the implications of ecosystem change, indicators need to be developed that describe not only ecosystem services, but also the ecological functions that deliver them, the benefits they provide and the interrelationships between them (Nicholson et al., 2009; de Groot et al., 2010b). Indicators of ecosystem functions and services should be ecological, reflecting their nature, while indicators of ecosystem benefits demonstrate the realized human use or enjoyment of an ecosystem service. Only when combining indicators of functions, services and benefits, can change (both positive and negative) be detected and appropriate management actions taken. No single indicator will be able to capture these multiple dimensions and composite indicators, or suites of indicators, will be needed for each ecosystem service.

The most appropriate spatial and temporal scale for indicator measurement is unclear and likely to be problem specific. Feld et al. (2009) found that most indicators are measured at regional or local scales, although functional indicators and indicators reflecting temporal differences are rarely measured at all, irrespective of scale. Many ecosystem services provided by the marine environment are global non-proximal (Costanza, 2008), meaning location does not matter, nor does the proximity of the location to the human beneficiaries. Furthermore, many marine species are mobile and different locations may be more or less important at different times of the year or during different stages in an organisms' life-cycle, all affecting the provision of ecosystem services. Ideally, indicators need to reflect this dynamic nature of ecosystem services. The remoteness of many marine ecosystems to their beneficiaries also presents challenges for indicator selection. It may be difficult to attribute specific benefits to specific locations within the marine environment.

To ensure indicator usability, they need to be assessed against agreed criteria. For marine ecosystem indicators, Link et al. (2009)

recommend such criteria. These include measurability (are data available?), sensitivity (can they detect change?) and specificity (is the change in the indicator a response to the pressure of interest as opposed to natural variability?). Dale and Beyeler (2001), more generally, identify five additional criteria: that indicators (1) respond to stress in a predictable manner, (2) are anticipatory (i.e., signify impending change), (3) predict change that can be averted by management, (4) are integrative (i.e., can indicate change over key gradients across an ecological system) and (5) have low variability in response. van Oudenhoven et al. (2012) define 12 criteria. Many overlap with those described above, but useful additional criteria require the indicators to be scalable, portable (or transferable) to other locations and be clear and understandable.

The above discussion raises a number of questions that this paper aims to answer:

- What ecosystem services are provided by the marine environment and can a classification relevant to the whole marine environment capture those of an offshore marine site?
- What indicators can be developed for all the ecosystem services identified, for the ecosystem functions that deliver them and the ecosystem benefits they generate?
- How usable are these indicators for the Dogger Bank case study?

3. Methods

3.1. Description of the case study

The Dogger Bank is a large sandbank in the southern part of the North Sea covering approximately 18,700 km^2. It is located in the Exclusive Economic Zones of the UK, Denmark, Germany and the Netherlands. While the North Sea has an average depth of about 60 m, the Dogger Bank is only 20–50 m deep (Diesing et al., 2009). This alters local hydrodynamics and promotes primary production by phytoplankton, providing food for other species, including commercially targeted fish species (Sell and Kröncke, 2013). Consequently, the Dogger Bank is a historic fishing ground where large-scale, industrial trawlers, mostly from the Dutch and Danish fleets, target demersal fish (e.g., plaice, megrim and turbot) and sandeels. There is currently some use of fixed netting techniques as well. The Dogger Bank is also an important location for actual and potential production of energy. Besides five operational gas platforms in the area, the UK government is planning the world's largest offshore wind farm to be installed on its section of the Dogger Bank. The Dogger Bank is vulnerable to the pressures created by the fishing industry and further development by the energy sector. Reflecting this, the UK, Dutch and German parts have recently been designated as candidate Special Areas of Conservation (cSACs) and management plans for the sites are being developed.

The Dogger Bank also delivers other ecosystem services. It acts as a nursery ground, providing suitable habitat for foraging and maturing fish species, such as plaice (Diesing et al., 2009; Hufnagl et al., 2013). It is of cultural importance as well, being a feeding ground for charismatic species such as the harbor porpoise, gray seals and many seabirds (Forewind, 2010). Fishers and archaeologists have found a number of prehistoric remains on the Dogger Bank, including teeth from sabre-toothed cats, mammoth skeletons, arrowheads and remnants from human settlements. A small number of recreational anglers and divers also visit the Dogger Bank every year.

Compared to many other offshore marine areas, the Dogger Bank is relatively well-studied. This is especially true for the UK sector. The consortium planning the wind farm construction has undertaken extensive surveys of the area (e.g., Forewind, 2013), as have the Joint Nature Conservation Committee (JNCC) in support of the application for SAC designation (Diesing et al., 2009). The bank has also been the subject of numerous scientific studies (e.g., Wieking and Krönke, 2003; Kröncke, 2011; Sell and Kröncke, 2013; Hufnagl et al., 2013). It makes an ideal location to explore the applicability of an ecosystem services classification and its corresponding indicators.

3.2. Selecting an ecosystem service classification

Given the number of ecosystem service classifications already in existence, the objective was not to develop a new classification, but to modify and amend an existing framework. The aim was also to find a classification that is sufficiently generic to be applicable to different marine sites, while being sufficiently flexible to ensure site differences can be explored in detail. This would facilitate its application to any marine ecosystem.

Definitions were also clearly distinguished at the outset, to ensure ecosystem functions or benefits were not included in the ecosystem service classification:

- Ecosystem services are the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010).
- Ecosystem functions are the ecological processes that control the fluxes of energy, nutrients and organic matter through an environment (Cardinale et al., 2012).
- Ecosystem benefits are the things that people create or derive from ecosystem services. Benefits are turned into products or experiences that are no longer functionally connected to the systems from which they were derived (Haines-Young and Potschin 2013).

As distinguishing between ecosystem functions, services and benefits is important, The Economics of Ecosystems and Biodiversity (TEEB) classification was used as a starting point (de Groot et al., 2010a), together with modifications suggested by Böhnke-Henrichs et al. (2013). Each ecosystem service and its definition were scrutinized for relevance at a general marine environment level (coastal, near- and off-shore) and the whole classification was reviewed for completeness. To ensure the classification is fit for purpose, the ability of the Dogger Bank to produce the ecosystem services identified was also examined. Using the expert judgement of the project team, relevance was determined by assessing whether the marine environment and the Dogger Bank could actually generate the ecosystem services identified. A number of alterations and additions were made through an iterative process.

3.3. Indicator selection

A two stage process was used for the selection of indicators. First, indicators for each marine ecosystem service in the classification were identified during an interdisciplinary expert workshop (henceforth, called 'generic indicators'). Second, these indicators were tailored to fit the Dogger Bank case study (from here on, called 'specific indicators'). This second step could then be repeated for other sites, if multiple sites were to be assessed.

During the workshop, the 63 participants were divided into six groups. Each group was allocated three ecosystem services and asked to (1) brainstorm indicators for each ecosystem service that could reflect the quantity and quality of the service, (2) suggest how each indicator could be measured (including units), and (3) identify potential data sources for each indicator.

Following the workshop, the project team assessed each generic indicator to ensure indicators of functions or benefits were not included. Once a list of generic ecosystem service indicators was compiled for each ecosystem service, the process was repeated focusing on the Dogger Bank. The indicators identified were adapted and amended to make them specific to the case study. This required an exploration of data available for the Dogger Bank, additional evidence within the ecosystem service indicator literature, and in the absence of these, expert opinion. Dogger Bank specific indicators were then assessed against a set of applicability criteria:

- Measurability: are there data available for the measurement and quantification of the indicator?
- Sensitivity: does the indicator detect change in the ecosystem service over time?
- Specificity: can the indicator respond over time to changes in management as opposed to natural variability? Is this response predictable and does it have low variability?
- Scalability: can the indicator be aggregated or disaggregated to a different spatial scale and still retain its ability to indicate the change of interest?
- Transferability: is the indicator useful for other locations and hence studies?

For each indicator, the five criteria were answered on a yes/no basis. If the answer was no, the indicator was re-examined and

Table 1
Proposed classification of marine ecosystem services, their description and relevance to the Dogger Bank. Modified from de Groot et al. (2010a) and Böhnke-Henrichs et al. (2013).

Ecosystem service	Description	Relevance to the Dogger Bank
Provisioning services		
1 Food provision:		
a) Wild capture sea food	All available marine flora and fauna extracted from unmanaged marine environments for consumption by humans	✓, extensive fishing (trawling)
b) Farmed sea food	Food from aquaculture for consumption by humans	X, no aquaculture in the area
2 Biotic raw materials (non-food):		
a) Genetic resources	The provision/extraction of genetic material from marine flora and fauna for use in non-medicinal contexts	?, unknown
b) Medicinal resources	Any material that is extracted from or used in the marine environment for its ability to provide medicinal benefits	?, unknown
c) Ornamental resources	Any material that is extracted for use in decoration, fashion, handicrafts, souvenirs, etc.	✓, growing market for mammoth and other Mesolithic remains
d) Other biotic raw materials	Extraction of all other renewable biotic resources	✓, harvesting of sandeels for animal feed and fertilisers
Regulating services		
3 Air purification	Influence of a marine ecosystem on concentration of pollutants from the atmosphere	✓, extent unknown
4 Climate regulation	The contribution of a marine ecosystem to the maintenance of a favorable climate through impacts on the hydrological cycle, temperature regulation, and the contribution to climate-influencing substances in the atmosphere	✓, extent unknown
5 Disturbance prevention or moderation	The contribution of marine ecosystem structures and functions to the dampening of the intensity of environmental disturbances such as storm floods, tsunamis, and hurricanes	X, area too far from the coast
6 Regulation of water flows	The contribution of marine ecosystems to the maintenance of localized coastal current structures	?, unknown
7 Waste treatment and assimilation	The removal of contaminant and organic nutrient inputs to marine environments from humans	✓, extent unknown
8 Coastal erosion prevention	The contribution of marine ecosystems to coastal erosion prevention	X, area too far from the coast
9 Biological control	The contribution of marine ecosystems to the maintenance of population dynamics, resilience through food web dynamics, disease and pest control	✓, extent unknown
Habitat services		
10 Migratory and nursery habitat	The contribution of a particular marine habitat to migratory and resident species' populations through the provision of critical habitat for feeding, or reproduction and juvenile maturation	✓, extent unknown
11 Gene pool protection	The contribution of marine habitats to the maintenance of viable gene pools through natural selection/evolutionary processes which enhances adaptability of species to environmental changes, and the resilience of the ecosystem	✓, extent unknown
Cultural services		
12 Leisure, recreation and tourism	The provision of opportunities for tourism, recreation and leisure that depend on a particular state of marine ecosystems	✓, limited to some sailing, diving and recreational angling
13 Aesthetic experience	The contribution that a marine ecosystem makes to the existence of a surface or subsurface landscape that generates a noticeable emotional response within the individual observer. This includes informal spiritual individual experiences but excludes that covered by service 17	✓, limited to those who go there
14 Inspiration for culture, art and design	The contribution that a marine ecosystem makes to the existence of environmental features that inspire elements of culture, art, and/or design. This excludes that covered by services 2c, 13, and 16	✓, extent unknown
15 Cultural heritage	The contribution of marine ecosystems to the maintenance of cultural heritage, and providing a `sense of place'	✓, extent unknown but links to Palaeolithic man
16 Cultural diversity	The contribution of marine ecosystems to social and cultural values and adaptations that pertain to living at coasts and exploiting marine resources	✓, extent unknown
17 Spiritual experience	The contribution that a marine ecosystem makes to formal and informal collective religious experiences. This excludes that covered by services 13 and 14	✓, extent unknown
18 Information for cognitive development	The contribution that a marine ecosystem makes to education, research, and individual and collective cognitive development	✓, extent unknown

✓: relevant, X: not relevant, ?: relevance unknown.

Table 2
Indicators for each of the ecosystem services identified in Table 1 as relevant to the Dogger Bank. As stated in the text, it is expected that the indicators will be compared over time and space to denote change in the system.

Ecosystem services	Generic marine ecosystem service indicators	Measurement (units)- measured over time	Dogger Bank specific indicators	Issues related to assessment criteria
1a: Food provision – wild capture sea food	Fish and shellfish populations, seaweed stock	Biomass (tonnes km^{-2}) or abundance (no. km^{-2}) of fish and shellfish; area (m^2) or biomass (tonnes km^{-2}) of seaweed	Population of nephrops and flatfish species such as plaice, turbot and lemon sole	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Quality of the fish, shellfish, seaweed stock	Species composition, age profile; length profile; percentage affected by disease; mortality rates	Quality of the populations of nephrops and flatfish species such as plaice, turbot and lemon sole	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
1b: Food provision – farmed sea food	Fish and shellfish populations, seaweed stock	Biomass (tonnes km^{-2}) or abundance (no. km^{-2} of fish and shellfish; area (km^2) or biomass (tonnes km^{-2}) of seaweed	N/A	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Quality of the fish, shellfish, seaweed stock	Percentage affected by disease; mortality rates	N/A	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
2a: Biotic raw material – genetic resources	Presence and diversity of species with potential/ actual useful genetic material	Presence/absence of desirable species; diversity of desirable species	Insufficient information to define indicators	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Quality of species with potential/actual useful genetic material	Endemism and uniqueness of species	Insufficient information to define indicators	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
2b: Biotic raw material – medicinal resources	Quantity of available raw material	Total quantity available in a fixed area (g/raw material)	Insufficient information to define indicators	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Quality of raw materials	Concentration of raw material (g l^{-1} seawater, g m^{-3} sediment)	Insufficient information to define indicators	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
2c: Biotic raw material – ornamental resources	Quantity of raw material	Biomass available in a fixed area (tonnes km^{-2})	Insufficient information to define indicators	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Quality of raw materials	Concentration (g l^{-1} seawater, tonnes km^{-2} sediment); purity	Insufficient information to define indicators	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
2d: Other biotic raw material	Quantity of raw material	Biomass available in a fixed area (tonnes km^{-2})	Population of sandeels (same measurement units as for food provision)	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Quality of raw materials	Concentration (g l^{-1} seawater, tonnes km^{-2} sediment); purity	Quality of the populations of sandeels (same measurement units as for food provision)	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
3: Air purification	Air–sea flux of pollutants	Modeled or empirically determined pollutant air–sea flux rates and direction (μmol pollutant d^{-1} m^{-2}, μg pollutant l^{-1} seawater d^{-1} m^{-2})	Insufficient information to define indicators	Role of different components of the marine ecosystem involved in this service is unclear. Lack of knowledge prevents indicator identification
	Distribution of air–sea fluxes of pollutants	Modeled or empirically determined maps of pollutant concentrations (μmol l^{-1} m^{-2} d^{-1}, μg air pollutant l^{-1} seawater m^{-2} d^{-1})	Insufficient information to define indicators	
4: Climate regulation	Air–sea and sediment–water fluxes of carbon and CO_2	Modeled or empirically determined (mg C m^{-2} d^{-1}, mg CO_2 m^{-2} d^{-1})	As per generic indicators scaled to the area covered by the Dogger Bank	
	Air–sea fluxes of other greenhouse gases (e.g., dimethyl sulfide, methane, nitrous oxide)	Modeled or empirically determined (μg greenhouse gases m^{-2} d^{-1})	As per generic indicators scaled to the area covered by the Dogger Bank	
	Levels of carbon in different components of the marine ecosystem	Modeled or empirically determined carbon levels: biomass of carbon (g m^{-2}); dissolved organic or inorganic carbon (mg C m^{-3}); suspended organic or inorganic carbon (mg C m^{-3}); buried particulate organic or inorganic carbon (mg C m^{-2})	As per generic indicators scaled to the area covered by the Dogger Bank	
	Permanence of carbon sequestration	Percentage of annual carbon turnover from sediments	As per generic indicators scaled to the area covered by the Dogger Bank	

Table 2 (*Continued*)

Ecosystem services	Generic marine ecosystem service indicators	Measurement (units)- measured over time	Dogger Bank specific indicators	Issues related to assessment criteria
5: Disturbance prevention and moderation	Capacity of water storage of habitat	Water storage capacity (m^3/area) for different intertidal habitats (e.g., sediment, saltmarsh, mangrove)	N/A	
	Reduction of wave energy by near shore and intertidal habitats	Change in wave energy ($J\,m^{-2}$) attributed to different intertidal and near shore habitats	N/A	
	Changing shoreline	Change in beach profile (slope (gradient) and width (m) and stability) over time determined empirically from photos, satellite, LiDAR, ARGUS camera and modeled	N/A	
6: Regulation of water flows	Salinity/freshwater input	Change in salinity, tidal and freshwater flow rates ($m^3\,s^{-1}$)	Insufficient information to define indicators	
	Changing shoreline	Change in beach profile (slope (gradient) and width (m) and stability) over time determined empirically from photos, satellite, LiDAR, ARGUS camera and modelled	N/A	
	Rates of tidal and wind driven currents	Direct measures of flow and currents ($m^3\,s^{-1}$) and turbidity ($mg\,m^{-3}$ or NTU)	Insufficient information to define indicators	
	Seabed morphology	Changes in seabed morphology using side-scan sonar	Insufficient information to define indicators	
7: Waste treatment and assimilation	Absolute levels of waste in the water column	Chemical analysis (contaminant concentrations) and visual analysis	As per generic indicators scaled to the area covered by the Dogger Bank	Difficult to attribute to specific elements of the ecosystem structure and processes as knowledge is not available
	Presence of pathogens; outbreaks of *E. coli* infections; hospital admissions	Total coliforms or other pathogens (quantity per milliliter of water)	As per generic indicators scaled to the area covered by the Dogger Bank	Difficult to attribute to specific elements of the ecosystem structure and processes as knowledge is not available
	Benthic biodiversity levels/ratios/no. of sensitive species	Different biodiversity indices	As per generic indicators scaled to the area covered by the Dogger Bank	Indicates health of system which may indicate capacity for waste assimilation if waste inputs are known
	Toxicity levels within species	Chemical analysis (contaminant concentrations)	As per generic indicators scaled to the area covered by the Dogger Bank	
	Number of shellfish area closures		N/A	May not necessarily reflect change in ecosystem service; for example it could reflect changing risk appetite of consumers, producers or regulators
	Harmful algal bloom outbreaks	Remote sensing, water sampling to detect frequency and extent; modeling to determine future frequency and extent	As per generic indicators scaled to the area covered by the Dogger Bank	
8: Coastal erosion prevention	Beach profile (slope and width); extent of maintenance and improvement required to provide protection	Change in beach profile (slope (gradient) and width (m) and stability) over time determined empirically from photos, satellite, LiDAR, ARGUS camera and modelled	N/A	Extent of maintenance/ improvement required may not necessarily reflect change in ecosystem service; for example it could reflect changing levels of risk aversion by consumers, producers or regulators
	Presence and elevation of biogenic habitat e.g., saltmarsh beds; seagrass beds; bivalve, coral and polychaete reefs	Volume (m^3 or km^3), or area covered (m^2 or km^2), density (biomass or abundance m^{-2}) and elevation of (height above mean seawater level)	N/A	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Presence of mitten crab	Presence of mitten crab (no. per unit area – could be estimated as number of burrows)	N/A	
9: Biological control (checks and balances)	Presence/absence/ frequency of pests (e.g., algae blooms, foam, sea lice on farmed salmon)	Count data	As per generic indicators specifically applied to control of pests and HABs that affect fish species utilized by fisheries, mammals, seabirds and other marine organisms occurring in area	Specificity problematic: difficult to distinguish impacts of climate change from other impacts

Table 2 (*Continued*)

Ecosystem services	Generic marine ecosystem service indicators	Measurement (units)- measured over time	Dogger Bank specific indicators	Issues related to assessment criteria
10: Migratory and nursery habitat	Area of habitat or density of biogenic habitat creating species "used" or identified as important for nursery or reproduction	For example, extent of seagrass, maerl or kelp beds (km^2)	As per generic indicators scaled to the area covered by the Dogger Bank	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Number and diversity of species using the area for nursery or reproduction	Abundance m^{-2} and species diversity	Spawning: abundance of cod, sandeels, plaice, nephrops; nursery: abundance of sprat, nephrops	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
	Dependence of off-site (commercial) populations	Proximity to dependant populations or their migration routes; size (abundance) and health (viability) of off-site populations	As per generic indicators scaled to the area covered by the Dogger Bank	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
11: Gene pool protection	Genetic diversity	Diversity of species and sub-species, phylogenetic distance, Biodiversity Intactness Index (BII)	As per generic indicators scaled to the area covered by the Dogger Bank	Specificity problematic: difficult to distinguish impacts of climate change from other impacts
12: Leisure, recreation and tourism	Sea space available for recreation	Number of km^2 of sea with safe water quality available for recreational use	As per generic indicators scaled to the area covered by the Dogger Bank	May not necessarily reflect change in ecosystem service; for example it could reflect changing levels of risk aversion of consumers, producers or regulators
	Number and quality of beaches	Number and size of blue flag beaches	N/A	May not necessarily reflect change in ecosystem service; for example it could reflect changing levels of risk aversion by consumers, producers or regulators
	Water quality	Chemical analysis (contaminant concentrations) and visual analysis; total coliforms or other pathogens (quantity per milliliter of water)	As per generic indicators scaled to the area covered by the Dogger Bank	
	Abundance and diversity of key species of recreational interest	Count data	Species of recreational interest e.g., harbour porpoise, grey seal, seabirds, fish	
	Area of biotopes of key interest to recreational users	For example, extent of seagrass, maerl or kelp beds (km^2)	As per generic indicators scaled to the area covered by the Dogger Bank	
13: Aesthetic experience	Uniqueness of a site	1/(number of sites with similar features)	Insufficient information to define indicators	Uniqueness would increase if all other similar ecosystems degrade
	Abundance of key species of individual interest	Count data	Species of individual interest e.g., harbour porpoise, grey seal, seabirds, fish	
	Area of biotopes of key interest to individuals	For example, extent of seagrass, maerl or kelp beds (km^2)	As per generic indicators scaled to the area covered by the Dogger Bank	
14: Inspiration for culture, art and design	Species, habitat or ecosystems that have or can potentially inspire any piece of artwork	Insufficient information to define indicators	Insufficient information to define indicators	Generic indicators cannot be developed
15: Cultural heritage	Species, habitats or ecosystems that can potentially form the core of contribute to a cultural custom, rite or way of life	Insufficient information to define indicators	Insufficient information to define indicators. Some links to Palaeolithic people	Generic indicators cannot be developed
16: Cultural diversity	Generic indicator cannot be developed	Insufficient information to define indicators	Insufficient information to define indicators	Generic indicators cannot be developed
17: Spiritual experience	Species, habitats or ecosystems that is being or can potentially be worshipped or be of significance to a religious belief	Insufficient information to define indicators	Insufficient information to define indicators	Generic indicators cannot be developed
18: Information for cognitive development	Species, habitats or ecosystems that are being or can potentially be studied to increase scientific knowledge	Number of such species, habitats, ecosystems	Insufficient information to define indicators	Generic indicators cannot be developed
	Species, habitats or ecosystems that are being or can potentially be studied for educational purposes	Number of such species, habitats, ecosystems	Insufficient information to define indicators	Generic indicators cannot be developed

amended where possible. Problems with this approach were noted.

Suggested indicators that were identified as being indicators of functions or benefits were also captured to allow a more complete ecosystem service assessment. As these indicators are not as well developed as those for their corresponding ecosystem service and were not fully assessed against the criteria, nor tailored for the Dogger Bank, they are presented differently.

4. Results

4.1. The classification adopted

The modified ecosystem service classification used to direct the indicator selection process is presented in Table 1. A number of amendments were made to the TEEB and Böhnke-Henrichs et al. (2013) classifications. Some irrelevant services were removed (e.g., the maintenance of soil fertility) and terms were clarified. For example, the definitions of cultural services in the TEEB framework can be considered as an expression of the preferences of an individual, rather than properties of the ecosystem (e.g., aesthetic experience, inspiration for culture art and design). There are some components of the ecosystem or natural environment, however, which make a contribution to culture. It is this contribution that should be considered the service.

Considerable discussion was given to the habitat services proposed by the TEEB typology. TEEB defines habitat services as "the importance of ecosystems to provide living space for resident and migratory species (thus, maintaining the gene pool and nursery service)" (TEEB, 2010; p. XXXV). These services can be considered important for safeguarding the future use of ecosystems; however, they can also be construed as "supporting services". The availability of migratory and nursery habitat supports the provision of food, while the maintenance of the gene pool supports biodiversity as a whole. Nevertheless, each of these can be managed for directly. Efforts can be devoted to the protection of areas that are important migratory and nursery grounds. For example, seasonal, spatial closures to fisheries (under EU regulations) of areas in the North Sea during cod spawning result in losses of food provision and income from these areas. Such losses imply that these areas have a value as nursery habitats and for gene pool protection, although the value of these habitat services is likely to be greater than just the change in income experienced. The position of habitat services is therefore likely to change, being services in some situations, but functions in others. This will vary according to the temporal and spatial boundaries given to the assessment.

Management plans for the Dogger Bank cSACs will likely include fisheries closures. This will allow the Dogger Bank to be managed in the future for its nursery habitat as well as for its gene pool protection. This suggests that habitat services should be retained in the classification (in keeping with TEEB, 2010; EEA, 2013; Liquete et al., 2013). However, these services will be future services provided by the Dogger Bank. As the Dogger Bank is open to fishing in 2014, an assessment and valuation of its ecosystem services would include the provision of wild capture sea food. As food provision is currently supported by these habitat services, an assessment of the migratory and nursery habitat and gene pool protection today would result in double counting. Nevertheless, such an assessment would become necessary in future following changes in management and if related changes in ecosystem services are to be explored. This highlights the temporal dimension of some ecosystem services and the difficulty in identifying clear boundaries between ecosystem functions and ecosystem services.

4.2. Indicator selection

The final selection of ecosystem service indicators is shown in Table 2. The first round of indicator selection from the expert workshop emphasized the importance of providing clear definitions. Not all experts were familiar with ecosystem service terminology, consequently the output generated indicators for ecosystem functions, services and benefits. For example, the amount (tonnes) of fish landed for human consumption was proposed as an indicator of the service "wild capture sea food" but this is an indicator of the benefit and not the service provided. The fishing activity used to land the fish will be highly selective and reflect quota allowances, thus, landings do not indicate the full potential of the ecosystem to provide the service. The indicator selection process also reiterated the need for multiple indicators for each ecosystem service, function and benefit. The agreed indicators of the "wild capture sea food" service were fish stock population size and quality of the fish stock, each of which are comprised of a number of measures.

Cultural service indicator selection also proved challenging. It is difficult to identify the specific contributory role of an ecosystem to many cultural services, and hence to identify indicators of these services. To illustrate, aesthetic experiences are inherent to an individual, but to identify indicators of the service of 'aesthetic experiences' the specific elements of a marine ecosystem that contribute to that experience must be known. These can then be used to indicate the state of the service. Many of the indicators suggested at the workshop were indicators of ecosystem benefits rather than of ecosystem services. This reemphasized the need for a suite of three indicator types for a complete ecosystem service assessment: indicators of functions, services and benefits.

Generic indicators of regulating and habitat services were relatively straightforward to select, but were more challenging at the specific level, mostly due to a lack of knowledge on how ecosystem functions generate corresponding services. Assessment against the applicability criteria also highlights quantification difficulties due to the lack of data. This is a problem for many provisioning and cultural services as well.

Indicator assessment suggested that the indicators selected will be sensitive to change over time. What change they will respond to, however, is unclear due to the current lack of evidence. In practice, many of the indicators identified are expected to lack specificity as signals from, for example, climate change become confounded with other sources of change (e.g., fishing). Nevertheless, they may indicate short-term changes (e.g., the cessation of demersal trawling) and therefore, support management decisions. Where the indicator selected for the Dogger Bank is the same as that for the generic indicator, scalability and transferability are assured across marine areas. However, modification is often required; for example, fish stock indicators need to be tailored to the stocks actually caught on the Dogger Bank.

Ecosystem function indicators for provisioning services are explored at the generic level (Table 3a), a result of data scarcity, but also because the functions are likely to be the same for all indicators. Among regulating services, some subdivision of the contributing functions can be made (Table 3b). Considerable overlap is evident between these functions and those contributing to provisioning services (and the same is likely true for cultural services). A one-to-one relationship does not occur between ecosystem functions and ecosystem services. Changes in ecosystem functions will likely indicate changes across multiple ecosystem services. Ecosystem function indicators were not assessed against the applicability criteria because of the difficulty in tailoring these indicators to the Dogger Bank and because of the known absence of data to characterize them. Indicators of the ecosystem functions that contribute to cultural ecosystem services were not explored. Evidence is only available for two of the Dogger Bank cultural ecosystem service indicators (abundance and diversity of key species of recreational interest and area of biotopes of key interest to recreational users) and the links between them and ecosystem functions are currently unclear.

Indicators of ecosystem benefits (Table 4) are also identified at the generic level and were not assessed against the applicability criteria. The indicators presented are exemplars, often high level and do not represent a comprehensive selection. Refining the indicators to the scale of the Dogger Bank proved demanding. Many of the benefits (and services that generate them) are not location specific and linking them to the Dogger Bank was not possible within the scope of this study. It is also clear that changes in the benefit indicators may result from shifts in individual or societal preferences, rather than from change in the ecosystem. More work is needed to identify relevant and applicable ecosystem benefit indicators.

5. Discussion

5.1. Applying an ecosystem service classification

There are several ecosystem service classifications available within the literature, many of which could potentially be applied to the marine environment. What is essential with a classification is clarity in definitions to ensure that only ecosystem services are captured and not a mixture of ecosystem services, functions and benefits. This led to many definitions being amended in the classification used in this study. Tailoring the classification to an offshore marine site was relatively straightforward requiring only minor modifications. When it was unknown whether the Dogger Bank contributed to a service (e.g., regulation of water flows), the service was retained for further investigation at the indicator stage, while irrelevant services were removed (e.g., disturbance prevention or moderation).

5.2. Distinguishing between indicators of functions, services and benefits

Identifying applicable function, service and benefit indicators remains a challenge. The greatest challenge is the lack of suitable data for the marine environment, as well as limited understanding of the links between ecosystem functions, services and benefits. Measuring indicators of functions, services or benefits in isolation may lead to incorrect conclusions. Potentially these indicators might point in different directions. For example, continued fishing activities and landings do not necessarily reflect any accompanying decline in fish stocks. When landings and stocks are measured together they can indicate where potential problems lie and where management and policy activity should focus. This reiterates the need for a suite of indicators that can more fully capture the effects of ecosystem change, both positive and negative.

Combining indicators of services and benefits to explore the impacts of management or policy options may be confounded by the spatial disconnect between the service providing area (e.g., the Dogger Bank) and the service benefiting area (e.g., coastal populations of the countries bordering the North Sea and beyond). Many of the benefit indicators presented in Table 4 are not specific to a particular location. Distinguishing the role of the Dogger Bank in these indicators has not been attempted, but is likely to be difficult, if not impossible. The direct beneficiaries of the Dogger Bank ecosystem services may be relatively few and mainly confined to the small number of people who go there (e.g., fishers, wind farm constructors, recreational sailors, divers and anglers). While service indicators may describe change as a result of human activities on the Dogger Bank, any corresponding change at the benefit level may be too difficult to detect. This raises questions about appropriate scales for the assessment of services and benefits, which is likely to be context specific.

Table 3a
Indicators of selected ecological functions contributing to the delivery of ecosystem services in Table 1. Provisioning services.

Function	Primary production	Maintenance of food web dynamics	Nutrient cycling to maintain food web dynamics for target species	Supply of larvae and gametes of target species	Support breeding population of suitable size and quantity	Provision of suitable habitats
Unit	Annual g C per unit area/ volume	Changes in community composition (abundance, biomass, species diversity per unit time)	Fluxes of nitrates, phosphates, silica (g per unit area/volume per unit time)	Number per m^3 per unit time	Male:female ratio; adult:juvenile ratio	Area of habitat (km^2 or m^2); quality of habitat; Number of juveniles
1a: Food provision – wild capture sea food	✓	✓	✓	✓	✓	✓
1b: Food provision – farmed sea food	✓		✓			✓
2a: Biotic raw material – genetic resources	✓	✓	✓	✓	✓	✓
2b: Biotic raw material – medicinal resources	✓	✓	✓	✓	✓	✓
2c: Biotic raw material – ornamental resources	✓	✓	✓	✓	✓	✓
2d: Other biotic raw materials	✓	✓	✓	✓	✓	✓

✓ indicates that the function is relevant to the ecosystem service

Table 3b
Indicators of selected ecological functions contributing to the delivery of ecosystem services in Table 1. Regulating services.

Key ecosystem services	Examples of ecosystem functions that deliver the service	Indicators of functions and their measurement (Units)	Comments and issues related to assessment criteria
3: Air purification	Absorption of atmospheric pollutants in seawater	Micromoles or micrograms of pollutants per litre over time and space (μmol l^{-1} m^{-2}, μg air pollutant l^{-1} seawater m^{-2})	The role of different components of the marine ecosystem in this service is unclear
4: Climate regulation	Pelagic and benthic fixation of carbon through photosynthesis	Concentration of chlorophyll (mg m^{-2} or mg m^{-3}) primary productivity (mol C m^{-2} d^{-1})	
	Deposition and sequestration of carbon through hydrodynamic transport of advection and sinking	Carbon exported as DOC and/or POC (mol C m^{-2} d^{-1})	Hydrodynamics determined through modeling
	Deposition and burial of carbon in seabed sediments through bioturbation	Carbon storage (g C m^{-2} $time^{-1}$) – carbon buried in sediments; depth of carbon in sediment; persistence of carbon in sediment (g C m^{-2} y^{-1})	
	C storage in living biomass (seagrasses, salt marshes, fish, benthic organisms etc.)		
	Calcification by marine organisms	(g Ca m^{-2} y^{-1})	
	Biogenic production/assimilation of greenhouse gases (e.g., dimethyl sulfide, methane, nitrous oxide) by phytoplankton, pelagic microbiota, benthic micro- and macro-algae	Production of greenhouse gases (μg greenhouse gases m^{-2} d^{-1})	Biogenic production of greenhouse gases is as yet poorly understood as is the role of these gases in climate regulation
5: Disturbance prevention and moderation	Production and maintenance of healthy, living, biogenic physical structure that reduces and dampens extreme wave energy	Extent (km^2) and health of seagrass/saltmarsh/ oyster bed/biogenic reefs: density of living organisms, measures of growth and production, optimum ecophysiology	
	Production of biogenic physical structure that reduces and dampens extreme wave energy	Accumulation of mollusc shells: depth, volume and mass of biogenic structure per unit area over time	
	Bioturbation that increases sediment accumulation	Bioturbation measures such as burrow extent, turnover and stability per unit time, sediment accumulation and deposition due to the presence of bioturbating organisms	
	Production and maintenance of living saltmarsh beds that absorb excess water during extreme rainfall events or extreme high tides	Extent (km^2) and health of saltmarsh: density of living organisms, measures of growth and production, optimum ecophysiology	
6: Regulation of water flows	Hydrodynamic processes	Mass transport of water from advection flux (m^3 m^{-2} d^{-1}) determined, for example, from hydrodynamic modelling	The role of different components of the marine ecosystem in this service is unclear
	Deviation and entrainment of very localized flows through presence of epibenthic biogenic structures	Density (e.g., proportion of habitat occupied (%), volume (m^3)), complexity (e.g., measured by species diversity, rugosity, fractal distance) of epibenthic structure	
7: Waste treatment and assimilation	Microbial degradation, mineralization, transformation and conversion of toxicants to less toxic substances; burial of toxicants	Success of these processes can be suggested by the presence of resilient and healthy communities indicated by biodiversity levels/ ratios/no. of sensitive species	Healthy communities may exist due to lack of pollutants and waste to be treated or assimilated and may not necessarily indicate these processes are happening
	Degradation, mineralization, transformation and conversion of toxicants to less toxic substances	Degradation and mineralization rates measured as bacteria metabolism, concentrations of organic matter over time and space, chemical analysis for contaminants	There are a multitude of contaminants and toxicants and a multitude of degradation, mineralization, transformation and conversion pathways to be considered, many of which are poorly known
	Dilution and dispersal of toxicants through hydrodynamics	Diffusivity (mol(toxicant) m^{-2} s^{-1}) and advection (mol(toxicant) m^{-2} s^{-1}) flux determined, for example, from hydrodynamic modeling	
	Burial of toxicants through bioturbation	Chemical analysis in sediments and water; bioturbation measures such as: burrow extent, turnover and stability per unit time, sediment accumulation and deposition	
	Sequestration of toxicants by living organisms	Body biomass of toxicants	
	Storage of excess organic carbon in living biomass and burial in sediment	Carbon storage – carbon in living organisms; carbon buried in sediments; depth of carbon in sediment; persistence of carbon in sediment	
	Microbial reduction and cycling of excess nutrient facilitated through bioturbation	Nutrient levels and/or rates of nutrient cycling; bioturbation measures such as: burrow extent, turnover and stability per unit time, sediment accumulation and deposition	
	Food web facilitated organic carbon storage; reduction and cycling of excess nutrient	Production and biomass at different trophic levels	
8: Coastal erosion protection	Presence of healthy seagrass/saltmarsh/oyster or mussel bed/biogenic reefs	Extent (km^2) and health of seagrass/saltmarsh/ oyster bed/biogenic reefs: density of living organisms, measures of growth and production, optimum ecophysiology	
	Accumulation of mollusc shells	Accumulation of mollusc shells: depth, volume and mass of biogenic structure per unit area over time	
	Bioturbation		

Table 3b (*Continued*)

Key ecosystem services	Examples of ecosystem functions that deliver the service	Indicators of functions and their measurement (Units)	Comments and issues related to assessment criteria
		Bioturbation measures such as burrow extent, turnover and stability per unit time, sediment accumulation and deposition	
9: Biological control (checks and balances)	Production and maintenance of predators and competitors to control nuisance organisms	Absence/presence/abundance of controlling species and of nuisance species	
	Maintenance of resilient and robust community structure	Species diversity (α, β, and γ) and relative comparisons of multivariate community structure	
10: Migratory and nursery habitat	Production and maintenance of suitable habitat	Area of suitable habitat (m^2); quality of habitat; presence and abundance of target species for ecosystem service e.g., number of juveniles or spawning adults of target species utilizing habitat	
	Production and maintenance of complex structure providing suitable habitat including shelter from predators	Density (e.g., proportion of habitat occupied (%), volume (m^3)), complexity (e.g., measured by species diversity, rugosity, fractal distance) of epibenthic structure; density (% area covered, burrow entrances m^{-3}), complexity (rugosity, fractal) and volume (m^3) of infaunal burrows	
	Provision of food resources	Presence and abundance of target food species and supporting food web for target species for ecosystem service	
11: Gene pool protection	Provision and maintenance of suitable habitat	Area of suitable habitat (m^2); quality of habitat; presence and abundance of species/communities of concern for gene pool	
	Provision and maintenance of complex structure providing suitable habitat	Density (e.g., proportion of habitat occupied (%), volume (m^3)), complexity (e.g., measured by species diversity, rugosity, fractal distance) of epibenthic structure; density (percentage area covered, burrow entrances m^{-3}), complexity (rugosity, fractal) and volume (m^3) of infaunal burrows	
	Provision of food resources for key species/communities of concern	Presence and abundance of target food species and supporting food web for key species/communities of concern	
	Maintenance of resilient and robust community structure	Species diversity (α, β, and γ) and relative comparisons of multivariate community structure	

5.3. Indicator measurability and sensitivity

Indicators for many of the services delivered by the Dogger Bank, and at the more generic level, cannot be defined (e.g., biotic raw materials, regulation of water flows, and many cultural services), despite the relatively well-studied nature of the Dogger Bank. Existing data is inappropriate for the ecosystem service indicators selected. Ecological data largely relate to physical characteristics of the site, characterization of the biological communities present and commercial fisheries data (e.g., Diesing et al., 2009). Sampling is often sporadic and not necessarily repeated in the same location. Ecosystem service assessments require data that help explain the role of ecosystems in delivering ecosystem services (i.e., the links between ecosystem functions, services and benefits). This is problematic for future assessments and has been highlighted as one of the main challenges for the incorporation of ecosystem service assessments and valuation into marine planning (Börger et al., 2014). How the indicators selected may respond to human activity and natural events is largely unknown.

The uncertainty surrounding any indicator selected for ecosystem functions or services may therefore be substantial. An "honest declaration" of uncertainty is needed (Müller and Burkhard, 2012) and different decision contexts may need different degrees of precision. Scoring procedures could be employed to demonstrate how well indicators are supported by scientific evidence, to assess the quality of the indicators selected and their potential utility to management activities (Kershner et al., 2011).

5.4. Indicator specificity

Identifying indicators that respond to a specific change in the ecosystem is important if indicators are to support ecosystem management. Of the ecosystem service indicators identified in Table 2 that are measurable and sensitive to change, many are likely to change in response to multiple stressors (e.g., climate change and other human activities). Unless the indicators can indicate short-term change, their use in understanding the impact of, for example, invasive species or the construction of wind turbines on the Dogger Bank, becomes limited. Nevertheless, these indicators may highlight where to look when change occurs. If the indicator can show that a function or service is changing, the causes of this change and possible management actions can be explored. Identifying the exact cause of change, however, will always be challenging in such a complex environment.

Greater understanding is needed of the components of the ecosystem that are responsible for ecosystem service provision, be they components of populations, species, guilds, food webs or even habitats (Luck et al., 2003; Kremen, 2005). Indicators must be reliably linked to these components and the functions they carry out. There is still a considerable gap in this understanding, but improving the scientific basis behind the ecosystem services

Table 4
Example indicators for some of the ecosystem benefits generated by the ecosystem services in Table 1.

Ecosystem services	Examples of ecosystem benefits	Indicators of benefits and their measurement (units)
1a: Food provision – wild capture sea food	Nutrition from wild catch seafood consumption	Grams protein/year/head or per household
	Wild catch seafood landed for human consumption	Landings data at particular times and places (tonnes)
	Fisheries revenues and contribution to Gross Value Added (GVA)	Monetary value (e.g., in £, $ or €)
	Employment in fisheries	Number of jobs
1b: Food provision – farmed sea food	Nutrition from farmed seafood consumption	Grams protein/year/head or per household
	Farmed seafood landed for human consumption	Landings data at particular times and places (tonnes)
	Aquaculture revenues and contribution to GVA	Monetary value (e.g., in £, $ or €)
	Employment in aquaculture	Number of jobs
2a: Biotic raw material – genetic resources	Quantity of genetic resources landed	Tonnes
	Knowledge of genetic material available for future use	Count of known existing genes of potential use (relating to option value)
	Revenues generated from the use of marine genetic resources and contribution to GVA	Monetary value (e.g., in £, $ or €)
	Employment in industries using marine genetic resources	Number of jobs
2b: Biotic raw material – medicinal resources	Use of marine medical resources in medicines	Number of medicines, improvements in mortality rates and quality of life, etc.
	Revenues generated by businesses using marine medical resources (e.g., pharma- and neutra-ceuticals and their contribution to GVA	Monetary value (e.g., in £, $ or €)
	Employment in industries using marine medical resources	Number of jobs
2c: Biotic raw material – ornamental resources	Contribution to ornamental uses	Tonnes
	Revenues generated by businesses using marine ornamental resources and their contribution to GVA	Monetary value (e.g., in £, $ or €)
	Employment in industries using marine ornamental resources	Number of jobs
3: Air purification	Health (human, farm animals and pets)	Health costs avoided: monetary value (e.g., in £, $ or €)
	Crop productivity	Unit of measurement is unknown
4: Climate regulation	Shadow price of carbon (Treasury Green Book, CO_2 equivalent)	Monetary value (e.g., in £, $ or €)
5: Disturbance prevention and moderation	Less prevention and control of erosion	Avoided costs of prevention and control of erosion: monetary value (e.g., in £, $ or €)
	Damages avoided loss of land	Avoided costs: monetary value (e.g., in £, $ or €)
	Damages avoided loss of production	Avoided costs: monetary value (e.g., in £, $ or €)
	Damages avoided emotional costs	Avoided costs: monetary value (e.g., in £, $ or €)
	Decrease in insurance costs (adverse selection)	Avoided costs: monetary value (e.g., in £, $ or €)
6: Regulation of water flows	Avoided additional fuel consumption due to maintenance and/or enhancement of navigation channels	Avoided costs: monetary value (e.g., in £, $ or €)
7: Waste treatment and assimilation	Avoided adverse health effects	Health costs avoided: hospital admissions (as long as accompanied by exposure information)
	Waste removal and burial	Costs of primary vs tertiary sewage treatment; replacement cost analysis; cost to change the system to comply with EU directives vs paying infraction costs: monetary value (e.g., in £, $ or €)
	Water filtration (reduction in turbidity).	Tourism industry dependent on water quality: number of visitors to beach
	Clean status of beach and/or water quality, linked to tourism	Blue flag status against tourism; WTP and how much to pay and how far to travel to a clean beach
8: Coastal erosion prevention	Natural protection for land/houses	Insurance costs avoided and hedonic pricing: monetary value (e.g., in £, $ or €)
	Reduced cost of coastal protection measures	Cost of hard vs soft defence
9: Biological control (checks and balances)	Biosecurity (through maintenance of ecosystem health)	Avoided outbreaks of human diseases related to change in environmental quality
	Avoided remediation	Avoided costs: monetary value (e.g., in £, $ or €)
10: Migratory and nursery habitat	Dependence of off-site fisheries/catch percentage	
	Maintenance of fishing activity	Contribution to employment (no. of jobs) and revenue (monetary value e.g., in £, $ or €)
11: Gene pool protection	Potential option of future use	Meta-analysis, choice experiments, analysis of option value: Monetary value (e.g., in £, $ or €)
	Protected species and habitats	Level of investment made in protection. Monetary value (e.g., in £, $ or €)
	Origin verification (w.r.t. culturally important species)	Price premium compared to other sources: Monetary value (e.g., in £, $ or €)
12: Leisure, recreation and tourism	Number of rested people	Number of sick days avoided
	Coastline and seascape watching	Number of participants
	Wildlife watching	Number of wildlife watchers
	Beach usage	Number of beach visits
	Water usage	Number of swimmers, divers, surfers, boaters
13: Aesthetic experience	Extent of a site to be watched and enjoyed	Number of tourist photos taken
		Number of visits to a site

Table 4 (*Continued*)

Ecosystem services	Examples of ecosystem benefits	Indicators of benefits and their measurement (units)
		Number of scuba-divers (Hedonic) property prices
14: Inspiration for culture, art and design	Marine themed media (e.g., films) Marine themes artwork and installations Use of marine themes in design (bionics, biomimetics) Employment	Number of films, revenue generated (e.g., in £, $ or €) Number of films, revenue generated (e.g., in £, $ or €) Number of products developed and revenues generated Number of jobs
15: Cultural heritage	Cultural importance of a site	Discourse analysis to identify associations between relevant themes
16: Cultural diversity	Indicator and unit of measurement are unknown	
17: Spiritual experience	Spiritual and religious significance to the marine environment	Number of people that attach spiritual and religious significance to the marine environment, discourse analysis
18: Information for cognitive development	Knowledge generated from natural patterns/prototypes	Number of documentaries/movies/paintings/advertisements derived from a particular site/ecosystem. Number of research articles and scientific findings

concept will strengthen its political relevance and practical application (Seppelt et al., 2011).

5.5. Indicator scalability and transferability

Often it is only the generic indicators that are useful at larger scales and are transferable to some extent. To be meaningful for a particular site, indicators need to be made specific. For example, fish stocks are found across the North Sea and can be used as an indicator of the potential for food provision, but food provision from the Dogger Bank is contributed to by specific stocks such as plaice, turbot and lemon sole. The indicators selected in this work suggest that community structure of biota is a relevant indicator for a number of regulating ecosystem services, such as waste treatment and assimilation, climate regulation and air purification. To be useful to management, it needs to be specific to the location and context of interest, the service of interest and, in the case of waste treatment and assimilation, the waste of interest.

These examples suggest that the scalable and portable criteria may not be of primary concern for the identification of relevant indicators in all cases. They also highlight the need for additional contextual indicators, for example, the quantity of waste or contamination that is entering the system, the quantity that is removed by dilution alone and where is it removed to (e.g., locked up in sediments or within the bodies of organisms).

6. Conclusions

Exploring the application of an ecosystem service classification and related ecosystem service indicators to the Dogger Bank identified a number of issues. Ecosystem service classifications can capture the ecosystem services delivered by an offshore marine site, but generic level classifications, such as TEEB (2010) and EEA (2013) need to be tailored to each location. Irrelevant ecosystem services need to be removed and the definitions of each service fine-tuned to better reflect the case study site. Distinctions between ecosystem services, functions and benefits must also be made clear.

Using the classification developed, indicators for the full suite of ecosystem services were derived as well as for associated functions and benefits. This provides a novel contribution as studies typically focus on only a limited number of services, and rarely assess the full complement of ecosystem services, functions and benefits. The relevance and applicability of these indicators, however, cannot always be guaranteed. Data scarcity for the marine environment results in many indicators being unquantifiable. Indicator specificity is a particular problem. Indicators of functions, services and benefits will likely respond to a number of different causes of change. Understanding how a specific location contributes to ecosystem service provision and the benefits they generate, and how they will respond to change remains a challenge.

Tailoring generic level indicators to a specific case study can be achieved with meaningful results for ecosystem services, functions and benefits. All of these indicators should be assessed in conjunction to obtain a more complete understanding of the implications of ecosystem change. Focusing on just ecosystem service or function or benefit indicators may misrepresent a situation and lead to counterproductive management interventions.

Despite these challenges, there is potential to apply ecosystem service indicators to positive effect. With increasing emphasis on marine management, the EU Marine Strategy Framework Directive,[1] the EU Biodiversity Strategy,[2] and the Intergovernmental Platform on Biodiversity and Ecosystem Services[3] are all currently developing indicators to help monitor their implementation and progress. By identifying what indicators can best describe ecosystem services, functions and benefits, effort can be made to ensure that they become applicable through focused monitoring and evaluation programs.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) within the Ocean of Tomorrow call under Grant Agreement No. 266445 for the project Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors (VECTORS). This paper is based on the outputs of a workshop held in Rome 2012 as part of the VECTORS project involving researchers from multiple disciplines (including natural and social sciences and economics) and from subsequent refinements. We thank the participants of that workshop for their contributions. We would also like to thank two anonymous reviewers whose comments helped us to substantially improve our paper.

References

Atkins, J.P., Burdon, D., Elliott, M., Gregory, A.J., 2011. Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. Mar. Pollut. Bull. 62, 215–226.

Austen, M.C., Malcolm, S.J., Frost, M., Hattam, C., Mangi, S., Stentford, G., Benjamins, S., Burrows, M., Butenschön, M., Duck, C., Johns, D., Merino, G., Mieszkowska, N., Miles, A., Mitchell, I., Smyth, T., 2011. Marine. The UK National Ecosystem Assessment Technical Report, UK National Ecosystem Assessment. UNEP-WCMC, Cambridge, 459–498.

Böhnke-Henrichs, A., de Groot, R., Baulcomb, C., Hussain, S., Koss, R., Fofana, A., 2013. Typology and indicators of ecosystem services for marine spatial planning and management. J. Environ. Manage. 130, 135–145.

[1] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056

[2] http://ec.europa.eu/environment/nature/biodiversity/comm2006/2020.htm

[3] http://www.ipbes.net

Börger, T., Beaumont, N.J., Pendleton, L., Boyle, K.J., Cooper, P., Fletcher, S., Haab, T., Hanemann, M., Hooper, T.L., Hussain, S.S., Portela, R., Stithou, M., Stockill, J., Taylor, T., Austen, M.C., 2014. Incorporating ecosystem services in marine planning: the role of valuation. Mar. Policy 46 (0), 161–170.
Balmford, A., Fisher, B., Green, R.E., Naidoo, R., Strassburg, B., Turner, K.R., Rodrigues, A.S.L., 2011. Bringing ecosystem services into the real world: an operational framework for assessing the economics consequences of losing wild nature. Environ. Resour. Econ. 48, 161–175.
Barbier, E.B., 2007. Valuing ecosystem services as productive inputs. Econ. Policy 22, 177–229.
Borja, Á., Elliott, M., Carstensen, J., Heiskanen, A.-S., van de Bund, W., 2010. Marine management – towards an integrated implementation of the European Marine Strategy Framework and the Water Framework Directives. Mar. Pollut. Bull. 60 (12), 2175–2186.
Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 63, 616–626.
Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact on humanity. Nature 486 (7401), 59–67.
Cooper, K., Burdon, D., Atkins, J.P., Weiss, L., Somerfield, P., Elliott, M., Turner, K., Ware, S., Vivian, C., 2013. Can the benefits of physical seabed restoration justify the costs? An assessment of a disused aggregate extraction site off the Thames Estuary, UK. Mar. Pollut. Bull. 75, 33–45.
Costanza, R., 2008. Ecosystem services: multiple classification systems are needed. Biol. Conserv. 141, 350–352.
Dale, V.H., Beyeler, S.C., 2001. Challenges in the development and use of ecological indicators. Ecol. Indic. 1, 3–10.
de Groot, R.S., Fisher, B., Christie, M., Aronson, J., Braat, L., Gowdy, J., Haines-Young, R., Maltby, E., Neuville, A., Polasky, S., Portela, R., Ring, I., 2010a. Integrating the ecological economic dimensions in biodiversity ecosystem service valuation. In: Kumar, P. (Ed.), The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London and Washington, pp. 9–40.
de Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010b. Challenges in integrating the concept of ecosystem services and values in landscape planning: management and decision making. Ecol. Complexity 7, 260–272.
Diesing, M., Ware, S., Foster-Smith, B., Stewart, H., Long, D., Vanstaen, K., Forster, R., Morando, A., 2009. Understanding the Marine Environment – Seabed Habitat Investigations of the Dogger Bank Offshore Draft SAC. JNCC, Peterborough.
EEA, 2013. Towards a Common International Classification of Ecosystem Services. CICES Version 4.3, January. .
Egoh, B., Drakou, E.G., Dunbar M.B., Maes, J., Willemen, L., 2012. Indicators of Mapping Ecosystem Services. A Review. European Commission Joint Research Centre Report EUR 25456 EN.
The State of the World Fisheries and Aquaculture. FAO, Rome.
Feld, C.K., Martins da Silva, P., Paulo Sousa, J., De Bello, F., Bugter, R., Grandin, U., Hering, D., Lavorel, S., Mountford, O., Pardo, I., Pärtel, M., Römbke, J., Sandin, L., Bruce Jones, K., Harrison, P., 2009. Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and spatial scales. Oikos 118 (12), 1862–1871.
Fisher, B., Turner, R.K., 2008. Ecosystem services: classification for valuation. Biol. Conserv. 141, 1167–1169.
Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. 68, 643–653.
Forewind, 2010. Dogger Bank Zonal Characterisation Report. Version 4, October. 200 pp.
Forewind. 2013. Draft Environmental Statement – Teesside A and B. Report Prepared for Forewind by Royal Haskoning DHV.
Haines-Young, R., Potschin, M., 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August–December. EEA Framework Contract No. EEA/IEA/09/003.
Haines-Young, R., Potschin, M., Kienast, F., 2012. Indicators of ecosystem service potential at European scales: mapping marginal changes and trade-offs. Ecol. Indic. 21, 39–53.
Hernández-Morcillo, M., Plieninger, T., Bieling, C., 2013. An empirical review of cultural ecosystem service indicators. Ecol. Indic. 29, 434–444.
Hufnagl, M., Peck, M.A., Nash, R.D.M., Pohlmann, T., Rijnsdorp, A.D., 2013. Changes in potential North Sea spawning grounds of plaice (*Pleuronectes platessa* L.) based on early life stage connectivity to nursery habitats. J. Sea Res. 84, 26–39.
Kershner, J., Samhouri, J.F., James, C.A., Levin, P.S., 2011. Selecting indicators portfolios for marine species and food webs: a Puget Sound case study. PLOS One 6 (10), e25248.
Kröncke, I., 2011. Changes in Dogger Bank macrofauna communities in the 20th century caused by fishing and climate. Estuar. Coast. Shelf Sci. 94, 234–245.
Kremen, C., 2005. Managing ecosystem services: what do we need to know about their ecology? Ecol. Lett. 8, 468–479.
Layke, C. 2009. Measuring Nature's Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators. WRI Working Paper. World Resource Institute, Washington, D.C. .
Link, J.S., Yemane, D., Shannon, L.J., Coll, M., Shin, Y.-J., Hill, L., de Fatima Borges, M., 2009. Relating marine ecosystem indicators to fishing and environmental drivers: an elucidation of contrasting responses. ICES J. Mar. Sci. 67 (4), 787–795.
Liquete, C., Piroddi, C., Drakou, E.G., Gurney, L., Katsanevakis, S., Charef, A., Egoh, B., 2013. Current status and future prospects for the assessment of marine and coastal ecosystem services: as systematic review. PLOS One 8 (7), e67737.
Luck, G.W., Daily, G.C., Ehrlich, P.R., 2003. Population diversity and ecosystem services. Trends Ecol. Evol. 18 (7), 331–336.
Müller, F., Burkhard, B., 2012. The indicator side of ecosystem services. Ecosyst. Serv. 1, 26–30.
Mace, G.M., Bateman, I., Albon, S., Balmford, A., Brown, C., Church, A., Haines-Young, R., Pretty, J.N., Turner, K., Vira, B., Winn, J., 2011. Conceptual framework and methodology. The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, pp. 11–26.
Milcu, A.I., Hanspach, J., Abson, D., Fischer, J., 2013. Cultural ecosystem services: a literature review and prospects for future research. Ecol. Soc. 18 (3), 44.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Current States and Trends. Island Press, Washington, D.C.
Nicholson, E., Mace, G.M., Armsworth, P.R., Atkinson, G., Buckle, S., Clements, T., Ewers, R.M., Fa, J.E., Gardner, T.A., Gibbons, J., Grenyer, R., Metcalfe, R., Muourato, S., MuÛls, M., Osborn, D., Reuman, D.C., Watson, C., Milner-Gulland, E.J., 2009. Priority research areas for ecosystem services in a changing world. J. Appl. Ecol. 46, 1139–1144.
Niemeijer, D., de Groot, R., 2008. A conceptual framework for selecting environmental indicator sets. Ecol. Indic. 8, 14–25.
Reyers, B., Bidoglio, G., O'Farrell, P., Schutyser, F., Dhar, U., Gundimeda, H., Paracchini, M.L., Gomez Prieto, O., 2010. Measuring biophysical quantities and the use of indicators. In: Kumar, P. (Ed.), The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London and Washington, pp. 114–147.
Sell, A.F., Kröncke, I., 2013. Correlations between benthic habitats and demersal fish assemblages—a case study on the Dogger Bank (North Sea). J. Sea Res. 80, 12–24.
Seppelt, R., Dormann, C.F., Eppink, F.V., Lautenbach, S., Schmidt, S., 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. J. Appl. Ecol. 48 (3), 630–636.
Syrbe, R.-U., Walz, U., 2012. Spatial indicators for the assessment of ecosystem services: providing: benefiting and connecting areas and landscape metrics. Ecol. Indic. 21, 80–88.
TEEB, 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. In: Kumar, P. (Ed.), Earthscan, London and Washington.
Turner, K., Schaafsma, M., Elliott, M., Burdon, D., Atkins, J., Jickells, T., Tett, P., Mee L., van Leeuwen, S., Barnard, S., Luisetti, T., Paltriguera, L., Palmieri, G, Andrews, J., 2014. Coastal/Marine Ecosystem Services; Principles and Practice. UK National Ecosystem Assessment Follow-on Project Work Package 3b Marine Economics. Report to Defra, The Welsh Government, NERC, ESRC and AHRC.
UNEP-WCMC, 2011. Developing Ecosystem Service Indicators: Experiences and Lessons Learned from Sub-Global Assessments and Other Initiatives. Secretariat of the Convention on Biological Diversity, Montréal, Canada.
Wallace, K.J., 2007. Classification of ecosystem services: problems and solutions. Biol. Conserv. 139, 235–246.
Wieking, G., Krönke, I., 2003. Macrofauna communities of the Dogger Bank (central North Sea) in the late 1990: spatial distribution, species composition and trophic structure. Helgol. Mar. Res. 57 (1), 34–46.
van Oudenhoven, A.P.E., Petz, K., Alkemade, R., Hein, L., de Groot, R.S., 2012. Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecol. Indic. 21, 110–122.