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Suggestions for additions and valuation of ecosystem services

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Natural capital accounts (NCA), also known as ecosystem accounts, is an approach for systematically measuring and monitoring the condition of ecosystems and corresponding ecosystem services over time, with the aim to support research, decision-making and planning. It is argued that natural resources will be more sustainably used and managed when the relationship between ecosystems and economic and other human activities is considered. In a reflection of the Statistics Netherlands (CBS) report *Natural capital accounts for the North Sea: The physical SEEA EEA accounts* (CBS, 2019), the objective of this report is to identify and improve ecosystems, conditions and physical accounts for the North Sea as well as to identify methods and sources to calculate values (prices) of ecosystem services provided, in preparation for the North Sea natural capital accounts.

Key words: Marine ecosystems; ecosystem services; ecosystem services values; natural capital accounts; North Sea

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Preface

Rijkswaterstaat and Wageningen University and Research have frequently cooperated in studying and assessing economic aspects of water quality and water quality management. In the last few years, the more traditional economic analyses of policy interventions have been supplemented by studies into the value of ecosystem-based management.

Ecosystem services, ecosystem services values and Natural Capital are increasingly recognised in the international, European and Dutch policy arenas. Influential initiatives such as TEEB (the Economic of Ecosystems and Biodiversity) and the Natural Capital Coalition have played an important role in this.

More recently, the value of marine ecosystems has been recognised. The development of internationally agreed upon methods for calculating this value is in full swing (see e.g. the 2018 European Marine Board publication on this topic).[1] Wageningen University and Research aspires a role in developing methods and tools for ecosystem services valuation and for that reason welcomes Rijkswaterstaat request to not only review a CBS report on this topic but also provide recommendations for future ecosystem accounting. We hope this report is a step in the joint development of Natural Capital accounting for the North Sea.

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[1] See http://www.marineboard.eu/marine-ecosystem-modelling.

Summary

Statistics Netherlands (CBS) has investigated whether and how natural capital accounts can be prepared for the Dutch continental shelf (DCS). In 2019 the CBS prepared the report *Natural capital accounts for the North Sea: The physical SEEA EEA accounts* (CBS, 2019), to test the compilation of the physical SEEA EEA[2] accounts for the Dutch part of the North Sea. Key objective of the SEEA EEA is to measure ecosystem condition and ecosystem services such that these are aligned with the System of National Accounting (SNA). In this report, however, Rijkswaterstaat Water, Verkeer & Leefomgeving (WVL) and CBS (2019) both noted a tension between information that one ideally would like to see presented and information that could potentially be included.

The purpose of this assignment is to identify and improve ecosystem, condition and physical accounts for the North Sea as well as to identify methods and sources to calculate the values (prices) of ecosystem services provided, in preparation for the North Sea natural capital accounts. To this end, this study i) provides a critical assessment of the CBS (2019) report; ii) identifies missing ecosystem services relevant to the North Sea; iii) offers an inventory of information sources on the geographical distribution of these missing ecosystem services relevant to the North Sea; iv) identifies methods and information sources for the calculation of price tags for these missing ecosystem services relevant to the North Sea; and v) gives recommendations and conclusions on how to improve natural capital accounts for the North Sea.

The assessment showed that the CBS report is valuable as a pilot, and should be seen as such, that illustrates how a SEEA EEA can be constructed. However, it excludes relevant ecosystem services as well as their monetary valuation for reasons to do with the project's terms-of-reference (TOR), budget restrictions and data availability. As a consequence, the CBS report gives a limited view of the North Sea ecosystem services, focusing on only few (mainly provisioning) and ad-hoc ecosystem services that are not dependent on the quality of the ecosystem (except for fisheries). We conclude that various other biotic and abiotic provisioning, regulation & maintenance and cultural services are relevant for the North Sea. Moreover, integral assessments of the supply, use and value of ecosystem services require appropriate indicators that are measured at specific locations, spatial scales, temporal scales and frequencies, as well as appropriate measuring methods.

European and national databases can contribute to identifying the geographical distribution of ecosystem services potentially relevant to the North Sea, while global and regional databases can assist with the assessment of ecosystem services values potentially relevant to the North Sea. A full-fledged SEEA EEA should take into account the complete range of relevant ecosystem services and values – including biotic and abiotic services for which the supply and value is not directly relatable to existing markets and/or associated conventional statistical indicators.

[2] System of Environmental Economic Accounting (SEEA) – Experimental Ecosystem Accounting (EEA).

1 Introduction

Natural capital accounts (NCA), also known as ecosystem accounts, is an approach for systematically measuring and monitoring the condition of ecosystems and corresponding ecosystem services over time, with the aim to support research, decision-making and planning. The key motivation for ecosystem accounting is the notion that ecosystems and the economy do not consider the vital relationship between people and the environment. As a consequence, current economic accounting focuses on economic and other human activities, corresponding prices (as reflected through markets) and values. Ecosystem accounting aims to also include ecosystem services, prices (mostly not reflected through markets) and values. It is argued that natural resources will be more sustainably used and managed when the relationship between ecosystems and economic and other human activities is considered.

Statistics Netherlands (CBS) has investigated whether and how natural capital accounts can be prepared for the Dutch continental shelf (DCS). In 2019 the CBS prepared the report *Natural capital accounts for the North Sea: The physical SEEA EEA accounts* (CBS, 2019), to test the development of the physical SEEA EEA[3] accounts for the Dutch part of the North Sea – in particular the a) extent account, b) condition account and c) physical supply and use tables for ecosystem services. The key objective of the SEEA EEA is to measure ecosystem condition and ecosystem services such that these are aligned with the System of National Accounting (SNA).

In relation to the CBS (2019) report, Rijkswaterstaat Water, Verkeer & Leefomgeving (WVL) identified as well as CBS (2019) noted a tension between information that one ideally would like to see presented and information that could potentially be included. For reasons relating to project terms-of-reference (TOR), budget restrictions and data availability, the CBS report included only a limited selection of ecosystem services,[4] did not consider the quality of the ecosystems, focused on ecosystem services that are independent of the quality of the North Sea, and did not develop monetary accounts. The purpose of this assignment is to i) identify and improve ecosystem-, condition- and physical-accounting for the North Sea and ii) identify methods and sources for calculating ecosystem values for the North Sea, for the preparation of natural capital accounts for the North Sea.

To advise Rijkswaterstaat on the natural capital accounts for the North Sea, and to provide advice on missing ecosystem services that can be included, the following steps were taken:

- Step 1: Critical assessment of the CBS (2019) report (Chapter 3);
- Step 2: Identification of missing ecosystem services relevant to the North Sea (Chapter 4);
- Step 3: Inventory of information sources about the geographical distribution of the missing ecosystem services relevant to the North Sea (Chapter 5);
- Step 4: Identification of methods and sources for calculation of prices for the missing ecosystem services relevant to the North Sea (Chapter 6); and
- Step 5: Recommendations and conclusions on how to improve the CBS natural capital accounts for the North Sea (Chapter 7).

The corresponding methods are described in Chapter 2.

[3] System of Environmental Economic Accounting (SEEA) – Experimental Ecosystem Accounting (EEA).

[4] Namely: marine fishing, sand and gravel extraction, gas and oil extraction, wind generation, use of space, and nature-related recreation and tourism.

2 Methods

To advise Rijkswaterstaat on the natural capital accounts for the North Sea and to provide advice on missing ecosystem services that can be included, the following steps were developed:

Step 1 – Critical assessment of the CBS (2019) report:
The critical assessment entails, first, a description of the limitations of the CBS (2019) study, including the limitations mentioned by the authors as well as those identified by us. Second, we describe and assess the different accounts developed in the CBS (2019) study and compare these with internationally recognised classification systems. Finally, we conclude with general remarks on the report and subsequent recommendations.

Step 2 – Identification of missing ecosystem services relevant to the North Sea:
The CICES V5.1 classification (Haines-Young & Potschin, 2018) is used to identify ecosystem services relevant to the North Sea that were not assessed in the CBS (2019) report. We thereby focus on biotic and abiotic provisioning, regulating & maintenance and cultural ecosystem services. The missing ecosystem services are identified through an expert workshop held at Wageningen Economic Research on 21 November 2019 (including Dr. P.C. Roebeling, Dr. S.W.K. van den Burg, M. Skirtun and Dr. K. Soma) as well as expert feedback (Dr. K. Hamon) and a review of relevant literature (e.g. Beaumont et al., 2007; Böhnke-Henrichs et al., 2013; Haines-Young & Potschin, 2018).

Step 3 – Inventory of information sources about the geographical distribution of the missing ecosystem services relevant to the North Sea:
This inventory starts with a discussion on the importance of a structured, consistent and operational methodology that is specifically adapted to marine ecosystems, thereby building on relevant publications (e.g. Böhnke-Henrichs et al., 2013; Haines-Young & Potschin, 2018) and research agendas (European Marine Board, 2018).[5] In turn, based on input obtained during the expert workshop and expert feedback (see Step 2), data sources are identified that allow for the quantification of marine ecosystem services indicators relevant to the North Sea. Finally, the identified relevant ecosystem services (from Step 2) are, via potential indicators, related to these data sources.

Step 4 – Identification of methods and sources for calculation of prices for the missing ecosystem services relevant to the North Sea:
First, an overview is provided on methods used to value ecosystem services. Second, based on input obtained during the expert workshop and expert feedback (see Step 2), ecosystem service value databases are identified that can be used as a basis to value ecosystem services relevant to the North Sea. Finally, the identified relevant ecosystem services (from Step 2) are, via potential indicators (from Step 3), related to these valuation methods and data sources.

Step 5 – Recommendations and conclusions on how to improve the CBS natural capital accounts for the North Sea:
Key conclusions and recommendations are derived from the results obtained in the previous steps, with the aim to contribute to the integral quantification of marine ecosystem services and values for the development of natural capital accounts for the North Sea.

[5] See http://www.marineboard.eu/marine-ecosystem-modelling.

3 Critical assessment of the CBS report *Natural capital accounts for the North Sea*

In this chapter we reflect on the draft version (dated 08-07-2019) of the CBS report *Natural capital accounts for the North Sea: the physical SEEA EEA accounts* (CBS, 2019). The objectives of the CBS study were, as formulated by the authors, fourfold:

1. Provide a short, comprehensive introduction on SEEA EEA and its physical accounts and how these accounts can be compiled for the marine environment;
2. Describe the general approach followed in this pilot project;
3. Present the results of the actual compilation of the experimental accounts for the Dutch part of the North Sea; and
4. List the recommendations resulting from the project and propose possible follow-up actions.

This chapter is organised as follows. First, we describe the limitations of the CBS (2019) study – including those outlined by the authors, as well as limitations identified by us (Section 3.1). Second, we describe and assess the different accounts developed in the CBS (2019) study (Section 3.2). Finally, we conclude with general remarks on the report (Section 3.3).

3.1 Limitations

The proposed approach to come to a National Capital Account is based on on-going initiatives to develop Experimental Ecosystem Accounting (EEA) under the United Nations System of Environmental and Economic Accounting (SEEA) (UN, 2014, 2018). In SEEA EEA, five core ecosystem accounts are distinguished:

1. Extent account: Develop an ecosystem type map and extent account;
2. Conditions account: Determine the conditions of the ecosystem assets;
3. Physical ecosystem service supply and use accounts;
4. The monetary ecosystem service supply and use accounts; and
5. The ecosystem monetary asset account.

The first important limitation of the CBS (2019) study is its focus on accounts 1 to 3, only. The monetary valuation of ecosystem services provided and used (account 4) and the assessment of the monetary value of the ecosystem asset account (account 5) were not considered.

Second, the authors acknowledge that the SEEA EEA does not function in isolation (see p.10), but should be linked to standard economic accounts (the SEEA Central Framework accounts) and thematic accounts. This is not foreseen in the CBS study.

Third, the study provides a snapshot, in time, of the value of natural capital in the North Sea. Echoing the authors, natural capital accounting and EEA can be valuable tools to monitor changes in the status of the ecosystem over time and/or be used to evaluate the impact of interventions. This report, being a single snapshot, does not provide data on temporal changes in natural capital.

Finally, a limitation lies in the fact that the authors have sought to go through the first three accounts of SEEA EEA despite being aware of the fact that data availability was limited. Moreover, the authors have used data availability as a criterion for selection of ecosystem services (see e.g. p.11, under 'Availability of indicators').

3.2 Accounts reflection

Before the different accounts developed in the CBS (2019) project are described and reflected upon, two general remarks are made. First, it is not always clear why certain choices were made. Although the authors described the applied approach in their Chapter 3, including the role of the Advisory Group, numerous choices were left unexplained. It is not clear, for example, what input internal and external specialists provided, and how this input was used. Similar remarks will be made in reflecting on the different accounts below.

Second, the authors described their struggle with availability of data. For example (CBS, 2019: p.11):

> 'In every step, we started with a list of data (sources) we wanted to use in the project, but after a while we discovered time and time again that a large part of the desired data were not available. To fill this 'white spots' as much as possible, we consulted external and internal data specialists.'

However, this struggle is not properly recorded and therefore cannot be used to guide future data collection and needs. What data did the authors seek? What data sources were consulted and why were these deemed unusable? Had this information been recorded, the study could inform discussions on future data collection needs.

3.2.1 Extent account

The objective of the extent account on the SEEA EEA is to map the different ecosystem types (ET) present in the study area, into mutually exclusive units that represent ecosystem assets (EA). This information could then, potentially, be linked to the conditions (account 2) and the ecosystem services supplied and used (account 3).

Recognising there are no international standards for ecosystem classification, the authors developed an approach based on the *Natuurtypenkaart* of the North Sea (WUR, 2011) – classifying ecosystem types based on five characteristics (water depth; summer stratification of the water column; salinity; sediment type; protection status). One point for discussion raised by the authors is how to deal with the fact that marine ecosystems extend throughout the water column. Two approaches are possible to deal with this (two-dimensional approach; three-dimensional approach), and the authors choose the two-dimensional (spatial) approach for more shallow waters in which each area can only be classified as one ecosystem asset.

The authors defined five biomes or ecosystem types for the North Sea: shoreline system; transitional waters; marine shelf – shallow waters; marine shelf – medium deep waters without stratification; and marine shelf – deep waters with stratification. For reasons not explained, the authors chose to include 'protection status' in the ecosystem characterisation, acknowledging that 'there can be huge differences between different protected areas, both in timing and content of the agreement' (CBS, 2019: p.16). It is not clear what is the perceived benefit of including protection status in the characterisation, and in case there are considerable differences between protected and non-protected areas flawed conclusions may be drawn (see also Section 3.2.2 on conditions account).

3.2.2 Conditions account

The objective of the conditions account is to 'provide insight into how the biophysical condition of ecosystems change and how those changes may influence the flow of ecosystem services supplied by those ecosystems' (CBS, 2019: p.19).

The approach taken is based on the identification of, mainly chemical, condition indicators and scoring the ecosystem based on these indicators – thereby assuming that this provides insight into the status of the ecosystem. This section suffers from a number of ambiguities and weaknesses:

- It is not made clear where the data on performance indicators comes from;
- Insufficient data is provided to understand what the indicators actually refer to; and

- It is not always clear whether a low or, alternatively, a high score indicator is desirable, making comparison between indicators difficult.

Furthermore, also this section makes a distinction between protected and unprotected areas (see e.g. Figure 5.3, p.21). The authors do not take into account that certain protected areas were selected as protected areas because of the high prevalence of e.g. birds. As a consequence, causal relationships cannot easily be distinguished. It is also not clear what meaningful conclusions can be drawn from the different scores given to protected and non-protected areas.

3.2.3 Physical ecosystem service supply and use accounts

The objective of the physical ecosystem service supply and use accounts is to quantify the supply of ecosystem services, and the value of their uses by economic units. CBS compiled the unit measure of ecosystem service accounts in biophysical terms, but left the monetary valuation of the ecosystem services and assets as possible 'next step' (CBS, 2019: p.27).

The authors used the CICES 5.1 classification of ecosystem services (Haines-Young & Potschin, 2018) and selected 6 ecosystem services (marine fishing, sand and gravel extraction, gas and oil extraction, wind generation and use of space) for further evaluation and quantification based on existing datasets. The main criteria for selecting these 6 ecosystem services (see Table 3.1) were: (1) relevance for the Dutch North Sea area, (2) data availability, and (3) budget limitations. Although a number of other potentially relevant ecosystem services (outside the 6 studied) were identified (see CBS, 2019: p.28), these were not included, likely due to project scope, budget constraints and/or data availability.

Table 3.1 *Overview of ecosystem service supply and use, included in the CBS (2019) study*

Ecosystems service	Indicator	Data	Comments
Marine fishing (CICES: Wild animals for nutrition, materials or energy)	Fish catch	Data from ICES, Wageningen Marine Research, www.searoundus.org	Problem with calculation fish catch in Dutch EEZ Validity of data source Sea Around US?
Extraction of sand and gravel (CICES: Mineral substances used for nutrition, materials and energy)	Total extraction of sand and gravel in million tonnes	UEPG (European Aggregates association)	No spatial data
Extraction of gas and oil (CICES: Mineral substances used for nutrition, materials and energy)	Volumes extracted in million Nm^3 and 1000 Sm^3	Ministry of Economic Affairs and Climate	No spatial allocation done, in principle possible
Generation of wind power (CICES: Non-mineral substances or ecosystem properties used for nutrition, materials and energy)	Electricity generation from wind power	Statline	
Use of space (CICES: n/a)	Use of space in km^2	Policy document on the North Sea 2016-2021	Not included in CICES 5.1 Methodological challenges, including double counting
Nature related tourism and recreation (CICES: Physical and experiential interactions with natural environment)	Number of tourists and number of hikers	NTBC-NIPO	How to draw the boundary between coast and North Sea Hiking selected for indicator, being the most popular outdoor activity

Overlooking this exercise, a number of questions arise on the choices made in CBS (2019):
- Why wasn't strictly adhered to the CICES classification? E.g., use of space is included in the evaluation, but not recognised in CICES 5.1.
- Why were two debatable ecosystem services (extraction of gas and oil; use of space), of in total six, considered?
- The selection of ecosystem services for further evaluation is important, and subject to discussion.

- Why were, with the exception of marine fishing, only ecosystem services included for which the supply is independent of the status of the ecosystem?
- Why were, with the exception of nature related tourism and recreation, only provisioning services included in the assessment? It is important to include non-provisioning services, if only to show that there are methods to include these in EEA (see Chapter 4).
- Why were some ecosystem services recognised as being relevant, still excluded? For example, on p.44 the authors do mention important regulating & maintenance services (e.g. flood protection).

3.3 Concluding remarks

The CBS (2019) report is a pilot to study if an SEEA EEA for the North Sea can be constructed. *The study is valuable as a pilot and should be seen as such*; the study shows how a SEEA EEA can be constructed but excludes relevant ecosystem services as well as their monetary valuation for reasons to do with the project's terms-of-reference (TOR), budget restrictions and data availability.

In the CBS (2019) study, the value of the North Sea is restricted to five provisioning services (marine fishing, sand and gravel extraction, gas and oil extraction, wind generation and use of space) and one cultural service (nature-related recreation and tourism). *A better understanding of the value of the North Sea should include a wider range of ecosystem services, including abiotic and biotic, non-provisioning and non-market based ecosystem services.*

For a future SEEA EEA, data availability is important. It would be helpful if the authors can shed more light on the data sources examined and considered for inclusion – i.e. it is not always clear which sources were consulted and, whether or not (and why), they were used in the study. Self-evidently, to come to a National Capital Account, the SEEA EEA should account for all five core ecosystem accounts. *Hence, the lack of suitable or useable data should not be a reason to exclude relevant ecosystem services from the analysis but rather, considered as an opportunity to guide future data collection needs*.

The suggestions to monitor the status of biodiversity, or even construct a 'biodiversity account' (see Chapter 8), are hard to reconcile with the selection of ecosystem services considered in Chapter 6. Also, the condition account is not related to the physical ecosystem service supply and use accounts. *If biodiversity accounting is to provide 'information on biodiversity in a structured, coherent and regularly updated manner' (p.41), a much broader set of indicators and data sources is needed.*

Finally, in Chapter 7 (Policy uses) the authors discuss how SEEA EEA can be used to inform policy-making. Although this chapter provides sensible arguments, these are not linked to the exercise developed in Chapters 3 to 6 – i.e. it is not clarified how SEEA EEA can enhance efficient (natural) resource use and effectively inform policy making. Hence, the arguments remain rather generic.

4 Identification of missing ecosystem services relevant to the North Sea

The Common International Classification of Ecosystem Services (CICES) has been designed to help measure, account for, and assess ecosystem services (Haines-Young & Potschin, 2018). It was developed in the context of the System of Environmental and Economic Accounting (SEEA), led by the United Nations Statistical Division (UNSD), and has been widely used in ecosystem service research for the development of indicators, mapping and valuation. CICES is intended to be a reference classification that allows translation between different ecosystem service classification systems, such as those used in the Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystems and Biodiversity (TEEB). In CICES, ecosystem services are defined as the contributions that ecosystems make to human well-being and that arise from living processes. Although in the latest version of CICES (V5.1) the focus remains on these biotic ecosystem outputs, the classification of ecosystem services is broadened as to also include abiotic ecosystem outputs. As a result, the CICES V5.1 classification is, generally speaking, consistent with the marine ecosystem services typology classification proposed by Böhnke-Henrichs et al. (2013).

In this chapter, CICES V5.1 is used to identify ecosystem services relevant to the North Sea that are not assessed in the CBS (2019) report. We hereby focus on biotic and abiotic provisioning (Section 4.1), regulating & maintenance (Section 4.2) and cultural (Section 4.3) ecosystem services. These results are obtained from an expert workshop held at Wageningen Economic Research on the 21 November 2019 (including Dr. P.C. Roebeling, Dr. S.W.K. van den Burg, M. Skirtun and Dr. K. Soma) as well as from expert feedback (Dr. K. Hamon) and assessment of relevant literature (e.g. Beaumont et al., 2007; Böhnke-Henrichs et al., 2013).

4.1 Provisioning ecosystem services

Table 4.1 provides an overview of the biotic and abiotic provisioning ecosystem services identified as being relevant for the North Sea, with examples included.

Table 4.1 *Biotic (green) and abiotic (orange) provisioning ecosystem services relevant to the North Sea*

Division	Group	Class	Example service
Biomass	Cultivated/wild aquatic plants for nutrition, materials or energy	In-situ cultivated plants/wild plants for nutritional purposes	Seaweeds
Biomass	Cultivated/wild aquatic plants for nutrition, materials or energy	Fibres and other materials from in-situ aquaculture / wild plants for direct use or processing (excluding genetic materials)	Seaweeds
Biomass	Cultivated/wild aquatic plants for nutrition, materials or energy	In-situ cultivated plants (aquaculture)/wild plants used as an energy source	Seaweeds
Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	Mussels; crayfish; oysters; lobsters
Biomass	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	Mussels; crayfish; oysters; lobsters

Division	Group	Class	Example service
Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	Fish; shellfish
Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	Fish; shellfish
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	Seaweed spores
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Higher and lower plants (whole organisms) used to breed new strains or varieties	Seaweeds
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	Mussel spats
Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	Wave/tidal energy
Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for material purposes	Oil (plastics); shells; sand; gravel
Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for as an energy source	Oil; gas
Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Wind energy	Wind energy
Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Solar energy	Solar energy

Note that, at this stage, the table does not differentiate between provisioning services that are already commercially used (for example fish) and ecosystem services that are considered for commercial use (such as seaweed and crayfish farming).

4.2 Regulating & maintenance ecosystem services

Table 4.2 provides an overview of the biotic and abiotic regulating & maintenance ecosystem services identified as being relevant for the North Sea, including examples.

Table 4.2 *Biotic (green) and abiotic (orange) regulating & maintenance ecosystem services relevant to the North Sea*

Division	Group	Class	Example service
Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	Uptake of nutrients from river effluents by algae
Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	Oysters; mussels; seaweeds
Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Visual screening	Beaches; dunes
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	Beaches; dunes

Division	Group	Class	Example service
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	Beaches; dunes
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (including flood control and coastal protection)	Dunes
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Wind protection	Beaches; dunes
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	Dispersal of seaweed spores
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	Tropical drift seeds found in North Sea
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	Natural mussel spat populations
Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	-
Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	-
Regulation of physical, chemical, biological conditions	Regulation of soil quality	Weathering processes and their effect on soil quality	Benthic
Regulation of physical, chemical, biological conditions	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	Benthic
Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	Influence of algal growth on nutrient dynamics
Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	Exchange of carbon with atmosphere
Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	Water evaporation
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by freshwater and marine ecosystems	Dilution of contaminants; accumulation of waste on seafloor
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)	Filtration rainwater by dunes for drinking water purposes
Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Mediation of nuisances by abiotic structures or processes	Beaches; dunes
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Mass flows	Sand banks; beaches; dunes
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Liquid flows	Beaches; dunes

4.3 Cultural ecosystem services

Table 4.3 provides an overview of the biotic and abiotic cultural ecosystem services identified as being relevant for the North Sea, including examples.

Table 4.3 *Biotic (green) and abiotic (orange) cultural ecosystem services relevant to the North Sea*

Division	Group	Class	Example service
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	Beach tourism; snorkelling; diving; recreational fishery
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	Beach tourism; recreation; leisure; observational activities (birds; mammals)
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	Sea life; bird life; ornithology
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	Excursions for lower, middle and higher education
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	Coastal communities; fishing communities
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	Beach tourism; coastal tourism; coastal communities
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	Culture of fishing communities
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	Runes around the North Sea
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	Aesthetics; photos; movies
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	Existence of marine mammals and seabirds
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	Protection of marine birds and mammals

Division	Group	Class	Example service
Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Physical and experiential interactions with natural abiotic components of the environment	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions	Beach tourism; beach activities; aquatic sports
Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Intellectual and representative interactions with abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable intellectual interactions	Recreation; leisure, physical appreciation (currents; erosion patterns; dune formation)
Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions	Aesthetics; photos; movies; shipwrecks

5 Inventory of information sources on the geographical distribution of the missing ecosystem services relevant to the North Sea

The assessment of marine ecosystem assets and services requires a structured, consistent and operational methodology that is specifically adapted to marine ecosystems. This requires the definition of relevant biomes or ecosystem types (CBS, 2019: shoreline system; transitional waters; marine shelf – shallow waters; marine shelf – medium deep waters without stratification; marine shelf – deep waters with stratification), selection and justification of an approach to define ecosystem assets for the marine environment (CBS, 2019: two-dimensional approach), the identification of relevant ecosystem service types (CBS, 2019: restricted number of mainly provisioning services based on CICES V5.1), the selection of appropriate indicators for their quantification (CBS, 2019: based on mainstream databases) and finally, the establishment of consistent indicator measurement protocols (spatial resolution, location, temporal resolution, frequency and method of measurement). For natural capital accounts it is crucial that these indicators are consistently measured over the years.

In this chapter we discuss the need to systematically classify, measure and quantify marine ecosystem service indicators (Section 5.1) as well as how to appropriately utilise currently available data sources to quantify marine ecosystem service indicators that are relevant to the North Sea (Section 5.2). In Section 5.3 we aim to best match the identified ecosystem services in the North Sea (Chapter 4) to the currently available data sources using potential indicators or proxies.

5.1 Data needs

Data needs are diverse and, as mentioned repeatedly in the CBS (2019) report, scarcely available for ecosystems services relevant to the North Sea. Current indicators, such as the ones used in the CBS (2019) report, are mostly focused on market-based ecosystem services and values, while most of the identified missing ecosystem services and values relevant to the North Sea (see Chapter 4) are non-market based (such as regulating & maintenance and cultural ecosystem services and values). Consequently, there is a need to systematically classify and measure marine ecosystem service indicators. This need is reflected by Böhnke-Henrichs et al. (2013), who argued that there is a lack of a well-structured, systematic classification and assessment of marine ecosystem services. Particularly, because (Böhnke-Henrichs et al., 2013: p.138): i) ecosystem services typologies developed with a terrestrial focus cannot be smoothly transferred to applications in marine environments; ii) use of extant typologies is problematic for economic valuation; and iii) several specific ecosystem service types and definitions found within existing typologies are not capable of reflecting changes in the state of marine ecosystems.

The marine ecosystem services typology classification proposed by Böhnke-Henrichs et al. (2013) is generally consistent with the CICES V5.1 classification (Haines-Young & Potschin, 2018; see Chapter 4). However, particularly interesting and useful in the Böhnke-Henrichs et al. (2013) paper is the operationalisation of this typology in quantifiable indicators, associated capital inputs and human benefits (see Table 5.1). As for the establishment of consistent indicator measurement protocols, we feel that for most of the marine ecosystem services (in particular for regulating & maintenance and cultural services) there is little consensus on what these protocols should be. In fact, discussions on methods for calculating marine ecosystem services and values are in full swing (see the 2018 European Marine Board publication on this topic).[6]

[6] See http://www.marineboard.eu/marine-ecosystem-modelling.

Table 5.1 *Operationalising marine ecosystem service typology: indicators, required capital input and human benefits (source Böhnke-Henrichs et al., 2013: p.141)*

ES	Indicators [a]	Other capital input required? Yes / No / depends	Direct benefits: Examples
Sea Food	Amount of fish landed [b] (Beaumont et al. 2006, Lange and Jiddawi 2009, Hunsicker et al. 2010) Amount of Sea Food harvested/year [b] (Kasperski and Wieland 2009, O'Higgins et al. 2010) Amount of fish harvested/km^2/year [b] (Cesar (1996); Ruijgrok et al. (2006) use unit ha/year)	e.g. fishing gear, fishing vessel, fuel	Nutrition, protein source, livelihood, pleasure: enjoy the taste
Sea Water	Number of days sea water is of insufficient quality for desired application Amount of Sea Water extracted per year per area [c]	e.g. desalinization plant, ship	Drinking water, health, safety (ballast water for shipping, cooling water for nuclear power plants), relaxation (recreation, leisure)
Raw Materials	Amount of fuel wood and amount of timer used from mangroves [b] (kg/household/year) (Hussain and Badola 2008) Amount of raw material extracted [b] (Beaumont et al. (2006); Ruijgrok et al. (2006) use unit m³/year) Amount of seaweed grown per year [c] (Lange and Jiddawi 2009)	e.g. labor, dredger, other extraction gear	Inputs to industrial processes, construction material for infrastructure, employment,
Genetic Resources	# of Genes utilized per year per area [b]	e.g. genetic engineering lab/facility	Industry products, nutrition, livelihood,
Medicinal Resources	# of undiscovered oncological drugs (Erwin, López-Legentil and Schuhmann 2010)	e.g. lab, facilities to process pharmaceuticals	Health
Ornamental Resources	Amount of Ornamental Resources (tons) used per year per area [b]	for personal use: directly beneficial, for commercial use indirect: labour, extraction gear, transportation	Pleasure (interior decoration – symbolic or other, use for fashion, jewellery), livelihood
Air Purification	Amount of fine dust/NOx or SO2 captured (kg/ha/year) (Ruijgrok et al. 2006)		health (via clean air)
Climate Regulation	Amount of CO_2 sequestered (Beaumont et al. 2006, Ruijgrok et al. 2006, Jialin et al. 2009, Wang et al. 2010)		Favourable living conditions, health and wellbeing
Disturbance Prevention or	# of freshwater wells or amount of drinking water protected from tsunami impacts (Sanford 2009)		Safety (protection of human life, coastal infrastructure, property,
Moderation			livelihood), (mental) health and wellbeing of coastal citizens
Regulation of Water Flows	Amount of sediment prevented from sedimentation in natural channels used for shipping (m^3/year) (Ruijgrok et al. 2006)		Maintenance of natural shipping lanes, Safety, livelihood (shipping sector)
Waste Treatment	Biochemical degradation capacity of COD (g/m^3/day) (Wang et al. 2010) Amount of N and P stored kg/ha/year (Souza and Ramos e Silva 2011)		Health (via clean Sea Water)
Coastal Erosion Prevention	Length of natural coast line (Wang et al. 2010) Amount of sediment prevented from erosion per ha of an ecosystem per year (Ruijgrok et al. 2006)		Protection of property and land (e.g. used for recreation, coastal protection, agriculture, industry), protection of land/ seascape, mental and physical health and wellbeing of coastal citizens
Biological Control	# of species (Species richness) (Beaumont et al. 2006)		Mental and physical health
Lifecycle Maintenance	Amount of fish caught outside an area [b] (Hussain and Badola 2008)	e.g. fishing gear, labour, fishing vessel	Nutrition (via Sea Food), health, livelihood, Warm glow (existence value satisfaction)
Gene Pool Protection	Genetic diversity per population		Warm glow (representing the existence value)
Recreation and Leisure	*For most frequently used indicators please refer to section 4* # of visits of an area [c] (Dehghani et al. 2010) # of trips per site per year [c] (Gao and Hailu 2011) # of days used for particular activity per person [c] (Tapsuwan and Asafu-Adjaye 2008) # of day trips per year and # of overnight stays [c] (Ruijgrok et al. 2006) # of hotel rooms in a region [c] (Lange and Jiddawi 2009) Square feet of beach/beach day[d] (Bell 1986) Amount or Catch rate of target fish species (Cameron and James 1987, Bockstael, McConnell and Strand 1989) # of visitors per season [c]; # of boats involved in trips [c]; # of dive operators offering trips [c] (Dicken 2010)	Depends: e.g. SCUBA diving vs. beach recreation	Feelings of relaxation, pleasure and enjoyment, health and wellbeing, happiness, rejuvenation, employment
	Annual access days [c] (Cameron 1988)		
Aesthetic Information	Square feet of beach/beach day[b] (Bell 1986) Beach day [c,b] (Bell and Leeworthy 1986)		Pleasure, feelings of stimulation, relaxation, rejuvenation, and enjoyment.
Inspiration for Culture, Art and Design	Amount of time (# or person days) dedicated to creation of culture, art and design per area per year [c]		Inspiration and the promotion of creativity, enjoyment, satisfaction, livelihood
Spiritual Experience	Amount of time (# of person days) dedicated for formal religious ceremonies that involve coastal/marine environments per area per year [c]		Feelings of spirituality, the ability to perform religious ceremonies
Information for Cognitive Development	Amount of time (# of person days) spent in education about, research regarding, or individual learning about an ecosystem/species/ etc. per area per year [c]	e.g. any tools to study marine organisms	Intellectual inspiration to pursue knowledge, satisfaction of curiosity, education
Cultural Heritage and Identity	# of households that consider an area or aspects of an area as cultural heritage [c] (Ruijgrok et al. 2006)		Cultural practices which define the heritage, sense of community, sense of place, belonging, health and wellbeing.

[a] Cells shaded grey: no indicator could be obtained from literature; indicators proposed here are considered to represent the ecosystem service in question as good as possible. However, depending on data availability for specific case studies these indicators may need to be adjusted.
[b] This indicator is directly linked with the state of the ecosystem. However, due to the indirect nature of this service, a change in human effort of using it may disguise these ecosystem state changes. For instance, increasing fishing effort can mask a reduction of fish stocks.
[c] This indicator is not or indirectly linked with the state of the ecosystem and rather reflects human activities.
[d] This Study assessed bundled services *Coastal Erosion Prevention, Recreation and Leisure, Aesthetic Information.*

5.2 Data sources

Various currently available data sources can contribute to the quantification of the geographical distribution of ecosystem services potentially relevant to the North Sea. It must be noted, however, that these data sources are neither complete nor sufficient to allow for an integral and meaningful assessment of marine ecosystem service indicators.

At the European level, EUROSTAT is the statistical office of the European Union, providing statistical data that enable comparisons between countries and regions (EUROSTAT, 2019). EUROSTAT provides country-specific time-series data for the EU-28, on general and regional statistics for economy and finance, population and socio-economic conditions, industry, trade and services, agriculture and fisheries, international trade, transport, environment and energy, and science, technology and digital society.[7]

The European Space Agency (ESA) hosts Sentinel Online (SO), which allows users to find information regarding the SENTINEL program, the individual Sentinel Missions, their operational focus and the Copernicus Thematic area they support (ESA-SO, 2019). The Sentinel open access hub provides complete, free and open access to Sentinel-1, Sentinel-2, Sentinel-3 and Sentinel-5P user products.[8] Sentinel spatial and time series data are also available via the Copernicus Data and Information Access Services (DIAS), through CREODIAS,[9] MUNDI,[10] Sobloo[11] and ONDA.[12]

The European Environmental Agency (EEA) Water and Marine Environment (WME) aims to provide timely, targeted, relevant and reliable information on water and marine issues as to support the implementation and evaluation of existing and upcoming EU water and marine policies (EEA-WME, 2019). It contributes to a comprehensive knowledge base that addresses the preservation, resilience and restoration of European water and marine ecosystems. This takes the form of reports, data, indicators and assessments, which are available on the EEA website and online information platforms. In particular, WISE (Water Information System for Europe) is the European information gateway to water issues (WISE, 2019) – comprising WISE-Freshwater[13] and WISE-Marine.[14] Relevant to this study is WISE-Marine, which is the gateway to information on European marine issues in support of ocean governance and ecosystem based management.[15]

The Copernicus Marine Environment Monitoring Service (CMEMS) provides products and services for all marine applications, and has been designed to respond to issues emerging in the environmental, business and scientific sectors (CMEMS, 2019). Using information from both satellite and in situ observations, it provides state-of-the-art analyses and forecasts daily, which offer an unprecedented capability to observe, understand and anticipate marine environment events. The Ocean Monitoring Indicators (OMIs) provides free downloadable trends and datasets covering the past quarter of a century.[16]

The European Marine Observation and Data Network (EMODnet) consists of over 150 organisations assembling marine data, products and metadata to make these fragmented resources available to public and private users relying on quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions to use (EMODnet, 2019). EMODnet contains a data portal on bathymetry, biology, chemistry, geology, human activities, physics and seabed habitats[17] and a data service catalogue where spatial and time-series data can be obtained[18] and viewed.[19]

[7] See https://ec.europa.eu/eurostat/data/database.
[8] See https://scihub.copernicus.eu/dhus/#/home.
[9] See https://creodias.eu/.
[10] See https://mundiwebservices.com/.
[11] See https://sobloo.eu/.
[12] See https://www.onda-dias.eu/cms/.
[13] See https://water.europa.eu/freshwater.
[14] See https://water.europa.eu/marine.
[15] See https://water.europa.eu/marine.
[16] See http://marine.copernicus.eu/science-learning/ocean-monitoring-indicators/.
[17] See http://www.emodnet.eu/portals.
[18] See http://www.emodnet.eu/geonetwork/emodnet/eng/catalog.search#/search.
[19] See https://www.emodnet.eu/geoviewer.

The European Atlas of the Seas (EAS) provides information about Europe's marine and coastal environment, based on spatial and time-series data from the EC, EC-agencies and EMODnet (EAS, 2019). EAS is an easy to use and interactive web-based geographic application, with data layers on, amongst others, algae production, aquaculture, blue indicators, employment, energy, environment, fisheries, litter, nature, population, sea bottom, sea life, seabed habitats, security, tourism, trade, transport and water analysis.[20]

At the national level for the Netherlands, Statistics Netherlands (CBS) is the statistical office that provides reliable statistical information and data (CBS, 2019b). StatLine is the database of the CBS that offers a wealth of time series data, organised by themes such as agriculture, energy, income and spending, leisure and culture, population, prices, trade, hotels and restaurants, and traffic and transport. Datasets are accessible through the data portal, where the user can freely select and download data.[21]

The Marine Information and Data Centre (IHM) serves as a platform for finding and sharing data about the North Sea, and aims to make marine information and data, including research data, accessible to everyone (IHM, 2019). Open spatial and time-series data can be selected and downloaded through a geo-viewer.[22]

The Wadden Sea Long-Term Ecosystem Research (WaLTER) provides advice on and fundamental monitoring of the Wadden Sea area, and provides the access point to spatial and time-series data for the Wadden Sea (WaLTER, 2019). A wide range of data can be accessed through the Dataportal[23] and the WaLTER Dashboard.[24]

Finally, the Ministry of Infrastructure and Water Management (RWS) collates a wide range of, generally open, spatial and time-series data for the Netherlands (RWS, 2019). The GeoWeb Catalogus contains information on, amongst others, archaeological sites, infrastructure, monuments, shipping accidents and water quality.[25]

5.3 Matching North Sea ecosystem services to potential indicators and data sources

In this section we relate the identified relevant ecosystem services (see Chapter 4) to corresponding potential indicators and associated data sources (from Section 5.2). As mentioned in Section 5.1, the assessment of marine ecosystem services requires the systematic classification, measurement and quantification of marine ecosystem service indicators. Here we identify potential indicators that can be used to measure and quantify the identified relevant provisioning (Table 5.2), regulating & maintenance (Table 5.3) and cultural (Table 5.4) marine ecosystem services relevant to the North Sea, and identify data sources that can form the basis to calculate these indicators.

An important distinction is made between market and non-market ecosystem goods and services. Market goods and services are those that are traded on existing markets and, hence, for which prices are established in these markets (e.g. produce sold on market or entree fees paid to services provider). Non-market goods and services are those that are not traded on existing markets and, hence, for which prices cannot be directly observed in markets (e.g. protection value of dunes or travel costs associated with recreation activities).

Provisioning marine ecosystem service indicators (Table 5.2) are mainly related to market goods, measured through production (non-renewable and renewable resources and energies) and catches (fish; shellfish). The production and catch data are consistently collated by the national statistical

[20] See https://ec.europa.eu/maritimeaffairs/atlas/maritime_atlas/.
[21] See https://opendata.cbs.nl/statline/#/CBS/en/navigatieScherm/thema.
[22] See https://ihm-open-data-viewer.infoprojects.nl/index_uk.htm.
[23] See https://www.walterwaddenmonitor.org/en/tools/dataportaal/.
[24] See https://www.walterwaddenmonitor.org/en/tools/wad/.
[25] See https://geoservices.rijkswaterstaat.nl/portaal/.

office (CBS), and are available through national (e.g. CBS and IHM) and international (e.g. EUROSTAT, EMODnet and EAS) data portals. Data can, generally, be directly related to the identified provisioning indicators and, hence, their quantification is fairly straightforward. For some emerging (such as seaweed) or experimental (such as some of the renewable energy sources) products, however, data are not readily available through these national statistics. In such cases information can potentially be obtained through the firms or organisations involved.

Table 5.2 *Biotic (green) and abiotic (orange) provisioning ecosystem services, indicators and data sources relevant to the North Sea*

Division	Group	Example service	Potential indicator	Data source a)
Biomass	Cultivated/wild aquatic plants for nutrition, materials or energy	Seaweeds	Production (t)	EMODnet; EAS
Biomass	Reared aquatic animals for nutrition, materials or energy	Mussels; crayfish; oysters; lobsters	Production (t)	EUROSTAT; EMODnet; EAS CBS
Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fish; shellfish	Catches (t)	EUROSTAT; EMODnet; EAS CBS
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seaweeds Seaweed spores	Production (t) Production (t)	EMODnet; EAS
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Mussel spats	Production (t)	EMODnet; EAS
Water	Surface water used for nutrition, materials or energy	Wave/tidal energy	Production (MW)	EUROSTAT; EMODnet; EAS CBS; IHM
Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Oil; gas Shells; sand; gravel	Production (t) Production (t)	EUROSTAT; EMODnet; EAS CBS; IHM
Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Wind/solar energy	Production (MW)	EUROSTAT; EMODnet; EAS CBS; IHM

a) CBS (2019b); EAS (2019); EMODnet (2019); EUROSTAT (2019); IHM (2019).

Regulating & maintenance marine ecosystem service indicators (Table 5.3) are, in contrast with provisioning marine ecosystem services indicators, mainly related to non-market goods and services. Potential corresponding indicators include:

- Nutrient and chemical assimilation, and filtration capacity of marine organisms, algae, plants and animals
- Visual surface screening capacity of beaches and dunes
- Erosion, flood and storm damage mitigation capacity of beaches and dunes
- Reproductive capacity of marine organisms, algae, plants and animals
- Seabed and water quality regulation capacity of benthic and algal populations; and
- CO_2 absorption and temperature regulation capacity of seas and oceans.

Regulating & maintenance marine ecosystem services indicators that are related to market goods and services, include waste disposal capacity by seas and oceans, and drinking water production by dunes.

Regulating & maintenance marine ecosystem services indicators related to non-market goods and services are usually not directly collated through national statistics. This is because these indicators are complex, not uniquely defined, dependent on various other indicators and/or highly spatially specific. For example, filtration capacity of marine organisms, algae, plants and animals is dependent

on species abundance and diversity, water pollution types and concentrations (which, in turn, affect species abundance and diversity), physical conditions (such as water temperature, soil types and currents) and management (for examples, see TNC, 2019). Hence, models are used to estimate these non-market regulating and maintenance ecosystem services in a spatially explicit way (see for example Mapping Ocean Wealth; TNC, 2019). Underpinning data required to feed such models are available through a wide range of data sources (see Table 5.3). Regulating & maintenance marine ecosystem service indicators related to market goods are, as for the provisioning marine ecosystem services, generally collated by the national statistical office (CBS) and available through national (e.g. CBS and IHM) and international (e.g. EUROSTAT, EMODnet and EAS) data portals.

Table 5.3 *Biotic (green) and abiotic (orange) regulating & maintenance ecosystem services, indicators and data sources relevant to the North Sea*

Division	Group	Example service	Potential indicator	Data source a)
Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Uptake of nutrients from river effluents by algae Oysters; mussels; seaweeds	Assimilation capacity (t) Filtration capacity (t)	E.g. Liu & Vyverman (2015); Smaal et al. (2019)
Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Beaches; dunes	Surface screening capacity (m^2)	-
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Beaches; dunes	Erosion rate (ha) Flooding area (ha) Storm damage (€)	EMODnet; EAS FloodMap CatNet
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Dispersal of seaweed spores Tropical drift seeds found in North Sea Natural mussel spat populations	Concentration Specie abundance and diversity	- EMODnet; EAS IHM E.g. Smaal et al. (2019)
Regulation of physical, chemical, biological conditions	Regulation of soil quality	Benthic	Nutrient fixation capacity (t) Specie abundance and diversity	- EMODnet; EAS IHM
Regulation of physical, chemical, biological conditions	Water conditions	Influence of algal growth on nutrient dynamics	Water quality Bathing quality	EMODnet; EAS IHM
Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Exchange of carbon with atmosphere Water evaporation	CO_2 absorption capacity (t) Evaporation capacity (mm)	NOAA-OceanViewer
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution of contaminants; accumulation of waste on seafloor Filtration rainwater by dunes for drinking water	Disposal capacity (t) Production (m^3)	- EUROSTAT CBS
Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Beaches; dunes	Surface screening capacity (m^2)	-
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Sand banks; beaches; dunes	Erosion rate (ha) Flooding area (ha) Storm damage (€)	EMODnet; EAS FloodMap CatNet

a) CBS (2019b); EAS (2019); EMODnet (2019); EUROSTAT (2019); IHM (2019).

Cultural marine ecosystem service indicators (Table 5.4) can be related to market and non-market goods and services. Potential indicators include users benefiting from (e.g. 'local' population,

excursions and visitors) as well as jobs and expenses associated with (e.g. hotel, restaurant and bar visits as well as gear and travel costs) coastal & marine tourism, recreation and activities as well as wildlife and cultural excursions and observations. In addition, there are also non-users benefitting from (i.e. 'wider' population) as well as jobs and expenses associated with (e.g. protected areas, funds, foundations and donations) coastal & marine biodiversity, existence, religion, aesthetics, culture, heritage, research & development and protection.

Table 5.4 *Biotic (green) and abiotic (orange) cultural ecosystem services, indicators and data sources relevant to the North Sea*

Division	Group	Example service	Potential indicator	Data source a)
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	- Physical and experiential interactions with natural environment - Intellectual and representative interactions with natural environment	- Beach tourism; snorkelling; diving; recreational fishery Recreation; leisure; observational activities (birds; mammals) - Sea life; bird life; ornithology Excursions lower, middle and higher education Coastal and fishing communities Beach tourism; coastal tourism; coastal communities	Population (#) Employment (#) Excursions (#) Visitors (#) Hotel nights (#) Restaurant & bar guests (#) Expenses (€) Specie abundance and diversity	EUROSTAT; EMODnet; EAS CBS; IHM
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	- Spiritual, symbolic and other interactions with natural environment - Other biotic characteristics that have a non-use value	- Culture of fishing communities Runes around the North Sea Aesthetics; photos; movies - Existence of marine mammals and seabirds Protection of marine birds and mammals	Cultural and heritage sites (#) Employment (#) Population (#) Visitors (#) Hotel nights (#) Restaurant & bar guests (#) Pictures (#) Movies (#) Specie abundance and diversity Protection status Donations (€)	EUROSTAT; EMODnet; EAS CBS; IHM; RWS Flickr; Instagram; YouTube; FaceBook
Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	- Physical and experiential as well as intellectual and representative interactions with abiotic components of the natural environment	- Beach tourism; beach activities; aquatic sports - Recreation; leisure, physical appreciation (currents; erosion patterns; dune formation)	Population (#) Employment (#) Excursions (#) Visitors (#) Hotel nights (#) Restaurant & bar guests (#) Expenses (€)	EUROSTAT; EMODnet; EAS IHM; RWS; CBS
Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	Aesthetics; photos; movies; shipwrecks	Cultural and heritage sites (#) Employment (#) Population (#) Visitors (#) Hotel nights (#) Restaurant & bar guests (#) Expenses (€) Pictures (#) Movies (#)	EUROSTAT; EMODnet CBS; RWS Flickr; Instagram; YouTube; FaceBook

a) CBS (2019b); EAS (2019); EMODnet (2019); EUROSTAT (2019); IHM (2019); RWS (2019).

Cultural marine ecosystem service indicators related to market goods and services comprise a limited set of users (such as tourists, visitors and excursions) that visit, create jobs and perform expenses (such as hotel, restaurant and bar visits) associated with coastal & marine tourism, recreation and activities as well as wildlife and cultural excursions and observations. Corresponding data are to a large extent collated by the national statistical office (CBS), and available through national (e.g. CBS, IHM and RWS) and international (e.g. EUROSTAT, EMODnet and EAS) data portals.

These cultural marine ecosystem services indicators are also related to non-market goods and services, comprising all users (i.e. the abovementioned tourists, visitors and excursions as well as the 'local' population) visiting, creating jobs and performing expenses (such as gear and travel costs) associated with coastal & marine tourism, recreation and activities as well as wildlife and cultural excursions and observations. These indicators are generally not directly collated through national statistics and, hence, models are used to estimate these non-market cultural ecosystem service indicators in a spatially explicit way (see e.g. Mapping Ocean Wealth; TNC, 2019). These models combine available statistical data (see Table 5.4) with additional data collection (e.g. postal codes from 'local' population, excursions and visitors), questionnaires (e.g. eliciting gear and travel expenses) and/or social media (such as Flickr, Instagram, YouTube or FaceBook).

Finally, cultural marine ecosystem services indicators related to non-market goods and services also comprise non-users (i.e. 'wider' population) that benefit from as well as create jobs and expenses associated with coastal & marine biodiversity, existence, religion, aesthetics, culture, heritage, research & development and protection. While some of these data can be obtained through national and international databases (such as protected areas, funds, foundations and donations; see Table 5.4), most of these indicators are not directly collated through national or international statistics. This is, again, due to the fact that these indicators are complex, not uniquely defined, dependent on various other indicators and/or highly spatially specific. Also here, models can be used to estimate these non-use and non-market cultural ecosystem services in a spatially explicit way – combining available statistical data (see Table 5.4) with additional data collection (e.g. mapping of spiritual, aesthetic or cultural sites), questionnaires (e.g. eliciting existence, spiritual or aesthetic 'values') and/or social media (such as Flickr, Instagram, YouTube or FaceBook).

6 Methods for calculation and identification of price tags for these missing ecosystem services relevant to the North Sea

This chapter provides an overview of methods used to value ecosystem services in general (Sections 6.1) as well as ecosystem service value databases that can be used as a basis to value ecosystem services relevant to the North Sea (Section 6.2). In Section 6.3 we aim to best match the identified North Sea ecosystem services (Chapter 4), via potential indicators (Section 5.3), to these valuation methods and currently available data sources.

6.1 Ecosystem services valuation methods

There is a wide range of ecosystem service valuation techniques available, based on revealed-direct, imputed, revealed-surrogate and stated willingness-to-pay (WTP) as well as benefits transfer (Table 6.1; see Austen et al., 2019). For the primary valuation of ecosystem goods or services (i.e. based on primary data), revealed-direct WTP uses market prices; imputed WTP uses costs of damage/replacement or values of substitutes that are based on market prices; revealed-surrogate WTP uses costs or values observed in surrogate markets; and stated WTP uses questionnaires to directly solicit respondents willingness-to-pay. Pros and cons of these primary ecosystem service valuation methods have been extensively described (see e.g. Pascual et al., 2010: Costanza et al., 2017).

For the secondary valuation of ecosystem goods or services (i.e. based on secondary data), benefit transfer (BT) is an economic valuation technique that uses valuation estimates from other areas (study sites) and applies them to a similar location (policy site) (Alves et al., 2009; see Brouwer, 2000). The key to BT is to accept that a 'perfect' estimate of economic service value cannot be obtained due to time and/or budget constraints and to, therefore, make the best possible use of the existing literature in order to evaluate the economic importance of a natural area. This is done by adapting and applying estimates from existing primary studies that best suit the new context, using one or more of the following BT methods:

i) benefit estimate transfer, which entails the extrapolation of estimates from one site to another (i.e. values are directly substituted from the study site to the policy site without amendments)
ii) benefit function transfer, which entails the transfer of economic functions between the sites (i.e. coefficients are used to determine the policy site values)
iii) meta-analysis, which combines the findings of independent studies related to the research topic as to statistically summarise the body of evidence relating to a particular issue and
iv) preference calibration, which uses existing benefit estimates derived from different methodologies and combines them to develop a theoretically consistent estimate for policy site values.

Pros and cons of these benefit transfer methods have, also, been extensively described (see e.g. Brouwer, 2000; Johnston & Rosenberger, 2010). Meta-analysis has shown to provide good estimates as compared to primary valuation studies (see e.g. Bateman et al., 2011) and, when applied using benefit function transfer, allows for the spatially and context specific estimation of ecosystem service values.

Finally, double counting in ecosystem services valuation is a frequent problem that causes uncertainty and poor reliability of ecosystem service value estimates. Causes of and solutions to double counting are discussed in Fu et al. (2020).

Table 6.1 *Examples of monetary valuation techniques to value benefits stemming from ecosystem services (source Austen et al., 2019: p.18)*

Category	Technique	Description	Marine ecosystem service example where used
Revealed WTP (direct market)	Market price	Market prices stemming from a normal production process	Capture fisheries, seaweed harvesting
	Production function	Values how changes in the quantity or quality of the ecosystem affects ES and ultimately the costs of production of the final benefit	Water quality in an estuary, filtration services provided by oyster reef in a bay
Imputed WTP	Damage cost avoided	Value of an asset is equivalent to the value of the economic activity or assets that it protects	Protection of coastal property from storm surges
	Replacement cost	Value is based on the cost of replacing the environmental function	Coastal defence
	Substitute cost	Value of a non-marketed product is based on the market value of an alternative product providing the same or similar benefits	Waste water treatment
Revealed WTP (surrogate market)	Travel cost	Inferred from the cost of travel to a site (i.e. expenses and value of time incurred)	Marine and coastal recreation use
	Hedonic pricing	Value of goods is based on the value of individual components	Sea view premium in property prices
Stated WTP	Contingent valuation	Survey technique asking a representative sample of individuals how much they are willing to pay to prevent loss of, or to enhance, an environmental good or service	Protection of a marine species or habitat, marine non-use values
	Choice experiments	Asking respondents to select their preferred package of environmental attributes at different prices and then inferring specific component values	Climate regulation, potential use of marine genetic materials
Transfer of values	Benefits transfer	Values estimated in one context and location are used to estimate values in a similar or different context and location	All of above

6.2 Ecosystem services value databases

Various data sources currently available can contribute to the assessment of ecosystem service values potentially relevant to the North Sea. These databases may, in some cases, provide value estimates for the North Sea though, in most cases, will provide value estimate for other areas. In the latter situation, these values could be applied to the North Sea using one of the benefit transfer methods. It must also be noted here that these data sources are not complete nor sufficient to allow for an integral quantification of marine ecosystem service values.

The TEEB Valuation Database, supported by the Ecosystem Services Partnership (ESP), is a database on monetary values of ecosystem services and contains over 1,350 data-points from over 300 case studies (ESP, 2019). This database will be developed further as one of the main ESP activities, in close collaboration with the biome expert group, the valuation thematic working group, the Marine Ecosystem Services Partnership (MESP) and the Ecosystem Valuation Toolkit (Earth Economics). The Marine Ecosystem Services Partnership[26] contains an ecosystem services assessment Toolkit, which provides an overview of economic valuation methods, associated studies and links to related sites.

The Environmental Valuation Reference Inventory (EVRI) is a searchable storehouse of empirical studies on the economic values of environmental assets and human health effects (EVRI, 2019). It contains over 4,000 valuation studies, including information about the study location, the valued environmental assets, the used methodological approaches and the estimated monetary values.

The GecoServ ecosystem services valuation database provides ecosystem service values for coastal and marine ecosystems from studies around the world (Santos & Yoskowitz, 2012). GecoServ has a

[26] See https://marineecosystemservices.org/.

data services catalogue where data can be selected and downloaded, searching by ecosystems, ecosystem services, valuation methods and countries.

The ValuES Methods Database contains profiles of a diverse range of methods, tools and sources for assessing ecosystem services and values around the world (ValuES, 2019). The database covers biophysical assessment methods, monetary valuation methods, social valuation methods, and frameworks and models for decision support.

The Ecosystem Valuation Toolkit (EST), supported by Earth Economics (EA), combines a large database of monetary values for natural assets with standardized biophysical attributes and web-based tools (EA, 2019). It enables to calculate values for a wide range of ecosystems and services at scales from local to global.

6.3 Matching North Sea ecosystem services to valuation methods and data sources

In this section we relate the identified relevant ecosystem services (see Chapter 4) and potential indicators (see Section 5.3) to corresponding possible valuation techniques and data sources. As we will see, the term 'price tag' should be interpreted with caution because, as with any price determined on the market, willingness-to-pay is not fixed in time and dependent on a range of factors (such as quality of and distance to the ecosystem, availability of and access to substitutes as well as characteristics of the valuing individual; see e.g. Bateman et al., 2011; Roebeling et al., 2016). In particular for capital accounts, where the value of capital assets is determined based on their production and services value, it is important that 'price tags' are determined and updated on an annual basis. Here we identify the value category, valuation technique and, where applicable, the data source to determine the 'price tag' for provisioning (Table 6.2), regulating & maintenance (Table 6.3) and cultural (Table 6.4) marine ecosystem services relevant to the North Sea.

Table 6.2 *Biotic (green) and abiotic (orange) provisioning ecosystem services, value categories, valuation techniques and data sources relevant to the North Sea*

Division	Group	Example service	Value category	Valuation technique and data source a)
Biomass	Cultivated/wild aquatic plants, reared aquatic animals and wild animals (terrestrial and aquatic) for nutrition, materials or energy	- Seaweeds - Mussels; crayfish; oysters; lobsters - Fish; shellfish	Revealed WTP (direct market) Transfer of values	Market price EUROSTAT; CBS EMODnet Benefit transfer
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi and animals	- Seaweeds Seaweed spores - Mussel spats	Revealed WTP (direct market) Transfer of values	Market price EUROSTAT; CBS EMODnet Benefit transfer
Water	Surface water and mineral substances used for nutrition, materials or energy	- Wave/tidal energy - Oil; gas Shells; sand; gravel	Revealed WTP (direct market) Transfer of values	Market price EUROSTAT; CBS Benefit transfer
Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Wind/solar energy	Revealed WTP (direct market) Transfer of values	Market price EUROSTAT; CBS Benefit transfer

a) CBS (2019b); EMODnet (2019); EUROSTAT (2019).

Provisioning marine ecosystem services are, as mentioned before, mainly related to market goods and, as such, associated WTP is revealed directly through the market (Table 6.2). These market prices are consistently collated by the national statistical office (CBS), and are available through national (e.g. CBS) and international (e.g. EUROSTAT and EMODnet) data portals. When prices are

unavailable, such as in the case of emerging or experimental goods, values can be obtained through benefit transfer.

Table 6.3 *Biotic (green) and abiotic (orange) regulating & maintenance ecosystem services, value categories, valuation techniques and data sources relevant to the North Sea*

Division	Group	Example service	Value category	Valuation technique and data source a)
Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Uptake of nutrients from river effluents by algae Oysters; mussels; seaweeds	Revealed WTP (direct market) Imputed WTP Transfer of values	Production function Substitute cost Benefit transfer
Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Beaches; dunes	Imputed WTP Revealed WTP (surrogate market) Transfer of values	Substitute cost Hedonic pricing Benefit transfer
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Beaches; dunes	Imputed WTP Transfer of values	Damage cost avoided Replacement cost Substitute cost Benefit transfer
Regulation of physical, chemical, biological conditions	- Lifecycle maintenance, habitat and gene pool protection - Regulation of soil quality - Water conditions - Atmospheric composition and conditions	- Dispersal of seaweed spores Tropical drift seeds found in North Sea Natural mussel spat populations - Benthic - Influence of algal growth on nutrient dynamics - Exchange of carbon with atmosphere Water evaporation	Revealed WTP (direct market) Imputed WTP Transfer of values	Production function Substitute cost Benefit transfer
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution contaminants; accumulation waste on seafloor Filtration rainwater by dunes for drinking water	Revealed WTP (direct market) Imputed WTP Revealed WTP (direct market) Transfer of values	Production function Substitute cost Market price EUROSTAT; CBS Benefit transfer
Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Beaches; dunes	Imputed WTP Revealed WTP (surrogate market) Transfer of values	Substitute cost Hedonic pricing Benefit transfer
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Sand banks; beaches; dunes	Imputed WTP Transfer of values	Damage cost avoided Replacement cost Substitute cost Benefit transfer

a) CBS (2019b); EUROSTAT (2019).

Regulating & maintenance marine ecosystem services are, as mentioned before, mainly related to non-market goods and services (Table 6.3). Associated WTPs can be imputed or revealed through surrogate markets and are, to a minor extent, revealed directly through the market. These values are generally not directly collated through national statistics as they are complex, not uniquely defined, dependent on various other indicators and/or highly spatially specific. For example, coral reef or beach & dune flood protection benefits depend on bathymetry and elevation, currents and tides, event return periods, population density, and built and natural capital values (see e.g. TNC, 2019; Roebeling et al., 2018). Hence, combined ecological/engineering and economic approaches can be used to estimate production functions, damage, replacement and substitute costs, travel costs and hedonic prices in a spatially explicit way (see for example Mapping Ocean Wealth; TNC, 2019; Roebeling et al., 2011). Underpinning data required to feed such approaches, are available through a wide range of data sources (see Table 5.3). Regulating & maintenance marine ecosystem service values related to market

goods are, as for the provisioning marine ecosystem services values, collated by the national statistical office (CBS) and available through national (e.g. CBS) and international (e.g. EUROSTAT and EMODnet) data portals. Alternatively, values can be obtained through benefit transfer.

Table 6.4 *Biotic (green) and abiotic (orange) cultural ecosystem services, value categories, valuation techniques and data sources relevant to the North Sea*

Division	Group	Example service	Value category	Valuation technique and data source a)
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	- Physical and experiential interactions with natural environment - Intellectual and representative interactions with natural environment	- Beach tourism; snorkelling; diving; recreational fishery Recreation; leisure; observational activities (birds; mammals) - Sea life; bird life; ornithology Excursions lower, middle and higher education Coastal and fishing communities Beach tourism; coastal tourism; coastal communities	Revealed WTP (direct market) Revealed WTP (surrogate market) Stated WTP Transfer of values	Market price EUROSTAT; CBS Production function Travel cost CBS Contingent valuation Choice experiments Benefits transfer
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	- Spiritual, symbolic, etc. interactions with natural environment - Other biotic characteristics that have a non-use value	- Culture of fishing communities Runes around the North Sea Aesthetics; photos; movies - Existence of marine mammals and seabirds Protection of marine birds and mammals	Revealed WTP (surrogate market) Stated WTP Transfer of values	Hedonic pricing CBS; Kadasterdata Contingent valuation Choice experiments Benefits transfer
Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	- Physical and experiential as well as - intellectual and representative interactions with abiotic components of the natural environment	- Beach tourism; beach activities; aquatic sports - Recreation; leisure, physical appreciation (currents; erosion patterns; dune formation)	Revealed WTP (direct market) Revealed WTP (surrogate market) Stated WTP Transfer of values	Market price EUROSTAT; CBS Production function Travel cost CBS Contingent valuation Choice experiments Benefits transfer
Indirect, remote, often indoor interactions with physical systems that do not require presence in environmental setting	Spiritual, symbolic etc. interactions with the abiotic components of the natural environment	Aesthetics; photos; movies; shipwrecks	Revealed WTP (surrogate market) Stated WTP Transfer of values	Hedonic pricing CBS; Kadasterdata Contingent valuation Choice experiments Benefits transfer

a) CBS (2019b); EUROSTAT (2019).

Cultural marine ecosystem services are, as mentioned before, related to market and non-market goods and services (Table 6.4). Associated WTPs by users and non-users can be revealed through direct and surrogate markets as well as stated preferences.

Cultural marine ecosystem service use values related to market goods and services are revealed directly through the market. These market prices are available from price data collated by the national statistical office (CBS), and are available through national (e.g. CBS) and international (e.g. EUROSTAT and EMODnet) data portals. In case market prices are unavailable, values can be obtained through benefit transfer.

Cultural marine ecosystem service use values related to non-market goods and services can be revealed through surrogate markets and stated preferences. These values are complex, not uniquely defined, dependent on various other indicators and/or highly spatially specific and, thus, generally not directly collated through national statistics. For example, coastal tourism values are dependent on quality of the ecosystem, distance to the site, proximity to substitute sites and user income (see e.g. TNC, 2019; Kragt et al., 2009). Hence, travel cost and hedonic pricing as well as contingent valuation, contingent behaviour and choice experiment methods can be used to estimate non-market cultural marine ecosystem service use values. Underpinning data for the former methods are, partially, available through the CBS and Kadasterdata (e.g. postal codes, distances and house prices), while for the latter methods collection of primary data is usually needed (e.g. through interviews, workshops and questionnaires). Alternatively, values can be obtained through benefit transfer.

Finally, cultural marine ecosystem service non-use values related to non-market goods and services can be revealed through, in particular, stated preferences. Also these values tend to be complex, not uniquely defined and dependent on various other indicators and generally hard to quantify (see e.g. TNC, 2019). For example, such values include intrinsic values (cultural and spiritual; scientific and existence), habitat values and outstanding universal values (TNC, 2019). Hence, contingent valuation, group valuation, contingent behaviour and choice experiment methods are needed to estimate non-market cultural marine ecosystem service non-use values. Underpinning data can be obtained through primary data collection (e.g. through interviews, workshops and questionnaires). Otherwise, values can be obtained through benefit transfer.

7 Recommendations and conclusions on how to improve the CBS natural capital accounts for the North Sea

In 2019 the CBS prepared the report *Natural capital accounts for the North Sea: The physical SEEA EEA accounts* (CBS, 2019), to test the development of the physical SEEA EEA accounts for the Dutch part of the North Sea – in particular the i) extent account, ii) condition account and iii) physical supply and use accounts for ecosystem services. The key objective of the SEEA EEA is to measure ecosystem condition and ecosystem services such that these are aligned with the System of National Accounting (SNA) – leading to more sustainable use and management of natural resources. The purpose of this assignment is to i) identify and improve ecosystem-, condition- and physical-accounts for the North Sea and ii) identify methods and sources to calculate associated ecosystem values (prices), for the preparation of the natural capital accounts for the North Sea.

The current assessment showed that the CBS report is valuable as a pilot, which demonstrates how a SEEA EEA can be constructed. However, for reasons related to the project's terms-of-reference (TOR), budget restrictions and data availability, the CBS (2019) study is limited in its assessment of the extent, conditions and physical ecosystem service supply accounts. Furthermore, the monetary valuation of ecosystem services provided and used, as well as the assessment of the monetary value of the ecosystem asset account, were not included.

As a result, the CBS report gives quite a limited view on the North Sea ecosystem services and values. Only few ecosystem services were included, and these were ecosystem services for which a monetary value can be easily calculated (i.e. market-based values). The supply of the included ecosystem services (with the exception of fisheries) is not dependent on the quality of the ecosystem (albeit that the quality can influence ecosystem service supply and values). Considered ecosystem services are selected ad-hoc (based on available data). An integral assessment of ecosystem services supply, use and values requires appropriate indicators that are measured at specific locations, spatial scales, temporal scales and frequencies as well as using appropriate measurement methods. Reviewing the CICES 5.1 classification of ecosystem services, we conclude that various other biotic and abiotic provisioning, regulation & maintenance and cultural services are relevant for the North Sea.

European and national databases are available that can contribute to assessing the geographical distribution of ecosystem services potentially relevant to the North Sea (see Chapter 5). Available global and regional databases in conjunction with various valuation techniques, can contribute to the determination and estimation of ecosystem service values potentially relevant to the North Sea (Chapter 6). In recent years, such valuation studies have been applied to inform policy making (see e.g. Mangi et al., 2011; Geurry et al., 2012; Gomes et al., 2018). Building on the experiences reported in the CBS report, a full-fledged SEEA EEA should take into account the full range of relevant ecosystem services and values – including biotic and abiotic services for which the supply and value (price) is not directly relatable to existing markets and associated statistical indicators.

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The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,500 employees (5,500 fte) and 12,500 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.