# Monetary valuation of biodiversity in the Dutch Part of the North Sea

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|---|---|
| Datum | 31 Augustus 2022 |
| Versie | 0.1 |
| Status | DEFINITIEF |

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| Datum | 31 Augustus 2022 |

# Preface

This work is the combined result of a master's thesis for the ERM program at the Vrije Universiteit Amsterdam, as well as a research assignment for Rijkswaterstaat and Statistics Netherlands.

Although I started off this project with the ambition of carrying out as many monetary valuations in the Dutch part of the North Sea as possible, I quickly realised that the topic of monetary valuation of biodiversity is one that is highly nuanced and debated. Furthermore, it touches on the edges our understanding of the functioning of ecosystems. As such, my report reflects this nuance. Along with an exercise in monetary valuation, this report provides on overview of the topic of monetary valuation of biodiversity. I hope that this work can serve as groundwork for future research on the topic.

I would like to thank my supervisors. Patrick Bogaart for his invaluable insight and guidance. Rob van der Veeren for his invaluable support and feedback.

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# Samenvatting

Momenteel is het Centraal Bureau voor de Statistiek bezig met het uitwerken van de natuurlijk kapitaalrekeningen voor het Nederlands deel van de Noordzee. Hierbij worden de ecosysteemactiva zoveel mogelijk zowel in biofysische als in monetaire termen beschreven. Natuurlijk kapitaalrekeningen (NKR) is een veelbelovend instrument om het sociaalecologische systeem van het Nederlands deel van de Noordzee op een geïntegreerde manier te beheren door de waarde van ecosystemen en hun diensten in geld uit te drukken.

De ontwikkeling van NKR kent nog zeer veel wetenschappelijke uitdagingen. Een daarvan betreft de integratie van "biodiversiteit" in NKR. Biodiversiteit kan op twee manieren in NKR worden opgenomen: 1, als onderdeel van de beschrijving van de toestand van het ecosysteem in de conditierekeningen, en 2, als specifieke aanvullende biodiversiteitsrekeningen.

Het primaire doel van dit rapport is om na te gaan hoe de waarde van biodiversiteit in geld kan worden uitgedrukt op een manier die die past binnen de NKR. Eén manier om biodiversiteit in de natuurlijk kapitaalrekeningen mee te nemen is door de relatie tussen biodiversiteit en de levering van ecosysteemdiensten in de conditierekeningen expliciet te maken. Dit betekent dat de biologische componenten van het Noordzee-ecosysteem die het belangrijkst zijn voor de levering van ecosysteemdiensten moeten worden bepaald, in de conditierekeningen moeten worden gemonitord, en vervolgens moet zo goed mogelijk een functionele relatie worden gelegd tussen de belangrijkste leveranciers van ecosysteemdiensten en de levering van finale ecosysteemdiensten. Door het verband tussen biodiversiteit en ecosysteemdiensten expliciet te maken, kan de waarde van veranderingen in biodiversiteit worden gelijkgesteld met de waarde van de daaruit voortvloeiende veranderingen in de levering van ecosysteemdiensten. Om dit goed te kunnen doen is echter beter inzicht in het functioneren van het Noordzee-ecosysteem nodig dan momenteel beschikbaar is.

Gezien de moeilijkheden die gepaard gaan met het bepalen van de monetaire waarde van biodiversiteit via de conditierekeningen, alsmede de beperkte aard van de biodiversiteit die op deze wijze kan worden meegenomen, worden in hoofdstuk 4 van dit rapport andere manieren verkend om de waarde van biodiversiteit in het Nederlandse deel van de Noordzee te bepalen. De meest geschikte methode om de waarde van biodiversiteit te bepalen hangt af van de definitie van biodiversiteit die men hanteert, die op haar beurt afhangt van het gebruik en de toepassingscontext waarvoor de waardering wordt uitgevoerd. Biodiversiteit kan worden opgevat als de diversiteit aan ecosysteemtypes, in welk geval de waarde van de biodiversiteit wordt weergegeven door de waarde van de finale ecosysteemdiensten die in de natuurlijk kapitaalrekeningen tot uitdrukking wordt gebracht. Een andere mogelijkheid is dat biodiversiteit verwijst naar specifieke ecosysteemdiensten of ook naar bepaalde belangrijke soorten en habitats zoals bepaald door reeds bestaande typologieën van biodiversiteit in de Noordzee. Elk van deze methoden leidt tot een andere interpretatie en waarde van biodiversiteit.

Een eerste poging om de baten van belangrijke biologische elementen te meten, wordt gedaan in hoofdstuk 5 van dit rapport. Hierin worden de baten van zeevogels in geld uitgedrukt. Daartoe zijn de relevante ecosysteemfuncties en -diensten van zeevogels in kaart gebracht, gekwantificeerd en vervolgens met behulp van economische waarderingsmethoden in geld uitgedrukt. Hoewel zeevogels waarschijnlijk een groot aantal belangrijke ecosysteemfuncties en -diensten in het Nederlandse deel van de Noordzee vervullen, konden er met de beschikbare gegevens over zeevogels (abundantie- en broedgegevens) slechts twee worden beoordeeld. Het gaat om de functie nutriëntencyclus, met een geschatte waarde van

830 000 euro in 2018, en de dienst toerisme en natuur (baten van het kijken naar vogels), met een geschatte waarde van 32,5 miljoen euro in 2018. Hoewel beide waarden belangrijke tekortkomingen kennen die het gebruik ervan in een kosten-batenanalyse kunnen beperken, onderstrepen ze desalniettemin het belang van het behoud van zeevogels.

Het berekenen van de monetaire waarde van biodiversiteit door de waarde van door specifieke soorten of habitats geleverde ecosysteemdiensten in beeld te brengen, is nuttig voor het bepleiten van de instandhouding van soorten en habitats. In het geval van zeevogels kon echter slechts een beperkt deel van de geleverde ecosysteemdiensten in geld worden uitgedrukt door het ontbreken van de benodigde gegevens. De met deze methode verkregen monetaire waarden zijn waarschijnlijk niet representatief voor de door een soort geleverde netto baten, aangezien voor een dergelijke volledige beoordeling enorme hoeveelheden informatie nodig zouden zijn. De gebruikte methode is dus geschikt om de instrumentele waarde van een specifieke door een biologische hulpbron geleverde ecosysteemdienst te laten zien, maar niet voor het bepalen van de volledige en holistische waarde van de biodiversiteit in het Nederlands deel van de Noordzee.

Een veelbelovende richting voor toekomstig onderzoek zou zijn om te proberen om de waarde van de ecosysteem- en soortenwaarderingsdienst voor het Nederlands deel van de Noordzee te bepalen. Deze ecosysteemdienst betreft de baten die samenhangen met het behoud van biodiversiteit in haar eigen belang, en meet dus de intrinsieke waarde van de biodiversiteit. In dit rapport wordt aangegeven hoe dit zou kunnen gedaan met behulp van de bestaande natuurpuntenmethode die voor het Nederlands deel van de Noordzee is ontwikkeld.

# Summary

Natural capital accounts for the Dutch part of the North Sea (DNS) are currently being developed, where as many ecosystem assets as possible are described both in biophysical and monetary terms. Natural capital accounting (NCA) is a promising tool for being able to manage the socio-ecological system of the DNS in an integrative way by revealing the value of ecosystems and their services in monetary terms.

The development of NCA still presents a fair number of ongoing research frontiers. Several of these research frontiers concerns the integration of ‘biodiversity’ into NCA. Biodiversity may be included in NCA in two ways: 1. As part of ecosystem condition accounts, and 2. As dedicated and complimentary biodiversity accounts.

The main aim of this report was to assess how the value biodiversity could be measured in monetary terms, in a way that is congruent with NCA. One way of accounting for biodiversity in natural capital accounts is to make explicit the link between biodiversity and ecosystem service provision in the condition accounts. This would involve determining biological components of the North Sea ecosystem that are most important for the provision of ecosystem services, monitoring these in the condition accounts and, to the best of our abilities, establishing a functional relationship between these key ecosystem service providers and the provision of final ecosystem services. Making explicit the link between biodiversity and ecosystem service provision would allow for the value of changes in biodiversity to be equated to the value of the resulting losses in ecosystem service provision. However, in order to be able to do this properly, a better understanding of the functioning of the North Sea ecosystem is required than is currently available.

Given the difficulties associated with determining the monetary value of biodiversity through condition accounts, as well as the limited part of biodiversity that would be included in this way, other means of assessing the value of biodiversity in the Dutch part of the North Sea are explored in chapter 4 of this report. The most appropriate method for assessing the value of biodiversity depends on the definition of biodiversity that one adopts, which in turn depends on the use and context of application for which the valuation is being carried out. Biodiversity may be understood as the diversity in ecosystem types, in which case the value of biodiversity is represented by the value of final ecosystem services revealed within natural capital accounts. Alternatively, biodiversity may refer to specific ecosystem services or also certain important species and habitats as determined by pre-existing typologies of biodiversity in the North Sea. Each of these methods results in a different interpretation and value of biodiversity.

A first attempt at measuring the benefits from important biological elements is carried out in chapter 5 of this report. Here the benefits obtained from marine birds are measured in monetary terms. This involved identifying relevant ecosystem functions and services performed by marine birds, quantifying these, and subsequently using economic valuation methods to determine a monetary value. Whilst marine birds likely perform a host of important ecosystem functions and services in the Dutch part of the North Sea, only two were able to be assessed with available data on marine birds (abundance and breeding data). These were the nutrient cycling function, worth an estimated 830 000 EUR in 2018 and the tourism and nature watching service (benefits from bird watching), worth an estimated 32.5 million EUR in 2018. Both of these values have significant limitations that may limit their use in a cost benefit analysis, but they nevertheless stress the importance of the conservation of marine birds.

Calculating the monetary value of biodiversity by revealing the value of ecosystem services provided by specific species or habitats is beneficial for the purposes of advocacy for the conservation of species and habitats. In the case of marine birds, only a minority of the ecosystem services provided could be expressed in monetary terms due to lack of data. The monetary values obtained using this method are unlikely to be representative of the net benefits provided by a species, as there would be huge information requirements for such a complete assessment. The method used is thus suitable for revealing the instrumental value of a specific ecosystem service provided by a biological resource, but not to estimate the complete and holistic value of biodiversity in the Dutch part of the North Sea.

A promising avenue for future research would be to try to estimate the value of the ecosystem and species appreciation service for the DNS. This ecosystem service concerns the benefits derived from the conservation of biodiversity for its own sake, and thus measures the intrinsic value of biodiversity. This report identifies how this could be done using the existing eco-point framework developed for the DNS.

# 1 Introduction

The Netherlands is one of approximately 40 countries (as of 2020) putting significant effort into the development and maintenance of Natural Capital accounts (UN, 2021). Using the recently internationally standardized System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA), Statistics Netherlands (CBS), in collaboration with Wageningen University, have developed natural capital accounts for the Netherlands. In 2019, the first steps towards building natural capital accounts for the marine extent of the Netherlands were undertaken (CBS, 2019). This first report included the physical supply and use tables for a limited number of ecosystem services and ecosystem types in the Dutch part of the North Sea. It omitted the monetary ecosystem services supply and use accounts but nonetheless established a good basis for a more complete North Sea account. In 2021, Rijkswaterstaat (the Ministry of Infrastructure and Water management), issued Statistics Netherlands a new project during which the existing work will be improved upon and extended where deemed necessary. The new project aims to expand the existing accounts by adding more ecosystem services and monetary supply and use tables as well as the asset account (amongst other additions).

Natural Capital Accounting (NCA) involves measuring the contribution in terms of ecosystem services that our underlying biosphere makes to human welfare and well-being. Natural capital accounts have a wide range of applications, one such application is to inform biodiversity-related policy and decision-making through general accounts of ecosystem extent, condition, service flow and asset value, as well as thematic accounts for biodiversity itself (SEEA, 2021; EU biodiversity strategy 2030). NCA and especially monetary valuation, has tended to be concerned with those goods and services that directly benefit humans, known as final ecosystem services. Markers of ecosystem health and the underlying biodiversity upon which the stable flow of final ecosystem services depends, have in turn been assessed by other means than NCA up until recently. According to CBS (2019), the accounting approach to biodiversity is an opportunity for information on biodiversity and biodiversity indicators to be presented in a coherent, structured, and regularly updated manner.

An accounting approach to biodiversity, opens the possibility of also including monetary values for biodiversity, as is standard in certain other parts of natural capital accounts. As it stands, not many studies have attempted to value biodiversity in monetary terms. Attributing a monetary value to changes in marine biodiversity and ecology would be of great value to a multitude of management applications, including maritime spatial planning, ecosystem management and the management of marine protected areas (MPAs), to name a few. Monetary valuation of biodiversity, if viable, could be used in the Dutch part of the North Sea as a tool for helping to make tradeoffs between the various economic interests in the area - mainly oil & gas extraction, fisheries, offshore wind energy and marine aggregates - with ecological incentives to achieve the environmental commitments of the Netherlands under the European marine strategy directive (MSFD) and OSPAR convention. Because perusing economic activity can often conflict with goals of protecting and maintaining biodiversity, having a common yard stick for comparison may be very useful.

## 1.1 Problem description and methodology

Biodiversity is inherently multidimensional. The term may refer to multiple levels of biological organization and may also be measured in multiple ways. As a result, there are many theoretical concerns regarding the methodology and validity of the monetary valuation of biodiversity (Laurila-Pant et al., 2015: etc). Nonetheless, the topic has never been explored specifically in the context of natural capital accounting or marine biodiversity. This report explores this research frontier in natural capital accounting for biodiversity in the context of the marine natural capital accounts for the Netherlands. The report utilizes literature on ecology and environmental economics, whilst seeking to relate results to ecosystem management and natural capital accounting. Questions explored in this study include: What is the relation between biodiversity and ES provision? What are means by which the benefits from biodiversity may be valued monetarily? What is the capacity for monetary valuation to measure changes in biodiversity and act as a policy tool? How can the benefits derived from important biological resources in the Dutch part of the North Sea be quantified monetarily?

## 1.2 Report outline

Following this introduction, Chapter 2 gives a brief overview of core concepts namely: ecosystem services, the SEEA EA (the UN accounting framework) and Biodiversity. Chapter 3 investigates the relationship between biodiversity and the provisioning of ecosystem services, detailing how this is accounted for within the SEEA-EA. Chapter 4 looks at monetary valuation of ES and biodiversity and reviews methods that can be used to estimate the monetary value of biodiversity. Chapter 5 describes a case study focusing on the monetary valuation of ecological functions and services provided by marine birds.

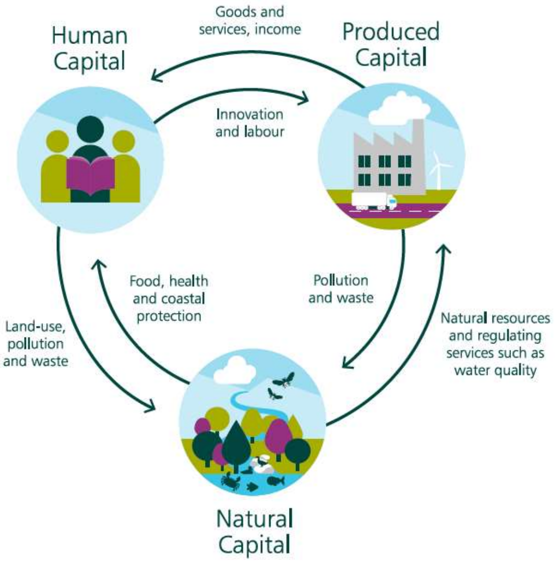
# 2 Background

## 2.1 Natural Capital Accounting

The term “capital” refers to a type of asset. Dasgupta (2021) notes that the term capital has been used to describe almost every asset, from knowledge (knowledge capital), to culture, norms and behaviour (cultural capital), and even religion (religious capital). Nonetheless, economic theory recognizes as capital only assets whose contribution to human well-being can be measured and therefore, recognizes three broad types of capital.

- ✓ **Produced capital** Includes manufactured goods and financial capital assets. Examples are machines, roads, the entirety of the built-environment and Intellectual property patents.
- ✓ **Human capital** Includes the health, education, and skills of people, quantified based on impacts on productivity
- ✓ **Natural capital** Includes the range of goods and services provided by the biosphere that contribute to human wellbeing. It is measured in terms of ecosystem services. Examples are food, carbon sequestration, nutrient cycling, a beautiful view from a mountain top.

**Figure 1. Different types of capital and their interactions**



Source: *The Economics of Biodiversity: The Dasgupta Review. Chapter 1*

The term natural capital has been used for over 30 years as a way of acknowledging the importance that nature and its resources play in the economy as well as for human well-being in a vast number of ways (Pearce, 1989). Since these initial claims, economists have developed how the value of natural capital (to humans) can be measured, forming what is now a rich literature on the topic (Freeman III et al., 2014). *Figure 2* shows how natural capital interacts with other forms of capital through various linkages. The figure reflects the importance of natural resources as inputs to manufacturing/production, consumption, and human life. The mere acknowledgement of natural capital as a form of capital reveals a perverse set of economic incentives in most of the world. The use and degradation of natural capital is actively encouraged at a faster rate than is optimal as is visible by common scenarios of subsidies and lack of markets for increasingly scarce natural resources (Dasgupta, 2021). Recent innovations in the way we measure environmental stocks and flows have thus resulted in an opportunity to integrate natural capital into our understanding of human well-being, economic activity, and national wealth, amongst other things.

Natural capital accounting is the tool used to build a registry of environmental assets in terms of stocks and flows within an accounting area (usually at a regional or national level). This is done by mapping ecosystems and their contributions to the economy in a spatially explicit manner. As of 2020, 40 countries had undertaken some form of natural capital accounting in accordance with UN standards. The scale, size and composition of these accounts vary, ranging from accounts for small regions of a country, to national and international accounts (UN, 2021). The INCA project is a notable example of NCA that has attempted to create an integrated system of ecosystem accounts for the entirety of the EU (+UK). The report, which was published in 2021, also shows potential policy applications of the accounting work (Vysna et al., 2021).

## 2.2 The SEEA – EA

SEEA stands for System of Environmental Economic Accounting. It is an international statistical standard for measuring the contribution of the environment to the economy. It is also the main accounting method used for NCA. It was released as an official accounting tool in 2012 as the SEEA CF - central framework - the aim of which was to respond to demands and needs for the integration of environmental statistics into national accounting. The SEEA CF measures environmental flows, stocks of environmental assets, and economic activities related to the environment within an accounting area. Typically, the accounting structure includes data on resources like water, minerals, energy, timber, fish, soil, land and ecosystems, pollution, and waste. Crucially, the SEEA utilizes principles in line with the system of national accounting (SNA). This means that the accounting structure used to report environmental data is designed to be coherent with the standard macroeconomic system of accounting used by most countries. In this way, the SEEA CF was a first standardized attempt at accounting for the stocks and flows of the environment and their contribution to GDP.

In 2013, the system of environmental economic accounting – Experimental Ecosystem accounting (SEEA-EEA) - was established as an additional framework by the UN statistical commission (in addition to the SEEA CF). The experimental label was dropped in 2021, when the framework was made an international standard (becoming the SEEA-EA). The accounting approach of the SEEA EA innovates on the SEEA CF by adding the monitoring of ecosystems and their services to the accounting process. This was done as a response to progress in the field of environmental economics and the widespread adoption by many institutions of the ecosystem approach as an important policy approach to natural resource management. For example, the EU now asks all member states to carry-out ecosystem mapping and assessments as part of their biodiversity strategy. The SEEA EA thus proposes a more comprehensive accounting framework for NCA than is used in the SEEA CF by accounting for ecosystem services in an SNA-compatible format.

Just like the system of national accounting, the SEEA EA records the stocks and flows of assets (in this case: ecosystem assets) in both biophysical and monetary values. The SEEA EA is comprised of 5 sub-accounts.

1. Ecosystem extent account

    This account records the total area of ecosystems, divided by ecosystem type and within a given accounting area (nation, region ect.). The account records this information over a period of time (e.g yearly), to be able to deduce changes in the physical extent and area of ecosystems.

2. Ecosystem condition account

This account records information on the quality of ecosystems in terms of a range of selected biotic and abiotic ecosystem characteristics. Ecosystem characteristics recorded in the condition account are key in the integrity of the ecosystem in question and support the stable supply of ecosystem services. Biotic ecosystem characteristics are often related to biodiversity in the ecosystem. These may be measures of the ecosystem compositional, structural, or functional state. Chapter 3 covers how biodiversity is accounted for in condition accounts.

3. Ecosystem services flow account – measured in biophysical terms

This account records the supply of final ecosystem services for each ecosystem asset as well as the use of these ecosystem services by economic units. This first ES flow account measures this information in biophysical units

4. Ecosystem services flow account – monetary terms

This account measures the supply and the use of ecosystem services just like the previous account but, does so in monetary units, based on the economic value of the ecosystem services provided.

5. Monetary ecosystem asset account – monetary terms

This account records the net present value of the flow of final ecosystem services throughout the lifetime of the ecosystems measured. By recording this value for each accounting period, changes in the stocks of ecosystem assets can be assessed.

In addition to the five main accounts of the SEEA - EA, thematic accounts may be formed for specific purposes (SEEA, 2021). Both a carbon and biodiversity account has been created for the Netherlands' terrestrial extent for example. This report is concerned with the marine extent of the Netherlands as an accounting area. Also known as the Dutch continental shelf or the Dutch EEZ. In 2019, the first *experimental*[1] physical ecosystem accounts using the SEEA EA framework were published for the Dutch part of the North Sea. This thesis focuses on information relevant for integrating biodiversity and biodiversity accounting in the Dutch marine natural capital accounts.

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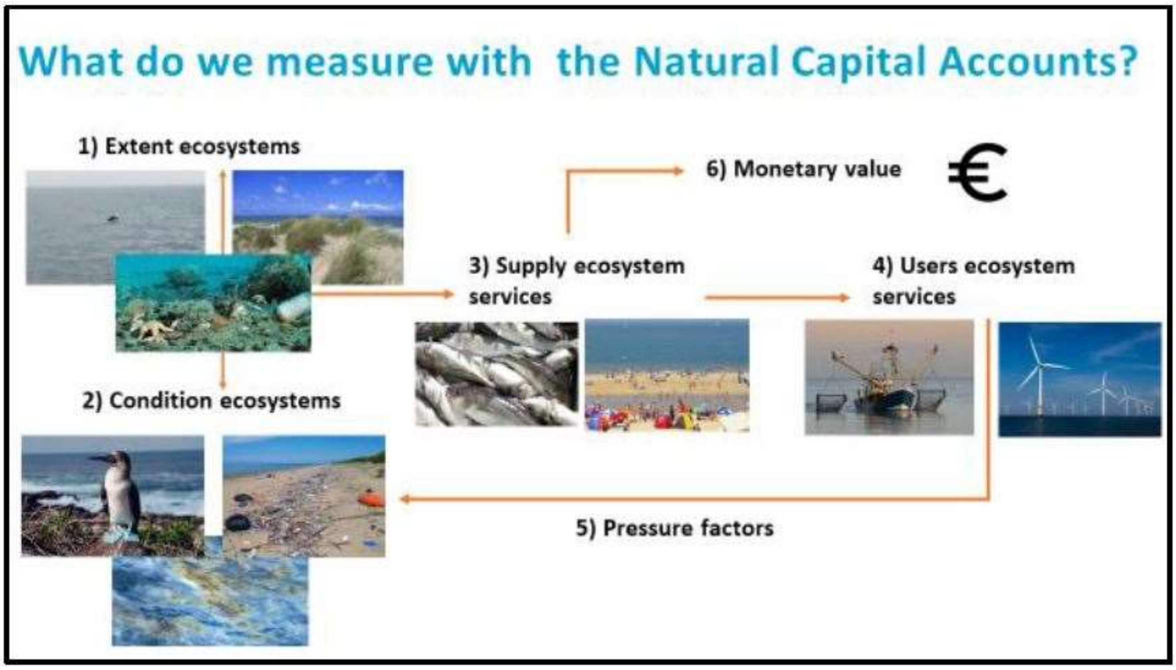
[1] Including experimental in the title of the report shows the novelty of NCA and Ocean Accounting in particular

**Figure 2. Illustration of marine natural capital accounts**



Source: *Retrieved from* CBS (2019)

### 2.3 Ecosystem services

According to the Common International Classification of Ecosystem Services, a final ecosystem service is defined as the contributions that ecosystems (i.e. - living systems) make to human well-being (Roy Haines-Young & Potschin, 2018). Ecosystem services is both a scientific concept and a policy approach. It is also the concept upon which the SEEA EA is founded. This concept has emerged off the back of the Millennium Ecosystem Assessment as a particularly accepted and comprehensive means of understanding the interaction between humans and the natural environment (socio-ecological systems). A final ecosystem service for the North Sea may be, for example: the fish that the sea provides as a provisioning service, the nutrients and carbon cycled as maintenance services, or the recreational water sports that the sea enables as a cultural service.

Different models and classifications of ecosystem services exist. Most notable are the Millennium Ecosystem Assessment (MA) classification and the Economics of Ecosystems and Biodiversity (TEEB) classification. Each classification defines slightly different services, although the aim of the frameworks is always the same: to evaluate the benefits derived from ecosystems. The CICES classification aims at integrating classifications and is the one used by the SEEA EA. According to this framework, there are three categories of final ecosystem services. These are:

1. Provisioning services.

   These services are nutritional, material (such as wood or leaves), biochemical (medicines), genetic, ornamental (skins, flowers) and energetic outputs from living systems.

2. Regulating services.

These services encompass all the ways in which living organisms mediate or moderate the abiotic and ambient environment of humans - in a way that affects human health, safety or comfort.

3. Cultural services.

These services are the non-material services, often non-rival, and non-consumptive in nature, that affect the physical and mental states of people. Typically, these are related to the environmental settings, locations and information derived from living systems. Benefits include educational, experiential, and spiritual benefits.

(4.) Intermediate services/ecosystem functions
See section 2.3.1.

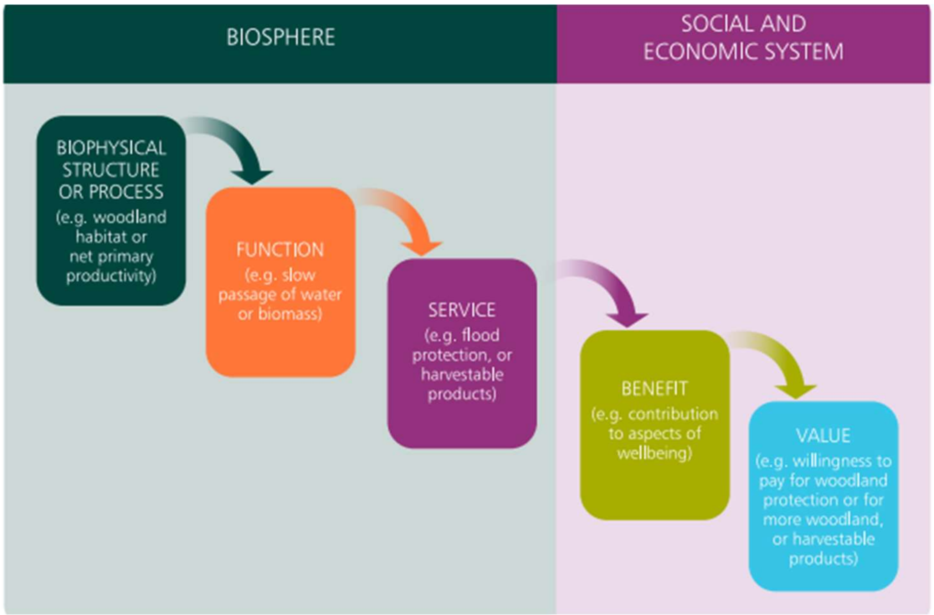
### *2.3.1 Ecosystem services vs. ecosystem function*

The ecosystem service concept and approach is fundamentally an anthropocentric model. The cascade model can be understood as a series of input-output processes in nature that lead to ecosystem services experienced and benefitted from by humans. According to the CICES classification, to be considered an ecosystem service, a natural process must directly benefit humans. This distinguishes ecosystem services such as fish obtained from fisheries from ‘ecosystem processes and functions’ like the flow of water or provision of phytoplankton, that are causally linked to benefits experienced by humans but not directly experienced as benefits themselves (Roy Haines-Young & Potschin, 2018). Certain ES classifications refer to such indirectly experienced processes as ‘supporting’ or ‘intermediate’ services to highlight the fact that they are an input into other processes from which humans derive benefits from. In practice, whether a process constitutes an ecosystem service of ecosystem function is context-dependent upon the given application. Intermediate services could thus be considered as a fourth category of ecosystem services.

### *2.3.2 The cascade model*

Figure 3 is an illustration of the cascade model of ecosystem services. It gives a more detailed understanding of how benefits are derived from ecosystems through distinct sets of features of the ecological and socio-economic aspects of a socio-ecological system. Although it is not explicitly stated, biodiversity (see definition in the next section) gives rise to biophysical structure and processes as well as functions in an ecosystem (Haines-Young & Potschin, 2010). For this reason, the assessment, mapping, and evaluation of ecosystem services is often implemented as a part of strategies aiming at reducing biodiversity loss. This was part of the strategy announced by the European Commission in 2010, for example (EU, 2010).

**Figure 3. Elements of a socio-ecological system**



*Source: The Economics of Biodiversity: The Dasgupta Review. Chapter 2*

## 2.4 Monetary valuation of ecosystem services

For the most part, monetary valuation of natural capital, is based on the Total Economic Value (TEV) framework (see *figure 5* and *figure 6*). This framework is used by economists to conceptualize the value of ecosystems and is a comprehensive framework that includes some particularly intangible values that humans place on ecosystems. Using the total economic value framework to understand the benefits derived from ecosystems implies that one acknowledges natural capital can be valued on the basis of its contribution to an individual's wellbeing/utility, i.e., biodiversity has instrumental value for our wellbeing. The TEV is a typology for understanding the instrumental value of natural capital and is the basis for much economic/monetary valuation. The following types of values can be distinguished:
Use values of ecosystem services:

- Direct use values

This is the value derived from biodiversity in the form of direct interactions with nature or ecosystems. This could be the value from extracting resources such as fish or it could be the value obtained from recreationally swimming in the sea.

- Indirect use values

This is the value derived from ecosystems without direct contact with them such as the carbon sequestered by the ocean or the flood protection provided by mangroves and bivalve mussel beds.

- Option value

This is the use and non-use value associated with still undiscovered benefits of biodiversity. This could be the potential pharmaceutical benefits of certain species which are currently unknown.

Non-use values of ecosystem services are non-tangible values and benefits derived from biodiversity. These values are sometimes hard to distinguish from each other in practice.
Non-use values of ecosystem services are:

- Existence values

This is the satisfaction derived from the knowledge that certain elements of biodiversity simply exist. This could be part of the benefit derived from the conservation of sea turtles whilst living in Iceland.

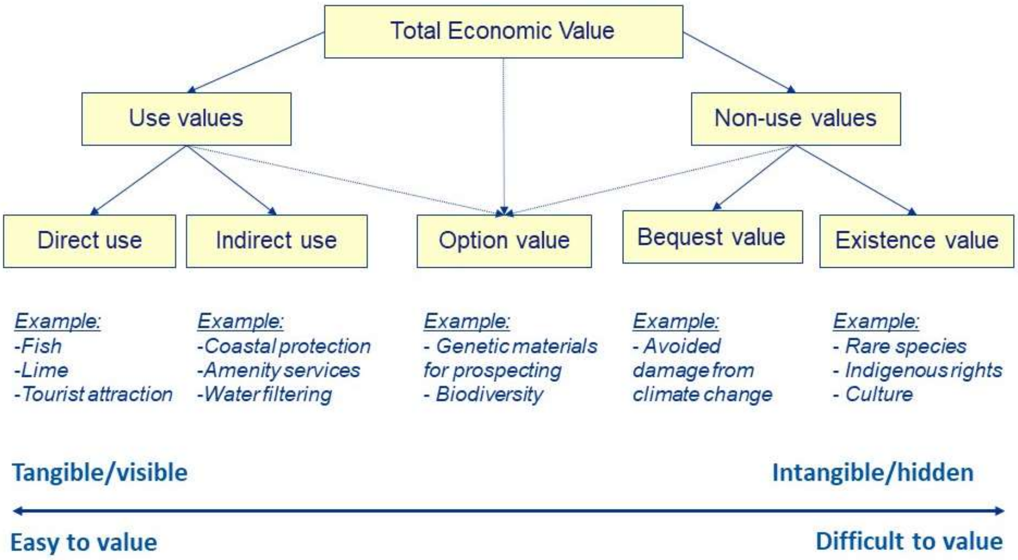
- Bequest values

This is the benefit derived from ensuring that ecosystems and biodiversity are passed onto future generations so that they can enjoy them. For example, willingness to pay to preserve a river so that your children may swim in it.

- Altruistic values

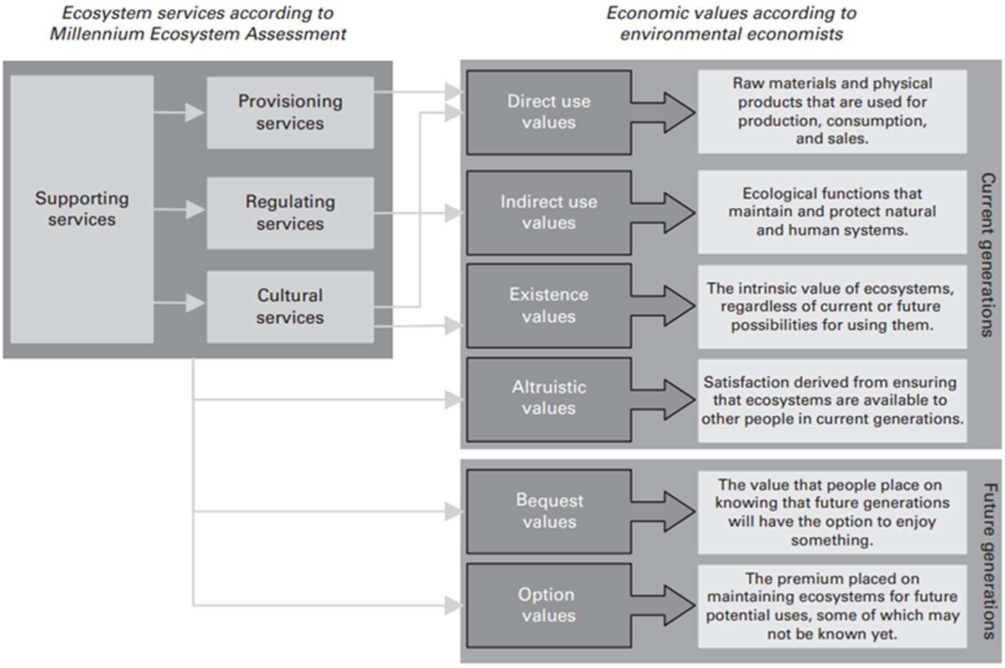
This is the satisfaction derived from knowing that others in the same generation enjoy the biodiversity and ecosystems. For example, the knowledge that indigenous tribes in the Amazon can enjoy an intact environment.

**Figure 5. The Total Economic Value taxonomy**



Source: (Dijkstra, 2022)

**Figure 6. Linkages between ecosystem services and TEV frameworks**



Adapted from Bouma & van Beukering (2015)

## 2.5 Biodiversity

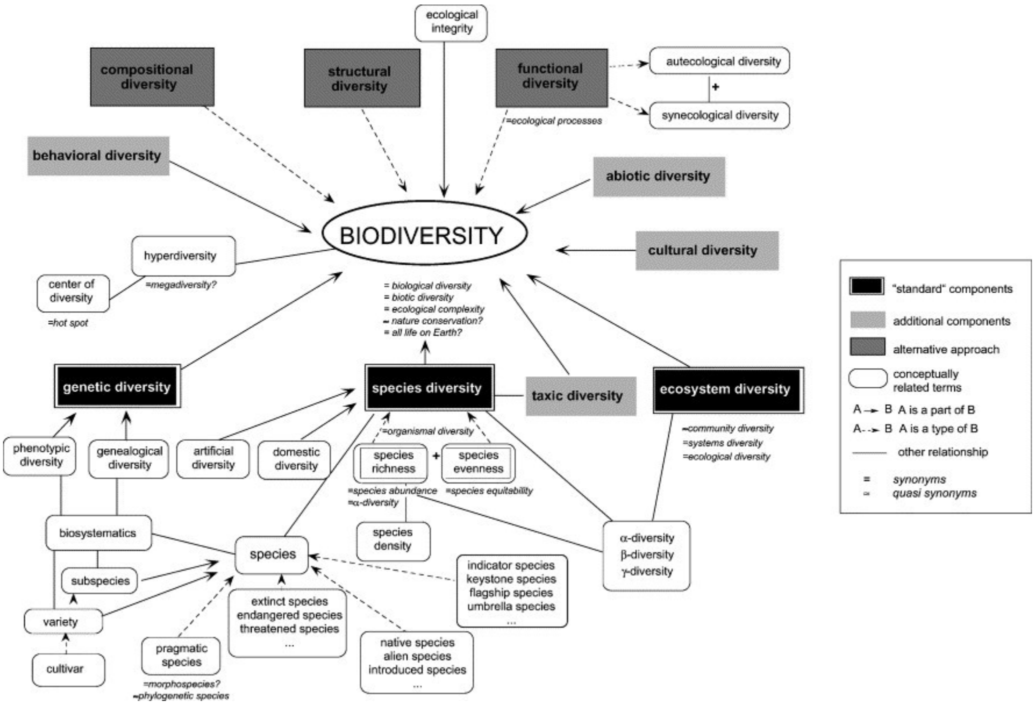
The term biodiversity is used to mean different concepts depending on the context in which it is being employed. It is therefore important to clarify what biodiversity is, and how it will be used in this study.

The Convention on Biological Diversity refers to biodiversity as '*the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems*. This definition is also the definition used in the SEEA accounting framework and is the working definition used for this paper as well. This conception of biodiversity uses biodiversity as a measure of the variability of life amongst a multitude of *elements* that also correspond to different levels of biological organization. These levels are: (i) genetic diversity, which comprises the genetic coding that structures organisms (nucleotides, genes and chromosomes), it is the diversity of genetic information within individuals of a population of species or, between populations; (ii) species diversity; (iii) ecosystem diversity, which can refer to populations, habitats or biomes (Gaston & Spicer, 2013).

Natural capital accounting is a form of accounting and measurement for biodiversity at the ecosystem or habitat level. This is a first level at which biodiversity may be conceptualized, thought of and evaluated. Biodiversity may also be conceptualized at lower levels of biological organization, such as genetic diversity or species diversity. Biodiversity conservation and policy tends to address biodiversity as species or habitat diversity (Gaston & Spicer, 2013). In this case, biodiversity is referring to the diversity of life within the ecosystems that are measured by NCA. NCA has mostly been concerned with the ecosystem level because this is the scale at which the benefits to humans becomes obvious and conveniently measurable. Another use of the term biodiversity is one that has little to do with the actual biodiversity of a system and is a generalization of the word to refer to the biosphere or nature in general. Using biodiversity in this way has become common, even in scientific texts (Farnsworth et al., 2015; Fung et al., 2015). The reader of this report should thus remain aware of the level of biodiversity that is being discussed at different moments throughout the text.

Gaston & Spicer (2013) stress that it is impossible to categorically define the biodiversity of an area or group of organisms. This is because no one measure can evaluate diversity, which may be expressed in a multitude of ways. For example, there exists measures of biodiversity to differentiate species based on evolutionary history, physiology or the role played in an ecosystem, to name but a few. As a result, no single measure of biodiversity characterizes the complete and multi-faceted diversity of a system. It is appropriate and necessary for multiple measures to be used. Nonetheless, in practice, biodiversity has tended to be measured in terms of species diversity because it is practical, widely applied and acts as a surrogate measure for other types of biodiversity. Abundance-based indices, such as the Living Planet Index are most commonly used. The most appropriate measure or indicator for biodiversity is ultimately dependent upon what one wants to describe and its practical suitability. This reveals an important implication, which is that the level of biodiversity and the measurement chosen for a given initiative, reveals implicit biases in the aspects of biodiversity that are considered important.

**Figure 4. The Complexity and aspects of the term Biodiversity**



Source: *retrieved from* Duelli & Obrist (2003)

### *2.5.1 Biodiversity indicators*

Biodiversity indicators and indices are useful to communicate specific aspects of the complexity of biological life succinctly and efficiently. Indicators of biodiversity are measures of the status of a biological system relative to policy or scientific goals, which traditionally have been biodiversity health and integrity as well as the monitoring of biodiversity. Indices are an aggregation of indicators into one measure (although the two terms are commonly used synonymously). Biodiversity indicators may be descriptive indicators, performance indicators, efficiency indicators, depending on what information is wanting to be captured and communicated (Teixeira et al., 2016). It should be clear at this point that biodiversity indicators are not always measures of diversity (although they can be) but rather are policy-oriented measurement that mainly aim at assessing ecosystem health and condition to inform conservation decisions. As such, biodiversity indicators often are related to the pressures faced by biological systems or specific aspects of biological structure and function and are indirectly related to biological diversity per se.
This is explored further in the next chapter.

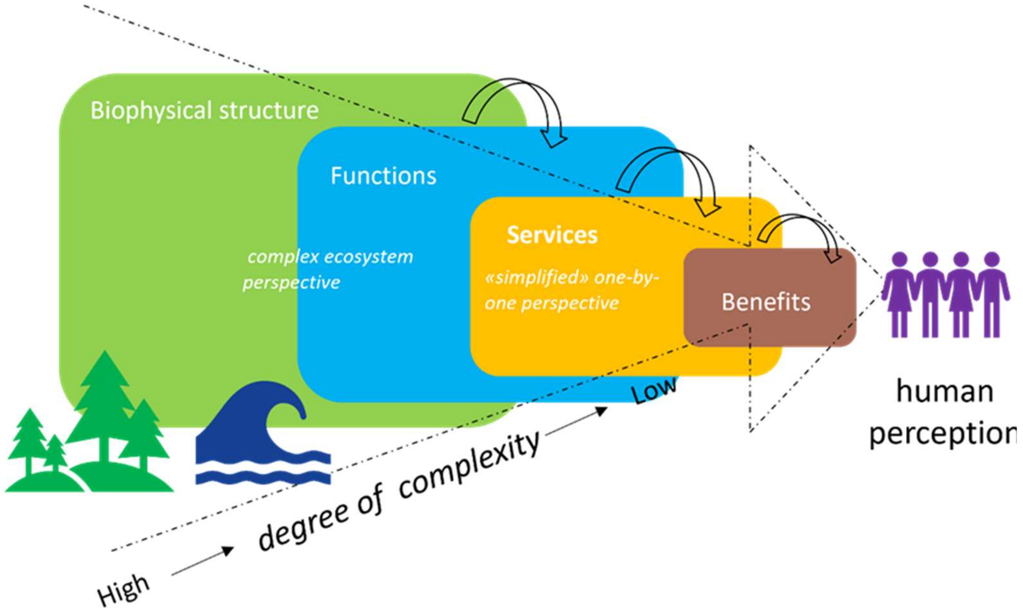
# 3 Biodiversity and ecosystem services

The previous chapter has explained how biodiversity is a measure with significant complexity. This chapter aims to clarify how biodiversity is related to ecosystem services as well as evaluate how this might be integrated into NCA in a way that supports the monetization of the benefits provided by biodiversity.

Early literature on biodiversity already speaks of composition, structure, and function as primary attributes of an ecosystem (Franklin et al., 1981; Noss, 1990). An important feature of the cascade model is that is it reduces in complexity along its chain, as is illustrated in figure 7. This allows for the benefits from ecosystem services (a socio-economic concept) to be abstracted from ecological concepts, by reducing the complexity of biological diversity to an individual service (La Notte et al., 2022). Biodiversity per se, is a *feature of* ecosystem structure, functions, and services, each of these attributes featuring biodiversity to different degrees of complexity. In this sense, biodiversity is an aspect of all elements in the cascade model, and thus an essential component that underpins their generation.

The cascade model of ecosystem services has been developed for several reasons. One of the main reasons has been to achieve consensus and find common language in the multidisciplinary work on ecosystems amongst ecologists, environmental scientists, geographers, and economists (Zhang et al., 2022). Since the ecosystem service concept is at the core of both the theoretical and practical work being carried-out regarding nature, its conservation, and its management, this report will look at biodiversity through this lens. How sensitive the provision of ecosystem services is to biodiversity is unclear and dependent on the ecosystem and service being considered. However, evidence tends to suggest a clear positive relation between biodiversity and ecosystem function in most environments, including the marine (Haines-Young & Potschin, 2010).

**Figure 7. Illustration of decreasing complexity along the cascade model**



Source: *Retrieved from* (la Notte et al., 2022)

As biodiversity loss becomes a more prominent environmental problem, there is growing interest in studying how biodiversity loss impacts ecosystem functioning and ecosystem service provision. The notion that biodiversity underpins ecosystem services is implicit in many arguments that advocate for conservation based on the importance of ecosystem services provided by natural habitats (Haines-Young &

Potschin, 2010). However, this link between biodiversity and ecosystem service provision is not linear. The body of literature investigating this question is known as Biodiversity-ecosystem function studies (BEF). On the one hand, only a limited number of individual species within an ecosystem are important for ES provision (Kleijn et al., 2015; Ricketts et al., 2016). On the other hand, Biodiversity-Ecosystem Function studies have also found species diversity and functional diversity to benefit ecosystem productivity and stability (Tilman et al., 2014). BEF studies investigate through models and natural experiments how species extinction or habitat destruction impact the functioning of ecosystems. Understanding this impact on ecosystem functioning is a prerequisite to being able to infer a change in ecosystem services resulting from loss of biodiversity.

## 3.1 Biodiversity-ES function studies

Theoretical and empirical research generally recognizes three broad relationships between biodiversity (as defined in section 2.5) and ecosystem function[2]. (Haines-Young & Potschin, 2010; Hooper et al., 2005). Lines A, B and C in Figure 8 represent these three possible relationships. Curve A shows a linear relationship between additional diversity and ecosystem function/service. Curve B represents a case of Saturation, where most species contribute only a little to overall ecosystem function/service. Curve C represents a situation where additional diversity in a system is Complementary. Complementarity occurs when species enhance each other's functioning, or overall function in the ecosystem. This may occur when there are facilitative interactions, whereby species alleviate harsh environmental conditions or provide key resources for other species. It may also occur, when additional species do not directly compete against each other for resources, either competing for different resources or for resources at different times (Hooper et al., 2005; Kremen, 2005; Tilman et al., 2014). Negative and null relationships can also be found in BEF literature (Strong et al., 2015). These are represented by lines D and F respectively.

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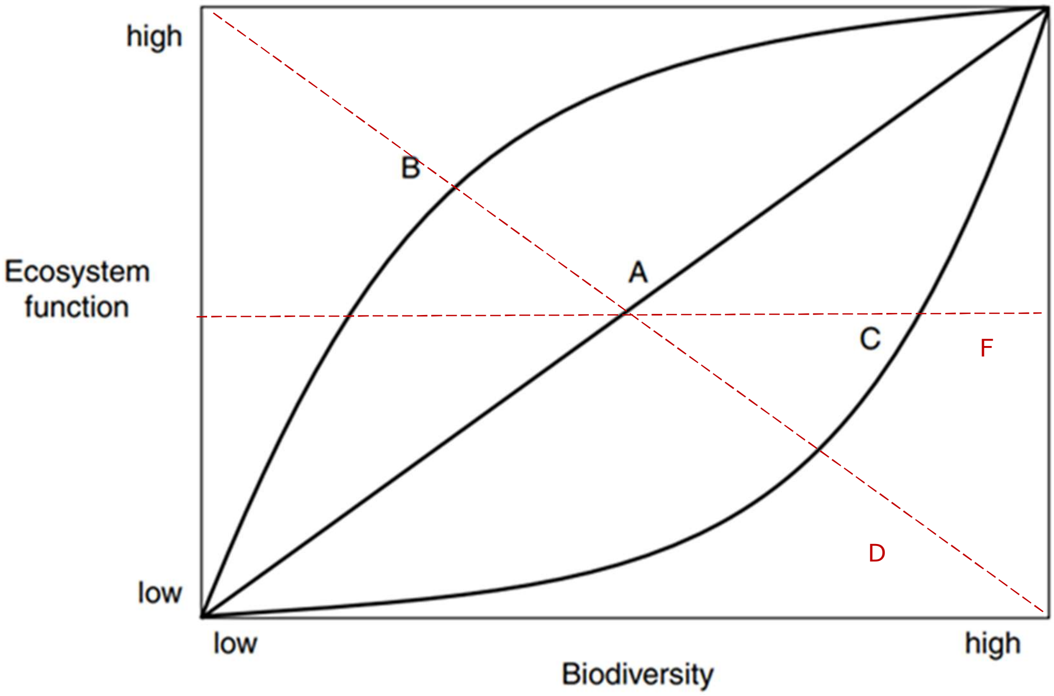
[2] Ecosystem functions are 'the physical, chemical and biological processes that transform and translocate energy or materials in an ecosystem' (Naeem, 1998)

**Figure 8. Possible relationships between biodiversity and ecosystem function/ES delivery**



Source: *Extracted from* Haines-Young & Potschin (2010). Modified

Saturating and linear relationships are the most common types of BEF relationships found (Cardinale et al., 2012; Kremen, 2005). BEF studies have been criticised for the applicability of their results to large scale systems, since very often they, are based on restrictive natural experiments and models where few variables are included. For example, factors such as food web structure and abiotic environmental features are known to affect ecosystem response to changes in biodiversity but are rarely accounted for in BEF studies (Tilman et al., 2014). Because of limitations of our knowledge of the mechanisms behind the appearance of BEF relationships, it is hard to generalise these across ecosystem types, functions, or habitats.

BEF studies consensus points

In their study published in nature, Cardinale et al. (2012) review and synthesize 20 years of BEF studies to identify consensus points in the literature. They also review studies that assess the relationship between biodiversity and ecosystem services directly and attempt to link these two approaches.

BEF consensus statements:

- Biodiversity loss reduces the efficiency by which ecological communities capture biologically essential resources, produce biomass, decompose, and recycle biologically essential nutrients with few exceptions
- Biodiversity increases the stability of ecosystem functions
- The impact of biodiversity on any single ecosystem process is nonlinear and saturating, such that change accelerates as biodiversity loss increases
- Diverse communities are more productive because they contain key species that have a large influence on productivity, and differences in functional traits among organisms increase total resource capture.
- Loss of diversity across trophic levels has the potential to influence ecosystem functions even more strongly than diversity loss within trophic levels.
- Functional traits of organisms have large impacts on the magnitude of ecosystem functions, which give rise to a wide range of plausible impacts of extinction on ecosystem function.

Two important mechanisms that control the functioning of ecosystems in response to biodiversity are the *Identity* and *diversity* of organisms. Identity effects, refers to the disproportionate contribution of certain organisms carrying specific biological traits to ecosystem functioning. A diverse community is more likely to contain a greater number of key organisms and traits for the overall functioning of the ecosystem (Cardinale et al., 2012). Diversity effects refers to the process whereby diverse biological species and functional traits can lead to different optimizing and complimentary resource use strategies. Especially in recent years, biologists have begun to measure the functional trait diversity of organisms and ecosystems by grouping species with the same biological traits together (Pavoine et al., 2009; Petchey & Gaston, 2006; Yang et al., 2021). This has several advantages, firstly, functional traits seem to be more easily related to ecosystem function and can even be directly related to certain ecosystem services (Cardinale et al., 2012; Tilman et al., 2014b). Furthermore, the processes that drive trait selection within a community are often well understood and linked to abiotic environmental factors (Bouma & van Beukering, 2015).

### *3.1.1 Evidence of BEF for the marine environment*

Many studies have evaluated BEF relationships in marine systems, however, very few reach conclusions that can be generalised beyond the local study area addressed. One example is Maureaud et al. (2019), who perform a large-scale observational study based on data from multiple European seas (including the North Sea). The authors try to relate fish biomass (considered an ecosystem function) to the level of biodiversity per grid cell. The researchers find a non-significant relationship between species richness and fish biomass across north-western European seas. However, by analysing the relation of species evenness[3] to total biomass, Maureaud et al. (2019) find a statistically significant corelation. Mauraud et al. (2019)'s findings signal the importance of dominating species to ecosystem function. They find that communities that were dominated by species whose traits are most adapted to the environmental factors such as the abiotic conditions, external pressures, and the local food chain, were likely to present higher levels of biomass. Specifically in reference to the Southern North Sea, they find that communities dominated by Benthivores, provide high biomass in the Southern North Sea likely because of the lack of larger predatory species that stick to colder waters, as well as the characteristically high benthic macrofauna biomass of the area. Apart from the Southern North Sea, which, was an exception, the research finds that higher population sizes of demersal species arise in environments that feature fish species that are higher up in the food web that take advantage of both the pelagic and benthic energy pathways as opposed to benthivorous consumers that primarily utilize the benthic food chain (Maureaud et al., 2019). The researchers also point to contradicting results in the field whereby related studies have found significant positive relations between reef fish biomass and species richness amongst coral reefs in other locations (Duffy et al., 2016; Mora et al., 2011)

(Strong et al. 2015) review the literature on marine biodiversity and marine ecosystem function relationships and assesses their capacity to be used for the monitoring of aggregate ecosystem functioning purely based on measures of biodiversity. In other words, the authors review the potential for marine biodiversity to be used as an indicator of ecosystem function. Table 1 shows a summary of the review. Most studies reviewed in the paper reported a positive BEF relationship, however null and negative relationships were also found. The authors state that studies relating to certain key ecosystem functions and biological components are still missing, and that these would be needed for a thorough extrapolation of ecosystem functioning from changes in biodiversity. Another important finding, which is in line

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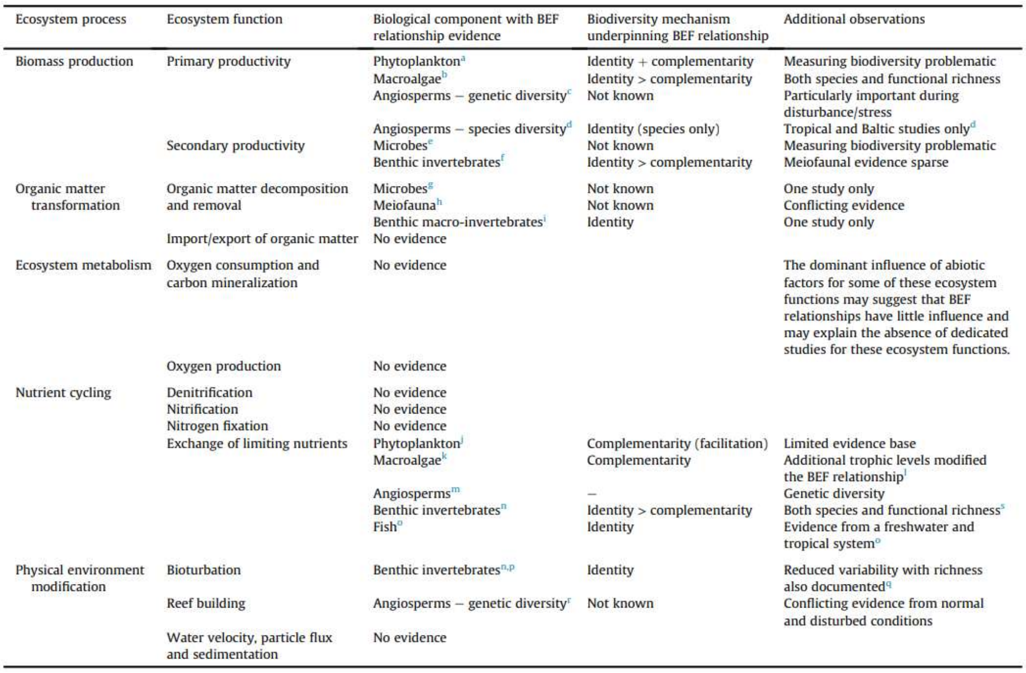
[3] Measure of biodiversity that looks at similarity in species abundance across a community

with those of Maureaud et al. (2019), is that the use of functional diversity made for more robust BEF relationships compared to the use of species richness. Another finding is that identity effects tend to be the main mechanism underpinning BEF relationships in most of the marine habitats and ecosystems reviewed.

When looking at specific systems such as the DNS, the link between the biodiversity of the sea and its ecosystem functioning is likely to depend upon the specific environmental pressures, abiotic and biotic features of the area, since these factors heavily shape the general functioning of marine ecosystems, as well as on the response of the biotic environment to changes in diversity (Maureaud et al., 2019; Strong et al., 2015). How much one can apply results from BEF studies done in other regions (even within the North Sea) is a question beyond the scope of this review, however general trends, such as the prominence of identity effects within the marine habitat, gives indications as to how and where relationships could be established in the DNS. Strong et al. (2015) point out that until we understand the relative importance of biodiversity effects on ecosystem functioning compared to the relative importance of the abiotic environment on the same functioning, it will be hard to use information regarding the BEF relationships to evaluate and predict the mechanisms of overall ecosystem function.

Unfortunately, BEF studies show that there is not enough knowledge of the functioning of ecosystems to be able to draw a causal link between the state of ecosystem biodiversity and the provision of ecosystem services. This is a point that has been brought up specifically for the DNS by several reports (Strietman et al., 2018; van den Akker, 2011). General conclusions from BEF studies could still be used to inform more pragmatic linkages between biodiversity and ecosystem services, such as through qualitative or semi-quantitative assessments of biodiversity-ecosystem service linkages. An example of a pragmatic methodology is presented later on in this chapter. Establishing how changes in biodiversity link to changes in the ecosystem functioning and in turn, ecosystem service potential of the North Sea would mean that the cost of forgone ecosystem services could be used a monetary value for the change in biodiversity. Establishing a causal link would also lead to more cost-effective ecosystem monitoring and management (Strong et al., 2015). Within the SEEA framework, the ecosystem condition account is the space where such a linkage between biodiversity and ecosystem service provision can be made explicit.

**Table 1. Summary of BEF studies related to the marine environment**



| Ecosystem process | Ecosystem function | Biological component with BEF relationship evidence | Biodiversity mechanism underpinning BEF relationship | Additional observations |
|---|---|---|---|---|
| Biomass production | Primary productivity | Phytoplankton[a] | Identity + complementarity | Measuring biodiversity problematic |
| | | Macroalgae[b] | Identity > complementarity | Both species and functional richness |
| | | Angiosperms – genetic diversity[c] | Not known | Particularly important during disturbance/stress |
| | | Angiosperms – species diversity[d] | Identity (species only) | Tropical and Baltic studies only[d] |
| | Secondary productivity | Microbes[e] | Not known | Measuring biodiversity problematic |
| | | Benthic invertebrates[f] | Identity > complementarity | Meiofaunal evidence sparse |
| Organic matter transformation | Organic matter decomposition and removal | Microbes[g] | Not known | One study only |
| | | Meiofauna[h] | Not known | Conflicting evidence |
| | | Benthic macro-invertebrates[i] | Identity | One study only |
| | Import/export of organic matter | No evidence | | |
| Ecosystem metabolism | Oxygen consumption and carbon mineralization | No evidence | | The dominant influence of abiotic factors for some of these ecosystem functions may suggest that BEF relationships have little influence and may explain the absence of dedicated studies for these ecosystem functions. |
| | Oxygen production | No evidence | | |
| Nutrient cycling | Denitrification | No evidence | | |
| | Nitrification | No evidence | | |
| | Nitrogen fixation | No evidence | | |
| | Exchange of limiting nutrients | Phytoplankton[j] | Complementarity (facilitation) | Limited evidence base |
| | | Macroalgae[k] | Complementarity | Additional trophic levels modified the BEF relationship[l] |
| | | Angiosperms[m] | – | Genetic diversity |
| | | Benthic invertebrates[n] | Identity > complementarity | Both species and functional richness[s] |
| | | Fish[o] | Identity | Evidence from a freshwater and tropical system[o] |
| Physical environment modification | Bioturbation | Benthic invertebrates[n,p] | Identity | Reduced variability with richness also documented[q] |
| | Reef building | Angiosperms – genetic diversity[r] | Not known | Conflicting evidence from normal and disturbed conditions |
| | Water velocity, particle flux and sedimentation | No evidence | | |

*Source: retrieved from* Strong et al. (2015)

## 3.2 Biodiversity as part of Ecosystem condition

In the SEEA - EA, ecosystem condition is defined as the quality of an ecosystem measured in terms of its abiotic and biotic characteristics (SEEA, 2021). An ecosystem condition account presents information related to several descriptors of ecosystem quality. Ecosystem quality, in this case, refers to 1. ecosystem health*, i.e., 'the capacity of an ecosystem to maintain its organization and autonomy over time and to resist external pressures', hence, related to anthropogenic pressure*. 2. ecosystem integrity, defined as '*the structure, composition, function and degree of self-organization of an ecosystem operating within a natural range of variability that exhibits little or no human influence*' and 3. ecosystem functioning*,* which is '*a descriptor that involves the biogeochemical and physical processes that take place within an ecosystem which contribute its overall performance'* (Rendon et al., 2019: p.1). All these descriptors are included in condition accounts through measures of the state, pressures and importantly, biodiversity of ecosystems (Rendon et al., 2019).

Biodiversity is thus considered to be an important measure of ecosystem condition. However, biodiversity is not the only factor accounted for in the assessment of ecosystem condition. Other commonly used components of condition accounts include measures of external pressures (e.g., related to human disturbance or pollution), landscape level characteristics associated with an ecosystem (e.g., fragmentation) and abiotic characteristics such as the physical and chemical state of ecosystems (Rendon et al., 2019; SEEA, 2021)[4]. One current and common knowledge gap in the application of NCA around the world regards how condition accounts should inform ecosystem service supply and use tables (Rendon et al., 2019). Condition accounts most of the time run in parallel to ES extent, ES flow and ES asset accounts, without being operationally linked together (la Notte et al., 2022). The result is a potentially

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[4] Note that measures of state, characteristics and even pressure (i.e. invasive species) may fall under the broader category of biodiversity but are not measures of biodiversity per se. A distinction in made here.

unrealistic scenario, whereby, models and estimates of ecosystem services are purely based on the extent of habitats and independent of changes in the health, integrity and functioning of those habitats in space and time.

There are a few reasons why condition accounts so far have rarely been linked to extent and service accounts during ecosystem accounting and mapping efforts. Firstly, the relationship between ecosystem quality (i.e., changes in the state, pressures, biodiversity) and ecosystem service delivery, is not very well understood for many ecosystem types and ecosystem services (Cardinale et al., 2012). A second reason is that it is ecosystem supply in particular that is impacted by changes in the condition of ecosystems (as opposed to demand for the ES), yet ecosystem capacity accounts remain part of the research agenda for the SEEA EA and have not yet been developed as part of the framework (SEEA, 2021: p.349). Thirdly, measures and indicators relating to ecosystem health, integrity and functioning have largely been developed for other reasons than assessing ESP, so there is a question of data applicability and availability. Nonetheless, there is no denying that linking condition accounts to extent and service accounts would provide not only more accurate NCA, but facilitate a wealth of decision-making processes, especially as it concerns estimating the impact and value of biodiversity loss and degradation.

It is worth noting that the linking of ecosystem quality to ecosystem service delivery is an ongoing and active field of research both in scientific literature as well as grey literature from private and public institutions (Cardinale et al., 2012; European Comission, 2015; van den Akker, 2011). Interestingly, from the research carried out during this report, this topic seems to be particularly relevant amongst the marine natural capital accounting community[5]. Rendon et al. (2019), who perform a review assessing the trends in the mapping and assessment of ecosystem condition in Europe find that the marine environments were the most widely researched ecosystem types. Designing condition accounts to incorporate links between biodiversity and ecosystem service supply in the marine environment is a clear first-step and pathway towards valuing changes in the state, pressures, and biodiversity of systems in socio-economic and monetary terms. Such an integrative design is also a clearly in line with the SEEA EA, which is founded on the conception that healthy ecosystems and biodiversity are essential in supporting human wellbeing and human economies (SEEA, 2021).

The next part of this chapter will aim to establish a methodology for integrating biodiversity into condition accounts by creating condition accounts that are linked to ecosystem service flow and asset accounts. Due to resource and time constraints a study specifically on the DNS is not carried out here although applicability to the DNS marine natural capital accounts is talked about. Hopefully this section can serve as inspiration for possible future research in this domain. Establishing operationally linked ecosystem conditions accounts for the DNS would be an important step in later determining the monetary value of changes in the states of biodiversity in the sea. Chapter 4 of the report touches on the economic tools and methods for revealing monetary values for biodiversity and ecosystems.

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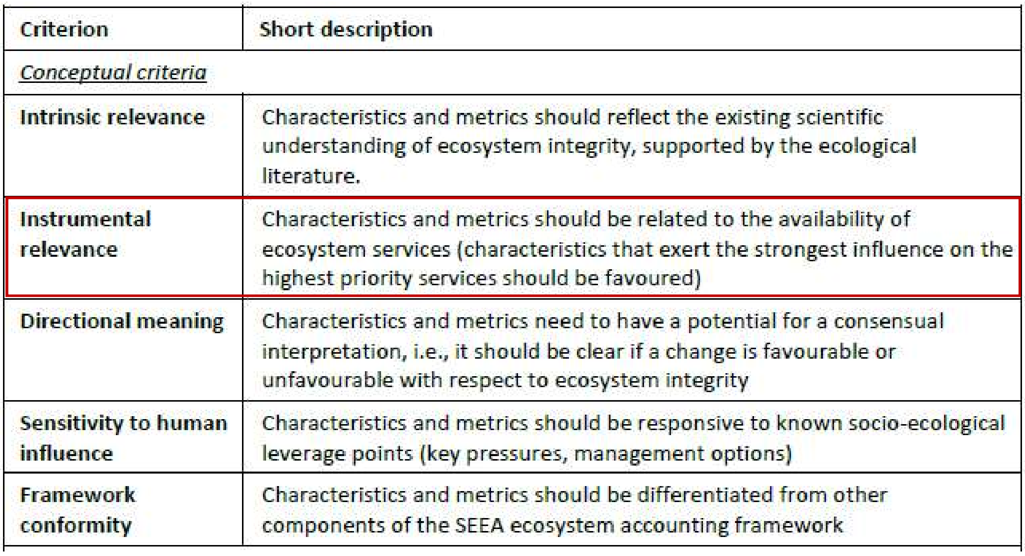
[5] This obviously may be a biased result since it is the area of interest of this paper. However this finding may also reflect specific biological and institutional features of the marine environment.

## 3.3 Assessing biodiversity as part of condition accounts

The SEEA EA outlines three stages to building an ecosystem conditions account (SEEA, 2021: p.87). The usefulness of the conditions account is largely determined by the two first stages. 1. The identification of the most relevant characteristics of the ecosystem, as it relates to the condition of the ecosystem type (ET) 2. The formalization of concrete, measurable variables to be used as metrics that represent and measure the given ecosystem characteristics chosen (Czúcz et al., 2021; SEEA, 2021). The SEEA EA framework also establishes a list of criteria to help select ecosystem characteristics that aims to set up condition accounts that are statistically useful and ecologically meaningful. Table 2 is retrieved from the SEEA EA manual and shows the conceptual criteria for selecting ecosystem characteristics for use in condition accounts. Note that the criterion of instrumental relevance clearly calls for characteristics with the strongest influence on ES delivery to be included.

**Table 2. Selection criteria for ecosystem characteristics**



| Criterion | Short description |
|---|---|
| *Conceptual criteria* | |
| **Intrinsic relevance** | Characteristics and metrics should reflect the existing scientific understanding of ecosystem integrity, supported by the ecological literature. |
| **Instrumental relevance** | Characteristics and metrics should be related to the availability of ecosystem services (characteristics that exert the strongest influence on the highest priority services should be favoured) |
| **Directional meaning** | Characteristics and metrics need to have a potential for a consensual interpretation, i.e., it should be clear if a change is favourable or unfavourable with respect to ecosystem integrity |
| **Sensitivity to human influence** | Characteristics and metrics should be responsive to known socio-ecological leverage points (key pressures, management options) |
| **Framework conformity** | Characteristics and metrics should be differentiated from other components of the SEEA ecosystem accounting framework |

*Extracted from:* SEEA (2021)

The first step in establishing operationally linked condition accounts would involve identifying elements of ecosystem health, integrity, and functioning that contribute most to the delivery of Ecosystem Services within the accounting area. The preliminary physical ecosystem conditions account for the DNS uses characteristics based on the indicators developed for the Marine Strategy Framework Directive. This is in line with the spirit of the SEEA EA, as accounts should be a place to bring together existing monitoring efforts, however, with the exception of the provision of fish, none of the other ecosystem services evaluated by the physical DNS accounts are dependent on the indicators in the conditions account, as is noted by (Roebeling et al., 2020). The current physical condition accounts for the DNS, thus perform badly in terms of instrumental relevance.

## Determining key ecosystem service providers

Kremen et al. (2005) and Balnavera et al. (2005) build a framework for determining the most important ecosystem service providers within a community, based on in Situ observation.

In their model, aggregate provision of ecosystem service $X$ is equal to the sum of the contributions of key ecosystem service providers (ESPs) to service $X$. Different species may contribute to overall ecosystem service with different efficiencies. To give the equations: $X = \sum_{j=1}^{j} c_{jx}$ & $c_{jx} = n_j \times e_{jx}$

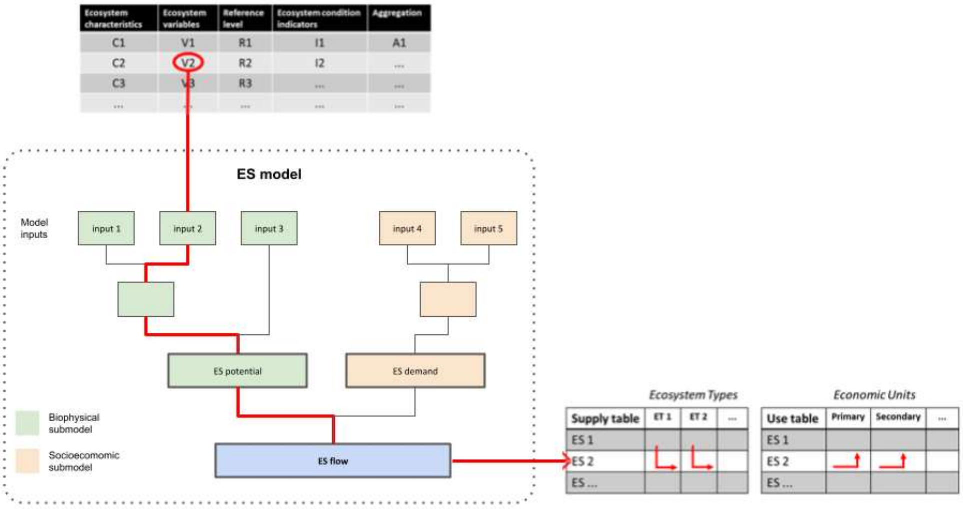
Where $c_{jx}$ is the contribution of species $j$ to ecosystem service $X$; $n_j$ is the abundance of species $j$; and $e_{jx}$, is the per capita efficiency of individuals of species $j$ at producing ecosystem service $X$.

By analyzing which species contribute disproportionately to ecosystem service provision, as compared to their relative abundance within an ESP community, the authors identify the most important species for the provision of the ecosystem service. However, the model neglects species-species and species-environment interactions.

When in Situ data is not available, key ESPs and their relative contributions to overall ecosystem service provision could be determined though a mix of BEF literature review and expert judgment. ESPs may be of various levels of biological organization (genetic, species/population or habitat) based on how best the ecosystem service in question is characterised (Kremen, 2005). Measures of ESPs can then be used as ecosystem characteristics. Measures can also be diverse in nature, i.e., species abundance, species richness, or of functional diversity (species traits) amongst other things. According to Strong et al. (2015), it is measures of functional species diversity that best characterize BEF relationships in the marine environment (trait diversity). Finally, it is important that ecosystem characteristics chosen respect the entirety of the criteria for selection, not just instrumental relevance.

The second step in building operationally linked ecosystem condition accounts involves building a model of ES supply that incorporates the ecosystem characteristics chosen as inputs to aggregate ES delivery potential within the ecosystem. As mentioned earlier, the SEEA EA does not include an ES potential/supply account however, according to La Notte et al. (2022), almost all spatial models assessing ES flow follow a supply-demand structure. Figure 9, from La Notte et al. (2022) shows how biodiversity-related ecosystem characteristics may be linked to ES supply as well as condition indicators used in condition accounts. When the functional relationship of the ecosystem characteristic to the ES potential is not well established in literature, generalised BEF functional forms shown in figure 8 could be used with expert judgement to form the ES potential model. However, building such a model is beyond the scope of this report. This topic is explored here as linking biodiversity related characteristics in the DNS to final ES potential, would facilitate the economic and monetary valuation of relevant changes in the condition of the DNS ecosystem.

**Figure 9. Schematic of the linkage of ecosystem condition accounts to supply and use tables**



Source : *retrieved from* La Notte et al. (2022)

A major limitation when it comes to quantitively linking biodiversity related ecosystem characteristics to final ES potential remains the major uncertainties in how structural changes in the marine food web or marine abiotic environment might change the functional relationship between biotic factors and ecosystem service provision. Developing our understanding of such interactions within the marine environment will be vital in improving both biophysical and monetary estimates of ES flow. A practical approach would be to create linkages between as many biophysical characteristics and processes as possible and modifying these as our understanding of ecosystem processes and functioning becomes better. This section has shown that it likely that some linkages can already be drawn within the DNS, especially if supported by expert opinions.

# 4 Methods for the monetary valuation of biodiversity

Chapter two has demonstrated that nature, its resources, and its assets are explicitly valuable to humans in many ways. It also demonstrated that biodiversity can be expressed in many ways. This poses a challenge for determining a monetary value of biodiversity, as the monetary value given to biodiversity, is dependent on the level and spatial scale at which we are interpreting biodiversity at, the type of biodiversity value being revealed, as well as the valuation method being used (Nunes & van den Bergh, 2021). This section will detail how various types of value for biodiversity can be understood through an economic and ecological lens, and subsequently, quantified monetarily.

## 4.1 Why value biodiversity monetarily?

Measuring the contribution of biodiversity in monetary terms enables better resource management. It allows for economic criteria such as cost-effectiveness, efficiency, and welfare maximization to be used in matters of optimal allocation and use of natural resources and capital (Bouma & van Beukering, 2015; Freeman III et al., 2014), even though decision makers may well have other objectives, such as sustainability or equity. However, being able to run cost-benefit analysis on natural capital is likely to be a welcome addition to the policy-makers toolkit. In a world where many environmental goods and services are exploited for free, monetary valuation of biodiversity can reveal concretely the worth of natural capital (Dasgupta, 2021). Monetary valuation of biodiversity can help with decisions that involve trade-offs between biodiversity and economy, as well as a number of other policy-uses. Bouma & van Beukering (2015) identify four broad reasons to value ecosystem services monetarily. These are adapted for the monetary valuation of biodiversity in general.

1. Advocacy
By highlighting the economic importance of biodiversity within an ecosystem or an area, valuation acts as a means to advocate for the importance of conservation, protection or sustainable use of biological resources, for example. It may help getting biodiversity-related issues on the agenda.

2. Decision-making
Monetary valuation of biodiversity helps decision-makers reach their economic and social goals with more accuracy by revealing the hidden benefits of biodiversity (that are often not accounted for) and enabling these benefits to be included in cost-benefit analyses.

3. Damage assessment
Monetary valuation of biodiversity can help prevent the damage of biological resources and loss of biodiversity, (e.g., oil spills) by revealing the value of these. Valuation also helps reach consensus on the amount of compensation that ensues from losses in biodiversity due to catastrophic or collateral events.

4. Internalizing externalities and price setting
Economic valuation of biodiversity can help inform the setting of prices and taxes related to harmful environmental activities. An example in the North Sea might be taxes on fishing or shipping or any other economic activity that is clearly harmful to biodiversity. By setting taxes on such activities, the socially optimal consumption of biological resources and the degradation of biodiversity is incentivized.

Many people are opposed to the idea of valuing biodiversity monetarily. This is mainly because they feel uncomfortable ascribing an instrumental value to biodiversity and instead feel that biodiversity has intrinsic worth and should be conserved for its own sake (Haines-Young & Potschin, 2010). There are strong moral reasons for why biodiversity might be considered to have its own personhood, independent of humans, and therefore the argument of intrinsic value of biodiversity should not be dismissed (Dasgupta, 2021.; Lovelock, 1995). Nonetheless, it could be argued that making any sort of private or public decision regarding biodiversity implies that one values biodiversity in an implicit way, which would merely be revealed through monetary valuation. It should also be noted that the two views are not irreconcilable. Most researchers who undertake monetary valuation of biodiversity acknowledge that the value obtained can only, in the best case, be a lower-bound estimate for the value of biodiversity given that its intrinsic worth is not measurable (Nunes & van den Bergh, 2001). Thus, this report pursues the monetary valuation of biodiversity, whilst acknowledging that this means of valuing biodiversity in a utilitarian manner is inherently limited in its ability to accurately portray the value of biodiversity.

## 4.2 Valuing ecosystem services monetarily

### *4.2.1 Economic valuation methods for the valuation of ecosystem services*

Economic valuation methods for valuing ecosystem functions and services monetarily fall under 4 principal categories. These are: (i) direct market valuation methods (ii) indirect market valuation methods (iii) non-market valuation methods and (iv) others (meta-analysis, value transfer and deliberative valuation). The advantages and disadvantages of each individual method are discussed in detail in several publications (Freeman III et al., 2014; van Beukering et al., 2015). A critical evaluation of the methods used for the case-study will be made in an applied way later in the paper.

**Direct market valuation** methods are the easiest to employ but not always possible. They use real-world markets either for the very ecosystem service or a complementary good/service to determine its value. For NCA this is the best method to use because the SNA is based on the concept of exchange values – values determined based on the market value, regardless of the institutional context.

- The Market price method (MP)

Value obtained from actual market transactions of ES. Ex: fish
Note: Easy to apply but many ES are not traded on markets.

- The Production function method (PF)

Used when an ecosystem service is an input in a production process. Ex: revenue of the provision of fishing trips to coral reefs is considered as a function of the quantity and quality of the coral reef + the labour and equipment used. Note: technically difficult and significant data requirements.

- Cost-based methods (CB)

Includes estimating the value of property protected or cost of action taken to avoid damage as a measure of the benefits provided by an ecosystem (damage cost avoided). Or estimating the cost of replacing an ecosystem/ ecosystem service (replacement cost). Or estimating the value of substituting the ES with an artificial or natural equivalent (substitute cost). Note: easy to apply but only provide rough surrogate values

**Indirect market valuation** methods are used to value ecosystem services that are not traded directly on the market or are not a clear input for a product traded on the market. These types of methods are used to reveal the value of the ecosystem service by looking at market data of related goods. This is often used for cultural services. Two important indirect valuation methods are:

- The Hedonic pricing method (HP)

  Using the market price of two identical products traded on the market that only vary in terms of the environmental characteristic/ES wanting to be measured to implicitly reveal the price of the ES.
  Note: large data requirements and all variables must be considered.

- The Travel cost method (TC)

  The travel cost incurred to visit a recreation site is considered as the implicit price to access that recreational service. Note: Large data requirements, often requiring a questionnaire.

**Non-market valuation** methods are used to determine values that are unable to be observed or inferred using market data. Non-market methods rely on hypothetical behaviour and markets (created through surveys) to measure the value of ecosystem services. The fact that actual behaviour is not observed is an important disadvantage. Nonetheless, non-market methods enable the measurement of non-use values and hypothetical scenarios of use/degradation. These methods can be used for a wide range of services but are not favoured by the SEEA EA. Non-market methods are:

- Contingent valuation method (CV)

  Directly asking people for their maximum willingness to pay for an ES. Note: can be applied to any ES but answers are hypothetical; Not favourable according to the SEEA EA.

- Choice experiment method (CE)

  Value for an ES is inferred by analysing the hypothetical trade-offs from people's declared willingness to pay for the hypothetical provision of different levels of the quantity and quality of an ES. Note: Less prone to bias than CV method but still hypothetical; Large data collection requirements and statistical analysis.

**Other** methods exist for valuing ecosystem services that rely on secondary data. These are:

- Meta-analysis

  Researchers gather available empirical data on ES to analyse and estimate a value. Note: time-consuming and case study specific features must be accounted for.

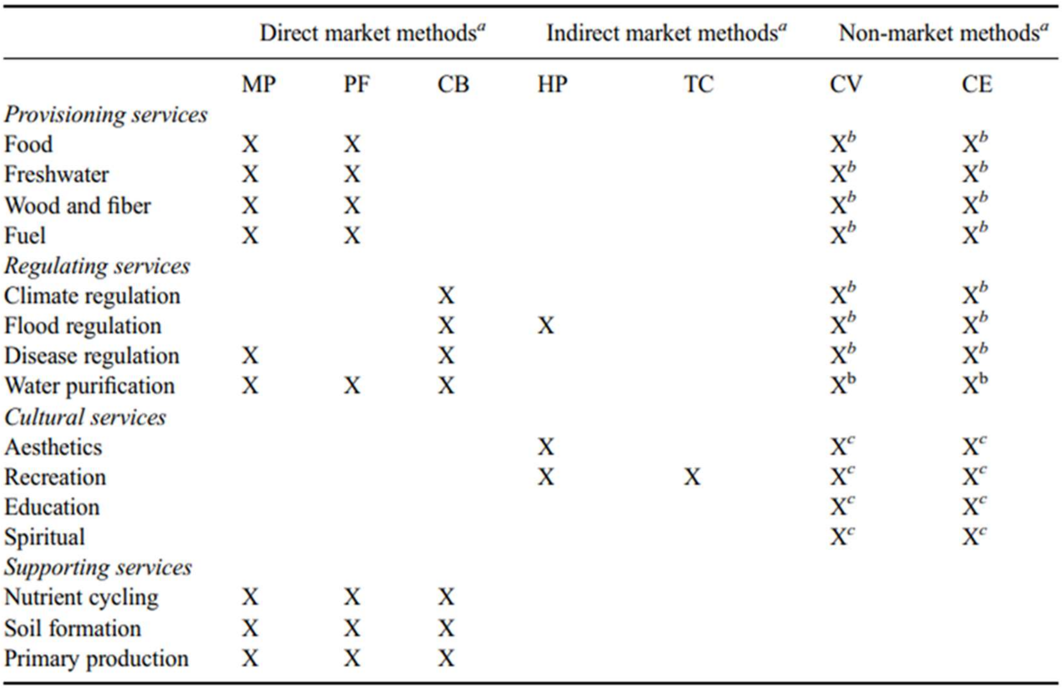
- Value transfer

  Value of ES in one location is estimated based on the value of the same ES at a different location. Note: Simple and cheap method but the two locations in question must be comparable.

- Deliberative valuation (can rely on primary data as well)

  Determining the value of an ES through group-based social exchange and reflection. Note: Requires stakeholder engagement and meeting.

**Table 3. Ecosystem services and likely valuation methods**



|  | Direct market methods[a] |  |  | Indirect market methods[a] |  | Non-market methods[a] |  |
|---|---|---|---|---|---|---|---|
|  | MP | PF | CB | HP | TC | CV | CE |
| *Provisioning services* |  |  |  |  |  |  |  |
| Food | X | X |  |  |  | $X^b$ | $X^b$ |
| Freshwater | X | X |  |  |  | $X^b$ | $X^b$ |
| Wood and fiber | X | X |  |  |  | $X^b$ | $X^b$ |
| Fuel | X | X |  |  |  | $X^b$ | $X^b$ |
| *Regulating services* |  |  |  |  |  |  |  |
| Climate regulation |  |  | X |  |  | $X^b$ | $X^b$ |
| Flood regulation |  |  | X | X |  | $X^b$ | $X^b$ |
| Disease regulation | X |  | X |  |  | $X^b$ | $X^b$ |
| Water purification | X | X | X |  |  | $X^b$ | $X^b$ |
| *Cultural services* |  |  |  |  |  |  |  |
| Aesthetics |  |  |  | X |  | $X^c$ | $X^c$ |
| Recreation |  |  |  | X | X | $X^c$ | $X^c$ |
| Education |  |  |  |  |  | $X^c$ | $X^c$ |
| Spiritual |  |  |  |  |  | $X^c$ | $X^c$ |
| *Supporting services* |  |  |  |  |  |  |  |
| Nutrient cycling | X | X | X |  |  |  |  |
| Soil formation | X | X | X |  |  |  |  |
| Primary production | X | X | X |  |  |  |  |

*Table retrieved from* (van Beukering et al., 2015)*. Does not include "Other" methods.*

### 4.2.2 Data restrictions related to the valuation of ecosystem services

Monetary valuation of ecosystem services often requires that a biophysical assessment of the ecosystem services of interest be carried out first. Subsequently, the methods listed above can be used. A primary and widespread constraint when it comes to ecosystem service assessment for natural capital accounting is that biophysical data regarding the ecosystem service potential is unknown. Many methods of assessing and mapping ES have been proposed since the popularization of the topic (Crossman et al., 2012; Dunbar et al., 2012; Martínez-Harms & Balvanera, 2012), however, much of the information regarding ES potential remains qualitative. Many studies use a matrix approach, where habitat types within an accounting area are associated with an expert-denoted score based on their potential to supply a list of ecosystem services (Burdon et al., 2017; Hattam et al., 2021). The lack of quantitative assessments of ES is a substantial challenge when attempting to value ES that must be navigated.

### 4.2.3 The issue of double counting

Table 3. shows that both ecosystem functions (intermediate services) and (final) ecosystem services can potentially be valued monetarily using the valuation methods described above. A large debate amongst the academic and NCA community has been whether ES classifications should include intermediate services or not (Roy Haines-Young & Potschin, 2018). The CICES classification chooses not to include intermediate services as ecosystem services. This is mostly so that double counting is avoided when adding up the total value of ecosystem services. If the value of an ecosystem function such as nutrient cycling is added to the value of an ecosystem service it supports, such as water purification services or recreation services, then it is likely that the aggregate value is overestimated by the amount of the overlap in the values between the function and service. (Fu et al., 2011), also identify 5 additional causes for double counting during ecosystem assessments and valuations beyond ambiguous

definitions and ES classifications, these include spatio-temporal scale dependence of ES and poor understanding of the complexities of ES.

### *4.2.4 Monetary valuation of ecosystem services as a means of valuing biodiversity*

The ecosystem approach, and the concept of ecosystem services has been integrated into many management strategies, showing its potential to act as an important policy and management tool. Natural capital accounts integrate ecosystem services into the system of national accounting. Monetary valuation of ecosystem services will thus be an important means of revealing the value of biodiversity in the years to come as NCA develops, with monetary valuations likely to benefit biodiversity for the reasons listed in section 4.1. Whereas the monetary valuation of ecosystem services is a theoretically robust method for revealing the instrumental values obtained from nature, chapter 3 has begun to analyse how this methodology has several shortcomings, when it is being applied, especially as it relates to biodiversity per se.

The primary shortcoming is that ecosystem services are a limited conception of biodiversity, revealing the end process (as it relates to humans) of a complex and interrelated web of abiotic and biotic interactions and energy transfers that are represented in the rest of the cascade chain. Thus, measuring the value of biodiversity through the value of ecosystem services always ascribes value to a particular level of biological organization without considering its linkages to other levels of biological organization and biological processes, which remain without *explicit value* (because their value is considered as contributing to the value of the final ecosystem service being considered). This nonetheless is a valid way of measuring the value of biodiversity, i.e., **the instrumental value of the diversity of biological life to humans is reflected in the total benefits obtained from those biological processes directly benefiting humans (ecosystem services)**. In reference to the DNS, the value of biodiversity would be the sum total of the monetary supply and use tables from the DNS natural capital accounts, to the extent that these are complete.

Measuring the value of biodiversity through the benefits obtained from ecosystem services is a good way of revealing the instrumental value of biodiversity, however, the bias of this method because of its anthropocentric perspective should not be dismissed. For example, amongst the endless number of biological organisms and processes that exist, it will undoubtedly be the case that this method reveals the value of organisms, processes and ecosystems that are most directly related to human welfare. Furthermore, our understanding of the ecological processes and organisms underlying the final ecosystems considered is so poor that even when they do have instrumental value to humans, their value often cannot be revealed (see section 3). Finally, even amongst those values and final ecosystem services that are admittedly important to human welfare, a substantial number are very hard to assess quantitatively and monetarily with current economic valuation methods, scientific information, and data.

The monetary valuation of ecosystem services reveals itself as a useful but limited method of evaluating the benefits arising from biodiversity. Other methods for revealing the monetary value of biodiversity exist and are explored next.

### *4.2.5 Valuation of biodiversity-related ecosystem services*

Another way of understanding the value of biodiversity within an accounting area would be to assess and monetize the value of ecosystem services and functions that are most related to biological diversity. This may take the form of revealing the contribution of certain key biological organisms to ecosystem services, such as important and vulnerable species and habitats (Plazaz-Jimenez & Cianciaruso, 2020; Watson et al., 2020) or, it may be monetizing only ecosystem services that are strictly related to biodiversity for the accounting area in question. Examples of such biodiversity related ecosystem services include 'Pest control', or 'Nursery population and habitat maintenance', or the cultural service: 'ecosystem and species appreciation'. It is undeniable that certain ecosystem services can be said to be more closely related to biodiversity in the strict sense (i.e., diversity in biological life), than others.

#### *4.2.5.1 Monetary value of ecosystem and species appreciation services*

According to the SEEA EA, ecosystem and species appreciation concerns 'the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use'(SEEA, 2021). This ecosystem service measures the non-use value of biodiversity and is related to the theme of biodiversity conservation and the bequest value of biodiversity. One significant attempt at measuring and valuing this service has been by Schweppe-Kraft & Ekinci (2021), who estimate the biophysical and monetary size of the flow and stock of this service for the German terrestrial extent.

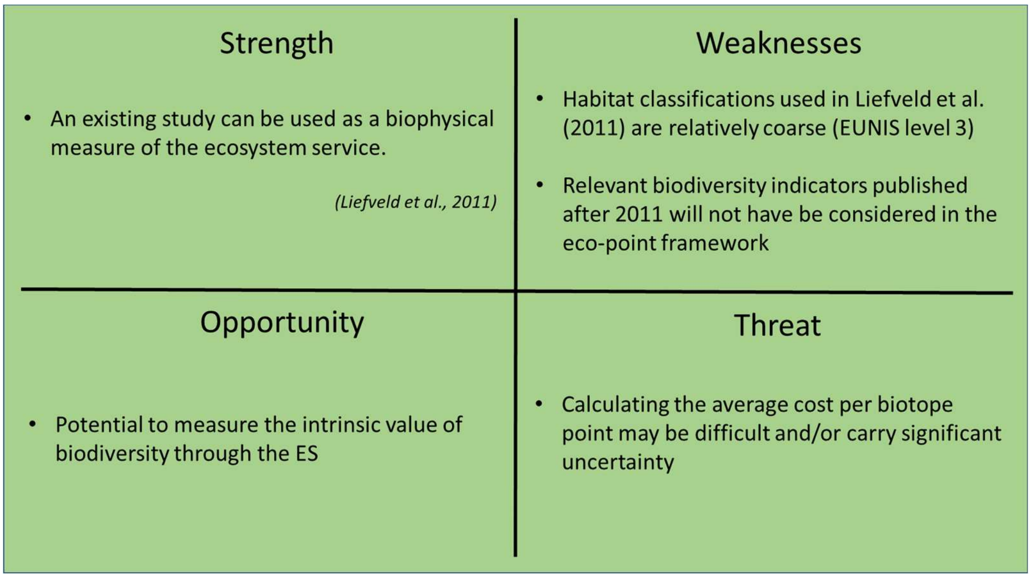
To do this, the authors reclassify common land-use and ecosystem classification systems to obtain 300 detailed ecosystem types for Germany's terrestrial extent. They then apply 'a biotope point' system, whereby each ecosystem type is assigned a biotope value, based on its condition. Biotope points consider ecosystem characteristics such as naturalness, age, the occurrence of endangered species or the degree of threat (Schweppe-Kraft & Ekinci, 2021). Biotope points range from 0 (pavements) to 24 (natural forests), increasing or decreasing by a maximum of three points depending on the condition of the ecosystem type. An average biotope value for each ecosystem type was calculated for Germany's terrestrial extent. The total biotope value for the country was estimated at 415.7 Mio. points in 2018, comprising the 'physical' asset of the ecosystem and species appreciation service.

To estimate the monetary value of the ecosystem service asset, the authors estimate the average cost of reaching an additional biotope point, based on an approximation of the costs of restoration of ecosystems and the assumption of linear improvement of a habitat. The average cost for an additional biotope point was estimated at €3,634. In 2018, Germany's biodiversity wealth, the stock of the ecosystem and species and appreciation service, was estimated to be €1,408 billion. Assuming a 3% return rate on capital, the annual ecosystem service flow is €45.3 billion, or €1,095 per household every year.

Using 'biotopes' as a basis of analysis is not unique to Schweppe-Kraft & Ekinci (2021). The term biotope is almost synonymous with the term habitat or ecosystem type, and often is used synonymously to these terms. The slight distinctions are that the subject of the habitat is species or population; the subject of the ecosystem type is usually structural relations, functions and services; whilst biotope can be understood as a slightly more wholistic term, where the subject is the biological community (Bastian et al., 2020; Schweppe-Kraft & Ekinci, 2021). A biotope approach has been used in other ecosystem service assessments, such as by Watson et al. (2020) to assess the natural capital value of water quality and climate regulation services within a marine extent in the UK.

The use of a point system based on ecological criteria is a promising means of assessing non-use values for biodiversity. In fact, a study has already built a framework for an eco-point system of evaluation for biodiversity in the Dutch North Sea (see section 4.5). As such the physical and monetary valuation of the ecosystem and species appreciation service for the Dutch part of the North Sea could viably be done by replicating the method used by Schweppe-Kraft & Ekinci (2021). The main difficulty lies in calculating the average cost for reaching an additional biotope point, for which Schweppe-Kraft & Ekinci (2021) do not provide a very detailed method. The authors point to the use of Habitat Equivalence Analysis, which involves estimating the total loss of ecosystem services within the concerned area. Below is a SWOT analysis for the monetary valuation of the ecosystem and species appreciation service in the DNS. Calculating this service is beyond the scope of this paper but could be the focus of future research.

**Monetary valuation of the ecosystem & species appreciation service**
**SWOT analysis**



**Strength**

- An existing study can be used as a biophysical measure of the ecosystem service.

*(Liefveld et al., 2011)*

**Weaknesses**

- Habitat classifications used in Liefveld et al. (2011) are relatively coarse (EUNIS level 3)
- Relevant biodiversity indicators published after 2011 will not have be considered in the eco-point framework

**Opportunity**

- Potential to measure the intrinsic value of biodiversity through the ES

**Threat**

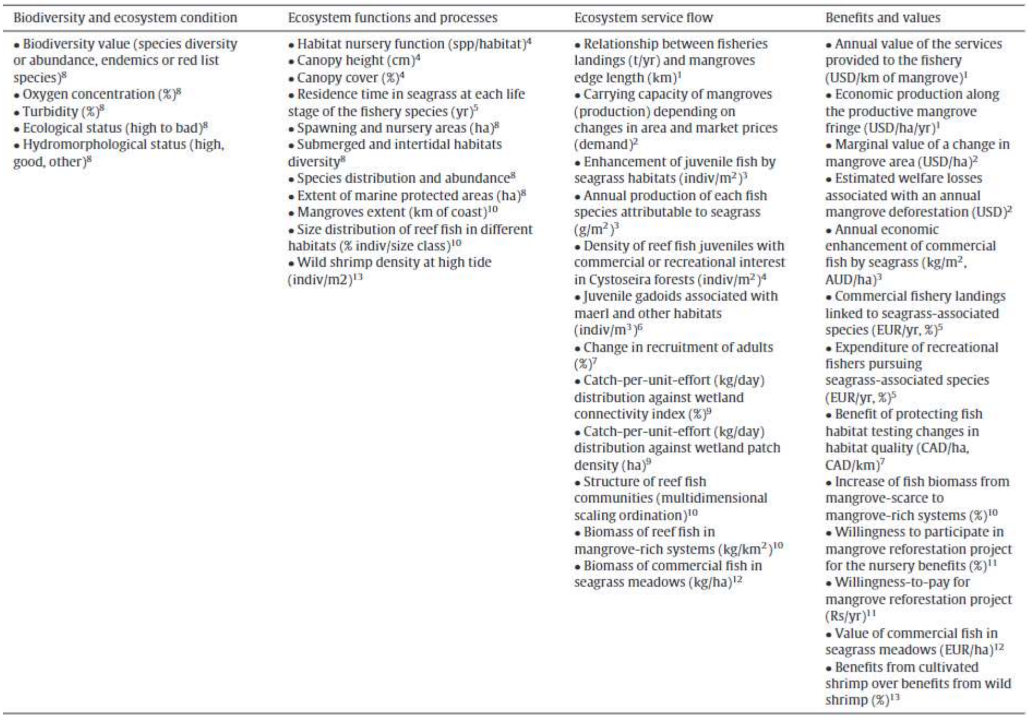
- Calculating the average cost per biotope point may be difficult and/or carry significant uncertainty

#### 4.2.5.2 *Nursery population and habitat maintenances*

The nursery population and habitat maintenance service is a regulating service according to CICES and is particularly relevant in the context of biodiversity in the marine environment because this service is heavily linked to fishing pressures (Jackson et al., 2015). Liquete et al. (2016) review the studies that have assessed the biophysical and monetary value of this service. They find that this service has been assessed using a wide variety of methods. These are summarised in table 4. Most studies valuing the monetary benefits of this service measure the added value for commercial fisheries (i.e. use a production function method).

Liquete et al. (2016) discuss the confusion in how the nursery population and habitat maintenance service should be treated during ecosystem mapping and natural capital accounting efforts. Because the service is classified as an ecosystem function/supporting service in a number of ES classification schemes (e.g. TEEB, Beaumont et al. (2008)), there is a question of whether it should be included during exercises of monetary valuation, so as to avoid risks of double counting. This is particularly relevant because the most popular method of monetary valuation for this service involves making explicit its link to provisioning services (see table 4). The authors conclude that the valuation of nursery population and habitat maintenance services are supportive when ES assessment is being used as policy tool for the protection of biodiversity, but that careful consideration should be taken to not account for the value associated with final fisheries twice.

**Table 4. indicators and proxies related to the nursery function extracted from peer-reviewed literature**



| Biodiversity and ecosystem condition | Ecosystem functions and processes | Ecosystem service flow | Benefits and values |
|---|---|---|---|
| • Biodiversity value (species diversity or abundance, endemics or red list species)[8]<br>• Oxygen concentration (%)[8]<br>• Turbidity (%)[8]<br>• Ecological status (high to bad)[8]<br>• Hydromorphological status (high, good, other)[8] | • Habitat nursery function (spp/habitat)[4]<br>• Canopy height (cm)[4]<br>• Canopy cover (%)[4]<br>• Residence time in seagrass at each life stage of the fishery species (yr)[5]<br>• Spawning and nursery areas (ha)[8]<br>• Submerged and intertidal habitats diversity[8]<br>• Species distribution and abundance[8]<br>• Extent of marine protected areas (ha)[8]<br>• Mangroves extent (km of coast)[10]<br>• Size distribution of reef fish in different habitats (% indiv/size class)[10]<br>• Wild shrimp density at high tide (indiv/m2)[13] | • Relationship between fisheries landings (t/yr) and mangroves edge length (km)[1]<br>• Carrying capacity of mangroves (production) depending on changes in area and market prices (demand)[2]<br>• Enhancement of juvenile fish by seagrass habitats (indiv/$m^2$)[3]<br>• Annual production of each fish species attributable to seagrass (g/$m^2$)[3]<br>• Density of reef fish juveniles with commercial or recreational interest in Cystoseira forests (indiv/$m^2$)[4]<br>• Juvenile gadoids associated with maerl and other habitats (indiv/$m^3$)[6]<br>• Change in recruitment of adults (%)[7]<br>• Catch-per-unit-effort (kg/day) distribution against wetland connectivity index (%)[9]<br>• Catch-per-unit-effort (kg/day) distribution against wetland patch density (ha)[9]<br>• Structure of reef fish communities (multidimensional scaling ordination)[10]<br>• Biomass of reef fish in mangrove-rich systems (kg/$km^2$)[10]<br>• Biomass of commercial fish in seagrass meadows (kg/ha)[12] | • Annual value of the services provided to the fishery (USD/km of mangrove)[1]<br>• Economic production along the productive mangrove fringe (USD/ha/yr)[1]<br>• Marginal value of a change in mangrove area (USD/ha)[2]<br>• Estimated welfare losses associated with an annual mangrove deforestation (USD)[2]<br>• Annual economic enhancement of commercial fish by seagrass (kg/$m^2$, AUD/ha)[3]<br>• Commercial fishery landings linked to seagrass-associated species (EUR/yr, %)[5]<br>• Expenditure of recreational fishers pursuing seagrass-associated species (EUR/yr, %)[5]<br>• Benefit of protecting fish habitat testing changes in habitat quality (CAD/ha, CAD/km)[7]<br>• Increase of fish biomass from mangrove-scarce to mangrove-rich systems (%)[10]<br>• Willingness to participate in mangrove reforestation project for the nursery benefits (%)[11]<br>• Willingness-to-pay for mangrove reforestation project (Rs/yr)[11]<br>• Value of commercial fish in seagrass meadows (EUR/ha)[12]<br>• Benefits from cultivated shrimp over benefits from wild shrimp (%)[13] |

Source: extracted from (Liquete et al., 2016)

## 4.3 Ecological value

In their special issue on the ecology of ecosystem services, Limburg et al. (1999) explain that the economic valuation of ecosystem services may not capture the benefits from nature perfectly. Furthermore, ecosystem services place human preferences at the centre of the value attributed to biodiversity, something that this chapter has acknowledged as legitimate but limited. This shows that criteria for economic welfare maximization based on the monetary valuation of ecosystem services should be integrated with other measures and understandings of value, such as social or ecological values.

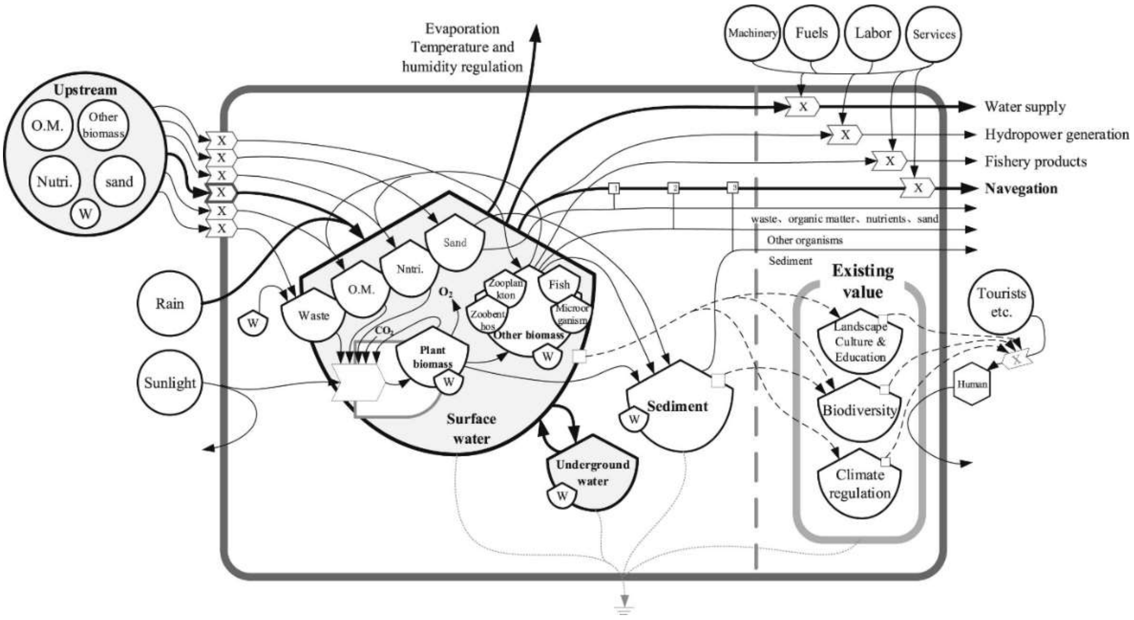
Discussion on ecological values in the ecological economics and environmental geography fields goes back to discussions on critical natural capital (strong vs. weak sustainability). De Groot et al. (2000) identify several ecological criteria for the criticality of nature that include things like the integrity of an area or, the uniqueness of an ecosystem or, its ecological fragility, as well as 4 more criteria. From this purely ecological perspective, biodiversity and ecosystems are close to invaluable since human survival is dependent upon the stable provision of ecosystem services (Limburg et al., 2002). Valuation of ecosystems from an ecological perspective entail identifying the key processes, functions, and interactions within an ecosystem, and probing through modelling which ones are most important, not only for the production of ecosystem services, but also for the health and stability of the ecosystem (Ulgiati & Brown, 2009). Such a system of value ascribes inherent value to the health and integrity of at least some critical ecosystems and processes, making it hard to ascribe monetary values (revealing human preference) to them, as these would technically be invaluable.

### *4.3.1 The Emergy accounting method: An ecological approach to valuation*

One approach in ecology literature that includes the use of monetary values originates from *systems ecology* and is called the 'emergy evaluation method' (EME). This is a biocentric method based on thermodynamics, where emergy (with an m, referring to memory), is a measure of 'the amount of energy, directly and indirectly required for the production of a good or a service' (Nadalini et al., 2021). EME standardizes all energy flows within an ecosystem to units of solar energy (seJ), including inputs from abiotic biological processes such as tidal energy and wind energy, using a conversion factor called the Unit Emergy Value (UEV). As a result, EME characterizes both the flow and stock of energy within ecosystems as well as the flow of energy from ecosystems to human systems. Several papers have used the emergy accounting method specifically within aquatic and marine systems to evaluate ecosystem service provision (Berrios et al., 2017; Rigo et al., 2021). Figure 10 is an emergy diagram created for river ecosystem services for example (Yang et al., 2019). Each arrow represents a transfer of emergy, and each biological resource, process and service has a value in solar emJoules (seJ).

What makes this method particularly interesting in the context of this study is its ability to measure flows of emergy between ecosystems and economy, and to arrive at the monetary valuation of ecosystems and their flows of services through a conversion factor known as the Emergy to Money Ratio (EMR). This measure represents the average amount of emergy required to produce one unit of money in the local economy. It is a ratio of the total emergy supporting a nation and its Gross Domestic Product that year (Vassallo et al., 2017). When converted to monetary equivalents, the value of natural capital and ecosystem services continues to represent the 'donor side' value, which is a measure of the natural capacity measured in terms of solar energy, indiscriminate of the relation to humans.

**Figure 10. Emergy diagram for river ecosystem services**



Source: retrieved from (Yang et al., 2019)

### *4.3.2 Emergy and biodiversity*

Emergy is simply a standardized unit of energy of work potential for the biosphere based on the second law of thermodynamics. It can be linked to several ecological principles and values, including but not limited to biodiversity. Odum (1996) argued that biodiversity would increase proportionally with the increase in renewable emergy in a system. The more species an ecosystem includes, the more solar energy is needed to support interactions among species in each cycle process (Campbell & Tilley, 2016). Concepts such as the energy related to genetic information transmission as well as the energy inputs needed to support a species/population, are directly related to biodiversity and can be made explicit through emergy accounting of a system. Yang et al. (2021) are an example of researchers that use emergy accounting for the evaluation of biodiversity. They use the "emergy-based static accounting method for maintaining biodiversity" to calculate the potential of China's biosphere to maintain biodiversity. They note that a significant limitation of the emergy method is its heavy data requirements. Thus, it seems that emergy values of ecosystems in and of themselves say little about biodiversity but when combined with a sufficient level of detail and accounting can be used to analyse aspects of ecosystem health and diversity closely linked to biodiversity.

The EME is well-suited for representing biodiversity because is it based on a systems analysis and can incorporate complexity in ecosystem processes and functioning better by explaining and predicting transfers of energy between organisms based on established principles of energy transfer and transformation. Inherent to the method is a detailed mapping of energy transfers that lead up to final ecosystem services, and thus there is a good understanding of the importance of the whole system in providing the ecosystem service. Creating such models requires good knowledge of the food web structures and ecosystem processes of analysed ecosystems however, carrying substantial data requirements.

The monetary value of emergy flows reflect the value of biodiversity based on the size and quality of energy stocks and transfers. In this value system, the value of an organism or process is correlated to its size, complexity and age. Even after the monetization of emergy flows and values, the value of biodiversity is based on the ability of a system to provide physical energy that allows for biological processes to use this as input to perform work or grow. This is regardless of the utility of these energy inputs to humans. As such, the EME provides an ecologically based value of biodiversity. Because emergy valuation requires a detailed analysis of energy flows within an ecosystem, the method could be used to measure and weigh the ecological importance of intermediate services and ecosystem processes that lead up to/contribute to final ecosystem services. Using the emergy method in this way could complement the shortcomings of the ecosystem service valuation method described earlier in section 4.2.4.

## 4.4 Prior attempts at valuing biodiversity in the Dutch North Sea monetarily

Liefveld et al. (2011) build a framework for quantifying the benefits from biodiversity-related measures in terms of eco-points. The study uses the EUNIS level 3 habitat classification and evaluate the potential improvement in terms of eco points in the North Sea habitat if two MSFD measures are implemented (introducing hard substrate items in the bottom protection zones and marine litter reduction). The report establishes a methodology for helping decision-making when established impacts on biodiversity from measures under consideration are known. Values used remain in terms of eco-points however and no monetary values are used.

More recently, a study by Wageningen university used a cost-based approach to determining the value of the good environmental state of the Dutch part of the North Sea (Strietman et al., 2018). The report claims that between 0.5 and 1.6 billion euros are spent by the Dutch government in measures to maintain the good environmental state of the marine extent of the Netherlands. These values can be seen as a lower-bound estimate to the willingness to pay for a positive state of the biodiversity in the Dutch part of the North Sea.

### 4.5 Choosing a method for valuing biodiversity monetarily

Nunes & van den Bergh (2001) convincingly argue that the valuation approach and method used for estimating the monetary value of biodiversity should be based on the objective and goal of the valuation in question. This is because different values of biodiversity may be relevant at for different goals. Deciding variables identified by the authors include: 1. Whether the objective is to measure intrinsic or instrumental value 2. What level of biological organization it being valued 3. Whether one is interested in measuring the value of overall biodiversity or a change in biodiversity.

The goal of this project is to measure values of biodiversity that are can be used for biodiversity accounting in the DNS. In theory, all of the methods evaluated could be used to account for biodiversity in monetary terms. This is especially because dedicated biodiversity accounts can be used to include additional information that does not fit the framework of the main accounts in the SEEA EA. The deciding factors on which method is used for the case study in chapter 5 were a matter of practicality in the face of limited data availability as well as time and resource constraints for this project. For example, given limited knowledge of the functioning of the DNS ecosystem, a broader scale monetary valuation method such as valuing the ecosystem and species appreciation services would likely be most favourable. However, biotope information for the DNS is still relatively coarse (EUNIS level 3) and estimating the restoration cost of an average eco-point is beyond the scope of this paper. Thus, for reasons of practicality, the method of revealing the contribution of important biological resources to ecosystem service provision is chosen.

# 5 Marine birds in the DNS

Marine birds are an iconic component of the North Sea ecosystem and feature heavily within the Dutch continental shelf, and along the Dutch coast. Marine birds include all birds that are reliant on either coastal or offshore-marine ecosystems during their annual life cycle. Two categories of marine birds can be distinguished from each other.

1. Seabirds, which includes petrels and shearwaters; gannets and cormorants; skuas, gulls, terns and auks. These are birds that are fully adapted to life at sea and only really come ashore during breeding season. These are pelagic species.

2. Waterbirds, which include shorebirds; ducks, geese, and swans; divers; and grebes. These are species that use the sea to forage but come ashore daily.

Seabirds in the Dutch part of the North Sea include birds originating from colonies in the British Isles, such as Guillemots and Razorbills, which come to ecologically productive areas within the DNS, such as the Frisian front to winter. It also includes species such as the Black-legged Kittiwake that breed in Helgoland as well as other offshore Dutch platforms. Finally, the coastal area, especially the Wadden Sea and the Voordelta areas, host a high number of piscivorous divers, grebes, cormorant, and terns, omnivorous gulls, and benthivorous sea duck (Camphuysen & Leopold, 1994). Marine birds are divided into 6 functional groups: Wading feeders; Surface feeders; Water column feeders; Benthic feeders; Grazing feeders.

**Northern Gennet**

Source : Rass (2010)

Source: https://www.vwgdekulert.nl/

**Common Guillemot**

Source : Schuurman (2022)

**Great crested grebes**

Source : (Pattyn, 2019)

**Sandwich tern**

Source : (Verdaat, n.d.)

## 5.1 State and health of marine bird populations in the North Sea

Historically, seabird populations in the North Sea have been affected by a wide range of pressures due to human use of coastal and marine ecosystems. This includes the direct harvesting of eggs, chicks and breeders in colonies, loss of habitat (coastal and land), overfishing, pollution (mostly from oil discharges), and – more recently - offshore wind farms (Leopold, 2017). According to OSPAR assessments, the abundance of marine birds has been unhealthily low in most of the North Sea since the mid-2000s, despite non-breeding birds in the greater North Sea (the part of the

North Sea containing the Dutch continental shelf) fairing slightly better. The population of a bird species is deemed healthy if the relative abundance (proportion of a species to the total bird population) of that species is above 0.7 (or 0.8 for species that only lay one egg) (OSPAR, 2017b).

Seabird populations however have also benefitted from increased food sources arising from anthropogenic activity. This is due for example, to a greater availability of smaller forage fish, whose predators are the target of fisheries. Another source of food that has benefitted marine bird populations is feed from discards and released catch from fisheries. Even offshore wind farms, despite the significant risks they entail, may also have positive effects on food availability for seabirds due to the formation of new underwater habitats (Noordegraaf, 2020).

## 5.2 Marine birds in the North Sea, their ecological functions and ecosystem services.

Marine birds are amongst the best-monitored animals in marine systems. Rijkswaterstaat has monitored populations since 1984 (Fijn et al., 2019). Marine birds have received particular attention because they are (relative to other biological groups) easy to count and, their abundance is considered to be a good indicator of the general state of the ecosystem (Green & Elmberg, 2014; Rajpar et al., 2018). Because birds are predators at the top of the marine food chain, they are particularly sensitive to changes in the state of lower trophic levels of the marine ecosystem. Their abundance is thus thought to reflect the status and health of the marine habitat, as well as respond to significant changes in the pressures that impact the marine habitat (OSPAR, 2017). Marine birds are used as indicators under the EU Marine Strategy Framework Directive (MSFD) and are part of OSPAR reporting obligations. They are an important indicator for assessing the good environmental status of the North Sea.

When it comes to the evaluation of the ecological role of marine birds in aquatic and coastal systems, the opposite is true. Due to their top predator status, marine birds have traditionally received little attention from studies on ecological functioning or ecological modelling, as their influence was assumed to be negligeable (Green & Elmberg, 2014). Increasingly, studies are finding that this is not the case and that marine birds do indeed play an important role in influencing a wide array of ecosystem processes and services on the local and global scale (Otero et al., 2018; Signa et al., 2021). Research about coastal and marine birds has continuously increased over the years and clarified certain important ecosystem functions and ecosystem services that marine birds contribute to. There remains a significant knowledge gap in understanding how the ecological contribution of marine birds changes across different spatial and temporal scales. As Green and Elmberg (2013) state: the same species of bird can feed and behave differently depending on the ecosystem being considered.

Earlier sections of this report have made the argument that research on ecosystem functioning should address knowledge gaps needed for the evaluation of ecosystem services. This ensures that BEF studies are geared towards practical goals and do not get lost in the complexities of ecosystem processes and functioning. The upcoming parts of this section will aim to estimate monetary values for ecosystem functions and ecosystem services provided by marine birds in the DNS. This method of quantifying the contribution of marine birds to the provision of ecosystem services was chosen because available literature provided the necessary data to do so in a manner that was consistent with the resource and time constraints for writing this report. Because the benefits provided by marine birds are often experienced indirectly or are a minority contribution to an ecosystem service, it seems important to reveal the value of benefits that might otherwise go unnoticed.

## 5.3 Method for revealing monetary values associated with marine birds in the DNS

### *5.3.1 Identifying ecosystem services*

The first step in valuing the benefits of marine birds monetarily is to assess which ecosystem services marine birds in the DNS provide. Despite increasing literature researching the ecological functions and services provided by marine birds, relatively little research has centered around North Sea ecosystems. As far as the author of this paper is aware, no evaluations of the ecosystem services provided by marine birds in the DNS have been carried out. This is important to mention for the reasons mentioned above, i.e., ecological functions and services vary depending on the local abiotic and environmental characteristics of ecosystems. As a best possible alternative, an evaluation of the ecosystem services provided by marine birds in the UK waters by Burdon et al. (2017) is used. All of the bird species monitored in the DNS are included in Burdon et al. (2017), which also includes a number of additional species specific to the UK, namely, the Manx shearwater, European storm-petrel, Leach's storm-petrel, European shag, Arctic skua, Mediterranean gull, little tern and Roseate tern. Table 2 shows the ecosystem functions and services provided by UK marine birds, taken as a point of departure for the functions and services provided by marine birds in the DNS.

### *5.3.2 Identifying available biodiversity indicators*

Next, the biodiversity indicators collected for marine birds in the DNS are identified. Because marine birds are used as an indicator of overall ecosystem condition, only two indicators relating to their abundance are available within the DNS. These are 1. Marine bird abundance (B1) and Marine bird breeding success/failure (B3), corresponding to indicators used for OSPAR reporting.

### *5.3.3 Literature review*

A search was conducted for literature related to the monetary valuation of marine birds using three academic databases: (i) Web of Science (ii) Science Direct and (iii) Google Scholar. First, a general search using the key words ‘economic valuation’; ‘monetary valuation’; ‘marine birds’; ‘seabirds’ was carried out on all three databases. Subsequently, a more specific search was also carried out using the ecosystem services identified by Burdon et al. (2017) as relevant to marine birds in the North Sea (see Table 2) as key words. Publication date was not used as a research criterion for the search. The criteria for selection of a study were two-fold: firstly, the study needed to present a monetary value for an economic or ecological value related to marine birds and secondly, the study needed to present such values for at least one seabird present in the Dutch part of the North Sea. This resulted in three different methods of monetary valuation being identified. These were studies using direct market valuation methods to evaluate an ecosystem service provided by marine birds (Replacement cost method); studies using indirect market valuation methods to evaluate the cultural services provided by marine birds (Travel cost method); studies using a replacement cost method to estimate the total economic value of marine birds. A few studies using non-market methods (stated preference method) that estimated the value of endangered marine bird species met the research criteria but were disregarded for lack of applicability to the DNS context because the studies were in a very different geographic location.

The result of the literature review was the identification of ecosystem functions and services provided by marine birds that were considered viably monetizable given current knowledge and data. Of the ecosystem functions and services listed in table 2, one ecosystem function and one ecosystem service that marine birds provide have been thoroughly assessed, quantified, and valued in scientific literature. These are: (i) the nutrient cycling function contributed to by marine birds and (ii) the tourism and nature watching (recreational) cultural service provided by marine birds.

## 5.4 Nutrient cycling by marine birds

Seabirds and waterbirds provide an essential service by cycling and distributing nutrients - mainly Nitrogen (N) and Phosphorus (P) - across a multitude of distances from their colonies. Marine birds are very important to global nutrient flows. As Otero et al. (2018) identify, the N and P flows from marine birds are of the same order of magnitude as any other global process cycling these elements. On a more local scale, the nitrogen and phosphorus released through the faeces of the birds can have a significant impact on primary productivity in both coastal systems (especially salt marshes) as well as marine systems (by enhancing e.g., phytoplankton productivity). This is because N and P are often limiting nutrients in these environments (Green & Elmberg, 2014). Young et al. (2011) reviews the literature on the impacts of seabird N on surrounding ecosystems. Most studies report a positive bottom-up effect of nutrient cycling from seabirds. The most robust evidence for increasing marine biodiversity from seabird nutrient deposition has come from studies tracking the enriched Nitrogen isotope from pelagic origin, up through the marine food chains in areas surrounding bird colonies. They find that macro algae show enriched Nitrogen (traceable to birds) in their composition. Findings suggest that N and P deposition from seabirds can benefit biodiversity by increasing primary productivity, but also can be linked to benefits up the food chain notably increased abundance of gastropods, bivalves, sponges, and copepods (Kazama, 2019).

Several studies have quantified the biophysical amount of Phosphorus and Nitrogen deposited by seabirds (Blackall et al., 2007; Graham et al., 2018; Otero et al., 2018). Using this data, Plazaz-Jimenez & Cianciaruso (2020) use the replacement cost method to value this ecosystem function provided by marine birds. To do this, they estimate the cost of replacing the equivalent nutrient deposition of seabirds, with human-made fertilizer sold on international markets. They estimate that nutrient deposition from seabirds is worth 454M USD globally. This study lays out a means to value the nutrient deposition provided by marine birds. By valuing this ecological function, the authors estimate the cost of various threats such as climate change and severe weather, bycatch and overfishing, energy production and mining etc., in terms of their cost to nutrient cycling. For example, they find that climate change threatens 80% of N and P deposition despite only threatening 44% of bird species. This is because climate change tends to threaten larger sized species. Valuation exercises such as these are clearly geared towards advocacy.

**Table 2. Ecosystem functions and ecosystem services provided by marine birds in the UK**

| Ecosystem functions | Definition | Role of Seabirds |
|---|---|---|
| **Nutrient cycling** | The influence of coastal and marine biota on the movement or exchange of organic and inorganic matter. | Seabirds have an influence on nutrient cycling processes. They are significant consumers of primary production; colonial seabirds in particular transport nutrients from pelagic waters to island and coastal breeding sites. The input of nutrients (e.g., nitrogen, phosphorus) can contribute to an increase in primary productivity within and or in the vicinity of the breeding site. A significant fraction of the nitrogen at breeding colonies is also lost as ammonia ($NH3$) emission to the atmosphere and can have an impact on the local ecosystem |
| **Formation of species habitat** | The contribution of coastal and marine biota to habitat formed by one species but providing suitable niches for other species. | Seabird colonies provide and enhance species and habitat diversity. Several global studies have shown the physical and chemical impact seabird colonies can have on the terrestrial habitat, and their subsequent effects on primary producers (e.g., plant) and consumers (e.g., arthropods). Of particular UK relevance are true burrow nesting seabird species such as Atlantic puffin and Manx shearwater which form burrows along sea cliffs and islands. These species can make a significant physical impact to the habitat by improving fertility and soil structure (i.e., biopedturbation) and potentially providing a suitable niche for other species to habit. |
| **Formation of seascape** | The contribution of coastal and marine biota to supporting the formation of different coastal and marine views (‘seascapes’). | Seabird colonies are part of the seascape. Colonial seabirds (e.g., Northern gannet, Black-legged kittiwakes, and auks) that nest in large numbers on cliffs and are widely distributed along the UK coastline in summer, are an inherent part of the seascape that is widely recognized by society. As such, these species score more highly than those seabird species, which may be of smaller size colony, of nocturnal habits or nesting in offshore islands (e.g., petrels and shearwaters). |
| **Biological control** | The contribution of coastal and marine biota to the maintenance of population dynamics, resilience through food web dynamics, disease, and pest control. | As a top predator, seabirds control marine organisms. Given the role of seabirds in marine food webs then they contribute to biological control as they feed on fish and other marine organisms. |
| **Waste breakdown and detoxification** | The presence of coastal and marine biota which have the potential to remove anthropogenic contaminants and organic inputs. | Seabirds play an important role in waste breakdown. Many seabird species are reliant on offal and discarded fish for their survival, in particular Northern gannets, Northern fulmars, large gull species and skuas. These scavenging birds contribute, albeit at low levels, to waste breakdown at sea and around harbours, and thus enable species lower down the food web to feed on organic inputs. This service is mostly provided by scavenging gulls; there is indirect evidence that |

| | | |
|---|---|---|
| | | Herring gull and Lesser black-backed gull, make a significant contribution to this service by breaking down and removing organic matter at landfill sites. |

| **Ecosystem Services** | **Definition** | **Role of Seabirds** |
|---|---|---|
| **Waste burial / removal / neutralisation** | Contribution of coastal and marine biota to achieving pre- defined policy standard related to waste levels in water by natural waste burial, removal, and neutralisation. | Seabirds are natural scavengers, and they contribute towards this good/benefit by recycling organic matter (e.g. discarded fish and offal) back into the marine ecosystem. This good/benefit is provided by the scavenging gull species, Northern gannets and skuas. Herring gull and Lesser black-backed gull make a significant contribution to this good/benefit to society by breaking down and removing organic matters at landfill sites. These species can travel from coastal colonies to inland landfill sites to exploit this food source. |
| **Tourism and nature watching** | Benefits from recreation, leisure driven by coastal seascapes and their associated coastal and marine biota. | Seabird species, as contributors to the natural seascape provide significant contributions in the form of tourism and in particular nature watching. For example, gull species are synonymous with the characteristic UK seaside. In addition, both Northern gannet and Atlantic puffin contribute to this good/benefit as they are charismatic species, and found in relatively large numbers around the coast. Species which are observed in lower numbers or breeding further offshore are considered to contribute less to this good/benefit (such as the petrels and skuas). Literature on site management and policy links seabirds to tourism and recreation. |
| **Spiritual and cultural wellbeing** | Ability to enjoy preferred lifestyle, culture, heritage, folklore, religion, creative inspiration, and spirituality; sense of place (use-driven) based on ecosystem aspects. | Seabird species form part of the seascape and therefore may contribute to spiritual and cultural well-being. |
| **Aesthetic benefits** | Enjoyment of the beauty of coastal and marine seascapes. | Seabirds form part of the natural UK seascape and therefore make significant contributions to aesthetic benefits. Species which are coastal and/or found in larger colonies are likely to provide more of this good/benefit than those that are observed in lower densities further offshore. |
| **Education, research** | Enjoyment of formal and informal education, research and science, knowledge systems, etc. in which coastal and marine biota play a role and are a source of information. | Seabird species have historically been well studied and therefore all have contributed to this good/benefit. |
| **Health benefits** | Relate to human physical and psychological health benefits<br>associated with the direct and indirect use of the coastal and marine environment. | All seabird species are deemed to contribute to physical health benefits (e.g. exercise from physical activity). Some species are deemed to contribute and reinforce positive psychological and mental health benefits both from the pursuit of activities (e.g. recreation, education) and through existence values that reinforce connections to the natural world. |

**Source:** *Retrieved and modified from* Burdon et al. (2017)
Note: Burdon et al. (2017) use a combination of academic literature and expert opinions to select the ecosystem functions and services presented in table 1. The original table in Burdon et al. (2017) includes provisioning services but is removed here as it is deemed not relevant to the DNS. Additionally certain terminology was changed to better match CICES. Given the inclusion of additional marine bird species for the construction of the table, it is possible that some of the ecosystem functions and services evaluated do not apply to the DNS. Furthermore, the role of marine birds is also likely to be different in the DNS for a number of services.

### *5.4.1 Monetary valuation - the nutrient cycling function provided by marine birds in the DNS*

Table 5 shows the result of replicating the replacement cost method used in Plazaz-Jimenez & Cianciaruso (2020) for the marine bird population of the Dutch part of the North Sea. It is estimated that marine birds in the DNS, excrete around 354 509 kg of N, and 59 410 kg of P in the sea annually. The nitrogen deposition of marine birds in the DNS is estimated to be worth $618\,086\,EUR$[6] in 2018-2019. The phosphorus deposition of marine birds in the DNS is estimated to be worth or $213\,287\,EUR$ in 2018-2019.

**Table 5. Nutrient deposition by marine birds in the Dutch North Sea**

| **Sea bird species** | **Estimated average yearly population on the DCS** | **Total N excreted by the population (kg N per year)** | **Total P excreted by the population (kg P per year)** | **Replacement cost in terms of Urea [CO(NH2)2]** | **Replacement cost in terms of TSP [(Ca(H2PO4) 2. x H2O]** |
|---|---|---|---|---|---|
| Northern Fulmar | 16 035 | 431 | 72 | € 751.03 | € 258.14 |
| Northern Gannet | 15 893 | 55 204 | 9 206 | € 96,248.03 | € 33,103.97 |
| Great Coromant | 32 | 48 | 8 | € 83.57 | € 28.72 |
| Little Gull | 7 080 | 857 | 150 | € 1,494.91 | € 539.56 |
| Kittiwake | 49 913 | 31 442 | 5 220 | € 54,819.49 | € 18,769.28 |
| Black-headed Gull | 203 | 62 | 10 | € 107.95 | € 37.14 |
| Common Gull | 2 040 | 908 | 151 | € 1,582.28 | € 543.62 |
| Herring Gull | 2 634 | 2 267 | 378 | € 3,953.22 | € 1,357.84 |
| Lesser Black-backed Gull | 11 295 | 9 134 | 1 522 | € 15,925.19 | € 5,474.15 |
| Great Black-backed Gull | 5 718 | 6 764 | 1 124 | € 11,792.69 | € 4,043.17 |
| Sandwich Tern | 4 959 | 1 117 | 187 | € 1,947.65 | € 672.99 |

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[6] Using exchange rates from August the 23rd 2022 and the average price of Urea over 2022. 1 USD=1.007354 EUR

| | | | | | |
|---|---|---|---|---|---|
| Common Arctic Tern | 34 704 | 4 309 | 723 | € 7,513.07 | € 2,601.14 |
| Great Skua | 353 | 418 | 69 | € 729.07 | € 247.45 |
| Atlantic Puffin* | 516 | 120 | 20 | € 209.67 | € 72.08 |
| Common Guillemot* | 236 302 | 208 922 | 34 820 | € 364,255.03 | € 125,209.77 |
| Razorbill* | 46 299 | 32 506 | 5 653 | € 56,673.36 | € 20,328.02 |
| **TOTAL** | **433 976 birds** | **354 509 kg** | **59 314 kg** | **€ 618,086.21** | **€ 213,287.04** |

**Species for which there is a maximum and minimum population estimate depending on statistical corrections. For these species the lower end of the confidence interval for the maximum estimated value is taken*

Technical note: No information regarding the nutrient excretion of the red-throated diver was found, leading to the omission of this species from the monetary valuation. Since the average yearly population of the red-throated diver is only estimated to be around 770 individuals (out of the approximately 430 000 birds monitored), omitting the species likely has a negligeable effect of the overall value estimate. Also, the dataset used for marine birds did not include Duck species.

### *5.4.2 Impacts on ecosystem functioning in the DNS*

No research into the ecological impacts of marine bird nutrient subsidies exists specifically for the Dutch part of the North Sea. Most studies evaluating the impact of marine bird nutrient deposition on ecosystem functioning and biodiversity have done so on, or, on the surroundings of large bird colonies (e.g. Graham et al. (2018); Sánchez-Piñero & Polis (2000). Studies on the impact of marine bird nutrient subsidies on seabird islands largely show a significant influence and impact on island primary production as well as species richness and compositional structure, although impact was not always positive (but mostly was) (Ellis, 2005). Seabird colony size does seem to be a determinant of the size and nature of the biological impact associated with nutrient deposition both on the terrestrial extent and surrounding coastal ecosystems. Kolb et al. (2010) for example, find that only islands over a certain threshold density of seabirds impact the abundance of invertebrates and algae in coastal waters, theorizing that island soil and vegetation might absorb N and P at lower densities. Whereas nutrient deposition from marine birds generally increases species abundance, richness and primary productivity, it is not clear whether such changes should be considered ecologically beneficial per se.

Amongst the studies that have evaluated open ocean systems (most relevant for the DNS), varied results have been found regarding the effects of nutrient deposition on ocean ecosystems. A few studies find no visible effect from nutrient deposition but, most studies report an increase in primary productivity, with some studies also finding impacts on marine consumers further up the food chain, as mentioned previously (Kazama, 2019; Zmudczyńska-Skarbek et al., 2015). The impacts of nutrient deposition could vary based on factors such as: water temperature and light conditions; sea-bottom topography; turbulence caused by waves; the flow of nutrients from other sources than marine birds (Kazama, 2019). According to the author, there is not enough research to make strong claims on how impacts of nutrient deposition could vary in open oceans, but research seems to suggest there is an effect of nutrient deposition on marine and coastal ecosystems.

At the time of writing this report, an ongoing study by the Netherlands Institute for Sea Research and Utrecht university hypothesises that marine birds sustain some of their own breeding and roosting sites in the Wadden Sea through their nutrient depositions (Royal NIOZ, 2021). This concerns small and sandy back-barrier islands, whose development depends on sediment stabilizing interactions steered by vegetation. Because these islands are usually nutrient poor, it is hypothesized that seabirds play an important role in sustaining the islands, by promoting vegetation through their nutrient cycling function. This project would be a first, in analysing the role of marine bird nutrient deposition in soft-sediment coastal ecosystems and is due to be completed in 2025.

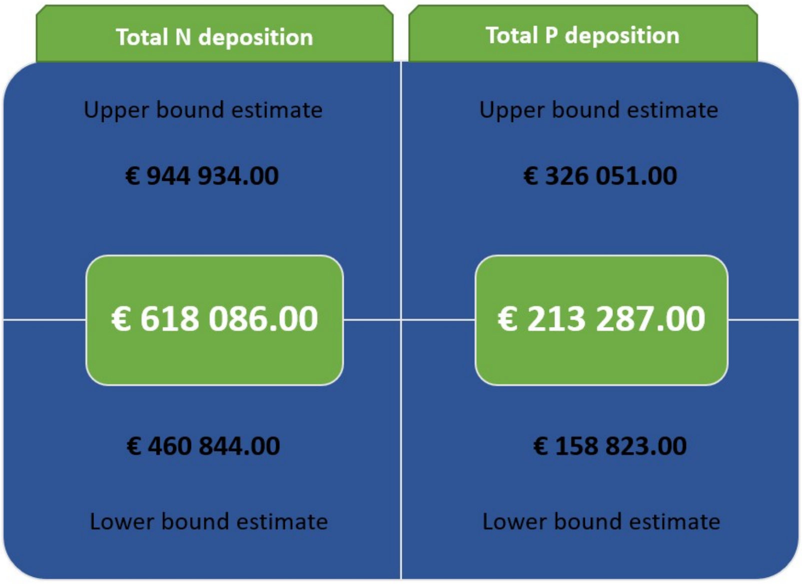
### *5.4.3 Benefits from nutrient cycling in the DNS*

One way of understanding the value of the change in ecosystem functioning and biodiversity occurring as a result of seabird nutrient depositions would be to associate final ecosystem services to the changes in question. Once again, not enough is known regarding the impacts of nutrient subsidies on the functioning of Dutch coastal and marine ecosystems for ecosystem services, let alone their benefits to be derived. Plazaz-Jimenez & Cianciaruso (2020) do manage to estimate the monetary value of the benefits of marine bird nutrient deposition to coral reef fisheries. This is one of the only systems where data robust enough to determine an ecological function based on marine bird nutrient deposition is possible (i.e., ability to relate change in nutrient cycling to change in ES provision) (Graham et al., 2018). Valuing the nutrient cycling ecosystem function can be seen as a concession and best alternative to this limitation. Perhaps more relevant than the value of benefits provided by marine bird nutrient cycling to humans through ecosystem services is the ecological value brought about through this function. Seabirds are a keystone species in a number of habitats, and as mentioned, their presence has been shown to significantly alter rates of primary productivity and the abundance, richness and composition of food webs in most studies (Grant et al., 2022). A number of studies also reported negative impacts of seabird nutrient deposition, mostly as a result of ‘guanotrophication’, whereby excessive nutrient loads caused eutrophic responses from the ecosystems analysed. Vizzini et al. (2016) monitor the response of coastal ponds in Italy and find that the pond with significant nutrient subsidies from gulls generally has less complex food web structure, eroding benthic pathways in favour of planktonic ones. Because of the significant variation in how nutrient subsidies from marine birds may affect biodiversity, and the fact that bird colonies are often away from human populations, perhaps measuring the value of seabird nutrient deposition in terms of ecological criteria such as those described in section 4, which are independent of human value makes more sense.

### *5.4.4 Sensitivity*

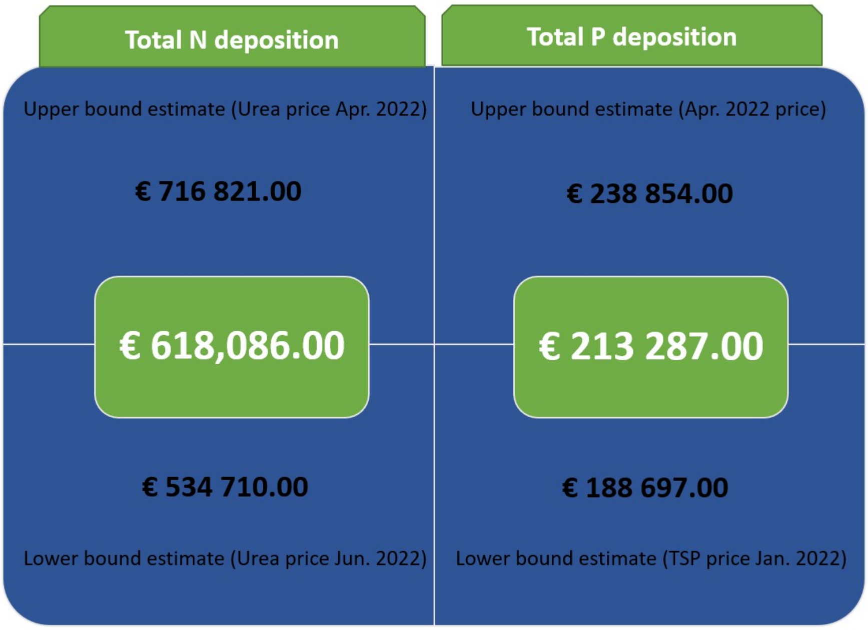
The monetary values found for the nutrient cycling function of marine birds depends highly on the price of fertiliser used for the calculation. Fertiliser prices, in turn, are highly volatile. The price of Urea for example, has increased by more than 300% in the past two years (Baffes & Chian Koh, 2022). The monetary estimates are also dependent upon the marine bird population estimates used. Population estimates of marine birds in the DNS are based on observational surveys. Estimates for the continental shelf are extrapolated from these. As such, the monetary values calculated for the nutrient cycling function of marine birds in the Dutch part of the North Sea reflect the uncertainty in bird population estimates. Figure 11 shows the replacement cost value using the lower and upper bound population estimates, corresponding to the 95% confidence interval of estimates reported by (Fijn et al., 2019). Figure 12 shows the monetary values, using the minimum and maximum price of fertiliser in 2022.

**Figure 11. Results of sensitivity analysis based on 95% confidence interval of marine bird population estimates in the DNS**



Much of the variation in the monetary estimates is due to uncertainty in the population of the Common Guillemots. Guillemots are by far the most common bird species across the Dutch continental shelf and contribute to around 50% of both Nitrogen and Phosphorous deposition. The population of Guillemots is corrected for availability bias when the populations are estimated. This is a statistical correction to account for the fact that birds may choose to dive when the monitoring plane flies over. This results in a significant uncertainty in the number of Common Guillemots, and thus, uncertainty in the valuation of their nutrient subsidies.

**Figure 12. Results of sensitivity analysis based on minimum and maximum fertiliser prices in 2022**



## 5.5 Tourism and Nature watching services provided by marine birds

Marine birds and marine bird biodiversity are important cultural assets. Marine birds can be the source of significant entertainment and scientific value, both of which are suspected to contribute to the cultural value from birds in the North Sea (Noordegraaf, 2020; Burdon et al., 2017). The most widely valued cultural service relating to marine birds are their recreational services, the ‘tourism and nature watching‘ services in table 1. Marine birds are appreciated by a wide range of people undertaking outdoor activities or experiencing natural landscapes on the coast or at sea. Appreciation from recreation may range from visual and auditory aesthetic experiences, to increases in well-being and feelings of connectedness to nature (Costa et al., 2012; MEA, 2005; Soga & Gaston, 2020; Tribot et al., 2018). Recreational services provided by marine birds are highly linked to other recreational services provided by other biological resources. Birdwatching tourism is often combined with other wildlife tourism, especially amongst casual birders. Around 20% of European travellers engaging in wildlife tourism reported also being interested in bird watching (CBI, 2021). The diversity in marine birds may itself be a source of value but it is not clearly understood which specific aspects of biodiversity are linked to cultural services (Sali et al., 2008). For example, different values may be derived from experiencing a large abundance of one bird species, or a large species richness of birds or even wildlife spectacles such as flocks of birds flying through the sky (Boeri et al., 2020)

In practice, it is hard to value the recreational benefits provided by marine birds alone, without also considering the other biological resources that are present in the habitats and landscapes where the birds are observed. In some cases, this might be possible, especially when it is clear that bird watching is the primary recreational activity that is being undertaken. This is the case in the study by Ruiz-Frau et al. (2013), who evaluate the economic value and geographic distribution of the non-extractive recreational activities that depend on marine biodiversity on the Welsh coast. The authors estimate the value of scuba diving, sea-kayaking, wildlife viewing cruises, and seabird watching activities separately. They do this by determining the daily average expenditure per activity per day on the basis of a 10x10km grid. Using information collected on travel cost and total duration of stay by means of a survey, the researchers estimate an average cost of 28±30 GBP p/d. The total economic expenditure derived from seabird watching activity in Wales was estimated at approximately 3.7 million GBP per annum (Ruiz-Frau et al., 2013).

Ruiz-Frau et al. (2013) were the only study found that estimated a monetary value for the experiential use service of marine birds. They did this by estimating the total expenditure associated with seabird watching on the Welsh coast. To calculate this value, the researchers needed to know the total seabird watching population in Wales and their average expenditure. As a best possible guess for the total seabird watching population, the researchers use the annual number of visitors to Royal Society for the Protection of Birds (RSPB) marine reserves in Wales. This implicitly assumes that these reserves are the only place where seabird watching takes place and that everyone visiting these reserves went solely for the purpose of birdwatching.

The Netherlands boasts an important birdwatching culture and community of avid birders. Two important organizations are Voegelscherming, a national bird nature conservation organization and magazine with approximately 150 000 members and the Dutch birding association, a non-profit organization run by volunteers that publishes scientific journals on a bi-monthly basis. The coastal areas of the Netherlands specifically, are known to host a high number of rare bird species throughout the year, making them attractive tourist destinations (Visdief, 2020).

### *5.5.1 Monetary valuation – Tourism and nature watching services provided by marine birds in the DNS*

The consumer expenditure method used by Ruiz-Frau et al. (2013) is similar to the travel cost method for estimating the value of an ecosystem service. Typically, consumer expenditure includes expenditure incurred on food and drink, accommodation, and travel costs for duration of the activity visit. This method is commonly used for assessing the value of outdoor recreation services. The consumer expenditure method has been used to calculate the nature recreation and nature tourism cultural services for the Netherlands, whose annual yearly supply in 2015 is estimated around €5 946 000 000 and €3 873 000 000 respectively. The consumer expenditure method is also used here to estimate the value of the tourism and nature watching ecosystem service provided by marine birds in the DNS.

To apply the consumer expenditure method, two pieces of information are needed. 1. An estimation of the total bird-watching population in the Netherlands and 2. Information regarding the average expenditure on birdwatching. As noted above, it is very hard to disentangle the tourism and nature watching benefits of marine birds from other elements of the coastal seascape that are likely to also contribute to the overall ecosystem service for the Dutch North Sea. Furthermore, no data exists regarding the specific expenditure of birdwatchers in the Netherlands. Nonetheless viable concessions are thought to be possible to arrive at a value using current knowledge and data.

### *5.5.2 Estimating the total bird watching population*

The best estimate of the Dutch birdwatching population comes from Doodeman, (2022)'s book 'Vogelaars (nooit) uitgevogeld' (bird watchers (never) figured out). The book is a popular educational book on birdwatchers but is published in collaboration with reputable organizations such as SOVON and Vogelbescherming. According to the book, there are around 75 000 birders in the Netherlands, corresponding to 0.43% of the population.

The physical natural capital accounts for the Dutch North Sea use hiking as an indicator for the nature recreation service because it is the most popular outdoor activity in the Netherlands. 2025 000 000 hikes took place in the coastal areas of the Netherlands directly surrounding the North Sea in 2015. To estimate the total birdwatching population on the coast, it is assumed that the proportion of birdwatchers to total population is the same for those undertaking hikes on the coast. Thus, it is estimated that $(2025\,000\,000\ \times 0.0043) = 8\,707\,500$ hikes are birdwatching hikes in coastal areas. i.e., hikes performed with the purpose of observing seabirds.

### *5.5.3 Estimating the average expenditure per hike*

Data regarding the consumer expenditure during hikes was retrieved from national surveys carried out by the Statistics Netherlands, ContinuVakantieOnderzoek (CVO) surveys. This data is publicly available for the year 2018 and is the same data that was used for estimating the expenditure costs of tourism and recreation services for the terrestrial part of the Netherlands.

**Table 3. Consumer expenditure for recreational hiking in the Netherlands in 2018**

| Average spending p.p. per hike | Euros |
|---|---|
| Entrance fees | 0.1 |
| Consumption | 0.8 |
| In store | 0.7 |
| Other costs | 0.2 |
| Transport costs (incl. parking) | 1.97 |
| Total | 3.77 |

Source: Retrieved form ContinuVrijeTijdsonderzoek 2018 basis rapport (p. 56) (CVTO, 2018)

### *5.5.4 Value of the final ecosystem service*

$$8707500\ \times 3.77 = 32\,827\,275\ \approx 32.8\,Million\ euros$$

The value of the tourism and nature watching ecosystem service provided by marine birds on the coast of the Dutch North Sea is estimated to be worth around 32.8 million euros annually.

### *5.5.5 Limitations and uncertainty*

If one is to compare the estimate calculated for the tourism and nature watching ecosystem service derived from the birdwatching population in the Dutch North Sea with the same ecosystem service in Wales, there is a difference in value of an entire order of magnitude (32.8 million vs. 3.7 million) (Ruiz-Frau et al., 2013). It is unlikely that such a large difference is justifiable given the similar sizes of the territories in question. Representing birdwatching trips in terms hikes likely overestimates the number of trips taken for the purpose of bird watching near the coast (8.7 million hikes). Although this only corresponds to around 2.3 birdwatching hikes per birder per week – which according to Doodeman (2022) would be within normal for an average birder – when one considers the fact that these hiking trips represent trips to the coast and disregard other inland hikes, this is likely an overestimate.

Nonetheless, the monetary estimate found makes sense within the context of the rest of the Dutch cultural services and Dutch natural capital accounts. There is consistency in the indicator used for estimating the tourism and recreation service. As would be expected, the share of the nature-related expenditure from birdwatching is only a small share of the total ecosystem service (estimated between 3.2 billion and 9 billion euros). It cannot be denied however that survey data specifically relating to birdwatching as an activity in the Netherlands would be ideal for ensuring a more robust and trustworthy valuation.

# 6 Discussion and Conclusion

## 6.1 On the underlying role of biodiversity in the provision of ecosystem services

Biodiversity can be considered a feature of the ecological side of the ecosystem cascade model, i.e., ecosystem structure, ecosystem function and ecosystem services. Diversity in biotic life of marine ecosystems is likely to play a role in the stability and magnitude of the provision of ecosystem services however a review of the literature on BEF functions in marine environments suggests that more research into certain complex dynamics such as the influence of species-species interactions across the food-web and the supporting role of the abiotic environment needs to be carried-out before causal links can be drawn between biodiversity and ecosystem service provision. Nonetheless, the current research in BEF relationships might be enough to support, top-down linkages between ecosystem service provision and biodiversity by identifying biological resources and processes that are key ecosystem service providers. There is room within the SEEA EA to integrate this information to create operationally linked ecosystem condition accounts, to enable more accurate natural capital accounting and monetary valuation of changes in the biological state of the Dutch part of the North.

Linking ecosystem condition to the supply and use of ecosystem services is a research frontier within the natural capital accounting and marine conservation communities. This line of research opens up questions about the ability of biodiversity indicators as currently devised under existing institutional frameworks to inform natural capital accounting. A JNCC draft report explores exactly this question for benthic biodiversity indicators in the UK. They find that traditional biodiversity indicators respond primarily to ecosystem pressures and do a less good job at indicating ecosystem functioning and ES provision. Whereas there is significant potential for natural capital accounting to be linked to, and contribute to decision-making regarding biodiversity, there is a clear need to for more research on the ecosystem functioning of marine systems to enable scientifically backed decision-support tools.

## 6.2 Methods and approaches for the monetary valuation of marine ecosystems in the DNS

Accounting for biodiversity may also be done through biodiversity accounts, in which case there is less of a need for the unified research and policy area advocated for prior. This report identified three approaches that can be taken to value biodiversity monetarily in the DNS. Broadly speaking, these methods revealed either the instrumental or intrinsic value of biodiversity. These included 1. Measuring the value of final ecosystem services as a means of valuing biodiversity in the DNS. This method essentially corresponds to the sum of the monetary ecosystem asset values identified by the NCA efforts for the DNS. 2. Revealing ecosystem services that are heavily linked to biodiversity. This could either take the form of quantifying and valuing the role of specific biological resources for the provision of ecosystem services, or 3. It could take the form of quantifying only certain ecosystem functions and services that are linked to biodiversity in the strict definition of the word. A promising example of the latter that was explored is using a biotope point system to value the ecosystem and species appreciation service in the DNS.

Depending on the context, it is possible that ecosystem functions (or intermediate ecosystem services) and ecosystem processes are the best measures biodiversity in a system. The evaluation and monetization of the ecosystem functions may cause an issue when included within natural capital accounts because of the risk of double counting the benefits from biodiversity. One way of integrating the value of ecosystem functions/intermediate services into natural capital accounting frameworks that monetize final ecosystem services would be to use the emergy method to disaggregate the contribution of ecosystem functions to the final ecosystem service. The emergy method is particularly well suited to the analysis of complex systems and has a value system independent of human preferences. As such, its use to represent important ecosystem functions and processes that might otherwise be left out of natural capital accounts for reasons of double counting could be beneficial to the complete evaluation of biodiversity within natural capital accounts.

Regardless of the valuation method under consideration, a commonality was that there are significant limitations to the employment of these methods due to poor data and information availability. Most valuation methods would benefit from proprietary research into ecosystem condition and ecosystem functioning within the DNS. However, the measurement of the ecosystem and species appreciation service could yet be done using an existing eco-point framework for the DNS. This service is unique in its ability to reveal the intrinsic value of biodiversity and has a precedent of being monetized. The main challenge in assessing this ecosystem service monetarily involves the calculation of an average cost per eco-point. Evaluating this ecosystem service based on the methods detailed in section 4.2.5.1 could be the subject of future research.

## 6.3 Monetary values for the benefits provided by marine birds in the DNS

Given practical limitations, the approach of revealing monetary values for key biological resources was taken with marine birds as the subject of valuation. Firstly, the value of the nutrient cycling function carried out by marine birds in the DNS was valued at around 830 000 EUR. Secondly, the value of the tourism and nature watching ES provided by marine birds was estimated to be around 32.8 Million EUR.

The valuation of the nutrient deposition function provided by marine birds says how much it would cost for man-made substitutes to carry-out the same function. However, only part of the nutrients cycled result in benefits for surrounding ecosystems. Because the exact benefits from the function cannot be determined, it is not advisable to use this value in a cost-benefit analysis. This is because the estimated value is in a sense incomplete. It does not incorporate costs (e.g., excess eutrophication) or benefits (e.g., increase in fish yield) to human welfare that the ecosystem function might be precursor to later on in the cascade. The value revealed has more of an ecological logic to it. The logic is the following: Disregarding the benefits, to humans, or, assuming that all nutrient deposition is beneficial in and of itself, the value of nutrient cycling is 830 000 EUR. Yet, we know that in some cases, open ocean systems do not visibly respond to nutrient loading and that in other cases, excess nutrient loads may be highly detrimental to human welfare. Because it is important to measure actual costs and benefits to human welfare during the decision-making process, the monetary value of nutrient cycling cannot be used for decision-making or price setting but may be useful in an advocacy setting.

Contrary to the value found the nutrient cycling function, the tourism and nature watching value represents economic benefits derived by the Dutch population from marine birds. This value likely overestimates the actual expenditure-cost value of the ES but is highly consistent with the rest of the cultural services valued in Dutch natural capital accounts.

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