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Impacts on ecosystem services due to changes in the state of the environment in the North-East Atlantic Ocean

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RWS INFORMATIONS

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Executive summary

In a global context where the health of the ocean is at risk, action is needed to address the loss of biodiversity and the functioning of marine ecosystems. The Northeast Atlantic is no exception to this. This area is characterized by a significant diversity of marine habitats which not only underpin high levels of biodiversity but at the same time support numerous economic activities. For this reason, the OSPAR Convention, being responsible for the sustainable management for this part of the ocean, recognizes the need for a holistic approach to the conservation and management of the marine system and its resources that considers the environmental impacts of human activities. This recognition is reflected in the OSPAR objectives of ensuring a clean, healthy, and biologically diverse sea with a sustainable use of its resources.

To implement its commitments, the OSPAR Commission is embarked on the periodic preparation of Quality Status Reports (QSRs) for the five North-East Atlantic regions intended to provide a holistic and integrated summary of the environmental status of the entire OSPAR maritime area. Currently, OSPAR is working towards the publication of the QSR 2023.

OSPAR through its work recognises the need to safeguard the good state of the North-East Atlantic because it underpins economies and lifestyles, provides food, helps regulate climate, is essential for the supply of energy and raw materials, is a source of recreation and inspiration, and supports millions of jobs. To this aim, OSPAR applies the ‘Ecosystem Approach’, defined as:

“The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity”.

Where ecosystem services are described as the final outputs from ecosystem structures, processes, and functioning that are directly (actively or passively) used by people.

However, so far, consideration of ecosystem services has not been included in OSPAR assessments. In this regard, following the recognition of the need for the integration of an ecosystem services assessment by the OSPAR Commission, the present work is specifically framed to fit into the context of the QSR 2023, with the aim of developing a methodology for a qualitative assessment of the impacts on ecosystem services resulting from environmental state changes in the OSPAR maritime area that can be used as a source of inspiration for the preparation of the QSR 2023 assessments.

This report is intended to contribute to the application of the ecosystem approach to achieve sustainable use of ecosystem goods and services following the Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030 (NEAES 2030). In particular, this work contributes to taking a further step towards various NEAES 2030 objectives, including the following:

- Strategic Objective 5: Protect and conserve marine biodiversity, ecosystems, and their services to achieve good status of species and habitats, and thereby maintain and strengthen ecosystem resilience;

- Strategic Objective 7: Ensure that uses of the marine environment are sustainable, through the integrated management of current and emerging human activities, including addressing their cumulative impacts;

- Operational Objective 7.03 (under the Strategic Objective 7): By 2025 OSPAR will start accounting for ecosystem services and natural capital by making maximum use of existing frameworks in order to recognise, assess and consistently account for human activities and their consequences in the implementation of ecosystem-based management.

- Operational Objective 12.01 (under the Strategic Objective 12): By 2025 OSPAR will develop a regional approach to applying nature-based solutions for carbon storage and implement specific measures to protect and restore relevant carbon sequestration and storage habitats, such as seagrass beds, kelp forests and saltmarshes.

The marine environment is a complex system. Understanding, assessing, and managing this system requires the application of a holistic approach that recognises the complexity of the system taking into account the diverse range of users and uses of its resources and considering the environmental, economic and social impacts of all human activities. If managed sustainably, marine ecosystems provide a range of ecosystem services that benefit society. Hence, to address the need for a framework that would allow for a system-wide analysis of the complex socio-ecological interactions in the North-East Atlantic, OSPAR is applying the DAPSIR (Drivers-Activities-Pressures-State-Impacts-Responses) framework for the QSR 2023. To apply all aspects of the ecosystem approach in the Quality Status Report 2023, OSPAR recognised the need of an understanding and integration of:

- The Drivers of change
- How human Activities and Pressures affect ecosystems
- The State of marine ecosystems and their changes
- The state change Impacts on marine ecosystem services (and possible consequent impacts on human welfare)
- Integrated management measures (Responses)

OSPAR QSR 2023 is covering all aspects of the marine environment through a range of thematic assessments, including underwater noise, marine litter, marine mammals, etc. These thematic assessments apply the DAPSIR framework, with the components of the DAPSIR setting out the different sections of the thematic assessments. This report is meant to support these thematic assessments by providing a method and information that can be used to complete the far-right part of the DAPSIR framework, and is therefore designed to:

- identify and provide a comprehensive list of marine ecosystem services that can be used in the context of OSPAR and
- develop a methodology for assessing the state change impacts on ecosystem services that can be applied to populate the 'Impacts on Ecosystem Services' sections within the various OSPAR thematic assessments.

The rationale behind the developed methodology is to link, for each OSPAR thematic assessment, the components of state change with the ecosystem services on which they impact, also including specification on the nature of the impact (e.g., positive or negative) and the magnitude of the impact (high/medium/low/unknown). This structure is important because it allows to describe whether a set of state changes described in a thematic assessment might have an impact on more than one ecosystem service, or the provision of one ecosystem service might be influenced by more than one thematic assessment. In this report, the results of the application of the methodology are presented for two case studies:

- Marine Litter (as an example of a pressure-related thematic assessment)
- Marine Mammals (as an example of a biodiversity state-related thematic assessment)

An analysis of state change impacts on ecosystem services is an important step also because it allows to derive the chain of influence on human well-being and economic activities that depend on the adequate provision of ecosystem services, and also on Drivers (and human Activities), thus closing the DAPSIR framework loop. To this end, in the context of this work an initial expert-based attempt to identify the drivers and activities most likely to be affected by changes in the provision of particular ecosystem services was also made.

The identification of a list of the most relevant marine ecosystem services applicable to the North-East Atlantic area and the development of a method that can enable state change impacts on ecosystem services to be assessed represents the link that has been missing in the OSPAR context to render more visible how changes in the state of the marine environment can translate into impacts on human welfare in terms of reducing and/or increasing the goods and benefits that humans derive from marine ecosystems.

The application of this methodology allowed to demonstrate how marine environment state changes caused by pressures from human activities can negatively affect a significant range of ecosystem services. This in turn can entail costs of degradation of the marine environment to society in terms of a reduction in the goods and benefits provided to people by marine ecosystems such as a reduction in seafood, medicine and blue biotechnology, a deterioration in coastal erosion prevention, in marine water quality, and a degradation of benefits to human psychology, health, and tourism activities. However, it is also crucial to emphasise how the application of this methodology allows at the same time to make evident the positive effects on human well-being that can result from the successful implementation of measures that lead to an improvement in the state of the marine environment. Consequently, the presented methodology fills the far-right part of the DAPSIR framework allowing to translate OSPAR assessments into a language that is essential for providing relevant information to policy makers.

It is important to stress that this work was not intended to present definitive results to be included in OSPAR work, but rather to sanction the beginning of the development of a methodological framework that would allow the integration of ecosystem services thinking within various OSPAR assessment workstreams, particularly with the aim of providing inspiration and support for the development of the section on impacts on ecosystem services within the QSR 2023 thematic assessments. This has stimulated several OSPAR experts to think about the importance of ecosystem services and to reflect on the level of relevance of selected ecosystem services in relation to their thematic assessment.

Being a first attempt to link state changes to the use of ecosystem services, this study also results in the following suggestions for future work:

- As a first suggestion, future work could focus on refining the presented methodology for assessing the impacts of a changing state of the marine environment on ecosystem services through specific additions and optimisations. A first improvement would be to seek to integrate quantitative information in relation to impacts on ecosystem service provision, potentially through economic valuation of ecosystem service flows (integrating NCA). Secondly, an explicit spatial approach could be pursued that would allow differentiation between, for example, areas with higher ecosystem service provision that receive a higher/lower magnitude of state change impact and areas with lower ecosystem service provision receiving higher/lower magnitude of impact.

- Another option to go quantitative would be to develop a case study purely focused on one or a couple of ecosystem services whose provision is more easily quantifiable, which would also allow for more spatial detail. One example is carbon storage, which is both more easily quantifiable than other ecosystem services and has high policy visibility. This would further contribute to building synergies with Strategic Objective 12.01, which focuses on developing a regional approach to applying nature-based solutions for carbon storage.

- Future work could also continue to explore the links between ecosystem services and the Drivers and Activities components of the DAPSIR framework and the consequences of impacts on ecosystem services on these components. This step forward may continue on the basis of the first attempt made in the context of one of the workshops related to this work to link ecosystem services with drivers and activities and close the DAPSIR loop. This further emphasises the link between ecosystem services and the human socio-economic domain.

Samenvatting

In een mondiale context waarin de gezondheid van de oceanen in gevaar is, moet actie worden ondernomen om het verlies aan biodiversiteit en de werking van mariene ecosystemen aan te pakken. Het noordoostelijke deel van de Atlantische Oceaan vormt hierop geen uitzondering. Dit gebied wordt gekenmerkt door een grote diversiteit aan mariene habitats die niet alleen de basis vormen van een grote biodiversiteit, maar ook tal van economische activiteiten ondersteunen. Daarom erkent OSPAR, de organisatie die verantwoordelijk is voor het duurzaam beheer van dit deel van de oceaan, de noodzaak van een holistische benadering voor de instandhouding en het beheer van het mariene systeem en zijn hulpbronnen waarbij rekening wordt gehouden met de milieueffecten van menselijk handelen. Deze erkenning komt onder meer tot uiting in de OSPAR-doelstellingen om te zorgen voor een schone, gezonde en biologisch diverse zee met een duurzaam gebruik van haar hulpbronnen.

Om haar verplichtingen na te komen, is OSPAR begonnen met de periodieke voorbereiding van Quality Status Reports (QSR's) voor de vijf regio's in het noordoostelijk deel van de Atlantische Oceaan, met als doel om een holistische en geïntegreerde samenvatting te geven van de milieutoestand van het hele OSPAR-zeegebied. Momenteel werkt OSPAR aan het voorbereiden van QSR 2023.

Met zijn werkzaamheden erkent OSPAR de noodzaak om de goede toestand van het noordoostelijke deel van de Atlantische Oceaan veilig te stellen, omdat deze de basis vormt voor welvaart en welzijn, voedsel verschaft, bijdraagt aan klimaatregeling, essentieel is voor de levering van energie en grondstoffen, een bron voor recreatie en inspiratie is, en miljoenen banen ondersteunt. Om dit doel te bereiken past OSPAR de 'Ecosysteembenadering' toe, die wordt gedefinieerd als:

"Het alomvattende geïntegreerde beheer van menselijke activiteiten op basis van de beste beschikbare wetenschappelijke kennis over het ecosysteem en de dynamiek ervan, om invloeden die van belang zijn voor de gezondheid van mariene ecosystemen te identificeren en daarop actie te ondernemen, en zo te komen tot een duurzaam gebruik van ecosysteemgoederen en -diensten en het behoud van de integriteit van het ecosysteem".

Hierbij worden ecosysteemdiensten omschreven als de uiteindelijke output van ecosysteemstructuren, -processen en -functies die rechtstreeks (actief of passief) door mensen worden gebruikt.

Tot dusver is in de OSPAR-evaluaties nog niet expliciet rekening gehouden met ecosysteemdiensten. Nadat de noodzaak van de integratie van een beoordeling van ecosysteemdiensten was erkend door OSPAR, is dit onderzoek specifiek opgezet om te passen in de context van het QSR 2023, met als doel om een methodologie te ontwikkelen voor een kwalitatieve beoordeling van de effecten op ecosysteemdiensten ten gevolge van veranderingen in de milieutoestand in het maritieme gebied van OSPAR, die kan worden gebruikt als inspiratiebron voor de voorbereiding van de thematische beoordelingen in het kader van het QSR 2023.

Dit rapport is bedoeld als bijdrage aan de toepassing van de ecosysteembenadering om te komen tot een duurzaam gebruik van ecosysteemgoederen en -diensten overeenkomstig de OSPAR strategie voor de bescherming van het mariene milieu in het noordoostelijke deel van de Atlantische Oceaan 2030 (NEAES 2030), en draagt met name bij tot het zetten van een nieuwe stap in de richting van verschillende NEAES 2030-doelstellingen, waaronder:

- Strategische doelstelling 5: De mariene biodiversiteit, ecosystemen en ecosysteemdiensten beschermen en in stand houden om een goede toestand van soorten en habitats te bereiken en daarbij de veerkracht van de ecosystemen in stand te houden en te versterken;
- Strategische doelstelling 7: ervoor zorgen dat het gebruik van het mariene milieu duurzaam is, door een geïntegreerd beheer van de huidige en nieuwe menselijke activiteiten, inclusief het aanpakken van de cumulatieve effecten daarvan;
- Operationele doelstelling 7.03 (gerelateerd aan strategische doelstelling 7): Uiterlijk 2025 zal OSPAR beginnen met het analyseren van ecosysteemdiensten en natuurlijk kapitaal door maximaal gebruik te maken van bestaande kaders om menselijke activiteiten en de gevolgen daarvan te herkennen, beoordelen en consequent te mee te nemen bij de uitvoering van ecosysteemgericht beheer.
- Operationele doelstelling 12.01 (gerelateerd aan strategische doelstelling 12): Uiterlijk 2025 zal OSPAR een regionale aanpak ontwikkelen voor de toepassing van op de natuur gebaseerde oplossingen voor koolstofopslag en specifieke maatregelen uitvoeren om relevante habitats voor koolstofvastlegging en -opslag, zoals zeegrasvelden, kelpwouden en zoutmoerassen, te beschermen en te herstellen.

Het mariene milieu is een complex systeem. Om dit systeem te begrijpen, te beoordelen en te beheren moet een holistische benadering worden toegepast waarbij de complexiteit van het systeem wordt erkend, rekening wordt gehouden met de diverse gebruikers en vormen van gebruik van de hulpbronnen, en de ecologische, economische en sociale gevolgen van alle menselijke activiteiten worden meegenomen. Mits duurzaam beheerd, leveren mariene ecosystemen een reeks ecosysteemdiensten die de samenleving ten goede komen. Om tegemoet te komen aan de behoefte aan een kader dat een systeem brede analyse van de complexe sociaalecologische interacties in het noordoostelijke deel van de Atlantische Oceaan mogelijk maakt, past OSPAR in QSR 2023het DAPSIR-kader toe (Drivers-Activities-Pressures-State-Impacts-Responses). Om alle aspecten van de ecosysteembenadering in het Quality Status Report 2023 te kunnen toepassen, heeft OSPAR daarom behoefte aan inzicht in en integratie van:

- De drijvende krachten achter de veranderingen in menselijke activiteiten
- De invloed van menselijke activiteiten en daarmee samenhangende druk op ecosystemen
- De toestand van mariene ecosystemen en hun veranderingen
- De verandering van de toestand en de effecten daarvan op mariene ecosysteemdiensten (en mogelijke daaruit voortvloeiende effecten op het welzijn van de mens)
- Geïntegreerde beheersmaatregelen (als antwoord op ongewenste ontwikkelingen)

OSPAR QSR 2023 bestrijkt alle aspecten van het mariene milieu via een reeks thematische beoordelingen, waaronder onderwatergluid, zwerfvuil op zee, zeezoogdieren, enz. In ieder deze thematische beoordelingen wordt het DAPSIR-kader toegepast, waarbij de onderdelen van het

DAPSIR-kader de verschillende onderdelen van de thematische beoordelingen vormen. Dit rapport is bedoeld om deze thematische beoordelingen te ondersteunen door een methode en informatie te verschaffen die kunnen worden gebruikt om het meest rechtse deel van het DAPSIR-kader te voltooien, en is derhalve bedoeld om

- een uitgebreide lijst van mariene ecosysteemdiensten te identificeren en te verstrekken, die in het kader van OSPAR kan worden gebruikt, en
- een methodologie te ontwikkelen voor de beoordeling van de effecten van veranderingen in het mariene milieu op ecosysteemdiensten die kan worden toegepast voor het invullen van het onderdeel "Effecten op ecosysteemdiensten" in de verschillende thematische beoordelingen.

De achterliggende gedachte van de ontwikkelde methodologie is om voor elke thematische OSPAR-beoordeling de componenten van de verandering van de toestand te koppelen aan de ecosysteemdiensten waarop zij van invloed zijn, waarbij ook de aard van de invloed (bv. positief of negatief) en de omvang van de invloed (groot/middelgroot/klein/onbekend) worden gespecificeerd. Deze structuur is belangrijk omdat ze het mogelijk maakt te beschrijven of een reeks veranderingen in de toestand die in een thematische beoordeling worden beschreven, een impact kunnen hebben op meer dan één ecosysteemdienst, of dat de levering van één ecosysteemdienst door meer dan één thematische beoordeling kan worden beïnvloed. In dit rapport worden de resultaten van de toepassing van de methodologie gepresenteerd voor twee casestudies:

- Zwerfvuil (als voorbeeld van een aan druk gerelateerde thematische beoordeling)
- Zeezoogdieren (als voorbeeld van een toestand gerelateerde thematische beoordeling van de biodiversiteit)

Een analyse van de effecten van veranderingen in het mariene milieu op ecosysteemdiensten is een belangrijke stap, ook omdat daarmee de effecten kunnen worden bepaald op het menselijk welzijn en de economische activiteiten die afhankelijk zijn van een toereikende beschikbaarheid van ecosysteemdiensten, en ook op de drijvende krachten achter de veranderingen in menselijke activiteiten, waardoor de DAPSIR kringloop wordt gesloten. Daartoe is in het kader van dit rapport een eerste, poging ondernomen om de drijvende krachten en activiteiten te identificeren die het meest waarschijnlijk zullen worden beïnvloed door veranderingen in de levering van bepaalde ecosysteemdiensten. Dit is gedaan op basis van een inschatting door deskundigen.

De identificatie van een lijst van de meest relevante mariene ecosysteemdiensten die van toepassing zijn op het noordoostelijke deel van de Atlantische Oceaan en de ontwikkeling van een methode waarmee de effecten van veranderingen in de toestand op ecosysteemdiensten kunnen worden beoordeeld, vormen de ontbrekende schakel in de OSPAR-context om te kunnen laten zien hoe veranderingen in de toestand van het mariene milieu zich kunnen vertalen in effecten op het menselijk welzijn in termen van vermindering en/of toename van de goederen en diensten die de mens aan de mariene ecosystemen ontleent.

Met deze methode is het mogelijk aan te tonen hoe veranderingen in de toestand van het mariene milieu, veroorzaakt door de druk van menselijke activiteiten, een negatieve invloed kunnen hebben op een aanzienlijk aantal ecosysteemdiensten. Dit kan op zijn beurt leiden tot kosten voor de samenleving als gevolg van de aantasting van het mariene milieu, in de vorm van een vermindering van de goederen en diensten die de mariene ecosystemen aan de mens leveren, zoals een vermindering van de productie van schaal- en schelpdieren, een verslechtering van de preventie van kusterosie, een verslechtering van de kwaliteit van het zeewater en een verslechtering van de baten voor de menselijke psychologie, de gezondheid en toeristische activiteiten. Het is echter ook van cruciaal belang om te benadrukken hoe de toepassing van deze methode het mogelijk maakt om tegelijkertijd de positieve effecten op het menselijk welzijn duidelijk te maken die kunnen voortvloeien uit de succesvolle implementatie van maatregelen die leiden tot een verbetering van de toestand van het mariene milieu. Daarmee vult de voorgestelde methode het meest rechtse deel van het DAPSIR-raamwerk in, en wordt het mogelijk om de OSPAR thematische beoordelingen te vertalen in een taal die essentieel is voor het verstrekken van relevante informatie aan beleidsmakers.

Het is belangrijk te benadrukken dat dit werk niet bedoeld was om definitieve resultaten te presenteren die direct in de OSPAR-werkzaamheden kunnen worden opgenomen, maar om een begin te maken met het ontwikkelen van een methodologisch kader dat de integratie van het denken in ecosysteemdiensten binnen verschillende OSPAR werkstromen mogelijk zou maken, met name met het doel om inspiratie en ondersteuning te bieden voor de ontwikkeling van het deel over de effecten op ecosysteemdiensten binnen de thematische beoordelingen van QSR 2023. De werkzaamheden die ten grondslag hebben gelegen aan dit rapport heeft verschillende OSPAR-deskundigen gestimuleerd om na te denken over het belang van ecosysteemdiensten en over de mate van relevantie van geselecteerde ecosysteemdiensten in relatie tot hun thematische beoordeling.

Aangezien dit een eerste poging is om veranderingen in de toestand van het mariene milieu te koppelen aan het gebruik van ecosysteemdiensten, resulteert deze studie ook in een aantal suggesties voor toekomstige werkzaamheden, waaronder de volgende:

- Een eerste suggestie is dat het toekomstige werk zich zou kunnen toespitsen op het verfijnen van de gepresenteerde methode voor het beoordelen van de effecten van een veranderende toestand van het mariene milieu op ecosysteemdiensten door middel van specifieke aanvullingen en optimalisaties. Een eerste verbetering zou erin kunnen bestaan om te streven naar de integratie van kwantitatieve informatie met betrekking tot de effecten op de levering van ecosysteemdiensten, mogelijk via de economische waardering van ecosysteemdiensten (met integratie van natuurlijk kapitaalrekeningen). Ten tweede kan worden gestreefd naar een expliciete ruimtelijke benadering die het mogelijk maakt om te differentiëren tussen, bijvoorbeeld, gebieden met een hogere ecosysteemdienstverlening die een grotere/kleinere impact van de toestandverandering ondervinden en gebieden met een lagere ecosysteemdienstverlening die een grotere/kleinere impact ondervinden.
- Een andere mogelijkheid om kwantitatief te werk te gaan, is een casestudy te ontwikkelen die uitsluitend gericht is op één of enkele ecosysteemdiensten waarvan de levering gemakkelijker kan worden gekwantificeerd, waardoor ook meer ruimtelijke details mogelijk zouden zijn. Een voorbeeld is koolstofopslag, die zowel gemakkelijker kwantificeerbaar is dan andere ecosysteemdiensten, als een hoge beleidsmatige prioriteit heeft. Dit zou bovendien bijdragen aan synergie met strategische doelstelling 12.01, die gericht is op de ontwikkeling van een

regionale aanpak voor de toepassing van op de natuur gebaseerde oplossingen voor koolstofopslag.

- In de toekomst kunnen ook de verbanden tussen ecosysteemdiensten en de componenten "drijvende krachten" en "activiteiten" van het DAPSIR-kader en de effecten van veranderingen in ecosysteemdiensten op deze onderdelen verder worden onderzocht. Hierbij kan worden voortgebouwd op de eerste poging die is ondernomen op basis van een van de workshops die in he kader van dit onderzoek zijn georganiseerd waarin is geprobeerd om ecosysteemdiensten te koppelen aan drijvende krachten en activiteiten en de DAPSIR kringloop te sluiten. Hierdoor wordt tevens het verband tussen ecosysteemdiensten en het menselijke sociaaleconomische domein verder benadrukt.

1. Introduction

1.1. Background – OSPAR, the North-East Atlantic Ocean, the ecosystem approach

The Convention for the Protection of the Marine Environment of the North-East Atlantic, the OSPAR Convention, was initiated in 1972 with the Oslo Convention for the Prevention of Marine Pollution by Dumping or Discharges from Ships and Aircraft. The interest in expanding the focus of the convention to include land-based sources of marine pollution led in 1992 to the combination of the Oslo Convention and the Paris Convention, resulting in the current OSPAR Convention. The OSPAR Convention represents the legislative mechanism through which an international cooperation of 15 governments and the European Union (EU) operates to protect the marine environment of the Northeast Atlantic through the monitoring and identification of potential threats and the collective implementation of measures to counter them (OSPAR, n.d. -a; OSPAR, n.d. -b; OSPAR, n.d. -c).

The OSPAR Convention conducts its work based on a regional subdivision of the North-East Atlantic. This subdivision consists of five regions (Figure 1):

Region I: Arctic Waters
Region II: Greater North Sea
Region III: Celtic Seas
Region IV: Bay of Biscay and Iberian Coast
Region V: Wider Atlantic

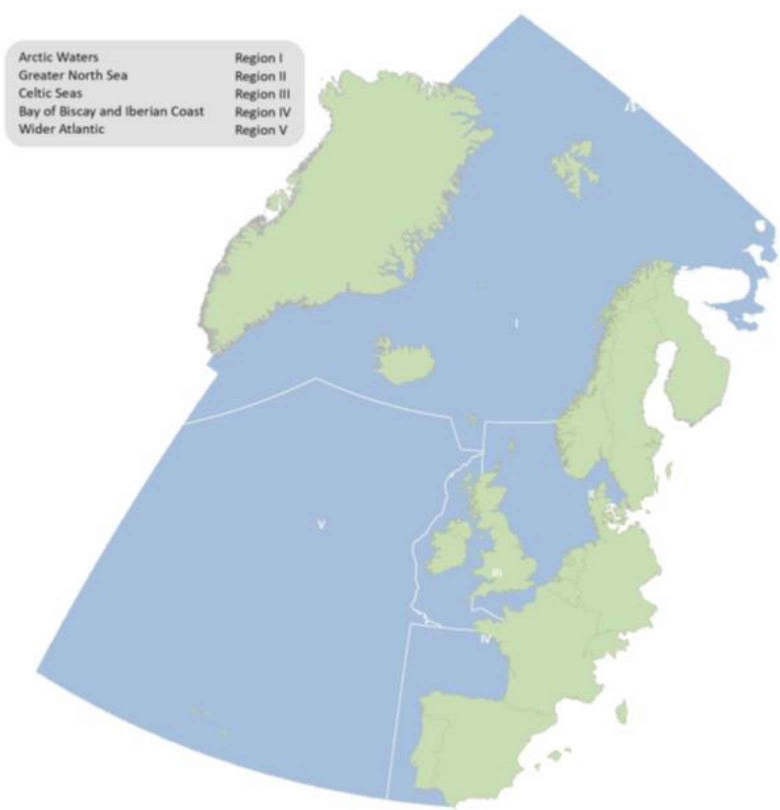


Figure 1. OSPAR regions of interest (OSPAR, 2019).

OSPAR regions exhibit different ecological characteristics and an important diversity of ecosystems. The Northeast Atlantic is characterized by a significant diversity of marine habitats, including fragile deep-water habitats such as hydrothermal vents, carbonate mounds, coral gardens, and sponge communities listed as threatened or declining, which not only underpin high levels of biodiversity but at the same time support numerous economic activities (OSPAR, n.d.-d). Among the major activities of significance to the maritime area of the OSPAR regions are fishing, large-scale aquaculture, shipping, offshore industrial activities for oil and gas production, deep seabed mining, plastic production and consumption, aggregate extraction, and tourism (OSPAR, n.d.-d).

Given the significant interaction of marine biodiversity, functioning, ecological structures, and socioeconomic activities in the Northeast Atlantic, the OSPAR Convention recognizes the need for a holistic approach to the conservation and management of the marine system and its resources that considers the environmental impacts of human activities (Elliott et al., 2017; OSPAR, 2019). This recognition is reflected in the OSPAR objectives of ensuring a clean, healthy, and biologically diverse sea with a sustainable use of its resources. In order to achieve these objectives, OSPAR processes primarily entail the application of the 'Ecosystem Approach'. This approach is defined as:

"*The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity*" (OSPAR, 2019, pp. 3-4).

The employment of the ecosystem approach by OSPAR is then used as key to inform policy and supporting decision-making (OSPAR, 2019). OSPAR's implementation of the ecosystem approach involves marine conservation actions such as the creation of protected areas or actions targeting certain species and habitats considered threatened or declining. The implementation of this approach also takes into account the monitoring and management of human socio-economic activities so that they can adapt to and respect the vulnerability and importance of marine ecosystems. The implementation of this approach is ensured by a general obligation of the Contracting Parties to apply the precautionary principle, the polluter pays principle, best available techniques (BAT), and best environmental practices (BEP) (OSPAR, n.d.-e, n.d.-f, n.d.-g, n.d.-h). The OSPAR Commission promotes the implementation of the ecosystem approach under the Convention on Biological Diversity. Specifically, OSPAR's work focuses on (OSPAR, n.d.-e):

1. *Promoting understanding and acceptance by all stakeholders of the ecosystem approach to the management of human activities, and collaboration among the various management authorities in the North-East Atlantic in implementing that approach;*
2. *Monitoring the ecosystems of the marine environment to understand and assess the interactions between and among the different species and populations of biota, the non-living environment and humans;*
3. *Setting objectives for environmental quality, underpinned by monitoring, in support both of the formulation of policy and assessments;*

4. *Assessing the impact of human activities upon biota and humans, both directly and indirectly through impacts on the non-living environment, together with the effects on the non-living environment itself*

OSPAR implements the ecosystem approach taking into account its role within the broader policy and legal framework and its international engagement. In this regard, through the implementation of its North-East Atlantic Environment Strategy, OSPAR will contribute to the delivery of the UN Sustainable Development Goals (SDGs) and the achievement of good environmental status under the EU Marine Strategy Framework Directive with the aim of continuously improving the protection and status of the North-East Atlantic (OSPAR, 2021).

To implement its commitments, the OSPAR Commission is embarked on the periodic preparation of Quality Status Reports (QSRs) for the five North-East Atlantic regions intended to provide a holistic and integrated summary of the environmental status of the entire OSPAR maritime area, set within the context of the physical, ecological, socio-economic features and a changing climate. In 1994, the OSPAR Commission decided to undertake the preparation of the first of these reports, the QSR 2000. In general, the QSR 2000 summarised the scientific information available in mid-1998, focusing in particular on environmental changes and the extent to which these result from human activities occurring in the OSPAR area, from natural variability, or from a combination of both. This also addressed the intention to adopt strategies to guide OSPAR's medium- and long-term work in five main areas, namely protection and conservation of ecosystems and biological diversity of the maritime area, hazardous substances, radioactive substances, combating eutrophication, and environmental objectives and management mechanisms for offshore activities. At the same time, the intention was to identify gaps in scientific knowledge that prevented full assessment of the environmental impact of certain human activities and to support environmental resource management and policy-making (OSPAR, 2000).

In advancing OSPAR's objectives towards a clean, healthy, and biologically diverse sea, the QSR 2010 followed the previous QSR 2000. The QSR 2010 reflects the collective effort made by Contracting Parties over the period 1998-2008 to manage, monitor, and assess the pressures and impacts on the North-East Atlantic marine ecosystems. The 2010 QSR reported progress on the five OSPAR thematic strategies i.e., the Eutrophication Strategy, the Hazardous Substances Strategy, the Radioactive Substances Strategy, the Offshore Oil and Gas Strategy and the Biodiversity and Ecosystems Strategy (OSPAR, 2010).

Following the QSR 2010, the OSPAR Intermediate Assessment 2017 (IA 2017) further develops OSPAR's understanding of the Northeast Atlantic and its status, demonstrating OSPAR's progress towards realising its vision. Seven years after the QSR 2010, the IA 2017 provided an update on the assessment of the state of marine ecosystems in the North-East Atlantic through improvements in monitoring methodology and new indicators. The IA 2017 was guided by the objective of using the most recent data available. For hazardous substances, the assessment used data up to and including 2015 while for eutrophication indicators, along with nutrient inputs, data up to and including 2014 were used (OSPAR, 2017p).

In 2017, the OSPAR Commission agreed to prepare the report following the IA 2017 for publication to OSPAR 2023, the QSR 2023, with the objective of providing an assessment of the overall state of the marine environment in the OSPAR maritime area. The main elements of the QSR 2023 are (OSPAR, 2019):

- *Assessment of ecosystem status, key pressures and impacts, and assessment of changes since QSR 2010 and IA2017*
- *Assessment of progress on the NEAES 2010-2020 thematic strategies, including:*
  - *Biological diversity and ecosystems*
  - *Eutrophication*
  - *Hazardous substances*
  - *Offshore oil and gas industry*
  - *Radioactive substances*
- *Evaluation of the effectiveness of OSPAR actions and measures*
- *Assessment of the impacts of climate change and ocean acidification*
- *Identification and review of new and emerging issues.*

The execution of the above processes will allow the QSR 2023 to identify knowledge gaps. This identification will then allow identifying priorities for improving the state of the marine environment and providing recommendations for the implementation of measures to address these gaps and ensure progress towards achieving OSPAR's strategic objectives. With the aim of informing the ecosystem-based approach to management and the evaluation of OSPAR strategies implementation and their effectiveness in improving the quality of the marine environment in the five regions of the OSPAR Marine Area, the QSR 2023 will produce different assessments. These assessments will present in a structured format information on what is known about the quality status of each of the five regions of the OSPAR maritime area (OSPAR, 2019). The QSR 2023 assesses the time period 2009-2021, presenting information on long-term trends for topics where this is relevant and possible. The produced assessments will evaluate the progress made in relation to the objectives of the QSR 2023 by making comparisons with the outputs of the QSR 2010 (1998-2008) and the IA 2017 (2009-2015). Where possible, a comparison could also be made against the QSR 2000 (OSPAR, 2019).

In a global context where the health of the ocean, including the North-East Atlantic, is at risk, action is needed to address the loss of biodiversity and the functioning of marine ecosystems. In this regard, it is recognised that key challenges include pollution, eutrophication, overexploitation of living and non-living resources, incidental bycatch, non-native species, underwater noise, and damage to the seabed. OSPAR through its work recognises the need to safeguard the good state of the North-East Atlantic also because it underpins economies and lifestyles, provides food, helps regulate climate, is essential for the supply of energy and raw materials, is a source of recreation and inspiration, and supports millions of jobs (OSPAR, 2021). From this perspective, the usefulness of applying the concept such as that of ecosystem services, *"the benefits that people obtain from ecosystems"* (MA, 2005), that allows the assessment of impacts on the goods and benefits humans derive from (marine) ecosystems is evident (see Chapter 2 for a more in-depth definition of ecosystem services).

As was the case for the previous OSPAR QSRs and IA, also for the QSR 2023 the OSPAR strategy entails the application of the ecosystem approach. In this regard, it should be noted that ecosystem services are explicitly mentioned in the ecosystem-based approach to management, and they are also included among the concepts of sustainable use of marine resources within the EU MSFD (OSPAR, 2021). However, so far, consideration of ecosystem services has not been included in OSPAR assessments.

Following the recognition of the need for the integration of an ecosystem services assessment by the OSPAR Commission, the present work is specifically framed to fit into the context of the QSR 2023, with the aim of developing an ecosystem services assessment methodology. Reflecting the OSPAR work focus on pressures and impacts on the marine environment of the OSPAR area, this report aims to develop a methodology for a qualitative assessment of the impacts on ecosystem services resulting from environmental state changes in the OSPAR maritime area that can be used as a source of inspiration for the preparation of the QSR 2023 assessments. This report is intended to contribute to the application of the ecosystem approach to achieve sustainable use of ecosystem goods and services following the Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030 (NEAES 2030).

NEAES 2030 is the vehicle through which the implementation of the OSPAR Convention in the period 2020-2030 occurs. The implementation of this strategy is part of OSPAR's contribution to achieving the UN SDGs under the Agenda 2030. Through NEAES 2030, OSPAR reaffirms its commitment to the protection of the North-East Atlantic with a vision of clean, healthy, and biologically diverse marine ecosystems that are used sustainably. For the realisation of this vision, the NEAES 2030 presents 12 strategic objectives grouped under four themes, presented in Box 1.

Box 1. Strategic Objectives presented in the OSPAR North-East Atlantic Environment Strategy 2030 (OSPAR, 2021).

To achieve clean seas we will:

- **Strategic objective 1.** Tackle eutrophication, through limiting inputs of nutrients and organic matter to levels that do not give rise to adverse effects on the marine environment;
- **Strategic objective 2.** Prevent pollution by hazardous substances, by eliminating their emissions, discharges and losses, to achieve levels that do not give rise to adverse effects on human health or the marine environment with the ultimate aim of achieving and maintaining concentrations in the marine environment at near background values for naturally occurring hazardous substances and close to zero for human made hazardous substances;
- **Strategic objective 3.** Prevent pollution by radioactive substances in order to safeguard human health and to protect the marine environment with the ultimate aim of achieving and maintaining concentrations in the marine environment at near background values for naturally occurring radioactive substances and close to zero for human made radioactive substances; and
- **Strategic objective 4.** Prevent inputs of and significantly reduce marine litter, including microplastics, in the marine environment to reach levels that do not cause adverse effects to the marine and coastal environment with the ultimate aim of eliminating inputs of litter.

To achieve biologically diverse and healthy seas we will:

- **Strategic objective 5.** Protect and conserve marine biodiversity, ecosystems and their services to achieve good status of species and habitats, and thereby maintain and strengthen ecosystem resilience; and
- **Strategic objective 6.** Restore degraded habitats in the North-East Atlantic when practicable to safeguard their ecosystem function and resilience to climate change and ocean acidification.

To achieve productive and sustainably used seas we will:

- **Strategic objective 7.** Ensure that uses of the marine environment are sustainable, through the integrated management of current and emerging human activities, including addressing their cumulative impacts;
- **Strategic objective 8.** Reduce anthropogenic underwater noise to levels that do not adversely affect the marine environment; and
- **Strategic objective 9.** Safeguard the structure and functions of seabed/marine ecosystems by preventing significant habitat loss and physical disturbance due to human activities.

To achieve seas resilient to the impacts of climate change and ocean acidification we will:

- **Strategic objective 10.** Raise awareness of climate change and ocean acidification by monitoring, analysing and communicating their effects;
- **Strategic objective 11**. Facilitate adaptation to the impacts of climate change and ocean acidification by considering additional pressures when developing programmes, actions and measures; and
- **Strategic objective 12.** Mitigate climate change and ocean acidification by contributing to global efforts, including by safeguarding the marine environment's role as a natural carbon store.

To achieve them, each of the 12 Strategic Objectives consists of several Operational Objectives. All these objectives are guided by the application of the ecosystem approach. In particular, considering ecosystem services, for achieving sustainable use of ecosystem goods and benefits reference can be made to:

- **Strategic Objective 5**: *Protect and conserve marine biodiversity, ecosystems, and their services to achieve good status of species and habitats, and thereby maintain and strengthen ecosystem resilience;*
- **Strategic Objective 7**: *Ensure that uses of the marine environment are sustainable, through the integrated management of current and emerging human activities, including addressing their cumulative impacts;*
- **Operational Objective 7.03** (under the Strategic Objective 7): *By 2025 OSPAR will start accounting for ecosystem services and natural capital by making maximum use of existing frameworks in order to recognise, assess and consistently account for human activities and their consequences in the implementation of ecosystem-based management.*

Moreover, reference can be made to Operational Objective 12.01 as ecosystem services can play a key role in the OSPAR regional approach as a means of measuring or at least highlighting the benefits of nature-based solutions for carbon storage:

- **Operational Objective 12.01** (under the Strategic Objective 12): *By 2025 OSPAR will develop a regional approach to applying nature-based solutions for carbon storage and implement specific measures to protect and restore relevant carbon sequestration and storage habitats, such as seagrass beds, kelp forests and saltmarshes.*

1.2. OSPAR, ecosystem services, and natural capital: summary of the current state of play

Particularly in relation to the integration of the ecosystem services and natural capital approach within the OSPAR context, the Intersessional Correspondence Group on Economic & Social Analysis (ICG-ESA) plays a key role.

Under NEAES Objective S7.03, work on a first analysis of the potential of a natural capital framework at the OSPAR level was supported last year by ICG-ESA. To assist ICG-ESA, the Netherlands recruited a student who prepared a report for the OSPAR ICG ESA on 'Natural Capital Accounting for the North-East Atlantic Area' (Alarcon Blazquez, 2021), making a significant contribution to the OSPAR approach in relation to the achievement of NEAES target S7.03. This report was badged as a QSR third-party assessment report.

At the ICG ESA meeting held on 20/10/21, the ICG decided to recommend to the OSPAR's Coordination Group (CoG) that OSPAR join the Global Ocean Accounting Partnership (GOAP). The Global Ocean Accounting Partnership is a free network of individuals and organisations working in the field of marine natural capital accounting and ocean accounting for the exchange of information, experience and lessons learned. The CoG agreed for the ICG-ESA to recommend this to the OSPAR Heads of Delegation for approval.

At their meeting in February 2021, The Intersessional Correspondence Group on managing the delivery of the QSR (ICG QSR) invited the ICG ESA to:

- develop a concept of ecosystem services that could be applied consistently across all thematic assessments.
- consider how information on ecosystem services could be brought together from the various thematic assessments as an input to the synthesis report, recognising that this would likely require a qualitative approach; and
- support those responsible for the thematic assessments in the development of their 'impact on ecosystem services' section, including the development of a list of ecosystem services and a methodology.

To do this, the Netherlands hired a student to help ICG-ESA deliver a study on 'Impacts on ecosystem services due to changes in the state of the environment in the Northeast Atlantic Ocean'. Members of various OSPAR working groups (ICG ESA, ICG QSR, the Intersessional Correspondence Group on Cumulative Effects Assessment (ICG Eco-C), and the OSPAR Secretariat) took their place in a steering group to make this project as useful as possible for QSR 2023. This steering group prepared the work announcement for the assignment, which was presented and discussed at the ICG QSR and ICG ESA meetings in April 2021. A draft work plan for this project was presented and discussed at the JAMP B14 meetings in September and BiTA, ICG QSR and ICG ESA meetings in October 2021. After these meetings, the annotated draft was sent around to ICG QSR members, thematic assessment leads, ICG ESA and many others for comments and suggestions. The present work represents the outcome of this whole process. During the course of the development of this work, the project lead had contacts with various thematic assessment leads and regular updates of this work were presented at ICG QSR, ICG ESA, and CoG meetings. Draft results were presented and discussed at a joint ICG ESA-Eco-C workshop held on 1 February 2022.

ICG-ESA are currently undertaking a review of the OSPAR NEAES operational objectives agreed at the recent Ministerial meeting to identify where economic and social analysis can add value. Initial progress on NEAES Operational Objective 7.03 through the aforementioned report (Alarcon Blazquez, 2021) analysed a limited number of ecosystem services. The number of ecosystem services examined is expanded through this report.

At present, ICG-ESA is already looking at taking a step further in order to advance the work on ecosystem services and natural capital accounting. This will be done through the realisation of two possible new projects, one focusing on the quantification and valuation of the ecosystem services described in this study with the aim of filling the physical and monetary supply and use tables (as a next step in the work on natural capital accounts for OSPAR) and the other focusing on what can be done with natural capital accounts to support NEAES.

1.3. Aim of the report

The purpose of this report is to develop a methodology to assess qualitatively the impacts on marine ecosystem services caused by changes in the state of the North-East Atlantic marine environment. This would allow considering and highlighting potential impacts on human welfare providing a better link between the dynamics of the natural and the social components of the ecosystem, by analysing the goods and benefits that society harnesses (or not) from the functioning of the North-East Atlantic marine ecosystems. Translated into the context of the OSPAR QSR 2023, the objective of this report is to develop a methodology that can be applied to populate the far-right part of the DAPSIR framework, i.e., the section on Impact on ecosystem services and resulting goods and benefits, which is applied in the various OSPAR Thematic Assessments.

The structure of the report reflects the steps implemented to develop this methodology:

- Application of the Ecosystem Services Concept, adopted Ecosystem Services Classification Frameworks, rationale behind the selection of specific ecosystem services, and use of ecosystem services to link changes in the State of (marine) environment to impacts on welfare (Chapter 2):

The ecosystem services concept is presented in detail. The ecosystem services classification frameworks utilised for selecting the list of ecosystem services considered in this work are introduced. The theoretical underpinnings of these classification frameworks, including the distinction between biotic and abiotic ecosystem services, the individual ecosystem services and their categories are addressed and integrated in a way that is deemed most appropriate for the purposes of this report and in a way to clearly present the selected ecosystem services so that it can be understood by readers with different academic backgrounds (economics, ecology, social sciences, etc.) and working in different workstreams. Therefore, the theoretical underpinnings of the mentioned classification frameworks are used as a starting point for identifying and selecting the ecosystem services to be assessed. Interconnections with the OSPAR's interest in the Natural Capital Account are also briefly addressed. In addition, it is illustrated how the concept of ecosystem services can be used to link changes in the state of the marine environment to impacts on human well-being, and it is presented how OSPAR thematic assessments could use information on ecosystem services to tell their story and why thematic assessments leads should be interested in ecosystem services and this work. The final section of Chapter 2 presents the methodology used to link marine environment state changes to impacts on ecosystem services in relation to OSPAR thematic assessments.

- Application of the DAPSIR framework (Chapter 2):

The DAPSIR framework adopted in the OSPAR workstreams for the implementation of the QSR 2023 is presented including its theoretical underpinnings, its relationship to the Ecosystem Approach, and the placement of this work in the perspective of the DAPSIR framework. An introduction and overview of the OSPAR thematic assessments is also presented.

- Ecosystem Services in the North-East Atlantic Ocean (Chapter 3)

17 marine ecosystem services are selected for this work. For each of the selected ecosystem services, Chapter 3 presents its detailed definition, describing the connection between marine

ecosystem components and the ecosystem services they provide and illustrating their importance in relation to the goods and benefits they provide to people.

- Linking OSPAR thematic assessments to ecosystem services – Marine Litter and Marine Mammals case studies (Chapter 4)

The results of the application of the methodology developed to link the marine environment state changes to the impacts on ecosystem services are presented for two case studies, the Marine Litter and the Marine Mammals OSPAR thematic assessments. Specifically, the marine environment state change components associated with these thematic assessments are linked to the affected ecosystem services, specifying the nature and the magnitude of the impact (as illustrated in detail in the methodology in Chapter 2). The information relating to the DAPSIR components of environment state changes is sourced from OSPAR published outputs, prioritizing the most recent IA 2017 results and other OSPAR published reports. In order to identify the linkages to and impacts of marine environment state changes on the selected marine ecosystem services and the rationale behind them, existing scientific literature is used. A workshop was then organised to gather views from OSPAR thematic assessment leads and external experts on the identified impacts on ecosystem services, which served to produce a final overview (also presented in Chapter 4) of the impacts on ecosystem services deemed most relevant in relation to the considered case studies.

- Discussion, conclusions, and suggestions for future work (Chapter 5)

The results of the application of the developed methodology for state change impacts assessment on ecosystem services in the North-East Atlantic Ocean are discussed. Key discussion points are addressed regarding:

- the usefulness of applying the concept of ecosystem services (within the context of the OSPAR QSR 2023) and assessing environment state change impacts on them;
- the workshops processes and outcomes;
- highlighted limitations;
- linkages with the work on Natural Capital Accounting and the contribution of this work to NEAES 2030 objectives;
- suggestions for future work.

2. Methodology

2.1. The Ecosystem Services concept and the adopted ES Classification Frameworks

In the Millennium Ecosystem Assessment (MA) ecosystem services were defined as “the benefits people obtain from ecosystems” (MA, 2005). However, this definition was considered to be rather general, failing to provide sufficient detail to the reader about the relationship between (marine) ecosystems and the socio-economic system that should be inherent in the same definition. For this reason, in several ecosystem services framework the ‘cascade’ model, initially proposed by Potschin and Haines-Young (2011), has been adopted allowing to identify ecosystem services as the bridge between the natural and the human world. Prior to the adoption of the cascade model, models adopted by frameworks such as the Millennium Ecosystem Assessment (MA) conceived the natural domain and ecosystem services on one side and the socio-economic domain on the other, with the width of the arrows between the two domains suggesting the relative importance of the links between their components (Figure 2; MA, 2005).

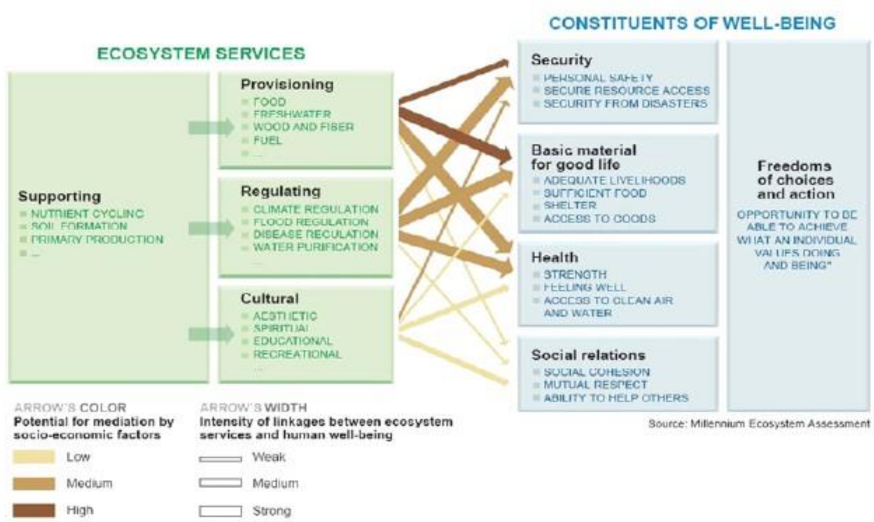


Figure 2. Ecosystem services – Social domain overview diagram of the Millennium Ecosystem Assessment (MA, 2005).

In contrast, the 'cascade' model depicts ecosystem services explicitly as a connecting element between the natural system and the socio-economic system, identifying the benefits and goods that people derive from ecosystem services separately from the economic values of these goods and benefits. It also shows more clearly that ecosystem services are underpinned by ecological structures and processes and the functioning of ecosystem components derived from them (Figure 3; Braat & de Groot, 2012). A more detailed consideration of the ‘cascade’ model applied to the marine environment is presented in the section 'Ecosystem Services to link changes in the state of (marine) environment to impacts on welfare' below.

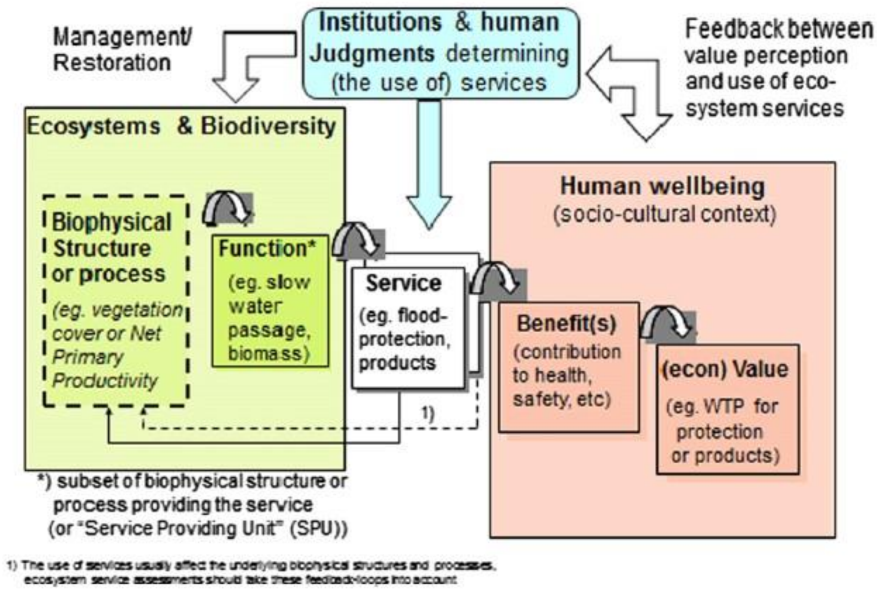


Figure 3. Cascade model (Braat & de Groot, 2012).

From this perspective, it is clear that in order to guarantee and safeguard the provision of ecosystem services, it is necessary to recognise which ecosystem components underpin the provision of ecosystem services and to use a clear and comprehensive definition of the concept of ecosystem services. In this regard, a zoom of the 'cascade' model is shown in Figure 4, illustrating more clearly the individual components of the natural domain, i.e., structures, processes, and functions, which together generate the flow that underpins the provision of ecosystem services.

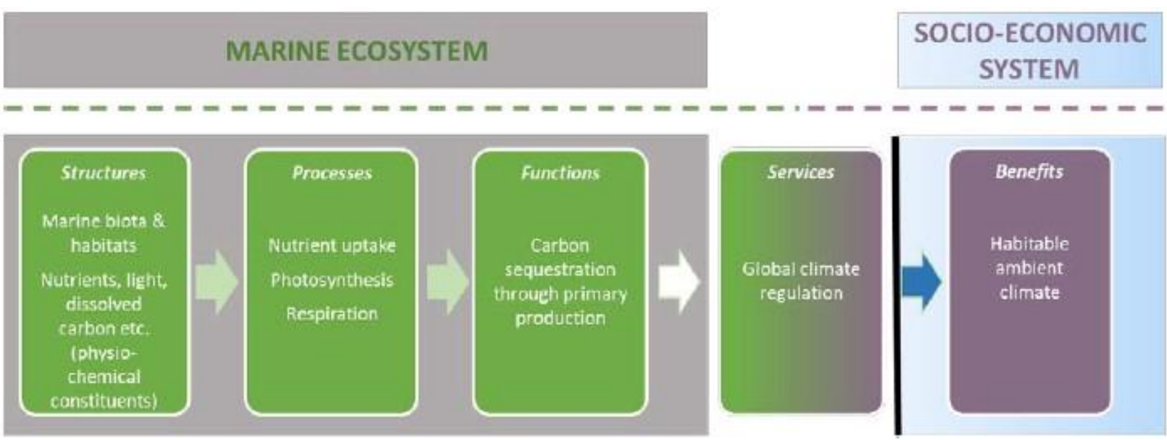


Figure 4. A zoom on a part of the 'cascade' model in relation to the provision of the ecosystem service '(global) climate regulation' and the benefit of a habitable ambient climate gained by society (Culhane et al., 2019a).

To adhere to the presented reasoning underlying the 'cascade' model, the following definition of ecosystem services is adopted in this report (modified from Culhane et al., 2019a):

Ecosystem services represent the flow of ecosystem capital that is generated as response to an active or passive human demand. Thus, ecosystem services are the final outputs from ecosystem structures, processes, and functioning that are then directly (actively or passively) benefited by people.

Following this definition, as stated by Braat & de Groot (2012), this report recognises that obtaining these final ecosystem outputs (goods and benefits) from a practical point of view requires some energy or economic investment (e.g., labour, capital) on the part of people. For example, even the simple provision of food by ecosystems to be benefited requires some form of human energy investment represented by hunting or harvesting work. Indeed, it is precisely in this regard that it is necessary to specify that the nature of the ecosystem services concept is purely anthropocentric. This stems from the fact that ecosystem structures, processes, and functioning present the capacity to provide services regardless of whether there are people who will benefit in some way from these services (Culhane et al., 2019a).

Ecosystem services can be subdivided into different categories that may vary slightly depending on the ecosystem service framework being considered. For example, in ecosystem services classifications such as the Millennium Ecosystem Assessment (MA, 2005) and The Economics of Ecosystems and Biodiversity initiative (TEEB, 2010) the categories of ecosystem services are considered to be four:

- Provisioning services (e.g., food from wild plants and animals)
- Regulation and maintenance services (e.g., erosion regulation)
- Supporting services (e.g., primary production and soil formation in the MA classification)
- Cultural services (e.g., aesthetic and educational services)

In addition to MA and TEEB, several other frameworks of ecosystem services exist that have more or less modified the classification (name and categories) of ecosystem services according to their respective scopes. In this report, three different classifications were mainly considered to create the list of ecosystem services considered most relevant to the objectives of the work:

➢ The UK National Ecosystem Assessment classification (Scott et al., 2014; Turner et al., 2014; UK NEA, 2014; UK NEA, 2011a; UK NEA, 2011b; UK NEA, 2011c; UK NEA, 2011d);

➢ The most updated version (v. 5.1) of the Common International Classification of Ecosystem Services (Haines-Young & Potschin, 2018);

➢ The EEA classification presented by Culhane et al. (2019a) that represents one of the most up to date ‘marine optimization’ of the CICES.

For the purpose of identifying the most appropriate list of marine ecosystem services and to be applied in this report, the theoretical underpinnings of these three classifications were used and sometimes partially integrated in the ways that were considered most appropriate for the objectives of this work. This was done according to:

- a comprehensiveness criterion: attempting to include all relevant marine ecosystem services without including too many ecosystem services, and

- a usability criterion: presenting categories, names, and definitions of ecosystem services that can be clearly understood by a wide range of experts and stakeholders with different backgrounds.

This has been done while always taking into account comparability with the referenced ecosystem services classifications and other international ecosystem services frameworks. Also for this reason, it was decided to opt for the integration of concepts from all these three classification frameworks rather than taking one and applying it the same as it was. However, the classification that has been most used to develop the reasoning of the ecosystem services approach, to perform the selection, and provide the definitions of the marine ecosystem services in this report is that presented by Culhane et al. (2019a) due to the fact that it represents one of the most accurate, up to date, marine optimization of the CICES.

The UK NEA classification was adopted by the UK NEAFO with the aim of identifying ecosystem services and the goods and benefits that society obtains from them with regard to the UK coastal and marine environment. As with the MA classification, the UK NEA classification distinguishes between provisioning services, regulating services, supporting services, and cultural services. The UK NEA classification also makes a distinction between 'intermediate' and 'final' ecosystem services with the aim of avoiding double counting when an economic valuation of ecosystem services has to be conducted. From this perspective, an ecosystem service is defined as ‘intermediate’ when it is only indirectly benefited by people and ‘final’ when its influence on human well-being is direct, meaning that people directly consume or use it (Turner et al., 2014).

However, in the context of the present work, the reasoning of the CICES classification (and of the EEA classification by Culhane et al., 2019a, which is based on the CICES classification reasoning) is used. The CICES considers all services as "final services". In this report, as also done by Culhane et al. (2019a), it is considered that all ecosystem services have a direct human use (active or passive) even through the avoidance (or limitation) of human intervention and related social costs. Furthermore, as specified in Culhane et al. (2019a), to help give a correct indication of ecosystem status and related service provision the approach applied must include the specification of all potential outputs of an ecosystem service both to the marine ecosystems themselves (contributing to the provision of other ecosystem services) and to society. Consequently, in this report for each ecosystem service it is specified whether, in addition to contributing directly to human well-being, it can also positively contribute to the provision of other ecosystem services (yet without the distinction between 'final' and 'intermediate' services).

Moreover, differently from the UK NEA classification, the CICES and EEA classifications recognise only three categories of ecosystem services: provisioning services, regulation and maintenance services, and cultural services. The present work also considers these three categories of ecosystem services:

- Provisioning services: they represent all materials provided by marine ecosystem components, i.e., the tangible results of the functioning of marine ecosystems. These marine outputs (e.g., seafood) can consequently be traded and/or consumed by people (Modified from Culhane et al., 2019a).

- Regulation and maintenance services: they represent the modalities by which the components of marine ecosystems control and/or modify the biotic and abiotic parameters that characterise and influence the 'ambient' environment experienced by people. These ecosystem outputs are not consumed in a tangible way as in the case of provisioning services but affect people's well-being (Modified from Culhane et al., 2019a).
- Cultural services: they include all outputs of marine ecosystems that have a non-material role in eliciting and/or representing physical, experiential, intellectual, spiritual, symbolic, or other cultural significance for people (Modified from Culhane et al., 2019a).

In Table 1, the ecosystem services considered in the EEA classification presented by Culhane et al. (2019a), grouped following the logic of the three categories of ecosystem services presented above, are shown.

Table 1. EEA ecosystem services classification by Culhane et al. (2019a).

Marine Ecosystem Services considered in the EEA classification by Culhane et al. (2019a)	
Ecosystem Services Categories	Marine Ecosystem Services Working Name
Provisioning Services	Seafood from Wild Plants and Algae
	Seafood from Wild Animals
	Plants and Algal Seafood from in-situ Aquaculture
	Animal Seafood from in-situ Aquaculture
	Raw Materials
	Materials for Agriculture and Aquaculture
	Genetic Materials
	Plant and Algal-based Biofuels
	Animal-based Biofuels
Regulation and Maintenance Services	Waste and Toxicant Treatment via Biota
	Waste and Toxicant Removal and Storage
	Mediation of smell/visual impacts
	Erosion Prevention and Sediment Retention
	Flood Protection
	Oxygen Production
	Seed and Gamete Dispersal
	Maintaining Nursery Populations and Habitats
	Gene Pool Protection
	Pest Control
	Disease Control
	Sediment Nutrient Cycling
	Chemical Condition of Seawater
	Global Climate Regulation
Cultural Services	Recreation and Leisure
	Scientific

	Educational
	Heritage
	Entertainment
	Aesthetic
	Symbolic
	Sacred and/or religious
	Existence
	Bequest

In order to identify and create the list of ecosystem services to be considered in this work, a simplification of the list of ecosystem services just presented was made by reducing the number of ecosystem services and by modifying the working names of the ecosystem services also based on the UK NEA ecosystem services classification. By integrating insights from the UK NEA and CICES, some revisions were made in accordance with the two criteria of comprehensiveness and usability mentioned above.

The ecosystem services considered in this report (Figure 5), for reasons of efficiency, clarity and to avoid that the lack of data for detailed ecosystem services such as ' Animal Seafood from in-situ Aquaculture' may lead to gaps in any eventual future exercises of economic valuation of ecosystem services, group together more ecosystem services as presented by EEA (2019a) that in the context of this work were deemed to be ‘minor’. For example, the ecosystem service 'Biomass and raw materials from in-situ aquaculture' considered in this report refers in aggregate to ‘Plants and Algal Seafood from in-situ Aquaculture’, ‘Animal Seafood from in-situ Aquaculture’, and the part of ‘raw materials’ from aquaculture. The same reasoning was applied for the provisioning service named in this report 'wild fish and other natural aquatic biomass and related raw materials'. The number of regulation and maintenance and cultural services has also been reduced. In addition, the working names of the ecosystem services have been modified to make them clearer in the way deemed most appropriate in the context of this work (in some cases differing from those in Culhane et al. (2019a)), and insights from Culhane et al. (2019a), UK NEA, and CICES (v. 5.1) have been integrated to provide detailed descriptions of each ecosystem service (as can be seen in Chapter 3). Biofuel provisioning services were not considered in this paper because they were deemed less relevant in the context of the work in relation to the OSPAR area than the other ecosystem services. Table 2 presents the list of ecosystem services considered in this work and places them in parallel with some of the ecosystem services that are part of the EEA classification by Culhane et al. (2019a).

Table 2. EEA ecosystem services classification by Culhane et al. (2019a) and list of ecosystem services considered in the present work.

	Marine Ecosystem Services considered in the EEA classification by Culhane et al. (2019a)	Present work
Ecosystem Services Categories	Marine Ecosystem Services Working Name	Marine Ecosystem Services Working Name
Provisioning Services	Plants and Algal Seafood from in-situ Aquaculture; Animal Seafood from in-situ Aquaculture; Raw Materials	Biomass and raw materials from in-situ aquaculture
	Seafood from Wild Plants and Algae; Seafood from Wild Animals; Raw Materials	Wild fish and other natural aquatic biomass and related raw materials
	Genetic Materials	Genetic material
Regulation and Maintenance Services		Regulation and maintenance of marine food webs
	Global Climate Regulation	(Global) climate regulation
	Erosion Prevention and Sediment Retention; Flood Protection	Coastal protection
	Waste and Toxicant Removal and Storage; Waste and Toxicant Treatment via Biota; Chemical Condition of Seawater	Water quality regulation
	Waste and Toxicant Removal and Storage; Waste and Toxicant Treatment via Biota; Sediment Nutrient Cycling	Sediment quality regulation
	Pest Control	Pest control
	Maintaining Nursery Populations and Habitats; Gene Pool Protection	Nursery population and habitat maintenance
Cultural Services	Recreation and Leisure	Recreation related services
	Aesthetic	Visual amenity services
	Educational; Scientific	Education, scientific, and research services
	Heritage; Symbolic; Sacred and/or religious; Entertainment	Spiritual, artistic, and symbolic services
	Existence; Bequest	Ecosystem and species appreciation
Other Marine Abiotic Outputs		Mineral substances used for material purposes
		Mediation of waste, toxics, and other nuisances by non-living processes

As can be seen in Table 2 in the list of ecosystem services considered in this report, 'regulation and maintenance of marine food webs' represents an addition that has been made to the regulation and maintenance services because it was considered in the context of this work to be a relevant ecosystem service supporting the provision of other ecosystem services. Moreover, as a separate category named ‘Other Marine Abiotic Outputs’, two abiotic ecosystem services were considered based on the CICES (v. 5.1). These marine abiotic ecosystem services are ‘Mineral substances used for material purposes’ and ‘Mediation of waste, toxics, and other nuisances by non-living processes’ based and modified from Haines-Young & Potschin (2018). The rationale for including abiotic services reflects the reasoning of CICES (v. 5.1) which considers natural capital to include all natural resources from which human society benefits, i.e., both biotic and abiotic components of ecosystems. Therefore, this approach potentially provides an appropriate entry point to describe and measure natural capital, also in accordance with OSPAR's aforementioned interest in natural capital accounting and qualitative assessment of the marine environment (Haines-Young & Potschin, 2018). Furthermore, it is important to note that these are not the only abiotic outputs of marine ecosystems as the provision of ecosystem services belonging to the regulation and maintenance and cultural service categories is also partly ensured by abiotic components. Overall, the reasoning behind the selection and inclusion of ecosystem services in this work is based on their relevance in contributing to the well-being of society in the OSPAR North-East Atlantic Ocean area.

After presenting the list of ecosystem services considered in this report and the reasoning behind it, to further emphasise its applicability and/or comparability, it is possible to briefly refer again to the categories of ecosystem services used. For instance, it can be mentioned the fact that Statistics Netherlands (CBS) in its ongoing work on natural capital accounting is also applying a similar ecosystem services approach, considering the three categories of provisioning, regulation and maintenance, and cultural services as included in this report.

In addition, it is worth highlighting that CICES represents the ecosystem services classification system developed specifically to support both ecosystem assessment and ecosystem accounting (EEA, 2015). Therefore, considering that the EEA classification referred to in this paper is also based on CICES, this demonstrates the suitability of the classifications used and the approach applied in this paper to identify the appropriate list of ecosystem services in view of both natural capital accounting and also the qualitative assessment of impacts on marine ecosystem services in the North-East Atlantic Ocean envisaged in this report.

2.2. Interlinkages with the Natural Capital Account

This section aims to highlight the interconnections between the approach and objectives of this report with the Natural Capital Account and its components.

As reported in Chapter 1, the ecosystem approach applied by OSPAR explicitly links the state of the marine ecosystems and their components with the ecosystem services they provide and that support human welfare. In this regard, the valuation of ecosystem goods and services is linked to the concept of Natural Capital, which is defined as "the world's stock of natural assets including geology, soil, air, water and all living things. It is from this Natural Capital that humans derive a wide range of services, often called ecosystem services, that make human life possible" (Judd & Lonsdale, 2021).

Based on the ecosystem approach, the Natural Capital Approach is a natural systems analytical approach that focuses on the quantity of natural capital resources (Extent Account), the condition of those resources (Condition Account), and the sustainability of their flows and the social and economic benefits they provide (Use Account; Alarcon Blazquez, 2021; Judd & Lonsdale, 2021).

From this perspective, the close relationship and flows between natural and social components is clear, as also illustrated above in relation to the concept of ecosystem services. As suggested by Judd & Lonsdale (2021), the natural domain and the socio-economic domain rather than being considered as two connected but separate systems (as has often been done so far) should be considered as a single (eco)system and integrated through the use of a unified framework represented by the DAPSIR framework (Drivers – Activities – Pressures – State – Impacts (on human welfare) – Responses, which will be addressed in more detail in the next section). The logic behind this framework is that the Drivers of basic human needs require human Activities to be satisfied. The pursuit of these activities induces Pressures on the environment that in turn lead to changes in the State of natural systems and their components. These changes influence human well-being through Impacts on ecosystem services (ecosystem goods and benefits). These changes in state and associated impacts require human Responses (Elliott et al., 2017).

Judd & Lonsdale (2021) report that there are clear synergies between the ecosystem approach and the Natural Capital Approach that can be highlighted and harnessed through the use of the DAPSIR framework. The ecosystem approach applied by OSPAR aims to integrate environmental, social and economic interests for the sustainable management of marine resources and to incorporate the Natural Capital Approach into this process. it is here that a clear link can be identified with the present work that sees this report focused on assessing the impacts of state change on ecosystem services as a step forward and a necessary intermediate step towards a future integration of Natural Capital Approach.

In 2021, the work conducted by Alarcon Blazquez (2021) represented the first attempt to integrate Natural Capital Accounting into OSPAR workflows towards achieving the NEAES 2030 objectives. However, Natural Capital Accounting is a challenging exercise and Alarcon Blazquez (2021) highlighted the need for improvements such as expanding the list of ecosystem services to be considered. The development and application of ecosystem accounting methods require the recording of physical and monetary measurement of changes in the provision of ecosystem services (Edens & Hein, 2013).

However, a proper integration of the Natural Capital Approach into the ecosystem approach applied by OSPAR needs the support of a proper understanding and assessment of the state of marine ecosystems and their components underlying the provision of ecosystem services and the impacts of state changes on ecosystem services (thus leading to a change in their flow). It is in this sense that the usefulness and interconnections of this work with the Natural Capital Account can be highlighted. By identifying and providing a comprehensive list of marine ecosystem services that can be used in the context of OSPAR and by developing a methodology for assessing the state change impacts on ecosystem services, this work can help facilitate the integration of the Natural Capital Approach in the coming future. In this report, also based on the work of Alarcon Blazquez (2021), the intention was also to consider and develop a list of ecosystem services and a methodology that can be used for both a qualitative and quantitative assessment of ecosystem services and their socio-economic benefits, and thus for a further integration of Natural Capital Accounting in future works. For example, as also done in the work by Alarcon Blazquez (2021), this report covers both biotic and abiotic marine ecosystem outputs.

This report, complementing the work by Alarcon Blazquez (2021), addresses OSPAR's simultaneous interest in both qualitative and quantitative (economic) assessment of the marine environment. In fact, the present work contributes together with the work by Alarcon Blazquez (2021) to the achievement of the NEAES 2030 towards the integration by 2025 within OSPAR of the accounting for ecosystem services and natural capital in order to recognise, assess and consistently account for human activities and their consequences in the implementation of ecosystem-based management

The above serves to emphasise the relevance and the broader applicability of this work. This report is not intended to be merely a stand-alone methodology development for the qualitative description of the marine ecosystem services in the North-East Atlantic Ocean and the way state changes impact on them but, in the overall OSPAR picture, it can be employed in future analyses for possible economic-quantitative measurements supporting a more extensive accounting of natural capital.

2.3. The DAPSIR Framework and OSPAR thematic assessments

The marine environment is a complex system characterised by simultaneous interactions between ecological structures, processes, and functioning, physical and chemical processes, and socio-economic dynamics. Understanding, assessing, and managing this system requires the application of a holistic approach that recognises the complexity of the system taking into account the diverse range of users and uses of its resources and considering the environmental, economic and social impacts of all human activities. If managed sustainably, marine ecosystems provide a range of ecosystem services that benefit society.

Hence, the need for a problem-structuring framework that would allow for a system-wide analysis of the complex socio-ecological interactions in the marine environment. In this regard, addressing and improving the DPSIR (Drivers-Pressures-State-Impact-Response) framework and the confusions that have often been highlighted about it, Elliott et al. (2017) proposed the application of the DAPSI(W)R(M) framework (Figure 5) in which Drivers of basic human needs require human Activities to be fulfilled. The execution of these activities induces Pressures on natural systems. The pressures then lead to State change of ecosystems and their components, leading to Impacts on ecosystem services (and consequently on human Welfare). Finally, these impacts require Responses (in the form of Measures).

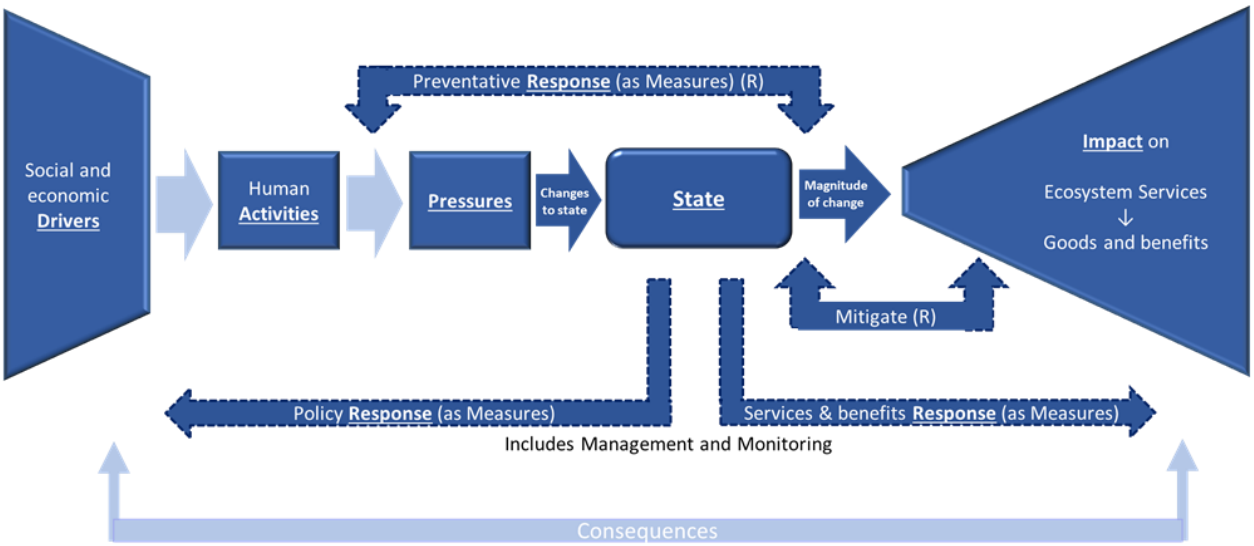


Figure 5. Visual presentation of the DAPSIR framework illustrating its components and their relation (Judd & Lonsdale, 2021).

To provide a brief example of the application of the DAPSIR framework in relation to the sustainable management of marine resources and the assessments to be conducted, as an example the Driver is to obtain food. To meet this basic need, the fishing Activity of bottom trawling is conducted, which then leads to seabed abrasion caused by the used fishing equipment (Pressure). This abrasion can cause damage to the seabed habitat leading to a change in the State of the benthic community and its functions. This state change can Impact on the provision of the ecosystem service of fish supply, reducing the fishable resources and leading to consequences for human welfare. To limit such fishing activities and minimise the related pressures on the seabed, a response (using management measures) such as gear changes or limiting the fishing period is necessary and possibly implemented (Elliott & O'Higgins, 2020).

The use of the DAPSIR framework is based on the embrace of a vision that employs the Ecosystem Approach to marine management, recognising the intertwining of the natural environment and anthropogenic dynamics (Elliott et al., 2017). The reason behind this vision is that socio-ecological dynamics should be assessed in ways that are understandable to policymakers and stakeholders if the ultimate goal is to provide analyses that can actually contribute to the improvement of marine management (Beaumont et al., 2007).

Precisely in relation to its goals of sustainable resource management in the North-East Atlantic, OSPAR is applying the DAPSIR framework in the context of its work for the QSR 2023. To apply all aspects of the ecosystem approach in the Quality Status Report 2023, OSPAR recognised the need of an understanding and integration of:

- The Drivers of change
- How human Activities and Pressures affect ecosystems
- The State of marine ecosystems and their changes
- The state change Impacts on marine ecosystem services (and possible consequent impacts on human welfare)
- Integrated management measures (Responses)

The structure of the OSPAR QSR 2023 thematic assessments reflects the integration of these components. 16 are the OSPAR QSR 2023 thematic assessments (Figure 6) and their function is to bring together several indicator assessments, other assessments (both OSPAR- and third-party assessments), data products and other information of relevance for the considered theme (OSPAR, 2019).

1. Marine Birds
2. Marine Mammals
3. Fish
4. Food Webs
5. Benthic Habitats / Sea Bed Disturbance
6. Pelagic Habitats
7. Non Indigenous Species
8. Marine Litter
9. Underwater Noise
10. Impact of Human Activities
11. Eutrophication
12. Atmospheric and riverine inputs
13. Hazardous substances
14. Offshore Industries
15. Radioactive Substances
16. Climate Change

Figure 6. Overview of the 16 OSPAR QSR 2023 Thematic Assessments.

A thematic assessment is an intermediate step/product of the QSR process. The first part of a thematic assessment is the executive summary. The second part is the main body of the thematic assessment, which applies the DAPSIR framework. With the aim of linking back to the QSR 2010 and assessing progress against the NEAES 2020, the thematic assessments will answer the questions used in the QSR 2010 reflecting on the findings for each of the five OSPAR regions:

1. What are the problems? Are they the same in all OSPAR regions?
2. What has been done?
3. Did it work?
4. How does this field affect the overall quality status?
5. What do we do next?

The answer to these questions will be provided in the executive summary of each thematic assessment, reflecting the broader content of the main body of text. The main body of text of each thematic assessment is structured to reflect the DAPSIR components. Table 3 (adapted from OSPAR, 2019) presents in more detail the relationship between each question in the QSR 2023, the QSR 2010, and the DAPSIR framework, with the components of the DAPSIR setting out the different sections of the thematic assessments.

Table 3. Relationship between each question in the QSR 2023, the QSR 2010, and the DAPSIR framework (adapted from OSPAR, 2019).

QSR 2010 Question	*Text as per the QSR 2023*	*DAPSIR Element (Text in bold below are the DAPSIR Elements)*
1. What are the problems? Are they the same in all OSPAR regions?	**a.** summary of the current state of knowledge on the threats to (pressures on) the marine environment, which should: i. include both threats to human health and to the environment; ii. bring out the links between the driving forces (uses and human activities) and pressures behind those threats, their actual and potential impacts and their relation to economic benefits and costs of degradation; iii. refer back to QSR 2010 and consider future developments in uses and activities that are likely to lead to new or changed threats in these fields; iv. consider the differences between the OSPAR regions;	**Pressure** exerted on the marine environment which may present a threat to the health of the marine ecosystem or its components or to human health Driving Forces = Social or Economic **Drivers** of change Human Activities = **Activities** Actual and potential Impacts of pressures on state = **Impacts** Cost = **Consequences** of Impacts (social, economic or environmental)
2. What has been done?	**b.** a brief description of the programmes and measures in place, under the OSPAR Convention or otherwise, for implementing the Thematic Strategies and the progress made with their implementation.	Programme of Measures = **Responses** (i.e. the actions taken and / or proposed to minimise Impact and improve State (management response))
3. Did it work?	**c.** an evaluation, in the terms of the OSPAR Convention, of "the effectiveness and adequacy of the actions and measures taken and planned for the protection of the marine environment". The section would look at the objectives of North-East Atlantic Environment	Effectiveness of the management measures taken (**Responses**) How are **Activities** changing to reduce pressure / changes in the ecosystem?

	Strategy (NEAES) 2010 – 2020 and give an estimation of whether the measures are sufficient for achieving the objectives of NEAES 2020 – 2030.	
4. How does this field affect the overall quality status?	**d.** an assessment of the effects of these driving forces, pressures, impacts and responses on the overall state of the marine environment; **e.** e. an evaluation of how far the status is from the NEAES quality objectives.	**Impact** and **State**
5. What do we do next?	**f.** an identification of the priorities for action (linking up with the objectives of the NEAES 2020 – 2030).	**Response?**

Each thematic evaluation covers all elements of the DAPSIR framework. However, depending on the topic covered in the thematic assessment, the amount of information relating to each component of DAPSIR may vary. For example, the extent to which DAPSIR components are covered may vary between a pressure-related thematic assessment (e.g., Marine Litter) and a biodiversity state-related thematic assessment (e.g., Marine Mammals; OSPAR, 2019).

The present work is designed to cover and provide a methodology for the development of the far-right part of the DAPSIR framework 'Impacts on Ecosystem Services' (Figure 7). The present work is designed to develop a methodology for assessing state change impacts on ecosystem services (and their magnitude). As can also be seen in the DAPSIR framework, this has been made possible by using available information relating to the State component of DAPSIR (which 'flows' into the Impact component). In this work, a first attempt (based on expert-estimate) of closing the DAPSIR loop linking the impacts on ecosystem services back to the drivers was also made. In the following sections the methodology applied will be explained in more detail.

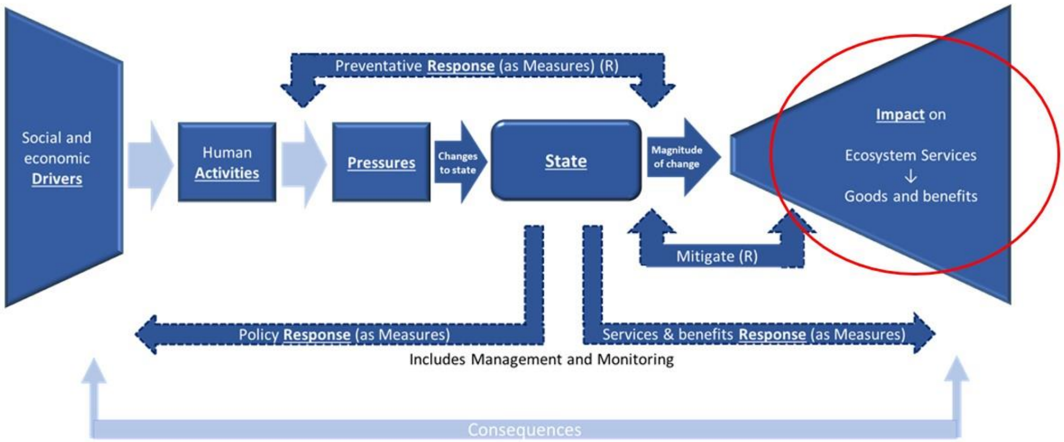


Figure 7. The visualisation of this work within the DAPSIR framework.

2.4. Ecosystem Services to link changes in the State of (marine) environment to impacts on welfare

This section is intended to further clarify how ecosystem services can be used to link changes in the State of (marine) environment to impacts on welfare, thus further highlighting the rationale behind the present work. As also previously mentioned, the term of ecosystem services was coined as a bridge between the natural domain and the social domain (Weitzman, 2019). To stress the connection between these domains, the 'cascade' model was adapted for marine ecosystems by Hasler (2016; Figure 8). From the marine 'cascade' it is evident how human wellbeing and the state of marine ecosystems are interconnected and this interconnection can be described, illustrated, and analysed through the very concept of ecosystem services.

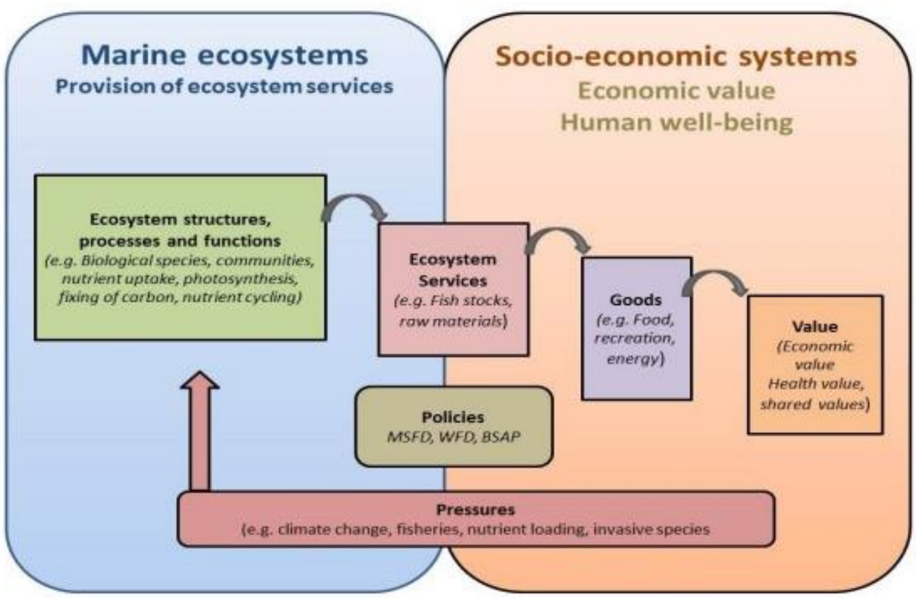


Figure 8. Cascade model adapted for marine ecosystems (Hasler, 2016).

A correct application of the DAPSIR framework entails an integrated marine ecosystem assessment that, integrating natural and social domain, explicitly include and understand the concept of human well-being. Breslow et al. (2016) define human wellbeing as "*a state of being with others and the environment, which arises when human needs are met, when individuals and communities can act meaningfully to pursue their goals, and when individuals and communities enjoy a satisfactory quality of life*" whereas the United Nations Environment Programme (UNEP) defines human wellbeing as "the extent to which individuals have the ability and the opportunity to live the kinds of lives they have reason to value" (UNEP, 2007). From this, it is clear that the concept of human wellbeing is intrinsically multi-faceted and ecosystem services are considered its fundamental environmental determinants (UNEP, 2007). Indeed, it is possible to illustrate how each of the considered categories of ecosystem services accounts for one or more components of human wellbeing thanks to the goods and benefits provided to people (Figure 9; Akinsete et al., 2019).

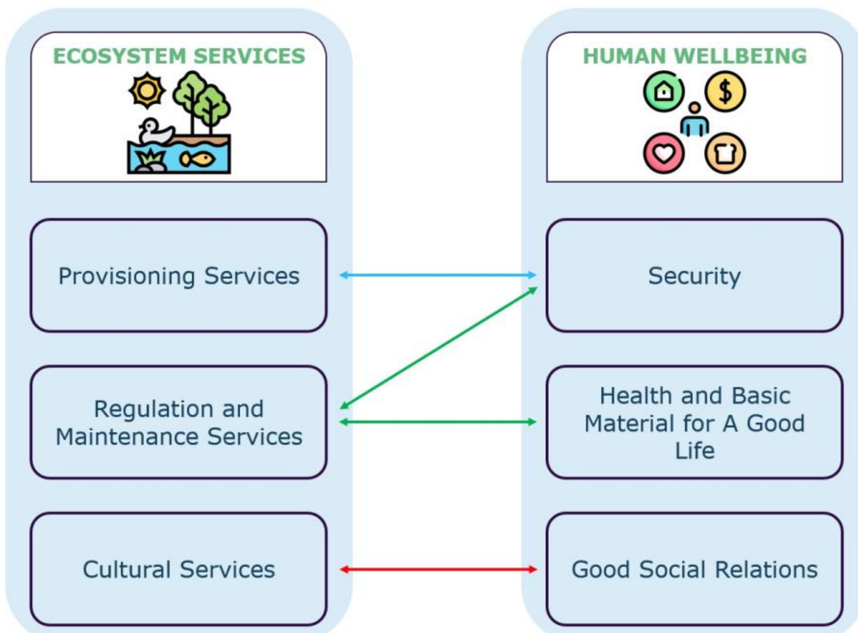


Figure 9. Interconnections between ecosystem services categories and the domains of human wellbeing (adapted from Akinsete et al., 2019).

Both the concept of human wellbeing and the concept of ecosystem services (being anthropocentric in its nature as previously noted) are inherently related to human needs and values (Wu, 2013). In this regard, to further emphasise how ecosystem services are related to human well-being and human needs, it is possible to briefly refer to the hierarchy of human needs developed by Maslow, one of the most influential psychologists of the 20th century (Figure 10; Maslow, 1954).

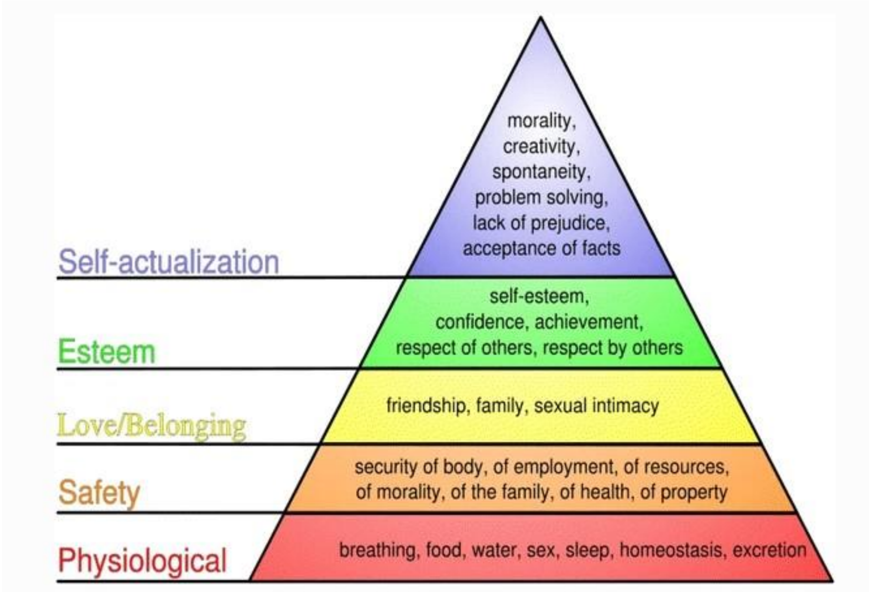


Figure 10. Maslow's hierarchy of needs (Maslow, 1954; Summers et al., 2012).

Ecosystem services have a direct effect on human well-being by influencing security, the availability of basic materials for a good life, health, and social and cultural relations. Together these elements are affected and in turn have an influence on the freedoms and choices available to people. To give an example, it has been shown that climate change, degradation of natural resources, loss of biodiversity, chemical contamination of food, air and water, and non-native species negatively affect physical well-being while contact with nature has positive effects on individual and community psychological well-being (Summers et al., 2012). Consequently, it is evident how ecosystem services are essential to fulfil needs which are at all "levels" of Maslow's hierarchy (e.g., basic needs, psychological needs and self-fulfilment needs). Thus, changes in the state of (marine) ecosystems, by impacting ecosystem services, affect human well-being.

The Water Programme of the International Union on the Conservation of Nature (IUCN) claims that ecosystem services are a useful tool for policymakers, acting as a bridge between ecological pressures and human well-being, thereby providing a framework for the identification of the impacts of these pressures on human well-being (IUCN, 2012; Figure 11). This is an approach adopted by ecosystem-based management, which seeks to take into account multiple pressures while holistically addressing the balance between ecological integrity and human well-being (Breslow et al., 2016). In this regard, as previously explained, OSPAR applies the ecosystem-based management approach as guiding principle and the present work reflect OSPAR's interest in exploiting the usefulness of the ecosystem services tool for ecosystem-based management.

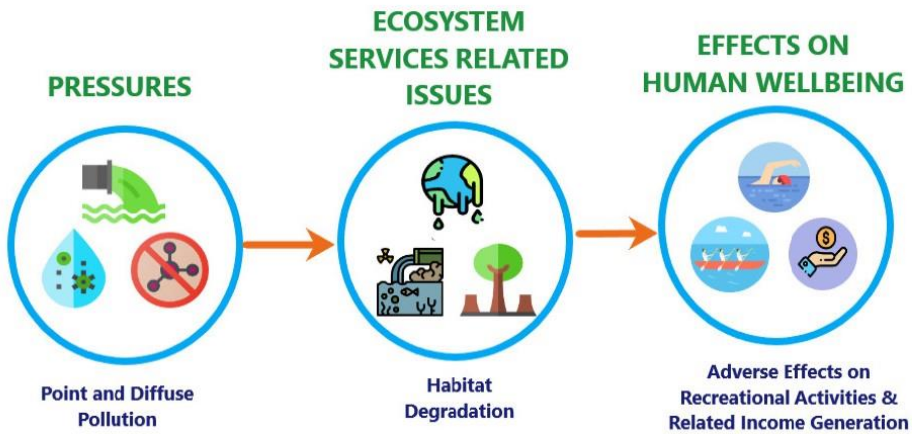


Figure 11. Graphical representation of the ecosystem services role in linking the pressures exerted on ecosystems to human well-being (Akinsete et al., 2019).

The above demonstrates how through an analysis of state change impacts on marine ecosystem services it can be then possible to derive the chain of influence on human well-being and consequently on Drivers (and human Activities), closing the DAPSIR framework loop.

2.5. OSPAR thematic assessments and Ecosystem Services

From what was previously mentioned about OSPAR QSR 2023 thematic assessments, it is clear that the thematic assessments provide entry point products for the implementation of the ecosystem approach. Considering socio-economic aspects affecting and being affected by the marine ecosystems, the thematic assessments highlight their transversal nature. Moreover, OSPAR thematic assessments are assessing, mainly in the 'State' section both the Ecosystem Extent and the Ecosystem Condition (Figure 12). Precisely in this respect, it is possible to note how the thematic assessments could use the information on ecosystem services and the methodology developed in this work to tell their story and why the thematic assessment leads should be interested in the outputs of this report. The present work, being intended to provide support and inspiration for the thematic assessments' section on 'Impact on Ecosystem Services' start to assess the "flow" of Natural Capital (as shown in Figure 12). Therefore, this report represents a step further in the direction of implementing a Natural Capital Accounting approach.

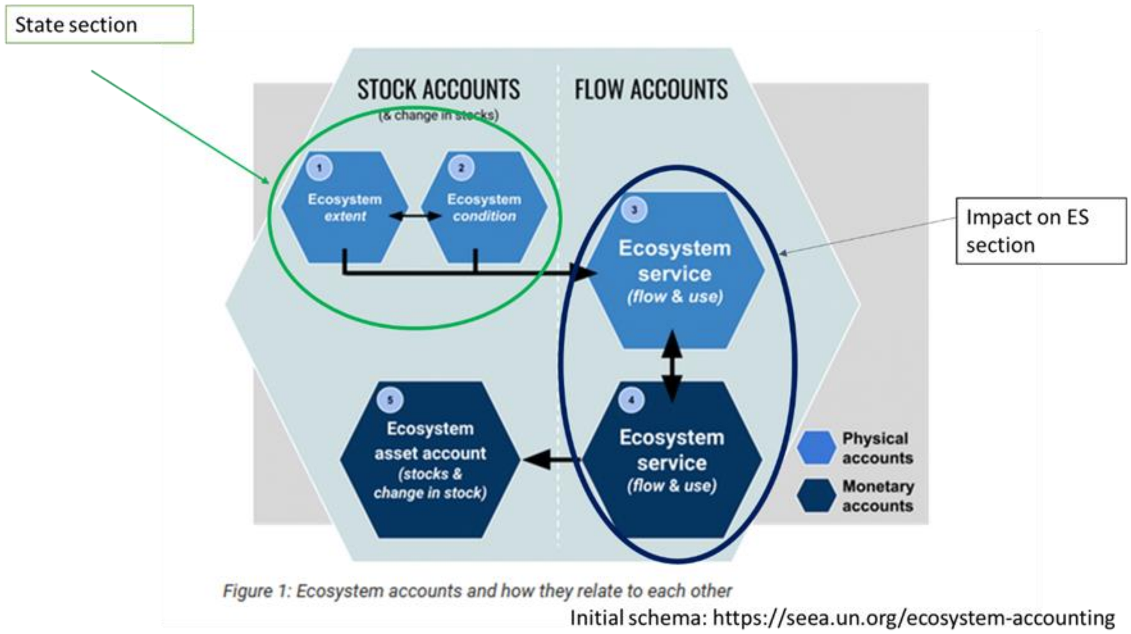


Figure 12. Ecosystem accounts, how they relate to each other, and the thematic assessment sections addressing them (adapted from SEEA, n.d.).

As a result, in the context of the OSPAR QSR 2023 thematic assessments, ecosystem services and the assessment of state change impacts on them allow to make concrete and visible what has been and is being analysed with respect to the pressures and changing state of marine ecosystems and the consequent links to benefits/harm to human welfare. If wanted, ecosystem services can be seen as the glue that allows the damages and/or gains detected in the environmental context of the Northeast Atlantic Ocean to be made more relevant and perceivable through an ecological-anthropocentric lens. Ecosystem services, starting with this work, can be deployed as a common perspective on presenting and understanding the complex relationships between the North-East Atlantic Ocean marine ecosystem and the socio-technical systems interlinked with it (EEA, 2015). In turn, applying this common perspective can facilitate implementation steps in subsequent policy-making processes.

2.6. Methodology for assessing the impacts on Marine Ecosystem Services due to the environmental state changes associated with OSPAR thematic assessments

In this report, in addition to a comprehensive list of marine ecosystem services, a methodology to assess the impacts on these marine ecosystem services due to the environmental state changes associated with OSPAR thematic assessments was developed. The rationale behind this methodology is to link, for each OSPAR thematic assessment, the components of state change with the ecosystem services on which they impact, also including specification on the nature of the impact (e.g., positive or negative) and the magnitude of the impact (e.g., high or low) (Figure 13). This structure is important because it allows to (visually) describe whether a set of state changes described in a thematic assessment might have an impact on more than one ecosystem service, or the provision of one particular ecosystem service might be influenced by more than one thematic assessment.

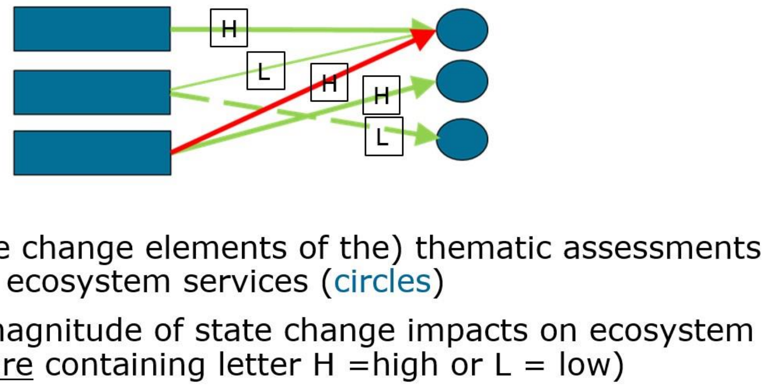


Figure 13. Illustration of the basic rationale behind the methodology developed to link marine environment state changes with the marine ecosystem services they impact on.

The information relating to the DAPSIR components of environment state changes associated with the considered OSPAR thematic assessment (required to fill in the boxes in the left-hand column in Figure 13) was sourced from OSPAR published outputs, prioritizing the most recent IA 2017 results and other OSPAR published reports. The reason for this is that the OSPAR assessments for the QSR 2023 are still ongoing, thus the most recent results have not yet been published. The boxes in the right-hand column in Figure 13 were filled in with the names of the ecosystem services that, according to the existing scientific literature, are the most relevant ecosystem services affected by state changes/environmental impacts associated with the thematic assessment under consideration. Therefore, the reasoning behind the identified state change impacts on ecosystem services was also based on existing scientific literature and provided as textual support to the visual section of the links between state changes and ecosystem services. Arrows were then used to link the state change/environmental impact boxes associated with the thematic assessments with the boxes representing marine ecosystem services. Each arrow represents the impact of a change in state/environmental impact associated with a thematic assessment on an ecosystem service. Regarding the development of the visual representation of state change impacts on ecosystem services, a legend was developed for the colours to be assigned to the arrows to indicate the possible different nature of the impact on ecosystem services (Table 4).

Table 4. Legend of the nature of impacts on ecosystem services.

→	Recognition of the existence of the state change impact on the considered ecosystem service but no clear negative or positive nature of the impact (e.g., when trends in state changes are highly variable) (black arrow)
→	Neutral impact, meaning that the environmental state, presenting a stable condition, is characterised by a neutrality of the impact on the considered ecosystem service (orange arrow)
→	Negative impact, meaning that an environmental state change/impact negatively affects the provision of the considered ecosystem service (red arrow)
⇢	Potential negative impact, meaning that an environmental state change/impact can potentially negatively affect the provision of the considered ecosystem service (red dashed arrow)
→	Positive impact, meaning that an environmental state change/impact positively affects the provision of the considered ecosystem service (green arrow)
⇢	Potential positive impact, meaning that an environmental state change/impact can potentially positively affect the provision of the considered ecosystem service (green dashed arrow)

Applying this approach, an initial version was prepared by the project lead containing:

- a first section representing the visual links between the boxes containing information on state changes/environmental impacts associated with the considered thematic assessment and the boxes of impacted ecosystem services and
- a second section containing the detailed rationale behind identified impacts on ecosystem services as a support to the first section.

In order to validate the content developed by the project lead in the two above-mentioned sections on the basis of expert judgement and to carry out the further step represented by the assignment of magnitude to the state change impacts on ecosystem services, a dedicated joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation was organised. On February 1st, 2022, this workshop took place. More than 40 participants joined the meeting with representatives of Contracting Parties, various OSPAR thematic assessments, different OSPAR bodies and Observers.

The content of the two sections prepared by the project lead in relation to each of the considered thematic assessments (visual linkages section and the supporting section containing the rationale behind identified impacts on ecosystem services) was shared one week before the workshop with the participants in the form of working documents. The workshop objectives were:

1) To support thematic assessment leads in the development of the “Impact on Ecosystem Services” sections of their thematic assessments.

2) To progress the thinking on the relationship between changes in state and ecosystem services thanks to expert judgement (also supporting the development of the present report).

The workshop participants were assigned to different break-out groups each focusing only on two thematic assessments. Each break-out group worked using the working documents containing the identified links between 'state changes/environmental impacts' and 'ecosystem services' in relation to their thematic assessment/s. The participants of each break-out group were asked to conduct a procedure consisting of 2 steps:

1) <u>Validation of the ecosystem services preselected based on existing information</u>: review whether the pre-populated identified ecosystem services are the most relevant in relation to the thematic assessment of interest and, if deemed necessary, remove some ecosystem services (box) with a view of preparing a thematic assessment chapter presenting the most relevant ecosystem services of that topic.

2) <u>Assignment of magnitude to impacts of state change on ecosystem services</u>: if possible, assign magnitude to the impacts (arrows) that have remained following the validation process in step 1 above using the scale low / medium / high / unknown, as described in the table 5 below, and provide reasoning behind this choice.

In this process, if deemed necessary, the experts involved could also change the identified nature of the impacts (colour of the arrow).

Table 5. Definitions of impact magnitude levels.

High (H)	Changes in the state of the marine environment **severely impact** the provision of the considered ecosystem service
Medium (M)	Changes in the state of the marine environment **impact** the provision of the considered ecosystem services **at an intermediate level**.
Low (L)	Changes in the state of the marine environment have a **little or no impact** on the provision of the considered ecosystem service
Unknown (?)	Level of **impact unknow**
Not applicable	Delete arrow

Based on the outputs of the workshop, the project lead prepared a new visual representation of the impacts on ecosystem services reflecting the expert-based opinion on the relevance of the ecosystem services in relation to each thematic assessment considered, the nature of the impacts, and the magnitude assigned to the impacts. The content representing the result of the whole application of the methodology from the two sections previously prepared by the project lead to the development of the ultimate visualisation of the impacts reflecting the outputs of the workshop are presented in Chapter 4 for two case studies:

- Marine Litter case study (a pressure-related thematic assessment)
- Marine Mammals case study (a biodiversity state-related thematic assessment)

The same methodology presented for the Marine Litter and Marine Mammals thematic assessments was applied by the project lead to other 10 OSPAR thematic assessments. However, in this report, only the two case studies of Marine Litter and Marine Mammals are presented because the content related to all the other thematic assessments needs to be further reviewed, possibly adjusted, and approved by OSPAR on the basis of the upcoming assessment results for the QSR 2023. For this reason, the work developed in relation to the other thematic assessments was maintained as an OSPAR internal working document.

As illustrated in the previous sections of this report, in some cases, impacts on ecosystem services might in turn affect the drivers related to basic human needs and the human activities undertaken as a direct consequence of the drivers to meet the needs of society. To this end, a mini-workshop was organised on the 10th of February, 2022, with expert economists from Rijkswaterstaat to make an initial attempt to link the identified ecosystem services with the drivers and human activities that underpin human economy. In other words, identifying the drivers and activities most likely to be affected by changes in the provision of particular ecosystem services, providing an initial expert-based attempt to close the DAPSIR framework loop. Several break-out groups were created, each assigned with only a small number of ecosystem services to focus on. Each break-out group, using the lists of drivers and human activities used in the OSPAR QSR 2023 thematic assessments, was asked to first link the preselected ecosystem services to the drivers that are believed may be affected by changes in the provision of those ecosystem services. Secondly, to link the preselected ecosystem services to the human activities that are believed to use and depend on the provision of those ecosystem services.

In order to provide a comprehensive overview of the results of the work done (including the outputs of both workshops), a factsheet has been designed for each ecosystem service as additional product of this report. A factsheet summarizes in a one-page format the relevant information and outputs of this work related to each of the ecosystem services. Each factsheet presents a concise definition of the ecosystem service under consideration, the state change/environmental impact components associated with the OSPAR thematic assessments that affect this ecosystem service, the drivers that may be affected by change in the provision of this ecosystem service, and the human activities that are most dependent on the provision of this ecosystem service. 17 factsheets, one for each ecosystem service considered, were prepared. However, as the content of the factsheets does not contain evidence-based information in its entirety and their content needs to be further reviewed, possibly adjusted, and approved by OSPAR on the basis of the upcoming assessment results for the QSR 2023, only an example of their structure is presented in this report (Figure 14).

PEST CONTROL

In-situ control of pests in the marine environment, including invasive non-native species, proliferating native species, nuisance algae and any species that may become a nuisance to humans. As an ecosystem service, when natural pest control mechanisms fail, there may be a cost to people to maintain desired environmental conditions or to prevent or minimise any damage to biomass stocks (wild or aquaculture) or other benefits that may be affected by pests. For example, invasions of jellyfish small enough to enter cages can damage salmon stocks reared through aquaculture processes. Another example is the excessive numbers of jellyfish that sometimes occur along beaches and can cause damage to bathing and, consequently, to the economic activities around it (Culhane et al., 2019). It should be noted that this ecosystem service is in turn dependent on the ecosystem service wild animals, plants, and other biomass and the ecological balance of all components of the marine ecosystem as it is underpinned by a stable marine food web (Culhane et al., 2019)A more in-depth definition is available in the related report (hyperlink).

State changes and impacts associated with OSPAR TAs (potentially) affecting this ecosystem service

Marine Mammals TA

- State of harbour porpoises
- State of harbour seals and grey seals
- State of coastal bottlenose dolphin

Fish TA

Non-Indigenous Species TA

Marine Litter TA

- Transport of biota and pollutants

Offshore Industry TA

Drivers that may be triggered by changes in the provision of this ecosystem service	Activities that are depending on this ecosystem services

Figure 14. Example of the ecosystem services factsheet structure.

3. Ecosystem Services in the North-East Atlantic Ocean

3.1. Overview and detailed description of the selected ecosystem services

Figure 15 presents a clearer schematic overview of the marine ecosystem services (and their categories) considered in this report and previously presented in Chapter 2.

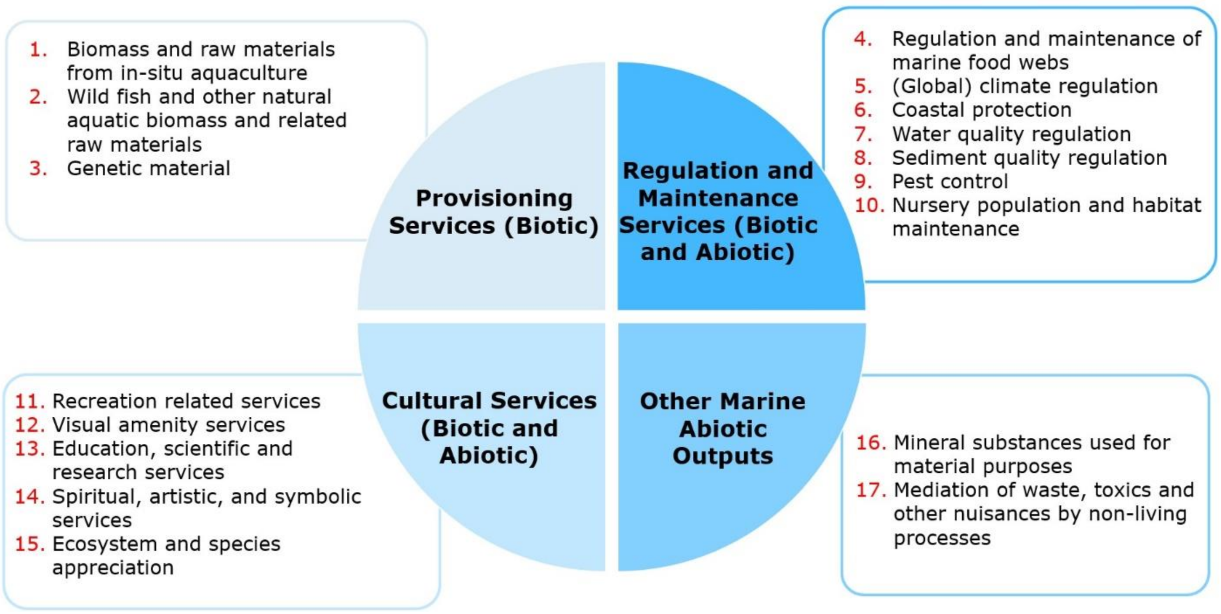


Figure 15. Schematic overview of the marine ecosystem services (and their categories) considered in this report.

The following presents for each of the selected ecosystem services its detailed definition, describing the connection between marine ecosystem components and the ecosystem services they provide and illustrating their importance in relation to the goods and benefits provided to people. It should be noted that some of these ecosystem services such as 'mineral substances used for material purposes', also reflecting expert opinion, were found to be not relevant in relation to the considered thematic assessments (see results of the joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation in Chapter 4). Nevertheless, recognising their existence and definition was considered important. It should be noted that the following detailed descriptions of each ecosystem service are of paramount importance, as the recognition of the components of marine ecosystems that contribute to the provision of ecosystem services and the role that ecosystem services play in providing goods and benefits to people is essential to correctly apply the presented methodology and understand how changes in the state of marine ecosystem components may in turn affect ecosystem services.

1) Biomass and raw materials from in-situ aquaculture


[1]

The ecosystem contributes to the growth of animals and plants (e.g., fish, shellfish, seaweed) in aquaculture facilities that are harvested by economic units for various uses.

Aquaculture (or mariculture), typically defined as the farming of marine aquatic animal and plant resources for various purposes, mainly commercial (FAO, 2020), is in this report identified as a human activity. As a human activity, aquaculture can either be linked to a positive effect or to a disruption of a variety of ecosystem services (Weitzman, 2019). For example, aquaculture positively augments the provisioning service identified in the biomass yielded and delivered through the same aquaculture activities. Some aquaculture activities, specifically bivalve aquaculture, can also contribute positively to the ecosystem service of water quality regulation since bivalve filter water and improve water clarity (Nielsen et al., 2016; Weitzman, 2019). However, at the same time, aquaculture activities can also adversely affect the provision of ecosystem services by, for example, facilitating the spread of disease in the marine environment, reducing oxygen, and introducing nutrients potentially increasing eutrophication (Baulcomb, 2013).

Biomass from in-situ marine aquaculture (or mariculture) is included among the provisioning ES as the aquaculture practice exploits the contribution of the surrounding marine ecosystem to the growth of aquatic animal and plants for the farming of fish, bivalves, crustaceans, and seaweeds (Weitzman, 2019). These products are then harvested by economic units for various uses. The related seafood production is mainly destined for ex-situ consumption.

In addition to providing an important and relatively stable source of nutrition (seafood), especially plant biomass from mariculture constitute a live product that can be used in the healthcare sector for the production of pharmaceutical agents, as well as in the aquarium industry for ornamental

[1] Note: all the images in this chapter were retrieved from the OSPAR website (https://www.ospar.org/).

purposes, or to provide suitable substrates for application in ecological restorations (e.g., seaweeds), overall positively affecting human well-being (Alleway et al., 2018; EEA, 2015; Weitzman, 2019). Also natural products such as agar or carrageenan can be obtained from algae reared by mariculture (Nayar & Bott, 2014). To provide some specific examples, macroalgae are used for agar as well as for dietary supplement production (Culhane et al., 2019). In addition, fish oils containing Omega-3 fatty acids can be extracted for health purposes (Rabasco & Rodriguez, 2000). Animal and plant biomass obtained through aquaculture activities is therefore capable of providing goods, intended as a final product (seafood) that can be traded, sold, and consumed, to the social system by harnessing, but sometimes compromising, the ecological functioning of the marine system (EEA, 2015).

Animals and plants from aquaculture facilities are what holds the capacity to provide the service. The rationale is that these organisms act as mediators of the biomass that is used or eaten by people but, at the same time, they represent the final service as they constitute the output in terms of the ecosystem good that is harvested for different uses. These organisms therefore represent the same biomass that people value and to which they attribute a nutritional benefit, linked to its consumption as food, or an economic benefit, linked to its sale as a result of various processes. The underlying ecosystem functions that enable biomass production are represented by the interactions of the reared organisms with the surrounding environment, as well as ecosystem processes such as feeding (e.g., filter-feeding bivalves). The organism, even in a semi-controlled context such as mariculture, performs the action of feeding on other marine biota, such as bacteria, plankton, and smaller fish, and uses the nutrition for growth (Culhane et al., 2019).

2) Wild fish and other natural aquatic biomass and related raw materials

Wild fish and other natural aquatic biomass and raw materials represents a provisioning service as the functioning of the marine ecosystem with its ecological dynamics contributes to the growth of such biomass sources that are benefited as a service by people and their socio-economic activities (EEA, 2015). Unlike the biomass obtained from aquaculture, this ES includes biomass harvested in non-cultivated production contexts, i.e., the catching and harvesting of wild marine living resources for nutrition or material use or processing (EEA, 2015; Haines-Young & Potschin-Young, 2018). This is a final ecosystem service.

This ES includes both wild plants such as macroalgae, macrophytes and wild animal biomass from vertebrates and invertebrates that are harvested or captured to serve as seafood or raw materials. Specifically, this ES can range from microalgae interesting for bioprospecting activities, fish, shellfish, and crustaceans for fisheries activities to marine mammals such as seals sometimes subject to illegal hunting (OSPAR, 2017a; Steinrücken, 2017). For example, referring to the supply of raw materials, shells can be traded in ornamental industry and macrophytes (e.g., Chondrus crispus or Fucus vesiculosus) are utilised in the cosmetic sector (Surget et al. 2015). Further, benthic macrophytes, including macroalgae, such as Dulse (*Palmaria palmata*) are harvested in littoral and sub-littoral habitats and are often a source of fibre in the diet of some North Atlantic regions (Culhane et al., 2019; Mishra et al. 2015).

However, the biomass of aquatic animals makes up the bulk of this ES. For example, cephalopods such as squid and octopus are caught and consumed in Europe and the North-East Atlantic regions, forming an important part of landings (Culhane et al., 2019; Pierce et al. 2010). Epifauna such as lobsters and infauna such as clams and small crustaceans harvested from benthic habitats are also included in this provisioning service. Another fundamental constituent of seafood from animals in non-cultivated settings is finfish from all marine habitats (Culhane et al., 2019; FAO, 2016). Animal outputs such as fish eggs are also part of this ES and consumed for culinary purposes (Culhane et al., 2019).

Wild fish and other natural aquatic biomass and raw materials represents the ES on which commercial fisheries rely. Consistently, due to its economic relevance and the relative ease of assessing its status through different indicators, this ecosystem service is one of the most analysed marine ecosystem services (Piet et al., 2017).

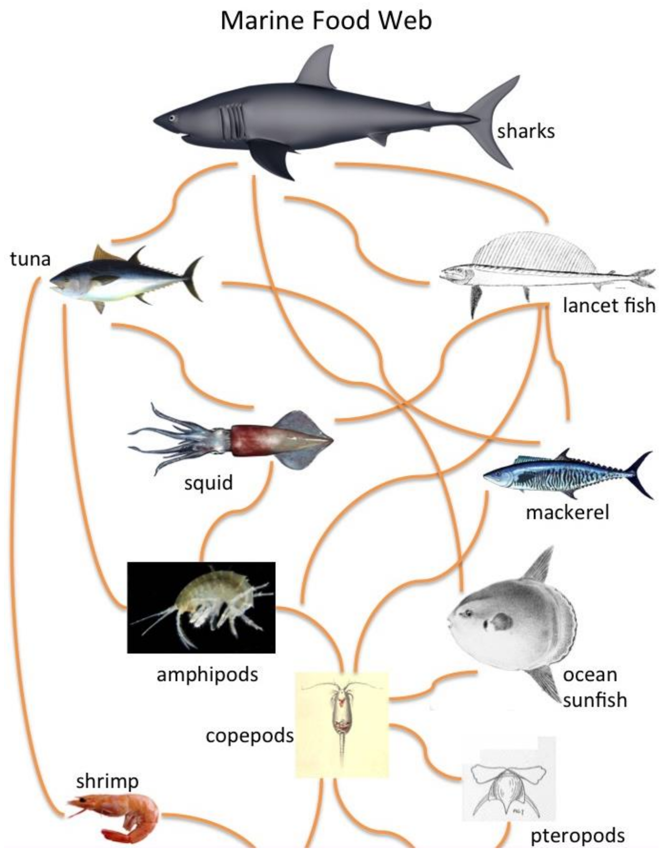
3) Genetic material

This ecosystem service represents the ecosystem contributions from all biota (in this specific case marine biota), including seed, spore or gamete production, that are used by economic units for example to develop new animal and plant breeds; in gene synthesis; or in product development directly using genetic material (Haines-Young & Potschin, 2018). The provisioning of genes, gametes, and/or spores is the basis for the provisioning of biomass, which is then benefited by humans as an ecosystem service (see ‘Biomass and raw materials from in-situ aquaculture’ and ‘Wild fish and other natural aquatic biomass and related raw materials’; Turner et al., 2014). However, genetic diversity (the diversity of the gene pool) of marine organisms can also be directly used and benefited by humans (Turner et al., 2014). This role refers to those cases where cells, tissues, and/or whole organisms are taken from their natural environment or aquaculture settings and then cultured in an artificial environment for biotechnology, bioengineering, bioprospecting, etc. e.g., in the food industry, pharmaceutical industry, and/or for other non-purely scientific research purposes (Culhane et al., 2019; EEA, 2015). Regarding purely scientific research, this pertains to the different ecosystem service 'Education, scientific, and research services'. Consequently, the final goods and benefits provided to humans by this ecosystem service are represented by goods and benefits such as medicines and blue biotechnology (term used to describe the application of technology, including biotechnology, to living aquatic organisms for the production of knowledge, goods, and services; Turner et al., 2014).

Genetic material (genes) represents a resource for humans as they offer the potential to meet possible future needs. Intra-species genetic variation provides a number of building blocks that can be used to improve desirable traits and characteristics of species that already provide goods to humans, for example aquatic species raised in aquaculture activities. Wild species that are closely related to reared species, through breeding or laboratory molecular techniques, can provide desirable genes that can lead to enhancements in the benefits provided by their domesticated conspecifics. For example, brown sea trout and wild salmon are also wild relatives of food animals found in aquaculture contexts (UK NEA, 2011b). At another level, chemicals within marine animal, plant, and microbial organisms may be useful to humans for pharmaceutical purposes. Thus, it is possible to argue that since it is uncertain what humanity's future needs will be, all species are potentially useful for this purpose and that it would be appropriate to aim for their survival. For example, the species and varieties used were selected for their productivity in current aquaculture systems. However, in view of environmental state changes associated with climate change, the use of new varieties better suited to certain environmental conditions may be essential in the near future. This highlights the importance of the provision of the ecosystem service of genetic material by marine organisms to support the current and future human welfare (UK NEA, 2011b).

Currently, the UK is one of the leading countries in the extraction and utilisation of genetic material from the marine environment for blue biotechnology and this sector is expected to grow significantly in the future (EEA, 2015).

4) Regulation and maintenance of marine food webs



The ecosystem contributes to the growth of wild animals, plants, and other biomass. Biomass is transferred in the ecosystem through trophic levels: primary producers, consumers, predator - prey relationships, scavengers, decomposers. Healthy marine ecosystems are dependent on maintaining these food webs supporting biodiversity and nature conservation (and providing a service to people, see ‘Wild fish and other natural aquatic biomass and related raw materials’). This ecosystem service has been intended to represent the supporting service from the contribution that ecological processes such as primary biomass production, the role primary production plays in supporting biomass production at higher trophic levels, and marine biomass interactions across trophic levels have in regulating and maintaining the balance of marine food webs. Therefore, this ecosystem service represents the role that biomass of all wild plants such as macroalgae, macrophytes and wild animal from vertebrates and invertebrates (fish, birds, marine mammals) have in the maintenance and functioning of marine food webs and ecosystems, also contributing to the provision of several other ecosystem services (Scott et al., 2014). Given these features, this service is not directly benefited by people.

5) (Global) climate regulation

The marine ecosystem contributes to the regulation of the chemical composition of the atmosphere and the ocean affecting local and global climate through the accumulation and retention of carbon dioxide and other GHGs (e.g., methane, nitrous oxide), and the control of the transfer of heat and moisture (UK NEA, 2011A). These processes affect climate parameters such as temperature, rainfall patterns, wind etc., contributing to the provision of a healthy and habitable ambient environment (climate and microclimate) to humans (EEA, 2019a; Turner et al., 2014).

The climate regulation by the marine ecosystem comprises the following physical and biological processes:

- Photosynthesis carried out by aquatic plant organisms and phytoplankton, representing the fundamental process that influences the levels of carbon dioxide in the atmosphere (UK NEA, 2011a). Photosynthetic organisms remove CO_2 through its sequestration in terms of primary production but also through consumption (Culhane et al., 2019).

- Marine organisms acting as a carbon sink in the ocean and facilitating carbon burial in seabed sediments (UK NEA, 2011a). Marine calcifying organisms are able to lock away calcium carbonate contributing to the removal of CO_2 from the ocean and in turn of the atmospheric CO_2. Bacteria also play a role, being able to reduce the levels of methane that originates from the ocean floor and then released into the atmosphere (Culhane et al., 2019). Moreover, marine organisms such as zooplankton through processes such as the export of particles by grazing, the fractioning of sinking particles, and the transport of particulate organic carbon at depth through its diel vertical migration, plays a crucial role in the functioning of the oceanic biological carbon pump that contributes to regulating atmospheric CO2 levels (Lomartire et al., 2021).

- Evaporation of water vapor from the ocean to the atmosphere (Gimeno et al., 2012).

- Ocean water surface albedo (proportion of incoming solar radiation that is reflected from the water surface) affecting the Earth's radiation balance, with the low albedo of the ocean causing it to absorb most of the incoming solar radiation (warming the water) and the high albedo of sea ice reflecting about 50-70 % of it (Perkins, 2019; UK NEA, 2011a).

Thus, it is clear how essentially all marine organisms store carbon, albeit in different ways and forms and that at the same time also abiotic components of the marine ecosystem contribute to the provision of this ecosystem service. Biogeochemical effects operate more on a regional or global scale, while biophysical effects have more local or regional effects (Turner et al., 2014). Furthermore, it should be noted that human demand for this ecosystem service is passive, as there is no active human effort to benefit from a habitable environmental climate (Culhane et al., 2019).

6) Coastal protection

The ecosystem contributions of linear elements in the seascape such as sand banks, dunes, coral reefs, saltmarshes, or mangrove ecosystems along the shore, in protecting the shore and the hinterland, thus mitigating the impacts of tidal surges or storms on local communities (UK NEA, 2011a). This service includes flooding prevention and erosion control. Sediment stabilization, sediment accumulation, buffering, and wave energy attenuation by macroalgae beds, microphytobenthos, macrophytes, epifauna and infauna are the processes underlying this ecosystem service (Culhane et al., 2019; Hu et al., 2014; Spalding et al., 2014; UK NEA, 2011a).

Biological structures such as macrophyte roots found in coastal saltmarsh ecosystems or other types of seafloor and coastal vegetation exhibit sediment stabilization capabilities. Biogenic reefs may exhibit the ability to retain and accumulate sediment, important for avoiding erosion processes associated with currents or wave motion. Kelp forest fronds can lower the risk or prevent flooding by breaking up wave energy prior to the impact on the coastline (Culhane et al., 2019; Hasler, 2016).

This ecosystem service is predominantly limited to littoral and (shallow) sub-littoral habitats, as it provides security for people and human-built structures in coastal areas (Culhane et al., 2019). Usually, this service is passively benefited by people thanks to natural elements already present in the marine ecosystem. However, this service can also be actively benefited as a result of ecological restoration measures as done, for example, with sea grass meadows (Culhane et al., 2019; Hasler, 2016).

7) Water quality regulation

Regulation, restoration, and maintenance of the chemical condition of marine water through the breakdown or removal of nutrients and other pollutants by marine ecosystem living processes that mitigate the harmful effects of the pollutants on human use or health (Haines-Young & Potschin, 2018). Waste and toxicant treatment, removal, and/or storage and regulation of chemical condition of seawater via biota are included (Culhane et al., 2019; Haines-Young & Potschin, 2018). This service is therefore mainly determined by ecosystem capture processes such as nutrient uptake by aquatic plant and microbial organisms (contributing to eutrophication mitigation), breakdown of organic pollutants, control and buffering of water acidification by marine life forms, and denitrification processes by microorganisms (Silbiger & Sorte, 2018; UK NEA, 2011a).

To provide some examples, coastal vegetation and mangroves have a role in purifying inland water flows to the ocean, the growth of algae has an influence on the dynamics of nutrients in seawater, zooplankton and mussels contribute via filtration and ingestion, oyster reefs and seagrass ecosystems provide water filtration processes, and different benthic populations have the ability to regulate water quality (Alarcon Blazquez, 2021; Hasler, 2016; Veretennikov, n.d.). This ecosystem service can positively contribute to the provision of other final ecosystem services such as biomass and raw materials from in-situ aquaculture, wild fish and other natural aquatic biomass and related raw materials, and recreation related services (e.g., water quality and clarity for bathing waters; UK NEA, 2011a).

8) Sediment quality regulation

Regulation, restoration, and maintenance of the chemical condition of marine sediments through the breakdown or removal of nutrients and other pollutants by marine ecosystem living processes that mitigate the harmful effects of the pollutants on human use or health. This ecosystem service is also passively used by humans because it positively contributes to the delivery of other ecosystem services such as climate regulation, the provision of aquatic wild or aquaculture biomass, and via cultural services (UK NEA, 2011a).

The very definition of (marine) sediment quality describes the ability of the sediment to function in a purely natural or human managed context, and thus be able to support all those processes that are part of the functioning of the marine ecosystem such as the productivity of aquatic organisms, improvement of water quality etc. Consequently, this ecosystem service includes all those processes on the part of the marine biota that underlie the maintenance of sediment quality (Haines-Young & Potschin, 2018). Among these processes are the storage and degradation of organic matter, the mediation of gases exchange between sediment, ocean water and atmosphere, the storage, degradation and transformation of nutrients and contaminants by organisms ecologically connected to the marine sediment (UK NEA, 2011a). Biota living within soft sediments have the capacity for anthropogenic waste treatment. Aquatic vegetation, benthic infauna, epifauna and bacteria, through their activities including filtration and nutrition contribute to marine sediment decomposition and fixing processes, breakdown of pollutants, mineralization of hazardous and toxic substances, and ensure a balance of the nutrient cycle of the sediment that underlies the quality and functions of the sediment itself (Culhane et al., 2019; EEA 2015; Hasler, 2016).

9) Pest control

In-situ control of pests in the marine environment, including invasive non-native species, proliferating native species, nuisance algae and any species that may become a nuisance to humans. As an ecosystem service, when natural pest control mechanisms fail, there may be a cost to people to maintain desired environmental conditions or to prevent or minimise any damage to biomass stocks (wild or aquaculture) or other benefits that may be affected by pests. For example, invasions of jellyfish small enough to enter cages can damage salmon stocks reared through aquaculture processes. Another example is the excessive numbers of jellyfish that sometimes occur along beaches and can cause damage to bathing and, consequently, to the economic activities around it (Culhane et al., 2019). So, the provision of this ecosystem service allows society to avoid economic costs thanks to the natural pest control function. This service can also positively contribute to the provision of other ecosystem services such as recreation related services or services such as 'regulation and maintenance of marine food webs' useful for the functioning of a healthy marine ecosystem. The service is mainly used passively in the marine environment (in situ), but an example of active use would be if a 'biological control' species were intentionally released as pest control. For example, wild perch are used to control sea lice in farmed salmon pens (Culhane et al., 2019). Furthermore, it should be noted that this ecosystem service is in turn dependent on the ecosystem service 'regulation and maintenance of marine food webs' and the ecological balance of all components of the marine ecosystem as it is underpinned by a stable marine food web (Culhane et al., 2019).

10) Nursery population and habitat maintenance

The ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g., for nurseries or migration) or the protection of natural gene pools (UK NEA, 2011d).

More specifically, the service nursery population and habitat maintenance describes the role of marine ecosystem components in providing suitable habitat, refuge from predation, and food resources for juveniles (of migratory or non-migratory species) and/or commercially important species (Culhane et al., 2019; Tuya et al., 2014). Nursery habitats are the most ecologically important habitats for juveniles, which are essential for growth. It should also be noted that nursery grounds, which may be represented simply by floating seaweeds or soft sediments, may lack significant physical structures such as rocky barriers but, nevertheless, play an essential role in the growth phase of the species (Culhane et al., 2019; Seitz et al., 2013). The contribution of marine habitats to the maintenance of gene pools and inter- and intra-specific genetic diversity through ecological and evolutionary processes are also included in this service (Ivarsson et al., 2017).

Therefore, this service may input to a number of different ecosystem services including biomass provision and recreation related services by sustaining juvenile populations of biotic groups that underpin such services (UK NEA, 2011d). Known nursery grounds include seagrass beds, biogenic reefs such as oyster and maerl beds, kelp forests but also nursery habitats mediated by abiotic elements such as soft sediments and hard bottoms (Seitz et al., 2013). This ecosystem service also includes links with biotic elements (marine animals or plants etc.) that are known to contribute through their activities such as feeding to the ecological maintenance of nursery grounds. Some examples of nursery grounds and biotic elements that contribute to their maintenance are as follows (Culhane et al., 2019):

- Macrophytes such as seagrass beds and macroalgae such as kelp forests in shallow sublittoral and littoral habitats.

- Deeper nursery habitats, such as deep-water corals, biogenic reefs etc.

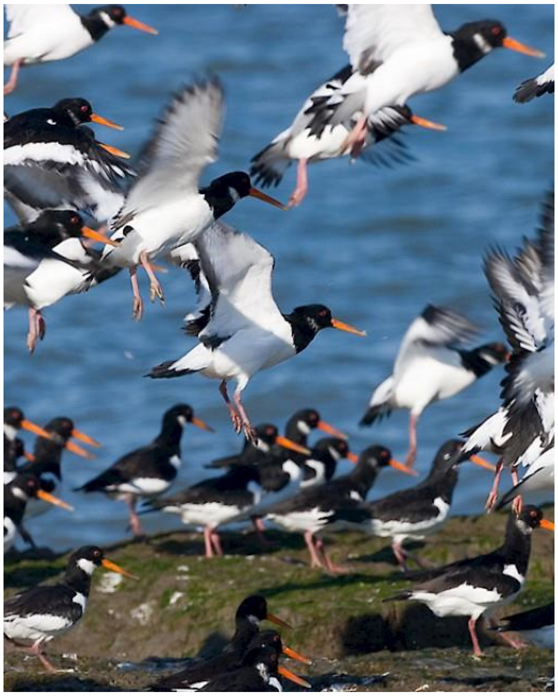
- Floating seaweed clumps (macroalgae) form rafts under which juvenile fish aggregate.

- Sea turtles can maintain distinct seagrass beds in shallow sublittoral habitats through their feeding activities.

- Infauna and epifauna maintain benthic habitats of commercially important species of demersal fish in soft sediment habitats. Thus, all soft sediment benthic habitats are included from littoral to lower bathyal (down to deepest fishing depth).

- Some marine organisms, acting as prey, contribute to the maintenance of nursery populations. This includes phytoplankton and zooplankton (in pelagic habitats); fish and cephalopods may also contribute (in pelagic and benthic habitats); epifauna, infauna and microphytobenthos (in benthic habitats).

11) Recreation related services



These are the contributions of marine ecosystems that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment (Culhane et al., 2019; UK NEA, 2011c).

For this ecosystem service, it is difficult to distinguish between physical and experiential interactions. For example, although swimming in the marine environment may be a simple physical activity not mediated by marine ecological components, it is still influenced by local features of the marine environment such as water quality, the presence of attractive and/or dangerous aquatic species, etc. (Culhane et al., 2019). This ecosystem service is provided by both marine biotic and abiotic elements of the seascape. These elements together contribute to the provision of recreational services for both locals and non-locals (i.e., tourists; UK NEA, 2011c).

Most marine biotic groups contribute through their role in enhancing and sustaining in-situ physical and experiential activities such as diving, swimming, recreational fishing, boating, and wildlife-watching. However, not all marine biotic components are relevant to the provision of this service. For example, benthic organisms in areas not visited or reached by divers are unlikely to provide this service. Organisms such as bacteria and microphytobenthos are not considered to contribute to the provision of this service (Culhane et al., 2019).

Thus, the provision of this ecosystem service depends both on the presence and state of the ecosystem components but also on the very human presence. Indeed, even if the marine ecosystem in a given area has a greater capacity to provide this service than a second area, this service will not be provided by the former if this area is not accessible to the people who are its beneficiaries (Culhane et al., 2019; O'Higgins et al., 2010).

12) Visual amenity services

These are the contributions of marine ecosystems to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual, arising from the aesthetic appreciation of the natural seascape. This service combines with other ecosystem services, including recreation related services to underpin amenity values (UK NEA, 2011c).

The provision of this ecosystem service by the seascape and its ecological components is based on the direct transmission of the feeling of "sense of place" resulting from their vision but also indirectly through the observation of artistic representations depicting marine ecosystems and landscapes. Consequently, people can use this service passively in-situ (unlike recreation related services that involve an active search for the experience) and actively or passively through viewing an artistic representation, picture, etc. in-situ or ex-situ (e.g., on the web; Culhane et al., 2019).

All components of the marine ecosystem have the potential to contribute to the provision of this service. It should be noted that in case of provision of this service ex-situ through images, artwork, books, etc., the provision does not necessarily reflect the current state of the ecological components that constitute marine ecosystems but potentially depicting a past and/or ideal condition of an environmental component. This characteristic differentiates this type of service from services such as provisioning or regulation and maintenance. This service may overlap with recreation related services since sensory benefits may also be experienced during recreational activities. To avoid this overlap, the context of the provision of this service needs to be specified, as recreation related services are in-situ and active (Culhane et al., 2019).

13) Education, scientific, and research services

These are the contributions of marine ecosystems in enabling people to use the marine environment through intellectual interactions with it (UK NEA, 2011c).

<u>Scientific:</u> Marine ecosystems and their components provide this service when they are used as the subject of both in-situ and ex-situ scientific research activities. However, the provision of this ecosystem service does not necessarily reflect the current state of the marine environment and its components. All components of the marine ecosystem can contribute to the provision of this service (Culhane et al., 2019).

<u>Educational:</u> marine ecosystems and their components provide this service when they are used as the subject of both in-situ and ex-situ educational activities. These educational activities may include lectures held in schools and universities, museums, and coastal information centres where people are informed about local marine life forms and habitats and their characteristics. However, the provision of this ecosystem service does not necessarily reflect the current state of the marine environment and its components (Culhane et al., 2019).

14) Spiritual, artistic, and symbolic services

These are the contributions of marine ecosystems recognised by people for their cultural, historical, aesthetic, sacred or religious meaning. These services may underpin people's cultural linkage with the surrounding environment, spiritually inspire people to express themselves in various form such as art and religion and bring to the surface memories born of the seascape that derive from cultural connections (UK NEA, 2011c).

Heritage: marine ecosystems and their components provide this service when they are part of cultural heritage and are used ex-situ (e.g., historical records) or in-situ (e.g., old cultural practices that continue today). Numerous groups of marine organisms contribute to this service. Thus, there is an example of provision of this ecosystem service wherever there is a historical cultural record, e.g., traditional whaling and seal hunting. However, this use is ex-situ and does not necessarily reflect the current state of the marine environment and its components, reflecting the past condition of the marine organism populations under consideration. In contrast, activities such as seal hunting are an example of heritage service provision that takes place nowadays and is dependent on the state of the marine environment and its components. Since this activity is also linked to a provision of biomass, this type of activity is considered both in the 'wild fish and other natural aquatic biomass and related raw materials' service and in the heritage component of this ecosystem service. This does not lead to 'double counting' in an eventual economic assessment because the benefit is different depending on the ecosystem service considered (Culhane et al., 2019).

Symbolic: Marine ecosystems and their components provide this service through marine biota having a symbolic role, and its use can occur either actively ex-situ (intentional symbolic representation) or ex-situ passively (e.g., welfare enhancement occurring unintentionally and as a result of symbolic use of a marine ecosystem component). Reference can be made to marine megafauna or other charismatic marine components (e.g., whales, turtles, birds, fish) that are often used as symbols of conservation societies, NGOs etc. Occurring ex-situ, the provision of this service does not necessarily reflect the current state of the marine environment and its components, possibly reflecting the past condition of the marine organism populations under consideration (Culhane et al., 2019).

Sacred and/or Spiritual: Marine ecosystems and their components provide this service when they contribute to spiritual and ritual experiences and/or identity (e.g., marine organisms that are considered sacred), and the use of this service can be active or passive. Organized religious, sacred, or spiritual practices can occur in-situ or ex-situ, for example in Europe the Spanish marine religious festival for the 'Virgen del Carmen', the patron saint of fishermen and divers or the religious practices carried out by the Sami of Finland and Sweden through which they venerate elements of the marine biota. As also noted for previous services, the provision of this service also occurs ex-situ and does not necessarily reflect the current state of the marine environment and its components (Culhane et al., 2019).

15) Ecosystem and species appreciation

This ecosystem service represents the well-being that people derive from the mere existence and conservation of the marine environment and its components for themselves and future generations, regardless of their direct or indirect use (UK NEA, 2011c).

Marine ecosystems and their components provide this service intrinsically to their existence. People benefit from this service simply by knowing that marine ecosystems and their components exist and are in good condition, regardless of whether or not they have the opportunity to see them directly or use them. Consequently, all components of marine ecosystems contribute to the provision of this service. This service is therefore actively used ex-situ as people do not need to be in-situ to realise that they benefit from the existence of marine ecosystems. By occurring ex-situ, the provision of this service does not necessarily reflect the current state of the marine environment and its components. Furthermore, since such a thinking mechanism about the existence of marine ecosystem components by humans can also be triggered by viewing artistic or other representations, this service may overlap with some of the cultural services outlined above. However, if an economic assessment were to be conducted, there would be no risk of "double counting" as the benefits derived by humans from these cultural ecosystem services are different (Culhane et al., 2019).

16) Mineral substances used for material purposes

Marine mineral resources include marine aggregates such as sand and gravel, minerals and metals such as manganese, tin, copper, zinc and cobalt, and dissolved chemicals such as salt and potassium. The extraction of marine aggregates, especially sand and gravel, is a long-established activity and an important economic activity in the OSPAR area. The supply of marine minerals, including rare earths and cobalt, can make a key contribution to meeting the rapidly growing demand for raw materials. Marine mineral resources have been extracted for centuries. In addition, mineral substances such as calcium and magnesium are extracted for example from maerl beds and used in fertiliser production by several countries, including France, at rates of up to 500,000 t/year (European Commission 2020; Haines-Young & Potschin, 2018).

17) Mediation of waste, toxics, and other nuisances by non-living processes

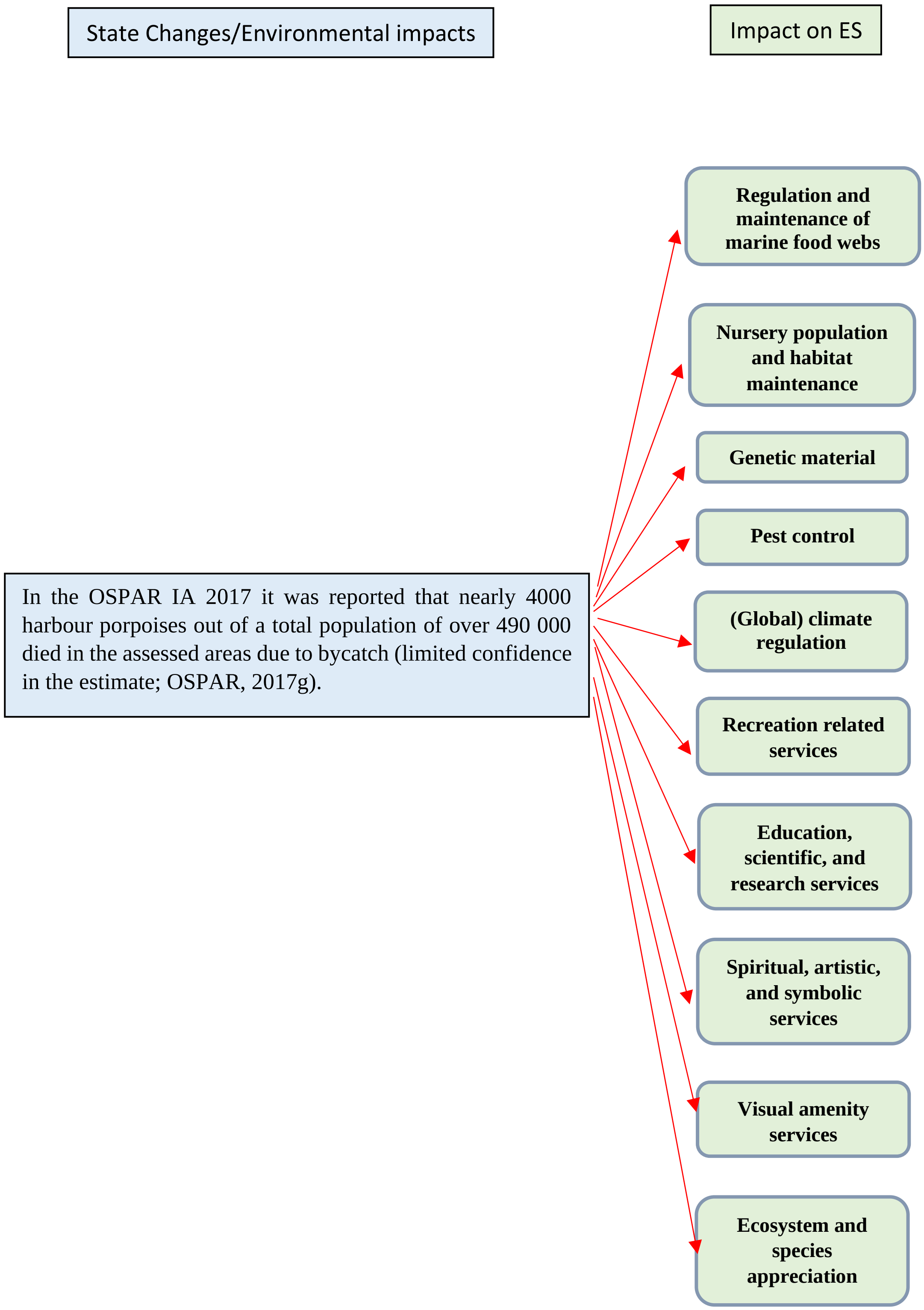
The contribution of the ecosystem in transforming biochemical or physical inputs to ecosystems via diluting wastes and toxic substances in marine water bodies or mediating wastes and toxic substances by other chemical or physical means such as sequestration, adsorption, accumulation, storage in marine sediments (EEA, 2015; Haines-Young & Potschin, 2018).

This service includes the waste remediation processes provided by abiotic components and that are not included in the water quality regulation and sediment quality regulation services by marine biotic components. Abiotic processes such as fluid advection and photochemical transformations play an important role in the provision of waste remediation both in terms of the introduction of wastes into the marine environment but also in their dilution, degradation, and dispersal, allowing wastes to remain in the system but at harmless levels (Watson et al., 2016). For example, leaching or dissociation of toxic contaminants from plastics can degrade under the influence of many abiotic processes including photothermal, oxidative and hydrolytic degradation pathways (Watson et al., 2016). Also, wastes and toxics can be subjected to abiotic transport processes such as mixing, tidal currents, water residence, dilution etc. (Watson et al., 2016).

4. Linking OSPAR thematic assessments to ecosystem services – Marine Litter and Marine Mammals case studies

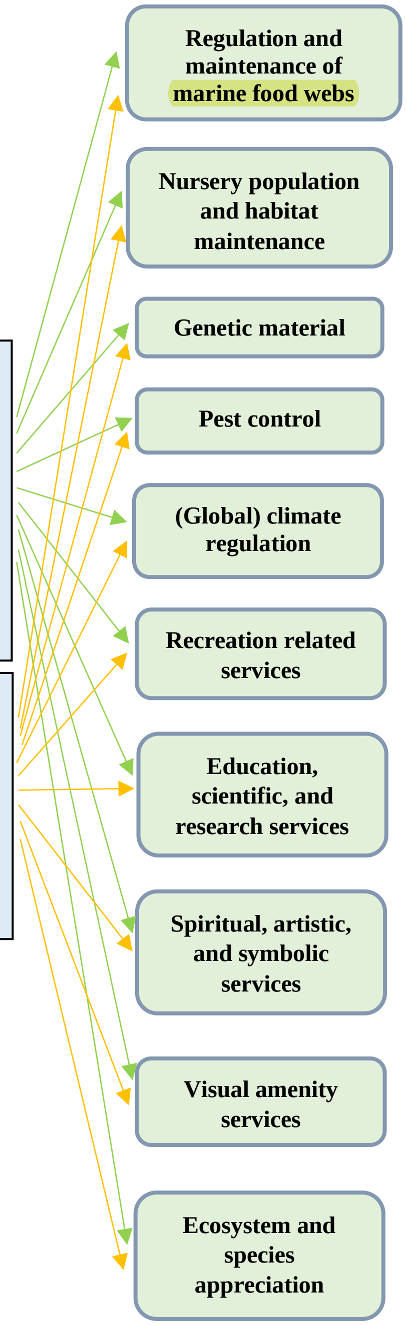
The result of applying the presented methodology to qualitatively assess impacts on marine ecosystem services due to changes in the state of the environment in the North-East Atlantic Ocean for the considered OSPAR thematic assessments is presented below. In order, the content for each thematic assessment consists of a first section representing the visual links between the boxes containing information on state changes/environmental impacts associated with the considered thematic assessment and the boxes of impacted ecosystem services and a second section entitled 'detailed rationale behind identified impacts on ecosystem services' which supports the first section by providing the rationale for the identified impacts based on the existing scientific literature. These two sections were prepared by the project lead prior to the joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation. A third section entitled 'Results of the joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation' presents the elaborated outputs of the workshop which, if deemed necessary by the involved experts, provided the project lead with the basis to prepare a new and more defined overview of the state change impacts on ecosystem services (reflecting the view of the thematic assessments experts).

4.1. Marine Mammals thematic assessment



In the context of the OSPAR IA 2017, it was reported that in general harbour seal abundance was stable or increasing in most of the Greater North Sea, with only a decline recorded in some areas. An increase in abundance and stability of distribution was reported for grey seals. Accordingly, in the Greater North Sea and parts of the Celtic Seas, there has been an annual increase in the number of born grey seals since 1992, but more significantly in the period 2009-2014 (OSPAR, 2017g).

Also reported within the context of OSPAR IA 2017, while coastal bottlenose dolphin populations declined during the 19th and 20th centuries, they have remained low, but stable, until the assessment period of the IA. However, it was observed that the population in the Sado Estuary (Portugal) has declined since the beginning of monitoring (1980s; OSPAR, 2017g).



Detailed rationale behind identified impacts on ecosystem services

Besides the physical damage or death of organisms, which can negatively affect ecosystem services in a relatively straightforward way, it should be noted that the alteration of feeding behaviour, reproductive behaviour, fertility, reproductive success, mobility etc. resulting from different environmental impacts can also affect ecosystem services. As is mentioned in the environmental impacts column of the previous section, it is known that the introduction of non-indigenous species, exposure to marine litter or other substances (e.g., PBDEs, PBCs) can lead to alterations in reproductive rates, fecundity, metabolic mechanisms while disturbances related to noise and other human activities can cause impacts such as displacement from habitats.

Human presence with its activities (e.g., ecotourism, coastal and offshore constructions, ship traffic, and related underwater noise etc.) can create disturbance to marine mammals, leading to (temporary) loss of breeding, nursery, haul out, and feeding habitats or displacement from such areas. This leads to increased energy expenditure by affected individuals with negative consequences for survival, reproduction (reproductive success/output) and fitness. Habitat loss and changes in marine mammals distribution can also result from impacts on the behaviour of marine mammals. Alterations in diving, swimming direction and migration routes, breathing, and resting patterns, vocalisation, changes in avoidance behaviour and masking may result following exposure to underwater noise. Behavioural impacts may also result in relation to exposure to electromagnetic fields (EMF, for example from installed electricity cables). Marine mammals may be injured and/or killed (including (local) extinction) as a result of collision (e.g., with tidal devices, commercial or recreational vessels etc.), bycatch (during commercial or recreational fisheries), extraction (commercial or traditional whaling still present in some OSPAR countries), exposure to underwater noise for example from seismic surveys associated to the offshore industry, ingestion, entanglement, and diseases caused/associated to marine litter (for more details see 'Marine Litter thematic assessment'), exposure to and bioaccumulation of synthetic and non-synthetic substances. All these impacts affect the health, survival, abundance, and distribution of marine mammals in the OSPAR maritime area.

Several traits have been identified in the literature relating to categories such as morphology, behaviour, demography, physiology comparable through different groups of marine megafauna (large fishes, marine mammals, and seabirds) that underpin ecosystem functions performed by these organisms and that in turn support the provision of ecosystem services by these organisms. These traits include for example body size, body mass, migration, mortality rate, fecundity, reproductive success, survival rate, reproductive location, feeding strategy. For example, dispersal performance and mortality rate (traits) are associated to nutrient transport (ecosystem function) that, in turn, allow the provision of ecosystem services such as ‘nursery population and habitat maintenance’ (through biodiversity promotion) and ‘regulation and maintenance of marine food webs’ (through nutrient cycling) (Tavares et al., 2019). Consequently, if these traits are adversely affected for example due to habitat loss or exposure to pollutants, negative consequences for the provision of ecosystem services can be expected. The identification of links between state changes/environmental impacts and ecosystem services was also based on this reasoning.

Indeed, with an observed improvement in the status of marine mammal populations an increase in associated ecosystem services can be expected. The opposite is to be expected with regard to population declines. Considering that, as was highlighted in OSPAR IA 2017 (and was also the case for OSPAR QSR 2010), harbour seal and grey seal populations are generally stable or increasing, it was assumed that the current link between the trend in seal populations and the ecosystem services provided by marine mammals is positive (green arrow). In addition, several deaths of harbour porpoises due to bycatch were observed in OSPAR IA 2017 (OSPAR, 2017g). Accordingly, the nature of the impacts that harbour porpoises' deaths can have on ecosystem services provided by marine mammals has been represented as negative (red arrow). Neutrality (orange arrow) was assigned to the nature of the impacts on ecosystem services related to coastal bottlenose dolphin trends, as their numbers in the 21st century remained low but stable. The following provides an elaboration of the ecosystem services provided by marine mammals and, where deemed necessary, of the identified links between the environmental impacts/state changes and ecosystem services illustrated in the previous section. In this respect, it should be noted that most of the existing literature concerning ecosystem services does not deal with ecosystem services provided specifically by a single category of marine mammals such as seals, but mainly deals with ecosystem services provided by marine mammals as a whole. Therefore, in analysing the ecosystem services that can be associated with species such as harbour porpoises, harbour and grey seals, and coastal bottlenose dolphin, reference will often be made to the generic role that marine mammals play in the provision of ecosystem services.

<u>Wild fish and other natural aquatic biomass and related raw materials</u>: Today, whale meat is consumed, albeit in a significant limited way, by local communities for subsistence and as a cultural practice (thus also related to spiritual, artistic, and symbolic services), as well as by countries such as Iceland and Norway. Among the Icelanders, for example, there has been limited consumption of whale meat in the post-World War II period and it is rather promoted to tourists as a novelty food product or exported (Cook et al., 2020). Marine mammals may also be subject to non-lethal effects related to the exposure and bioaccumulation of pollutants that do not directly compromise biomass supply but may compromise biomass quality as they accumulate in specimens whose meat may be consumed (Cook et al., 2020).

<u>Regulation and maintenance of marine food webs</u>: The movement of marine mammals such as sperm whales through the marine ecosystem contribute to the cycling of nutrients from deep ocean feeding areas to the surface, and large cetaceans also play a role in the transfer of nutrients downwards after death (Noordegraaf, 2020). Marine mammals such as whales and seals can increase primary productivity in their feeding areas by concentrating nitrogen near the surface through the release of faecal plumes that are likely to remain in the euphotic zone (Roman & McCarthy, 2010). Also, marine mammals with predatory role act as sources of nutrients which they redistribute to the marine ecosystem due to their high mobility and rapid turnover of nutrients via excretion and egestion. This movement of nutrients contributes to the growth of wild animals, plants and other biomass (e.g., increasing phytoplankton productivity) that support the balance of the entire food webs (Hammerschlag et al., 2019). Environmental impacts associated with underwater noise, interfering with foraging and communication, can alter predator-prey interactions (Erbe et al., 2018). This in negatively affect the balance of marine food webs (Smith

& Bannister, 2016). In addition, marine mammals, such as killer whales and seals, play key roles as top predators in the marine food web. For this reason, human/driven population declines of certain species of marine mammals could affect the availability of prey resources of other marine mammals, birds or fish populations, impacting food web dynamics (Hammerschlag et al., 2019; Smith & Bannister, 2016).

Nursery population and habitat maintenance: There is evidence that the abundance and distribution of marine mammals can significantly affect the structure and function of some habitats. For example, they are known to play a role in the maintenance of underwater habitats including kelp beds (Noordegraaf, 2020; Smith & Bannister, 2016). Therefore, their absence due to a decrease in their abundance could lead to an alteration of these habitats as well as related changes in food web dynamics (Smith & Bannister, 2016). In addition, after death, the whales' carcasses form an immediate rich habitat in the deep-sea environment that supports some whale-fall specialist invertebrates. Thus, the decline of marine mammals that perform this function may result in the degradation of habitats and species that occur in those habitats (Hammerschlag et al., 2019).

Genetic material: The physical movement of animals in the water column, especially large marine mammals such as whales, contributes to the distribution of nutrients and oxygen in the water, increasing primary production (as previously mentioned for the service of 'regulation and maintenance of marine food webs'). Areas with higher primary production also tend to be associated with greater availability of prey and biodiversity. By supporting greater biodiversity and thus the greater genetic diversity associated with it, large marine mammals contribute to the supply of genetic material in terms of intermediate service that is the basis for the supply of aquatic biomass that is then enjoyed by humans (final ecosystem service; Cook et al., 2020). Marine mammals themselves constitute a source of genetic material that can be used by humans for various purposes (final ecosystem services; Haines-Young & Potschin, 2018).

Pest control: Marine predators, including some marine mammals, benefit prey populations by removing sick and old individuals. If marine mammals with such a role at the top of the food web target sick individuals, this predation process may reduce infectious diseases that have a transmission host density dependent. However, this ecosystem service is derived from and limited to the reduction of prey density by predatory marine mammals. It is therefore possible to assume that a decline in such predators may lead to an increase in prey density with a possible increased spread of density-dependent infectious diseases (Hammerschlag et al., 2019). Similarly, if predatory marine mammals target non-native species as their prey, they may contribute to their control (Hammerschlag et al., 2019). Moreover, pest control is underpinned by a balanced food web and therefore all components of the marine ecosystem are relevant to the provision of this ecosystem service, including marine mammals (Culhane et al., 2019).

(Global) climate regulation: Large marine mammals, such as whales, contribute to climate regulation through the accumulation of large amounts of carbon in their bodies. After their death, the carcasses lock up significant amounts of organic carbon on the sea floor (Cook et al., 2020). Moreover, marine mammals, through their role in increasing primary productivity, influence carbon fluxes in the marine ecosystem (Riisager-Simonsen et al., 2020).

Recreation related services: On-site observation of marine mammals such as seals and whales occurs in several areas such as the Dutch coast, the Wadden Islands, the UK coast and so on. Porpoises can be seen for example along the Scottish coast (Noordegraaf, 2020). Therefore, negative impacts on the health of marine mammals and a decline in their abundance may in turn negatively impact the benefit many people derive from non-consumptive or low-consumptive use of marine mammals, especially through whale, dolphin and seal-watching tourism (Cook et al., 2020; Smith & Bannister, 2016). Furthermore, the sight of marine mammal individuals impacted by marine litter e.g., through entanglement during biodiversity-watching tourism may have a negative effect on this ecosystem service and may in turn affect other cultural ecosystem services such as ecosystem and species appreciation.

Education, scientific, and research services: Marine mammals are a central topic in many scientific research. Proof of this is the large number of studies involving marine mammals that can be found in different literature online databases (Noordegraaf, 2020). Also, public display of captive marine mammals can make people more aware and appreciative of them, but it is extremely controversial (Smith & Bannister, 2016). However, precisely because this ecosystem service can be also benefited ex-situ e.g., visiting a museum, a decline of marine mammals can also have a neutral impact on this ecosystem service as it is not directly influenced by the current state of marine mammal populations (Cook et al., 2020; Culhane et al., 2019).

Spiritual, artistic, and symbolic services: Marine mammals such as whales are a source of inspiration for various types of artistic expression, including sculpture, painting, drawing, and film-making. However, precisely because this ecosystem service can be also benefited ex-situ e.g., through artistic representations, the decline in marine mammal abundance can also have a neutral impact on this ecosystem service as it is not directly influenced by the current state of marine mammal populations (Culhane et al., 2019). In addition, marine mammals are known to play a role in the maritime culture and spiritual identity of several local communities, including Icelandic ones (Cook et al., 2020).

Visual amenity services: Marine mammals provide this service because they can convey a 'sense of place' through their direct vision or through their artistic representations (for example, works of art that use marine wildlife as inspiration; UK NEA, 2011c). Different marine mammals fall into what is termed a 'charismatic megafauna' (Cook et al., 2020). However, precisely because this ecosystem service can be also benefited ex-situ e.g., through the observation of an artistic representations, a decline of marine mammals can also have a neutral impact on this ecosystem service as it is not directly influenced by the current state of marine mammal populations (Culhane et al., 2019).

Ecosystem and species appreciation: This ecosystem service represents the value placed on species (charismatic or not) of marine mammals simply by knowing that they exist and that they and the natural environment where they are found are in good state, even if perhaps the very people who place this value on them will never see them. In fact, the relative rarity and aesthetic qualities associated with marine mammals means that their preservation is often appreciated even without a direct presence in the environment of the very people who place this value on them (Cook et al., 2020). This ecosystem service also includes knowing that future generations will have the opportunity to enjoy marine mammals (Noordegraaf, 2020). Therefore, a significant decline of marine mammal populations can negatively affect the provision of this service.

Results of the joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation

In the context of the joint ICG-ESA/ICG-EcoC workshop, the experts involved in relation to the Marine Mammals thematic assessment provided feedback based on the pre-populated 'state changes/environmental impacts – impact on ES' made available to them (here shown above). During this process, experts reported that all the presented ecosystem services are relevant in relation to marine mammals. More specifically, experts reported that, when looking at the OSPAR level, all the identified ecosystem services in relation to marine mammals are relevant. However, it was noted that at the regional level some ecosystem services may be less important. For example, marine mammals may have an impact on benthic habitats. This is not a major problem in nutrient-rich areas of the ocean but is more problematic in less nutrient-rich polar areas. In this regard, it was mentioned that there could be more detailed information at a smaller scale and that regional differences within the OSPAR area may be particularly important. This is the reason why a more detailed analysis at the regional scale is a relevant area for future work.

It was also highlighted that the links identified between the state of marine mammals and impacts on ecosystem services may better represent the linkages and roles that functional groups of marine mammals play in relation to ecosystem services rather than the roles of individual species. Indeed, when considering the level of individual marine mammal species, the situation becomes more variable (e.g., some whales feed in deeper parts of the ocean than other whales, and therefore have different functions in the ecosystem). Yet in both cases, estimating the size of the impacts will be difficult (if not impossible) due to the limited scientific information/evidence.

The experts reported that the identified nature of the impacts (arrow colour) on ecosystem services is reasonable. However, they were unable to estimate the size of the impacts on ecosystem services due to a lack of sufficient information/scientific evidence. In this regard, it has been noted that one way to address the problem of not being able to estimate the size of impacts could be to use the thresholds of marine mammal indicators to say something about whether the observed trend is considered a serious problem or not, and thus in turn, could be a relevant issue for which to analyse impacts on ecosystem services. In relation to considering indicator thresholds, it was also mentioned whether marginal change could be used to say something about impacts on ecosystem services (before exceeding thresholds) (e.g., testing it in certain cases). The previous suggestion could be taken into account when evaluating the approach to be applied in future work on the assessment of ecosystem services and the impacts on their provision.

Furthermore, during the discussion with the experts, it was reported that climate change has impacts on mammals, but the exact quantification of this impact is not yet known (also depending on different variables such as (regional) scale and functional groups).

Given that the experts agreed with the identified ecosystem services and the nature of the impacts on their provision, the previous visual representation of the impacts of changes in the state of marine mammals on ecosystem services did not change following the joint ICG-ESA/ICG-EcoC workshop.

4.2 Marine Litter thematic assessment

State Changes/Environmental impacts	Impact on ES
Ingestion: 690 marine vertebrates have been reported to ingest marine litter, most being plastic. Many of the affected species are protected (Provencher et al., 2016; Werner et al., 2016). Trophic transfer is an indirect but potentially important pathway for predators to ingest litter (leading to biomagnification). <u>Birds</u>: Northern Fulmars ingest plastic on a regular basis. Over the five-year period 2010–2014 inclusive, OSPAR's long-term goal in terms of plastic litter ingestion by seabirds was not achieved anywhere in the North Sea. Among all 525 fulmar stomachs analysed over this period, 58% contained more than 0.1 g of plastic, whereas OSPAR's long-term goal is to reduce this to less than 10%. Of all birds analysed, 93% had some ingested plastic, and average values per bird were 33 particles and 0.31 g. Fulmars from the English Channel had the highest plastics load, slightly lower levels being observed further north. Over the last five-year period no significant increases or decreases in ingested plastic mass were observed in the North Sea as a whole or in any of the five sub-regions. Biomagnification is also observed in birds and <u>obstruction of the gastro-intestinal tract is identified as a major cause of death</u> (OSPAR, 2017c). Stranded North Sea fulmars have more than 0.1g of plastic in their stomachs, exceeding Fulmar's threshold value of 10% (OSPAR, 2017c).	**Biomass and raw materials from in-situ aquaculture** **Wild fish and other natural aquatic biomass and related raw materials** **Regulation and maintenance of marine food webs** **Genetic material**

Reptiles: marine turtles ingest plastic. This causes sublethal effects (e.g., intestinal blockages, internal injuries, malnutrition, reduced growth, and reproduction rates; Werner et al., 2016).

Fish: A large proportion of individuals from a high number of species ingest microplastics. Microplastics have been found in the stomachs of commercial species such as herring, cod, mackerel. Differences between species are attributable to different feeding behaviors and higher amounts of plastic was recently observed in benthic species than pelagic species. For predatory fish, trophic transfer plays an important role. In recent analyses microplastics have been identified in gastro-intestinal tracts, gills and dorsal muscles. However, in general, no significant effects resulting from ingestion of these microplastics have been identified (Werner et al., 2016).

Invertebrates: Ingestion of microplastics: reduces the energy reserves of bivalve species; reduces the feeding rate, body mass, and metabolic and catabolic rate of the langoustine; reduces the number of offspring and egg size in marine benthic dwelling polychaete worms; adversely affects the primary production of lugworms; adversely affects feeding behaviour, growth, reproduction, and lifespan of zooplankton (Werner et al., 2016).

(Global) climate regulation

Sediment quality regulation

Water quality regulation

Recreation related services

Visual amenity services

Education, scientific, and research services

Spiritual, artistic, and symbolic services

Ecosystem and species appreciation

Entanglement

Mammals: entanglement in fishing gear (bycatch) was identified as one of the main causes of death of stranded harbour porpoises and common dolphins along the coasts. Minke whales are prone to entanglement (e.g., in North Sea) and litter can occlude blowhole of whales. Marine litter gets entangled around the necks of seals. In grey seals entanglement causes physical injuries, impairing feeding or leading to infection Warner et al., 2016).

Birds: Northern Gannets, Common Guillemots, spoonbills, European Shags, Kittiwakes, Cormorants and Northern Fulmars use marine litter as nesting material in breeding colonies in the OSPAR region (Werner et al., 2016).

Reptiles: Entanglements of leatherback turtles have been documented in the Atlantic Ocean and North Sea. Negative effects include lacerations, increased drag that can reduce the ability to forage or escape threats and may result in drowning or death by starvation (Werner et al., 2016).

Fish: Several species of demersal and pelagic fish end up entangled in ghost nets and derelict fishing gear. Abandoned nets entangled in the seabed (ghost fishing) shows similar catch rates to commercial nets continuing to fish for long periods. Entanglements of sharks have been recorded, causing injuries to dorsal muscles and pectoral fins, gill slits obstruction leading to breathing problems and death (Werner et al., 2016).

Wild fish and other natural aquatic biomass and related raw materials

Genetic material

Recreation related services

Visual amenity services

Education, scientific, and research services

Spiritual, artistic, and symbolic services

Ecosystem and species appreciation

Smothering, scouring and physical damage: Coral reefs such as gorgonians along southwest England are affected by smothering and entanglement by marine debris (sea fangles) of various kinds (domestic nature, fishing etc.). Smothering leads to reduced fitness and death of organisms underneath the litter reducing oxygen levels and photosynthesis, which in turn alters habitats and communities. This also alters the exchange of gas and nutrients between the sediments and the water column (OSPAR, 2017b; Werner et al., 2016). Also, **generation of artificial hardgrounds** is documented in the Baltic Sea. It was observed that numerous benthic communities are physically supported by different marine litter and hardgrounds. Overall, marine litter is found to be a refuge for both native and invasive species and the latter were mainly attached to non-plastic artificial materials. Thus, the introduction of additional hard surfaces creates artificial habitats that can be colonised by organisms not normally found there. This leads to altering assemblages of species (Werner et al., 2016). Litter is widespread on the seabed throughout the OSPAR area, with plastic as the predominant material (OSPAR, 2017c).

Physical presence and abundance on beaches and in the water: As reported in OSPAR IA 2017 beach litter is abundant throughout the OSPAR area, with a prevalence of plastics (OSPAR, 2017c).

(Floating) litter acts as a vector for **transport of biota** (e.g., invasive species, microbes, viruses) **and pollutants** (e.g., contaminants, leachate from breakdown) (Werner et al., 2016). Then, the subsequent ingestion of litter by marine organisms brings them into contact with these infectious biota or pollutants. To provide and example, Phthalates and BPA affect reproduction and induce genetic aberrations. Also, the risk of transfer of contaminants (such as chemical additives) to humans is well documented. Some of the leachates involved are known to be toxic mutagenic, carcinogenic or hormone disrupting and bio-accumulating (Werner et al., 2016).

Coastal protection

(Global) climate regulation

Sediment quality regulation

Regulation and maintenance of marine food webs

Nursery population and habitat maintenance

Pest control

Visual amenity services

Spiritual, artistic, and symbolic services

Recreation related services

Ecosystem and species appreciation

Biomass and raw materials from in-situ aquaculture

Wild fish and other natural aquatic biomass and related raw materials

Genetic material

Water quality regulation

Detailed rationale behind identified impacts on ecosystem services

As shown schematically, each state change / environmental impact associated with Marine Litter impacts on different marine ecosystem services. The following provides an elaboration on how marine litter can impact ecosystem services.

Biomass and raw materials from in-situ aquaculture: marine litter, by impacting on marine ecological components through ingestion, diffusion of invasive species, transmission of viruses, pathogens and various pollutants damages marine organisms reared in aquaculture processes and consequently reduces the provided biomass (Beaumont et al., 2019).

Wild fish and other natural aquatic biomass and related raw materials: marine litter, by impacting on marine ecological components through physical entanglement and other types of damage related to ingestion, smothering and damage of habitats, diffusion of invasive species, transmission of viruses, pathogens and various pollutants damages wild stocks of fish and other marine organisms and consequently reduces the provided biomass (Beaumont et al., 2019).

Regulation and maintenance of marine food webs: healthy marine ecosystems are dependent on maintaining the food webs underpinned by balanced trophic levels. Regarding smothering, the adverse effect on nutrient turnover resulting from a change in structure of primary producers' communities (mentioned for the ecosystem service of sediment quality regulation) can result in a cascade effect on the entire food-web (Green et al., 2015). Furthermore, marine litter as a result of ingestion (with associated contaminants, such as additives, or contaminants present in the marine environment and sorbed to marine plastic particles, such as PCB or heavy metals), spread of invasive species, pathogens through trophic levels can lead to the undermining of the food chain at the base of a healthy ecosystem (Beaumont et al., 2019). Changes in microbial assemblages linked to marine plastics are also observed as well as the colonisation of marine plastics by microbial groups that include pathogens (Bowley et al., 2021; Vaksmaa et al., 2021; Oberbeckmann & Labrenz, 2020). However, changes to the microbiome linked to pollution from marine plastics and their ecological repercussions are still an area of developing research (Lear et al., 2021). Consequently, litter has the long-term potential to change the ecology of the marine ecosystem, altering biodiversity and having unpredictable social consequences.

Genetic material: Lethal and sub-lethal effects on marine biota associated with marine litter (from entanglement, ingestion etc.) can compromise this ecosystem service both when considered as intermediate (negatively affecting marine biodiversity and the supply of marine biomass that it underpins) and final service (compromising genetic resources for humans potentially useful for future needs; Beaumont et al., 2019; Werner et al., 2016).

(Global) climate regulation: it is documented that seafloor smothering by marine litter can have a negative impact on climate regulation due to its adverse effect on the photosynthesis process. It has been observed that smothering and shadowing by marine litter on the seabed leads to a reduction in photosynthetic biomass (such as microphytobenthos including microalgae etc.) as a result of reduced light penetration (Green et al., 2015). Other adverse effects related, for example, to the ingestion of microplastics by zooplankton and other marine invertebrates (negatively affecting their growth, reproduction, and lifespan; Werner et al., 2016) may also adversely affect the fundamental contribution of these organisms in the provision of the ecosystem service of climate regulation. Indeed, zooplankton through processes such as the export of particles by grazing, the fractioning of sinking particles, and the transport of particulate organic carbon at depth through its diel vertical migration, plays a crucial role in the functioning of the oceanic biological carbon pump that contributes to regulating atmospheric CO_2 levels (Lomartire et al., 2021).

Coastal protection: considering the contribution of biotic elements such as coral reefs, microphytobenthos, and infauna to processes such as erosion control and thus to coastal protection, their degradation (and possible death) as a result of smothering or ingestion (as also illustrated for invertebrates) can more or less compromise the provision of this ecosystem service (Hope et al., 2020).

Water quality regulation: the illustrated lethal and/or sub-lethal effects related to marine litter can impair to varying degrees the ability of marine ecosystem components to provide water quality regulation, for example through: death of components such as reefs; death or adverse effects on invertebrate organisms such as mussels, given their contribution to water filtration (Nielsen et al., 2016).

Sediment quality regulation: seafloor smothering by sealing the surface can block oxygen diffusion, light diffusion (that in turn can alter the normal biological process of the biota living within sediments contributing to their maintenance) and prevent the deposition of organic matter into the sediment. For example, the negative effect on sediment microphytobenthos can adversely change the nutrient turnover considering that microphytobenthos has also an important role in influencing the quality and quantity of sediment organic matter (Green et al., 2015).

Pest control: the environmental impacts associated with marine litter such as its role as a vector for invasive species, non-invasive proliferating species, nuisance algae etc. impacts on the normal pest control service provided by the marine ecosystem by increasing the presence and range of non-indigenous species including e.g., toxic algae. Other negative effects of marine litter, such as increased mortality of species as a result of ingestion, disease etc. also have a negative effect on this ecosystem service if the affected species naturally contribute to pest control (Werner et al., 2016).

Nursery population and habitat maintenance: marine litter presents mainly negative impacts on the provision of this service. The generation of artificial hardgrounds it can deteriorate pre-existing in-situ habitats favourable to native species by altering the structure of habitat components (corals, biogenic reefs, microphytobenthos, etc.) and leading to changes in the assemblages of such species (e.g., more short-lived species). Moreover, it increases the range of habitats available for colonisation by invasive species (Beaumont et al., 2019; Werner et al., 2016).

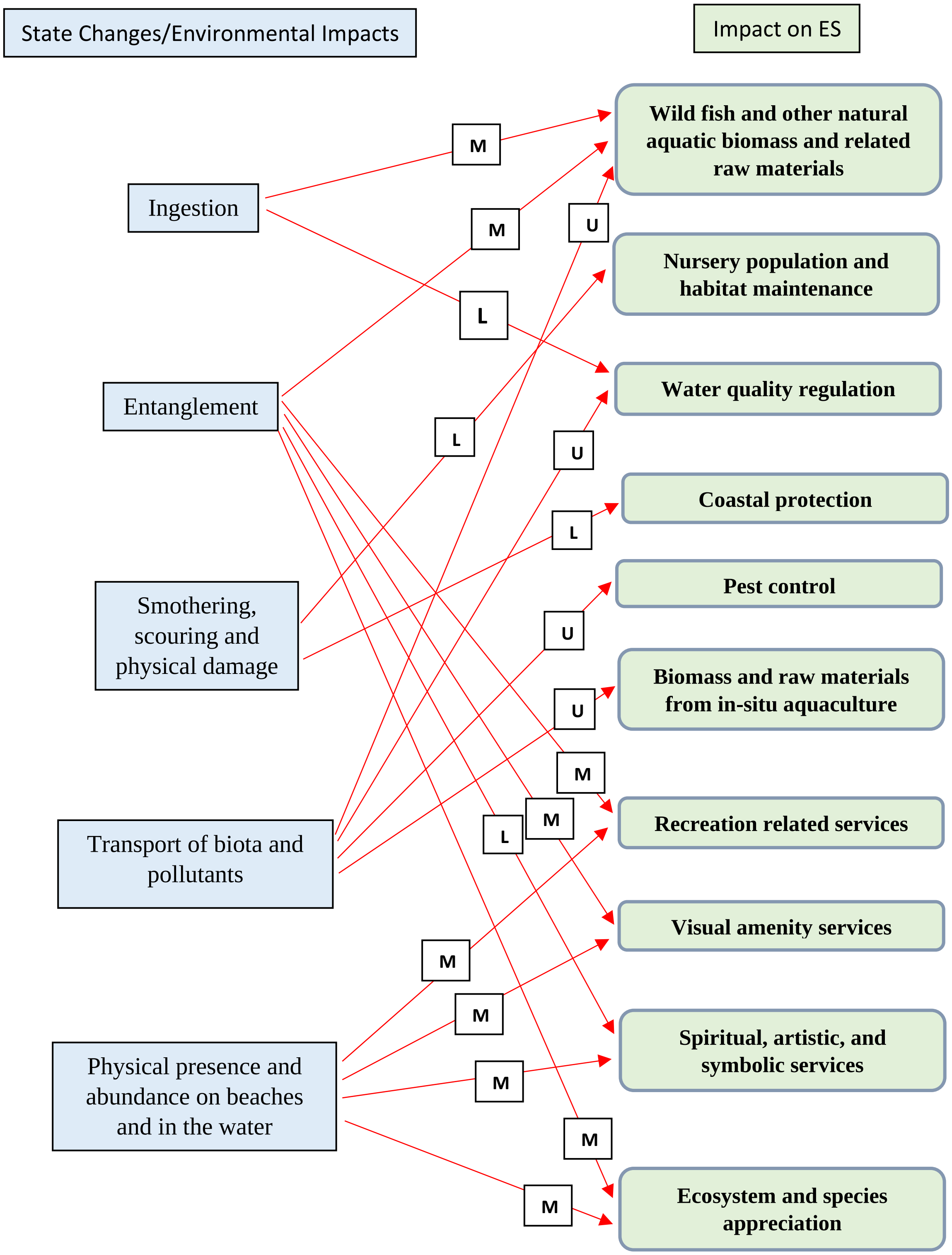
Recreation related services and visual amenity services: Visible pollution of marine litter (on beaches, on the seabed, entangled with species etc.) has a significant negative impact on experiential recreation since it is known that this is despised by humans, given its negative effect on the sense of place that can be associated with a marine location, sensory enjoyment and consequently on recreational activities. The presence of litter on organisms can reduce or disrupt the ability of such biotic components to underpin activities such as diving, wildlife-watching etc.

(Beaumont et al., 2019; Werner et al., 2016). A detrimental effect on people's mood and mental well-being following time spent on coastlines affected by litter pollution has been documented (Wyles et al., 2016).

Ecosystem and species appreciation: charismatic marine organisms such as birds, turtles and cetaceans are of cultural and/or emotional importance to individuals. Direct sighting and/or images and articles shared through the media of stranded cetaceans and seabirds with their stomachs full of plastic have a negative effect on human wellbeing in relation to the awareness of the damage and/or loss of these charismatic species (Beaumont et al., 2019). Furthermore, in relation to this ecosystem service, it can be mentioned that marine litter has negative effects on marine animal welfare, causing avoidable suffering to them (Werner et al., 2016). From an ecosystem service perspective, it could be argued that marine animal welfare can benefit humans when considering the satisfaction of the humans concerned in seeing animal welfare maintained. However, the direct beneficiaries are the marine organisms, and the issue of animal welfare may go beyond the concept of ecosystem services (Gunton et al., 2017).

Results of the joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation

In the context of the joint ICG-ESA/ICG-EcoC workshop, based on the pre-populated ‘state changes/environmental impacts – impact on ES’ diagram provided, the experts involved in relation to the Marine Litter thematic assessment provided comments on the previous descriptive sections which were amended accordingly. In addition, during the workshop the experts involved provided input including suggestions on how best to present the categories of state changes in the boxes of the 'State changes/environmental impacts' column, the ecosystem services they deemed most relevant in relation to state changes associated with marine litter, and expert-based estimate of the magnitude of state change impacts on the relevant ecosystem services (H = high impact, M = medium impact, L = low impact, U = unknown impact). The section below presents the linkages and impacts of state changes/environmental impacts on ecosystem services reflecting the expert input received during the workshop. The text in the state changes/environmental impacts boxes has been reduced to only the categories of state changes/environmental impacts to avoid repetition with the pre-workshop scheme (shown previously). For more in-depth information on the mentioned state changes/environmental impacts, the extended text of the boxes presented in the initial pre-workshop outline should be considered.


State Changes/Environmental Impacts
Impact on ES
Ingestion
Entanglement
Smothering, scouring and physical damage
Transport of biota and pollutants
Physical presence and abundance on beaches and in the water
Wild fish and other natural aquatic biomass and related raw materials
Nursery population and habitat maintenance
Water quality regulation
Coastal protection
Pest control
Biomass and raw materials from in-situ aquaculture
Recreation related services
Visual amenity services
Spiritual, artistic, and symbolic services
Ecosystem and species appreciation
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5. Discussion, conclusions, and suggestions for future work

This work arose in response to OSPAR's need to develop a list of marine ecosystem services that could be used in its workflows and application of the ecosystem approach, and the need to develop a methodology for assessing marine environment state change impacts on ecosystem services that could support the development of OSPAR thematic assessments. Chapter 3 presented the selected list of marine ecosystem services and their detailed descriptions, highlighting the importance of the goods and benefits provided by marine ecosystems to people for human welfare. In Chapter 4, Marine Litter and Marine Mammals OSPAR thematic assessments have been used as case studies to explore and illustrate the application of the methodology developed for assessing state change impacts on ecosystem services and its added values.

The identification of a list of the most relevant marine ecosystem services applicable to the North-East Atlantic area and the development of a method that can enable state change impacts on ecosystem services to be assessed represents the link that has been missing in the OSPAR context to render more visible how changes in the state of the marine environment can translate into impacts on human welfare in terms of reducing and/or increasing the goods and benefits that humans derive from marine ecosystems.

The concept of ecosystem services, bridging ecology (biophysical structures, processes, and functions) and human wellbeing (socio-cultural context), can be used as an effective tool to highlight the dependence of humans on the good state of ecosystems, the importance of conservation, and help decision-makers implementing measures. The ecosystem services tool allows the costs to society and human wellbeing arising from environmental state changes to be made visible.

The final completion of the application of the presented methodology was possible by means of the joint ICG-ESA / ICG-EcoC workshop on DAPSIR implementation and cumulative impact assessment within the context of the 2023 Quality Status Report on the 1st of February 2022. The ecosystem services workshop sessions allowed to:

- Support thematic assessment leads in the development of the “Impact on Ecosystem Services” sections of their thematic assessments.
- Progress the thinking on the relationship between changes in state and ecosystem services based on expert judgement.

This allowed the involved OSPAR and external experts to select only those ecosystem services they considered most relevant to the thematic assessments based on possible links between state changes and ecosystem services previously identified by the project lead. In addition, experts were able to give their opinion on the nature of the impacts on ecosystem services and provide an expert-based estimate of the magnitude of these impacts. The result of the application of this methodology for the two case studies presented in this report is what is reported in Chapter 4 under the title 'Results of the joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation'.

The workshop showed significant progress in the steps OSPAR is taking towards integrated ecosystem-based management. With this workshop, OSPAR has taken another step in previously unknown territory. All the involved experts acknowledged the value of the work done in this project in attempting the integration of the ecosystem services approach, enabling them to move one step closer to completing the DAPSIR framework within the thematic assessments and highlighting the close connection between the state of marine ecosystems and human well-being.

This has been demonstrated by the application of the methodology for the two case studies of the pressure-related thematic assessment (Marine Litter) and the state-related thematic assessment (Marine Mammals). The application of this methodology allowed to demonstrate how marine environment state changes / impacts associated with the presence of marine litter (e.g., ingestion, entanglement, physical presence and abundance on beaches and in the water) can negatively affect a significant range of ecosystem services including provisioning, regulation and maintenance, and cultural services. This in turn can entail costs to society in terms of a reduction in the goods and benefits provided to people by marine ecosystems such as a reduction in seafood, medicine and blue biotechnology, a deterioration in coastal erosion prevention, in marine water quality, and a degradation of benefits to human psychology, health, and tourism activities. Similarly, it has been possible to illustrate how a decline in the population of marine mammal species can have negative impacts on a wide range of ecosystem services, possibly leading to costs to society.

However, it is also crucial to emphasise how the application of this methodology allows at the same time to make evident the positive effects on human well-being that can result from the successful implementation of measures that lead to an improvement in the state of the marine environment. Regarding the Marine Mammals thematic assessment case study, through the application of this methodology it is possible to illustrate how a general improvement in the state of marine mammal populations (increased abundance) can in turn have positive effects on human well-being, leading to an increase in benefits such as improved climate quality, water quality, and enhanced benefits to human psychology, health, and tourism activities.

Consequently, the presented methodology fills the far-right part of the DAPSIR framework, which is the component that allows to render explicit in terms of losses and gains for society the costs of a degradation of the state of marine ecosystems and the value of implementing measures for the improvement of the state of marine ecosystems This allows to translate OSPAR assessments into a language that is essential for providing information to policy makers.

It is important to stress that this work was not intended to present definitive results to be included in OSPAR work, but rather to sanction the beginning of the development of a methodological framework that would allow the integration of ecosystem services thinking within OSPAR assessment workstreams, particularly with the aim of providing inspiration and support for the development of the section on impacts on ecosystem services within the QSR 2023 thematic assessments.

During the joint ICG-ESA/ICG-EcoC workshop on DAPSIR implementation, the Marine Mammals experts reported that in relation to their thematic assessment all the information currently available in the scientific literature regarding the link between the state of marine mammals and ecosystem services was used. This provides a positive signal for OSPAR since, having a well-grounded foundation of the methodological framework for assessing the state change impacts on ecosystem services, it could be possible to apply and enrich this framework with the upcoming results of the OSPAR assessments for the QSR 2023.

However, with the aim of further improving the integration of ecosystem services in the work of OSPAR, it is also necessary to report some limitations highlighted during the joint ICG-ESA / ICG-EcoC workshop.

Most importantly, it was reported by experts that it is difficult to estimate the magnitude (high/medium/low) of state change impacts on ecosystem services due to the limited information available in the existing scientific literature, and that this demonstrates how little is still known about such causality linkages. Indeed, this methodology is based on qualitative information due to the current lack of quantitative data regarding the provision of marine ecosystem services and changes in their provision as a result of marine state change impacts, particularly at the North-East Atlantic scale. In this regard, it has been noted by experts that the level of provision of marine ecosystem services and the magnitude of impacts on them can vary when considering different scales, due to the variability of ecological characteristics between geographical areas. For this reason, it has been argued that regional differences within the OSPAR maritime area may be particularly important when assessing ecosystem services and impacts on them.

Concerning the lack of quantitative data, it can be briefly mentioned that an existing tool that allows to quantitatively explore how changes in the state of (marine) ecosystems can induce changes in the provision of ecosystem services is represented by InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs). InVEST is a suite of spatially explicit models that uses maps as sources of information and provide results in either biophysical terms (e.g., tons of carbon sequestered) or economic terms (e.g., net present value of that sequestered carbon) in the form of spatial maps (Stanford University, n.d.). Thus, InVEST may be an option to overcome in the future the lack of quantitative data.

Furthermore, still to respond to the lack of quantitative data, the importance of the interconnection of the present work with the Natural Capital Accounting (NCA) work in relation to OSPAR objectives carried out last year (Alarcon Blazquez, 2021) can be underlined. Given the lack of quantitative information on the change in the provision of ecosystem services as a result of state changes of marine ecosystems, NCA may come into play. NCA, by making visible the economic contribution of ecosystem services to society, allows over-time comparisons that can be related to observed state changes of marine ecosystems. NCA can provide information on stocks and changes (increases and decreases) in ecosystem service flows, thus including accounting for the enhancement and/or degradation of marine ecosystems and the services they provide (Alarcon Blazquez, 2021). This is where these two works can complement each other. By showing the monetary value of goods and services related to marine ecosystems that are produced in different years and indicating the spatial location of the provision of certain marine ecosystem services, NCA could address the need for quantitative data and spatial detail highlighted during the workshop held in the context of this work. At the same time, this report, having presented a comprehensive list of ecosystem services that could be adopted in the context of the OSPAR QSR 2023 and a methodology for linking state changes with marine ecosystem services, can help to address some of the next steps that OSPAR can take in terms of NCA highlighted in the work of

Alarcon Blazquez (2021). For example, Alarcon Blazquez (2021) stressed the need to expand the list of ecosystem services to ensure that the coverage of the ecosystem account is as complete as possible and to decide how and which ecosystem service should be prioritised. In this respect, the present work has provided an opportunity to begin the process of integrating ecosystem service assessment into the working dynamics of OSPAR thematic assessments. This has led several OSPAR experts to engage with the importance of ecosystem services and to reflect on the level of relevance of selected ecosystem services in relation to their thematic assessment. Thus, this represents an interesting step that may help towards a more detailed prioritisation process in relation to the economic valuation of flows of goods and benefits from marine ecosystems to be applied in the future.

Another discussion point to be addressed is the connection between ecosystem services and the Driver and Activities components of the systemic DAPSIR framework. As mentioned above, the concept of ecosystem services acts as a bridge between ecology and the socio-cultural domain. In the context of the DAPSIR framework, the component of (impacts on) ecosystem services enables connecting back to the first DAPSIR framework component, the drivers, closing the DAPSIR framework loop to connect system components. The reasoning behind this connection is that the main societal drivers are related to basic human needs such as the need for food, energy, space, movement of goods, security, or recreation. These needs are served by the goods and benefits, i.e., ecosystem services, provided to society by the North-East Atlantic Ocean. In turn, human activities taking place in the marine environment of the north-east Atlantic are undertaken as a direct consequence of the drivers, in order to meet the basic human needs. Therefore, impacts on ecosystem services can influence human drivers and activities.

To close the DAPSIR framework loop, a second workshop (more limited than the first one) was organised in the context of this work on the 10th of February 2022 with the aim of linking the identified ecosystem services with the drivers and human activities that underpin human economy. Through this workshop it was possible to identify, based on the opinions of expert economists from Rijkswaterstaat (The Dutch Ministry of Infrastructure and Water Management), the drivers that may be affected by changes in the provision of the selected ecosystem services and the human activities that use and depend on the provision of the selected ecosystem services. The results of this process are provided in a table at the bottom of each ecosystem services factsheet. In this regard, it should be emphasised that, particularly due to time constraints, this workshop represents only a preliminary attempt to gather useful input for closing the DAPSIR framework loop and linking ecosystem services to human drivers and activities, and that the results reflect expert-based opinions rather than being evidence-based. Nonetheless, this provided an opportunity to illustrate a comprehensive picture of the potential value of employing the ecosystem services concept in the context of the DAPSIR framework and the OSPAR QSR 2023.

The results of the present work provide for the first time a comprehensive ecosystem services approach (as part of the application of the Ecosystem Approach), including a standardised list of marine ecosystem services and an ecosystem services methodology that can potentially be applied within OSPAR dynamics and throughout the QSR 2023 thematic assessments.

In relation to the list of marine ecosystem services selected in this paper, it represents a list that was deemed to satisfy both a comprehensiveness criterion, i.e., attempting to include all relevant ecosystem services without including too many ecosystem services, and a usability criterion, i.e., presenting names and definitions of ecosystem services that can be clearly understood by a wide range of experts and stakeholders with different backgrounds. For this reason, the names of some ecosystem services may deviate slightly from those of other ecosystem service frameworks. However, this has been done while always taking into account comparability with ecosystem services presented by other international frameworks. This does not preclude, if deemed necessary, the possibility of amending some names and/or definitions by OSPAR.

Furthermore, there is a limitation that needs to be mentioned in relation to ecosystem services and their use. The application of ecosystem services must be supported by a clear understanding of the ecosystem components that provide them and the ecological functions underlying their provision, particularly for the category of regulation and maintenance services. This is often still challenging as scientific knowledge is still progressing when it comes to these complex relationships between ecological functioning by specific ecosystem components and the provision of ecosystem services. Therefore, a number of uncertainties still exist, and uncertain relationships can be used as an argument to exclude some ecosystem services. This is an aspect that may make the application of ecosystem services appear in certain circumstances to be a more time-consuming exercise than others, and therefore not prioritised.

As a final positive point of discussion, it should be mentioned how the results of the application of the presented methodology help OSPAR to take a further step towards achieving the NEAES 2030 objectives, particularly Strategic Objective 5, Strategic Objective 7, Operational Objective 7.03, and Operational Objective 12.01 (presented in detail in Chapter 1). However, as also noted in the work of Alarcon Blazquez (2021), the results of this work on ecosystem services can not only help in the achievement of the objectives strictly related to ecosystem services but, by enabling the connection of environment, economy, and society, can contribute to a wider range of OSPAR objectives and to the practical application of the ecosystem approach.

Drawing on the above, suggestions for future work can be presented:

- As a first suggestion, future work could focus on refining the presented methodology for assessing the impacts of a changing state of the marine environment on ecosystem services through specific additions and optimisations. A first improvement would be to seek to integrate quantitative information in relation to impacts on ecosystem service provision, potentially through economic valuation of ecosystem service flows (integrating NCA). Secondly, an explicit spatial approach could be pursued that would allow differentiation between, for example, areas with higher ecosystem service provision that receive a higher/lower magnitude of impact from state change and areas with lower ecosystem service provision that receive a higher/lower magnitude of impact. A local scale might be too much detail to conduct such an analysis across the entire OSPAR maritime area, but one option would be to focus on differences in impacts of state change and ecosystem service provision between the five OSPAR regions, thus also reflecting the approach of the OSPAR thematic assessments. These refinements could overcome the current uncertainties in assigning magnitudes to the impacts of state change on ecosystem services.

- Another option to go quantitative would be to develop a case study purely focused on one or a couple of ecosystem services whose provision is more easily quantifiable, which would also allow for more spatial detail. One example is carbon storage, which is both more easily quantifiable than other ecosystem services and has high policy visibility. This would further contribute to building synergies with Strategic Objective 12.01, which focuses on developing a regional approach to applying nature-based solutions for carbon storage.

- Future work could also continue to explore the links between ecosystem services and the Drivers and Activities components of the DAPSIR framework and the consequences of impacts on ecosystem services on these components. This step forward may continue on the basis of the first attempt made in the context of one of the workshops related to this work to link ecosystem services with drivers and activities and close the DAPSIR loop. This further emphasises the link between ecosystem services and the human socio-economic domain.

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OSPAR's Quality Status Report 2023

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Our vision is a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification.