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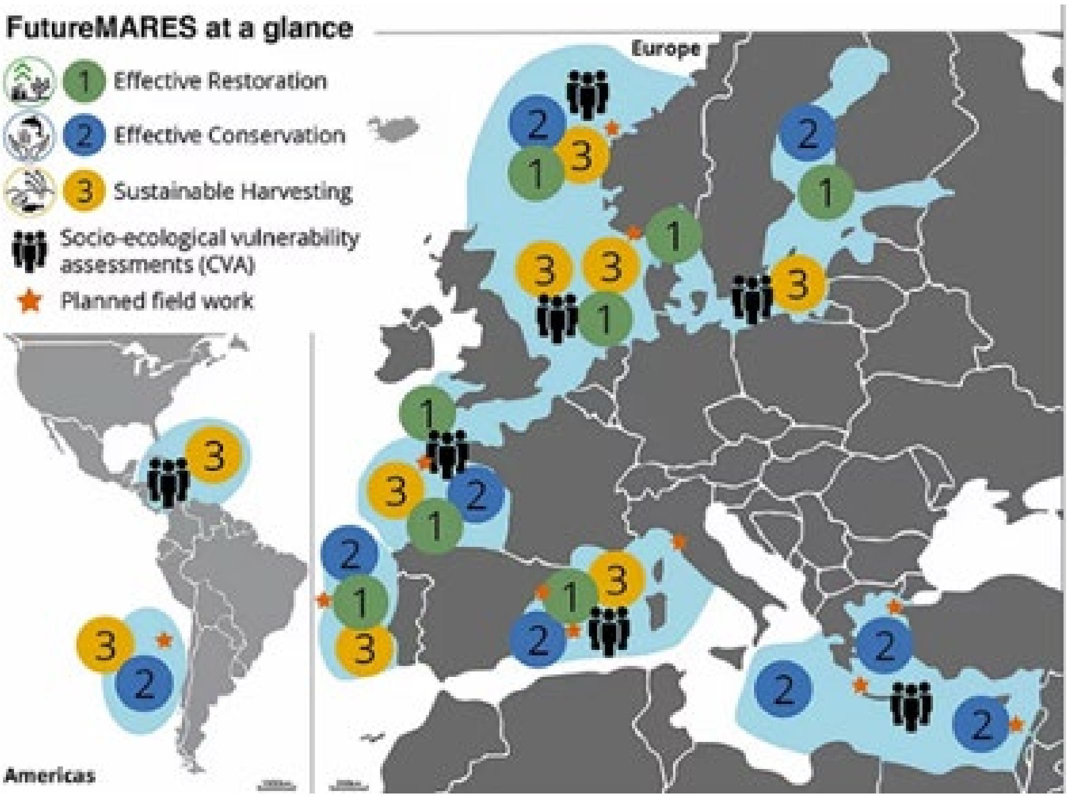
FutureMARES Project

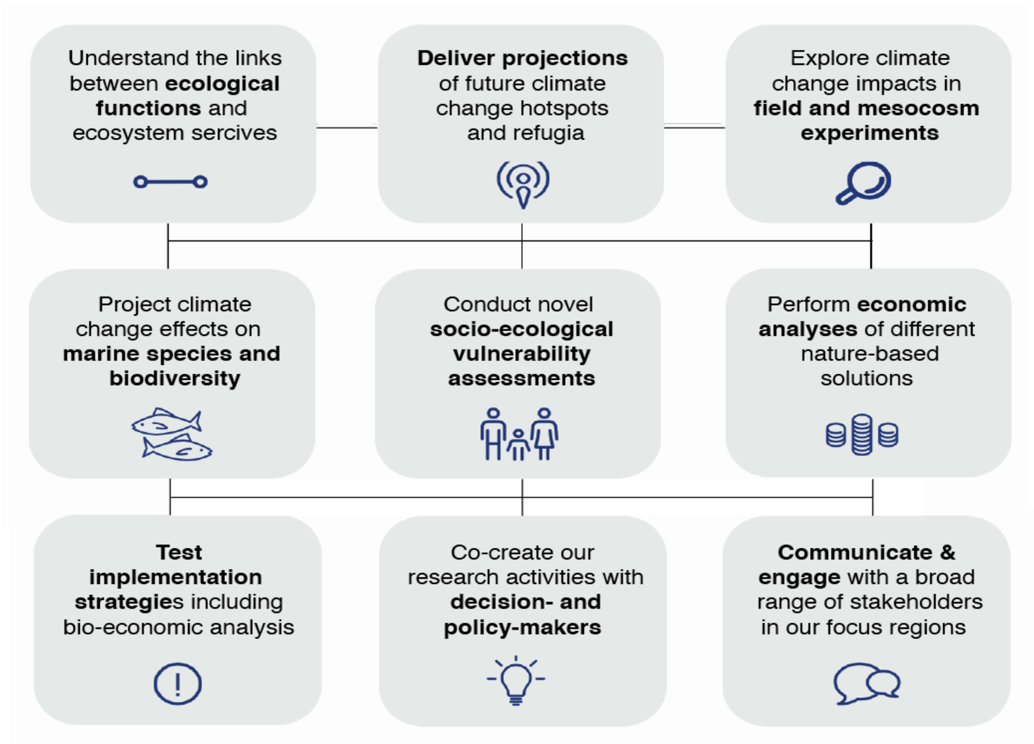
FutureMARES - Climate Change and Future Marine Ecosystem Services and Biodiversity is an EU-funded research project examining the relations between climate change, marine biodiversity, and ecosystem services. Our activities are designed around three Nature-based Solutions (NBS): **Effective Restoration (NBS1), Effective Conservation (NBS2) and, Nature-inclusive Harvesting of living marine resources (NIH)**



We are conducting our research and cooperating with marine organisations and the public in Case Study Regions across Europe and Central and South America. Our goal is to provide science-based policy advice on how best to use NBS to protect biodiversity and ecosystem services in a future climate.

FutureMARES provides socially and economically viable actions and strategies in support of nature-based solutions for climate change adaptation and mitigation. We develop these solutions to safeguard future biodiversity and ecosystem functions to maximise natural capital and its delivery of services from marine and transitional ecosystems.

To achieve this, the objectives of FutureMARES defined following goals:


Understand the links between **ecological functions** and ecosystem sercives
Deliver projections of future climate change hotspots and refugia
Explore climate change impacts in **field and mesocosm experiments**
Project climate change effects on **marine species and biodiversity**
Conduct novel **socio-ecological vulnerability assessments**
Perform **economic analyses** of different nature-based solutions
Test implementation strategies including bio-economic analysis
Co-create our research activities with **decision- and policy-makers**
Communicate & engage with a broad range of stakeholders in our focus regions

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List of symbols, abbreviations, and a glossary

BIOFIN	Biodiversity Finance Initiative
CBD	Convention on Biological Diversity
CC	Climate Change
CICES	Common International Classification of Ecosystem Services
DAPSI(W)R(M)	Drivers – Activities – Pressures – State (change) – Impacts on human Welfare – Response
ES	Ecosystem services
EUROSTAT	European Statistical Office
GDP	Gross Domestic Product
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
MSFD	(EU) Marine Strategy Framework Directive
NBS	Nature-based Solutions
NIH	Nature Inclusive Harvesting
OECD	Organisation for Economic Co-operation and Development
PAGE	Partnership for Action on Green Economy
SDG	UN Sustainable Development Goals
SEEA	System of Environmental Economic Accounting
SENDAI	Sendai Framework for Disaster Risk Reduction
SNA	Standard National Accounting
UNCCD	United Nations Convention to Combat Desertification
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

An assessment framework was developed for marine ecosystem services (ES) indicators on the socio-ecological effectiveness of nature-based solutions (NBS) and nature-inclusive harvesting (NIH) against climate-driven changes in marine species and habitats. This framework provides a common understanding on the health status of ecosystems, their services, and the impact of implementing NBS&NIH, which allows informing policymakers and the general public. For this assessment, two NBS were considered, restoration and the conservation of habitats and species, as well as the nature-inclusive harvesting (HIH) of living marine resources. The interaction between the biodiversity indicators with the socioeconomic, both response and pressure indicators, was established using the ES cascade, linked to other environmental (e.g., DAPSI(W)R(M)) and economic frameworks such as the Standard National Account (SNA) and the System of Environment Economic Accounting (SEEA). In total, 201 multidisciplinary indicators were identified through a literature review, and their suitability to assess the benefits of ES under a changing climate was evaluated. The indicators selected were also empirically verified within 27 Storylines from the FutureMARES consortium. Operationalization of ES indicators is essential to guide sustainable management and decision-making around the implementation of NBS&NIH to increase the adaption and mitigation potential of marine habitats and coastal communities.

A key objective of this task was to identify which ES are assessed throughout the ES cascade and which ones need further indicator development to ensure a holistic assessment approach the encompasses all aspects of the socio-ecological system.

Defining the Challenge

A critical and ongoing challenge around ES is that they need to be assessed in an interdisciplinary manner to be meaningful. This is particularly important when and where NBS are used for climate change adaptation and mitigation using the natural capital of ecosystems and for climate adaptation of dependent human communities. The framework summarizes in this deliverable report addresses this gap by linking relevant indicators to all ES that inform on NBS & NIH being addressed in FutureMARES.

Thus, the objectives of this research were to:

- (i) Create an objective and generally applicable framework that identifies which indicators measure the effects of NBS and/or NIH and the impacts of climate change (CC) on ES in coastal and marine areas.
- (ii) Select indicators that can help measure the effect of NBS and/or NIH on ES across the ES cascade model (from the environment to the socio-economic system).
- (iii) Identify gaps that need to be addressed to achieve better ecosystem assessments for sustainable approaches using NBS and NIH.
- (iv) Identify indicators that can measure pressures on the ecosystem and NBS and NIH to ensure that such pressures can be managed appropriately.

Scientific Approach

The work was divided into three steps. The first step was the development of an indicator assessment framework using expert knowledge through focus groups. Second, both peer-reviewed and grey literature (e.g., EU reports and online platforms) were searched for biodiversity, economic, and social indicators useful for measuring ES changes due to

the implementation of NBS and/or NIH and changes linked to CC. Indicators were then classified into key groups (e.g., supply- and demand-based groups for economic indicators) to identify the ES which are more frequently assessed with indicators relevant to these groups. To ensure a comprehensive list, indicators were preselected to represent different dimensions of the economy, biodiversity, and social aspects. In the third step, a gap analysis was performed to understand the extent to which literature indicators can be used for an integrated analysis of NBS&NIH impacts on marine ES. Moreover, the gap analysis was also performed at an empirical level, considering 27 storylines covering a high diversity of regions and NBS&NIH across European seas (see detailed explanation of each storyline at https://www.futuremares.eu/regions-Storylines). Pressure indicators were also collected and assessed. These ranged from local (such as abrasion due to fishing gear) to global pressures, including CC.

Contribution to the project

The key aim of the FutureMARES project is to examine the relations between CC, marine biodiversity, and ES. Therefore, identifying a set of suitable indicators that measure all these attributes is a key output of the project and contributes to it by providing researchers indicators on which to focus in the other Workpackages (WPs).

Research around ES is, by its very nature, interdisciplinary because of the need to capture all "features" and relevant questions of the socio-ecological system, from biodiversity to economic and social research questions. Therefore, this research uses the cascade model as a simplified way of introducing the essential research disciplines considered when assessing ES changes resulting from implementation of NBS and/or NIH. This work highlighted the difference between "capacity" and "flow" of ES, linking ES to the concept of Natural Capital. While capacity indicators were primarily based on ecological and biodiversity research, flow (of ES) was mainly captured through economic and social indicators.

The usefulness and contribution of this framework of selected indicators is analysed through the FutureMARES Storylines. Empirical evidence was captured through 27 FutureMARES Storylines, which used (in total) 70% of the identified indicators. Thus, in general FutureMARES will do a good coverage of the framework of indicators obtained from the literature review process showing a similar coverage of indicators across dimensions and groups withing those dimensions than the coverage provided by the previous literature review. Highly oriented to flow indicators within economic and social dimension while oriented to capacity indicators in the biodiversity and environmental dimensions. Covering all the ES considered: cultural, regulating and provisioning.

This research will contribute to setting a common framework to perform the economic analyses of the different NBS&NIH. Moreover, the employment of this framework of indicators will enhance the dialogue with policymakers leading to an impact beyond the scientific output of FutureMARES.

Dissemination and Exploitation

The results described in this report are being exploited within the FutureMARES project thanks to a set of workshops organized at the start and various other phases of the project. So far, the following invited talks and conferences have been produced:

- Oral presentation at the 3rd ESP (Ecosystem Services Partnership) Europe conference in 2021 of the outputs titled Nature-based solutions to climate change mitigation and adaptation: Indicators of Biodiversity by Ecosystem Services during session S8a - Integrating ecosystem services science and tools in implementing Nature-based Solutions, to better address global changes
- ICES WGECON – dissemination of the outputs during the 2022 annual meeting of the EU ICES Working Group WGECON.
- Oral presentation of the outputs in 2022 in collaboration with the H2020 Task Forces. Task Force 3 - Work Stream 3 on Valuing Benefits of NBS
- Oral presentation at the ECCWO (5th International Symposium on the Effects of Climate Change on the World's Oceans) to be held in April 2023, Bergen. The ECCWO5 symposium will bring together experts from around the world to better understand climate impacts on ocean ecosystems, the ecosystem services they provide, and the people, businesses and communities that depend on those services.

1. Introduction

Marine and transitional waters support a large portion of the global biodiversity and provide major contributions to society, harbouring key climate-regulating processes and habitats, contributing to worldwide food security, and supporting other valuable economic and wellbeing services and resources (Gattuso et al., 2018). Coastal zones are highly important and resource-rich environments, providing 90 % of catch from marine fisheries despite only covering 4% of the earth's land area and 11% of the world's oceans. More than one-third of the world's population lives in, and is dependent on, coastal zones. Their productivity is partly the result of the diversity of the natural capital they harbour (Barbier, 2017). This natural capital includes material resources (e.g., seafood and building materials) and non-material benefits (e.g., aesthetics contributing to the wellbeing and human health). The benefits that societies receive from nature are called ecosystem services (ES) or nature's contributions to people (Costanza et al., 1997; Díaz et al., 2015). In the literature, several ES classification frameworks can be found (e.g., Costanza et al., 1997; Costanza 2008; MEA 2005; TEEB 2010; Liquete et al., 2013; Haines-Young and Potschin, 2018). This research follows the Common International Classification of Ecosystem Services (CICES 5.1), which classifies ES into three overarching categories depending on whether the contributions to human wellbeing support: (i) the provisioning of material and energy needs, (ii) regulation and maintenance of the environment for nature and humans, and (iii) the non-material characteristics of ecosystems that affect the physical and mental states of people, that is their cultural significance.

Human activities can affect natural capital and ES provision by direct, local- and regional-scale impacts on biodiversity, habitats, and ecosystem processes or via global-scale changes such as climate change (CC) which affects overall ecosystem functioning. CC has been recognized as one key driver of change in global ecosystems and ES, including marine ecosystems (IPBES, 2019; Jaureguiberry et al., 2022). CC impacts on the marine system include rising temperatures, ocean acidification, deoxygenation, and sea-level rise (Gattuso et al., 2018 and references therein; IPCC, 2019). Ecosystem-based management, adaptive marine spatial planning, and habitat restoration can help support and enhance the natural capacity of marine and transitional ecosystems to adapt to, and mitigate, unwanted changes and maintain ES provision. These are considered "nature-based solutions" (NBS) (Cohen-Shacham et al., 2019; Davies et al., 2021; Girardin et al., 2021), defined as solutions that are "inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient and systemic interventions" (European Commission, https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en).
Methods for harvesting living marine resources, such as fishing, are excluded from the definition of NBS, but they are essential for the sustainable use of the natural capital of marine and transitional waters. Here we call the sustainable harvesting approach Nature-inclusive Harvesting (NIH). NIH centers on sustainable harvesting of seafood from fisheries and aquaculture that is flexible, adaptive, and managed on a whole-ecosystem basis. NBS linked to NIH can benefit both nature and human societies and this is critical for management decisions that help abate the combined CC and biodiversity crises.

Two NBS and one NIH were considered in this study: (NBS1) Effective Restoration Strategies of habitat-forming species that can act as 'climate rescuers', including seagrasses, salt marshes, mangroves, kelp forests, coral reefs, and shellfish reefs, which form natural coastal protection and thereby help to adapt to increased storminess, sea level rise and flood risks resulting from CC. Some of these habitats also sequester and store carbon (i.e., blue carbon) and thereby help to reduce the concentration of CO_2 in the atmosphere; (NBS2) Effective Conservation Strategies explicitly considering the range of impacts of CC and other hazards on habitat suitability for flora and fauna. Strategies explored include preserving the integrity of food webs and sustaining population connectivity across networks of climate refugia where bio-geophysical conditions are stable or changing slowly over multiple spatial and temporal scales; and (NIH) Sustainable Harvesting of seafood from fisheries and aquaculture that is flexible, adaptive, and managed on a whole-ecosystem basis needed for biodiversity conservation and restoration. Moreover, an ecosystem approach to fisheries management and NBS implementation needs a holistic approach. The interactions between the natural world and human society are complex and their analyses necessitate a robust assessment framework to track the changes that occur within these interactions (Atkins et al., 2011; Hattam et al., 2015) and the effectiveness of conservation and restoration actions. The need for regular assessment and monitoring of ecosystems has been highlighted through several national and international policies and initiatives such as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), Convention on Biological Diversity (CBD), and regionally via the Marine Strategy Framework Directive (MSFD), to name a few. Such assessments must promptly, objectively, and measurably demonstrate if and how changes occur to allow adaptive management actions.

Indicators are variables that can illustrate such changes if adequately selected and tested (Broszeit et al., 2017; Hattam et al., 2015; Kandziora et al., 2013). Environmental, ecological, and biodiversity indicators measure various aspects of the marine ecosystem and can also measure ES (Teixeira et al. 2016; Broszeit et al., 2017; Hattam et al., 2015). Balvanera et al. (2022) showed that a suitable indicator framework is needed when assessing and comparing ES across multiple regions and NBS. To provide data on the success of NBS and NIH, appropriate indicators must be used that measure both benefits to human society and nature. Moreover, indicators should capture both supply and demand aspects and common mismatches between them (Geijzendorffer et al., 2015). In addition, indicators can tell us about capacity and flow of ES. The capacity and flow concepts are linked to ES accounting where capacity is the state of the ecosystem assessed for one ES and flow is considered the regeneration and absorption rates that produce each ES if the ecosystem components remain in the same condition (La Notte et al., 2019).

Here we provide a framework that links indicators from different disciplines, also referred to as dimensions (natural sciences, economy, social sciences, policy) to twelve ES from provisioning, regulating, and cultural service types supporting science-based policy advice on assessing of NBS&NIH success in protecting future biodiversity and ES under CC. Thus, the objectives of this research were to:

(i) create an objective and generally applicable framework to assess the suitability of a selection of indicators to measure the effects of NBS&NIH and CC on ES in coastal and marine areas.
(ii) select indicators that can help measure the effect of NBS&NIH on ES across the ecosystem service cascade model who links the environment to the socio-economic system.
(iii) identify gaps that need to be addressed to achieve better ecosystem assessments for sustainable approaches using NBS&NIH.

(iv) Identify indicators that can help identify and measure pressures to the ecosystem and NBS and/or NIH to ensure that such pressures can be measured and appropriately managed.

2. Material and Methods

The work comprised chiefly of three steps (Figure 1). The first step was the development of an indicator assessment framework using scientific expert knowledge through the implementation of focus groups. Second, both peer-reviewed and grey literature (e.g., EU reports, online platforms) were searched for biodiversity, economic, and social indicators that are useful for measuring ES changes due to NBS&NIH and changes linked to CC and other pressures on ecosystems. Indicators were then classified into key groups (e.g., supply and demand-based groups for economic indicators) to assess which ES can be more frequently assessed with indicators relevant to these groups. To ensure a comprehensive list of indicators, they were preselected to represent different dimensions of the economy, the biodiversity, or the social aspects. In the third step, a gap analysis was performed to understand the extent to which literature indicators can be used for an integrated analysis of NBS and NIH impacts on marine ES. Moreover, the gap analysis was also performed at an empirical level, considering 27 Storylines covering a high diversity of regions and both NBS1, NBS2 and NIH (See detailed explanation of each storyline at https://www.futuremares.eu/regions-storylines). Separately to this assessment, pressure indicators were also collected and assessed. These ranged from local (such as abrasion due to fishing gear) to global pressures, and in particular CC.

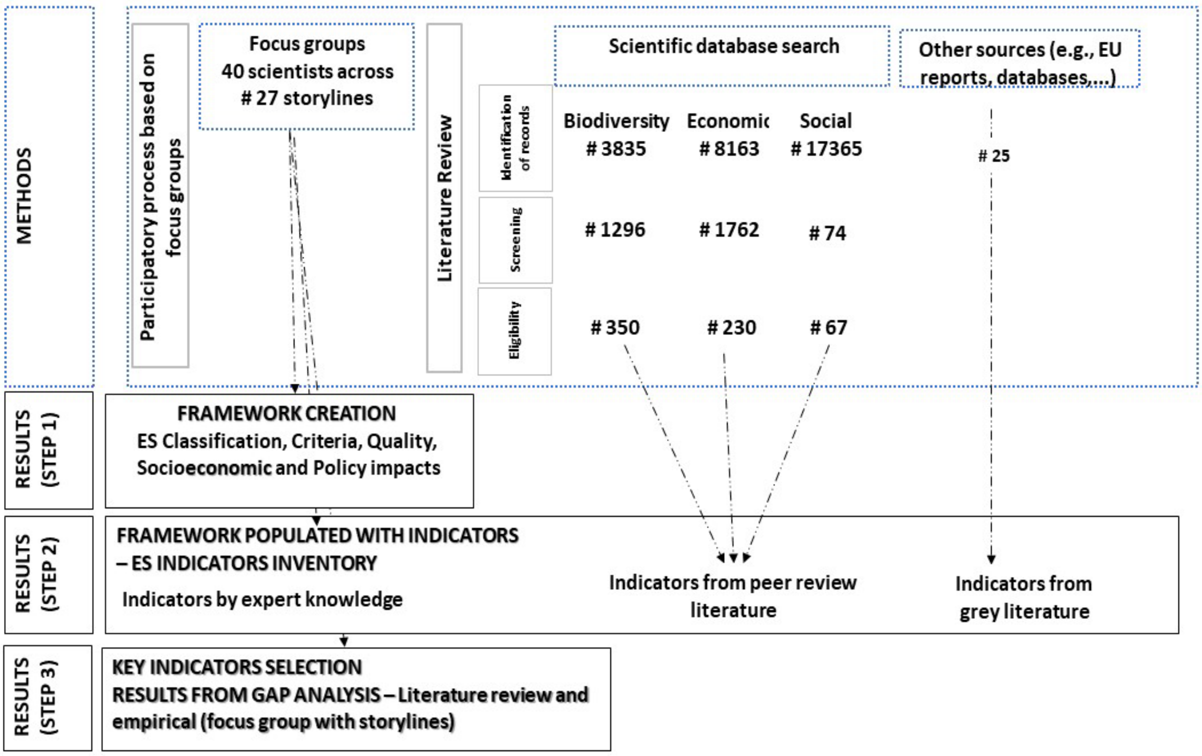

Figure 1. Work process and results of this study. Numbers in methods indicate publications found in each discipline. Search method based on Moher et al. (2009).

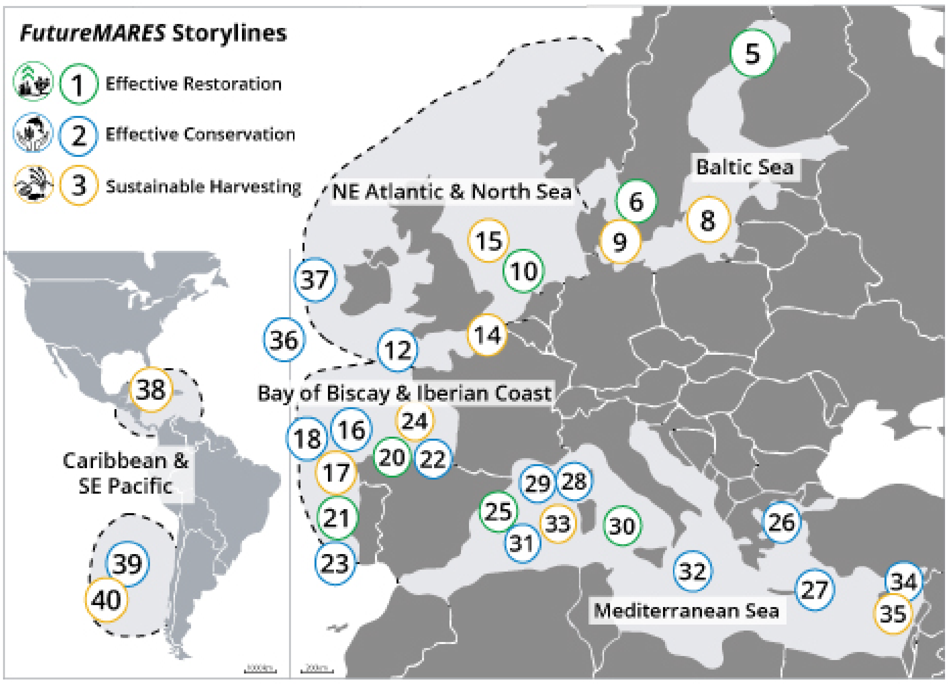

Figure 2. Storylines engaged in focus groups across the work progress (Figure 1)

Twenty-seven Storylines were involved in this task and together covered all the NBS&NIH (https://www.futuremares.eu/regions-storylines). They were spread around European Seas and included the Eastern Mediterranean. Regarding the questions addressed, they included habitat restoration such as seagrass beds and seaweed forests, mussel culture, soft sediments, fish and invertebrate pelagic and benthic assemblages, sea turtle conservation. Several Storylines assessed marine spatial planning including the location, size, and status of marine protected areas (MPAs).

Twelve marine ES were addressed in this report covering 20 of the total amounts of 48 classes of ES according to the CICES classification. These ES were chosen based on their relevance to marine ecosystems but also to ensure coverage of provisioning, regulating and cultural ES (Table 1). The provisioning ES included food provision and material provision. Five regulating services were addressed: climate regulation, bioremediation of waste, disturbance prevention, protection of species and habitats and pest control. Cultural ES consisted of cultural heritage, aesthetic experience, leisure and recreation, education, and existence.

Table 1. *ES addressed in this study, and descriptions based on CICES 5.1*

Ecosystem service section	Ecosystem service	Description	Short ES name
Provisioning	Wild animals (terrestrial and aquatic) for Nutrition,	Wild animals used for nutritional purposes	Food provision
	Wild plants (terrestrial and aquatic) for nutrition	Wild plants used for nutrition	
	Reared aquatic animals for nutrition	Animals reared for nutritional purposes, e.g., through aquaculture such as fish, shellfish	
	Cultivated aquatic plants for nutrition	Cultivated plants grown for nutritional purposes, e.g., plants through aquaculture	
	Wild and cultivated aquatic plants for materials or energy	Material provision through wild plants and those from aquaculture	Material provision
Regulating	Regulation of chemical composition of atmosphere and oceans	Regulation of climate by sequestration and storage of carbon dioxide and other green-house gases	Climate regulation
	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bioremediation by micro-organisms, algae, plants, and animals	Bio-remediation of waste
	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection),	Disturbance prevention
	Regulation of baseline flows and extreme events	Control of erosion rates	
	Lifecycle maintenance, habitat, and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	Protection of habitats and species
	Lifecycle maintenance, habitat, and gene pool protection	Seed or gamete dispersal	
	Lifecycle maintenance, habitat, and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	
	Pest and disease control	Pest control (including invasive species)	Pest control
Cultural	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	Cultural heritage
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences, e.g., Seaview	Aesthetic experience
	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation, or enjoyment through passive or observational interactions, e._g. wildlife watching	Leisure and recreation
	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation, or enjoyment through ACTIVE or IMMERSIVE interactions, e._g. snorkelling, SCUBA diving	
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	Educational
	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	Existence

2.1. Step 1. Focus groups with marine scientists: a multidisciplinary approach

The European project FutureMARES supporting this research is an interdisciplinary project bringing together several disciplines, including biology and ecology, social sciences, policy, and economics. A method to assess and select multidisciplinary indicators was developed based on expert knowledge through personal interviews and focus groups with scientists within the FutureMARES project. Both methods were used to identify criteria for selecting key indicators from the scientific literature and expert knowledge (Table 2). The focus groups applied a participatory approach. A first focus group consisting of 40 scientists examined 15 Storylines and identified the main framework blocks of information (described at Table 2): (i) *background of the indicator, (ii) ES classification, (iii) Criteria, (iv) Quality, (v) Socioeconomic and policy, (vi) data location and, (vii) references*. One outcome of this focus group was a draft list of indicators. After an interactive feedback process, a second focus group was organized to validate the framework.

***Table 2:** Assessment criteria to describe each indicator in the framework.*

Block	Description
Background	This section identifies the indicator, the type of indicator as identified for this study, the source and if data are available
Link to FutureMARES	This section is used to link each indicator to the FutureMARES Storylines and to the selected NBS&NIH
ES Classification	The link to ES (using CICES 5.1), and assessment if the indicator measures ES capacity or flow.
Social benefits	This section links each indicator to the social benefits they provide (ES and NBS&NIH).
Economic benefits	Links the indicator to the economic benefits that they help provide through ES (ES and NBS&NIH).
Criteria	Scientific background and relevance, the capacity to respond to CC, response in time and space and, the possibility of setting targets, and if they can measure tipping points (according to IPCC: “A level of change in system properties beyond which a system reorganises, often in a non-linear manner, and does not return to the initial state even if the drivers of the change are abated. […]”) are assessed in this section.
Quality	Quality control of the indicator : is it cost-effective, accurate, precise, and easy to measure.
Societal Uses	The societal usefulness of the indicator is assessed here by looking at criteria of policy and societal relevance, ease of communication to lay people, and if it measures mitigation or adaptation.
Data location	Data location if available and reference(s)

2.2. Step 2: Search for suitable indicators based on literature review and classification.

The primary question and aim of this work step was to “review & test ecological, social and economic indicators of ecosystem services in relation to policy targets and climate change and their link to NBS&NIH”. The search for suitable indicators was carried out threefold (Figure 1). First, a set of relevant scientific review manuscripts was identified, including Crossman et al. (2013) ; Queiros et al. (2016) ; Englund et al. (2017) ; Muller et al. (2018); Broszeit et al. (2017); Czúcz *et al.* (2018). Second, a scientific literature review was conducted, and databases were searched based on the PRISMA Statement guidelines (Moher et al., 2009). The final search criteria used for each discipline and the final numbers of selected publications are listed in Table 3. Third, grey literature consisting of EU commissioned and other reports was used to review international initiatives such as the Strategy Plan of Biodiversity, Biodiversity Indicators Partnership, IPBES, UNSC SGD indicators, UNCCD, UNFCCC, UNECE SEEA Climate Indicators, Ramsar, SENDAI, Global Biodiversity Outlook, EU Biodiversity Strategy 2020, Poverty-environment Indicators, BIOFIN, World Bank, EU SDG Indicators set, MSFD, TEEB Database, EAP, PAGE, BIOFIN, EUROSTAT, OECD indicators, among others.

***Table 3.** Final criteria in Search strings for each discipline and number of publications found.*

Discipline	Search string used		Number
	Included topics	**Excluded topics**	
Environmental and biodiversity	“Ecological indicators”, Indicators, “ecosystem service*”, “ecosystem function*”, “climate change”, “Nature Based solution*”, NBS, marine OR coastal.	forest*, soil, river*, freshwater, farm*, agri*, terrestrial, boreal, tree*. **Excluded Research Areas**: Forestry, soil science, water resources, urban studies, regional urban planning, agriculture, agronomy, imaging science, meteorology atmospheric science.	350
Economic	“Economic assessment”, “ECON* indicator*”, “ecosystem service*”, “ecosystem function*”, "climate change", "Nature Based solution*”, marine OR coastal	forest*, soil, river*, freshwater, farm*, agri*, terrestrial, boreal, tree*, savannah, desert, landscape, wood	230
Social	"Social assessment", "social indicator*", "ecosystem service”, "ecosystem function*", "climate change", "Nature Based solution*”, marine OR coastal	forest*, soil, river*, freshwater, farm*, agri*, terrestrial, boreal, tree*, savannah, desert, landscape, wood	67

For ease of comparison, indicators were grouped according to the subject they measure, and those groups were loosely described (Table 4). Here, we use the term biodiversity indicator as an umbrella term for indicators that measure any aspect of the ecology, biology, or biodiversity of marine, coastal or transitional systems. For example, the depth limit of spermatophytes, or the mean length of fish in the community are both considered biodiversity indicators. The focus was on biodiversity indicators that can be linked directly to ecosystem services (following Broszeit et al. (2017)), so not all biodiversity indicators were included in this work. Environmental indicators are those that include abiotic features and/or pressures such as nutrients in the water or sea surface temperature. Pressure is defined as: 'the mechanism by which an activity or natural event affects the ecosystem' (OSPAR, 2011). Pressures can negatively affect any ES and NBS and/or NIH. Pressure indicators, therefore, do not measure the effectiveness of NBS or NIH on ameliorating ES provision. However, these indicators are valuable in that they help assess negative changes impacting ES as well. As the potential success of NBS and/ or NIH. Seven categories of pressure indicators were created including *general:* to capture those indicators that can be applied to several pressures (such as some MSFD indicators to measure anthropogenic impacts); *fishing*: any indicator measuring negative effects on the biodiversity through catch and bycatch, *physical:* any pressures exerted on the seafloor be they through trawling or other habitat alterations; *nutrients*: any eutrophication indicators and excluding other forms of pollution; *pollution*: pollution through chemicals such as oil, or other materials and sewage; *NIS*: any pressure created by non-indigenous species; *oxygen*: oxygen is usually measured to assess hypoxic or anoxic conditions rather than measuring the state of the ecosystem and so this indicator was included as pressure indicator. CC indicators were included in the general pressure indicator group and include ocean acidification and sea surface temperature. Deoxygenation cannot be attributed to CC alone and was placed in a separate group.

The economic indicators included are well linked to the key SNA (market indicators) and SEEA-EA (non-market indicators) frameworks. Economic growth can be seen as an increase in the capacity of an economy to produce goods and services, comparing one period to another. Two economic growth calculations were considered: the demand perspective (called demand approach) based on the Gross Domestic Product (GDP) and its components (Exports, Imports, households' consumptions) and the supply perspective based on a production function and associated profitability. Both approaches are usually assessed through the so-called market-based SNA. However, economic indicators also include those able to monetarize non-market-based values (e.g., cultural values associated to NBS and/or NIH). Also, indicators that establish a link with CC were especially considered for both demand and supply approaches under SNA.

For social indicators, the IPBES framework for Nature's Contributions to People (NCP) (Diaz et al., 2018) was used to classify indicators among different categories. This classification offers the ideal framework to capture different aspects covered by the indicators, as it encompasses the environment, society, and human-nature relationships. Following Carmen et al., (2020), we adapted the IPBES NCP for the purpose of indicator classification. The IPBES framework (Table A 3) uses three overarching themes to classify the different types of NCP (i.e., nature, contributions, and people). Since we focus on social indicators capturing societal aspects and human-nature relationships, we used the categories contained under the dimension People. Under the People dimension, there were four categories: cultural aspects, health & wellbeing, governance & justice, and economic aspects. In addition, we added a category that captured the quality & quantity of the NBS from a societal perspective (Table 4).

2.3. Step 3: Analysis of selected indicators and gap analysis

The primary analysis consisted of assessing if each ES has indicators from each discipline, allowing a multidisciplinary assessment. In addition, NBS1, NBS2 and/or NIH were also assessed to see if indicators existed for each from each discipline. A gap analysis was then performed to identify which further indicator types need to be developed to strengthen ES monitoring.

Table 4. *Group descriptions for a comprehensive list of indicators representing all disciplines.*

Dimension	Groups	Description
Biodiversity and environmental indicators	**Harvest**	Indicators included in this category range from commercial fish and shellfish to seaweed used for food production and for any other materials and products (e.g., cosmetics). An example is percentage of commercial fish in Good Environmental Status.
	Assemblages	Based on Cooke, (1984): A collection of species inhabiting a given area, the interactions between the species, if any, being unspecified. This included indicators on the state of benthic and other communities.
	Habitat	This included indicators where the habitat was important such as its nursery role or height and density of forest-forming macroalgae.
	Protected species/charismatic groups	Indicators were placed in this category when they measured aspects of specific species such as marine bird abundance. This group did not only include protected species but also charismatic species / megafauna.
	Threat to humans	Environmental indicators that measure threats to humans such as sea level rise are listed in this category.
	Miscellaneous	A number of indicators that did not fit anywhere else but can be important for ES such as cultural services (e.g. Number of papers or patents).
	Pressures	Pressures were split into different subcategories such as nutrients or NIS (non-indigenous species). A general group was also defined to allow incorporation of indicators that measure effects of any type of anthropogenic pressure.
Economic indicators	**SNA/GDP – Output approach**	Business indicators included are used to estimate the GDP following an output approach, which implies the estimation of the production value (once the ecosystem service is used by people).
	SNA/GDP – Output approach under CC	The traditional business indicators are modified to consider the Global Emissions by Gas of each sector (fishing sector, tourism activities, …) when developing the activity using the ecosystem service. These maritime sector contributions to CC are measured.
	SNA/GDP – demand approach	Business indicators included are used to estimate the GDP demand approach including the exports, imports, and the final consumption of households on different products and services. Demand indicators identify the consumer´s need for an ecosystem service.
	SNA/GDP – demand approach under CC	The use of a variety of ecosystem good and services by households contribute to Global Emissions by Gas which is added to the demand-based indicators to measure the demand contribution to CC.
	Non-market-based indicators	Monetary values estimated through statement approach method based on i.e., surveys to elicit willingness to pay value. These indicators are mainly used to assess non-tangible cultural ecosystem services which are closely linked to the people´s per social well-being.
	Proxies	Physical based indicators in contrast to the previous quantitative indicators, which are expressed in monetary terms. This notation follows Fernández-Macho et. al., 2015.
Social indicators	**Quantity and quality of NBS from a people's perspective**	Indicators measuring the quantity and quality of the NBS. This can include access, facilities, location, connectivity
	Cultural aspects	Indicators capturing aspects such as stewardship, identity / sense of place and heritage values.
	Health and wellbeing	Indicators capturing the capacity of the NBS&NIH to promote health and wellbeing including social relations, physical and mental health, education and knowledge and safety and security.
	Governance & justice	Indicators capturing governance practices and procedural and distributional justice within the NBS and/or NIH.
	Economic aspects	Indicators on the relationship between the NBS and/or NIH and economic aspects. The classification of social indicators is based on IPBES including specifically economic aspects as part of the social indicators.

3. Results

3.1 A general framework: collecting and classifying ecosystem services indicators

Through the implementation of focus groups, a general framework was designed. The first part of the framework identifies indicator sources and potential links with any of the

NBS and/or NIH. The indicator title, definition and measurement unit are included to clearly delineate space, time, and quantification. Further sections identify the ES (using the CICES classification). The link to ES should be established despite difficulties in finding exclusive indicators (Czúcz et al., 2018) since indicators usually represent more than a single CICES class. To link the ES to the human and social system, the framework considers a complete list of social and economic benefits relating to those ecosystem elements (ES and NBS and/or NIH). Human Activities are initially identified from the Statistical Classification of Economic Activities in the European Community (abbreviated as NACE) but are mainly related to living resources or coastal tourism.

The framework introduces a criteria block emphasizing the scientific basis and relevance, the capacity to respond to CC, responsiveness in time and space, as well as the possibility of setting targets and tipping points. The criteria block is followed by a quality block, where cost-effectiveness, accuracy, precision, and ease of sampling are considered. Societal uses are also considered given that it is critical to select socially relevant indicators, easily communicated to policymakers, relevant to management measures to a certain degree and, therefore, able to measure mitigation or adaptation. If policy-relevant, the indicator is linked with the most relevant piece of legislation (e.g., SDG and MSFD biodiversity indicators are useful because they are widely applicable). The last part of the catalogue includes fields related to the data location, when available, which might validate the indicator. Table A 2 presents the list of fields included in the framework.

3.2 Ecosystem services indicators

The list of indicators is presented as a way of operationalizing and quantitatively documenting changes in different ES resulting from NBS and/or NIH implementation. Indicators for ES must integrate and balance biodiversity, social, economic and response aspects of the complex flow of ES from the natural to the socioeconomic system (ES cascade model) under CC (Figure 3). Table 5 summarizes the output list of indicators illustrating how they cover four large dimensions, with each of them linked to key specific frameworks (i.e., SNA, SEEA, IPBES). Also, this whole output system was linked to the ”Drivers, (D) Pressures (P), State (S), Impact (I) and Response (R)’’ (DPSIR), a conceptual chain of causal linkages for analysing the flow through multidimensional impact analysis. Elliott et al. (2017) argued for an extension of the DPSIR framework to DAPSI(W)R(M), in which (D)rivers of basic human needs require (A)ctivities that lead to (P)ressures in the environment, which can cause (S)tate changes that can have an (I)mpact on (W)elfare.

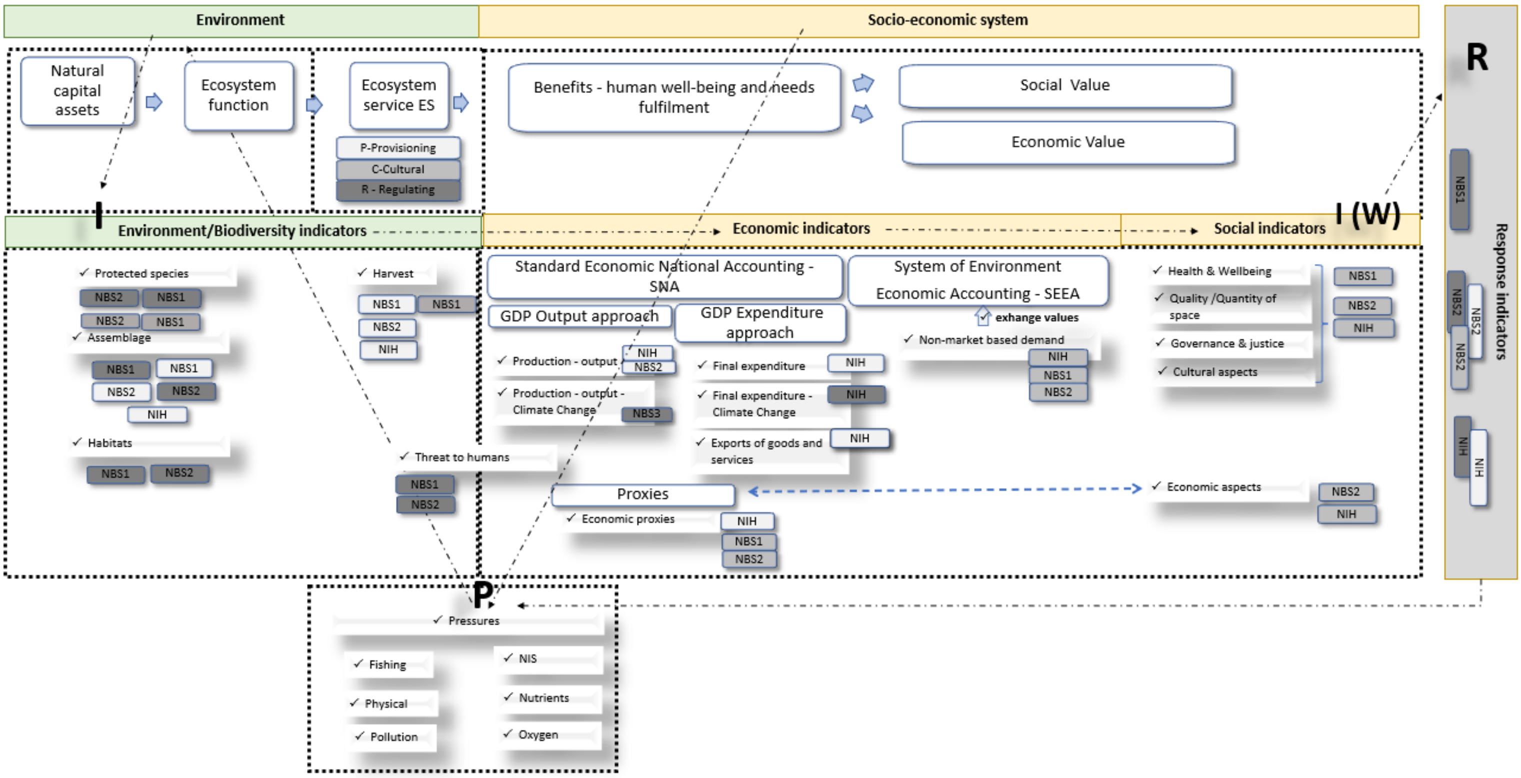

Figure 3. *ES indicators (P=provisioning, C=cultural, R=regulating) through the ES cascade and DPSI(W)R frameworks linked to SNA/SEEA economic accounting frameworks and IPBES classification. DAPSI(W)R stand for respectively: Driver, Activities, Pressure, State, Impact(Welfare), Response*

In total, 201 distinct indicators were assessed. Some of these (Figure 4) are useful for more than one NBS&NIH (accounting for a total of 334 indicators, Table 5). Table 5 shows the relative importance of the number of indicators per NBS and/or NIH, based on the dimension and specific group. Biodiversity & environmental as well as Pressure indicators are the most numerous in the list, representing 34% and 23% of the total, respectively. The common usage of these indicators was reflected in both the literature review and from the focus groups discussions with the Storylines (see detailed list in Annex). Globally, there were significant differences in data with the scientific indicators (environmental and biodiversity indicators) being more for consultative and more frequently used both by organizations and more frequently appearing in the literature compared to socioeconomic indicators. Due to the higher use of biodiversity indicators, it is easy to find indicators which are highly correlated, despite being different measurements (i.e., the indicator coastal protection supply is defined as coastal protection capacity minus coastal protection exposure) and, therefore, this contributes to increasing the number of biodiversity indicators in contrast to what happens in the remaining dimensions. This is also evidenced by the number of these different indicators. For example, 60% of the total number are biodiversity and environmental indicators – 55% when removing highly correlated indicators - while only 12% of the economic indicators are used, mainly related to the output approach group. This might indicate important differences in how policy makers integrate those indicators. The lower number of socioeconomic indicators indicates that the optional use of these data is more prevalent than the optional use of scientific data.

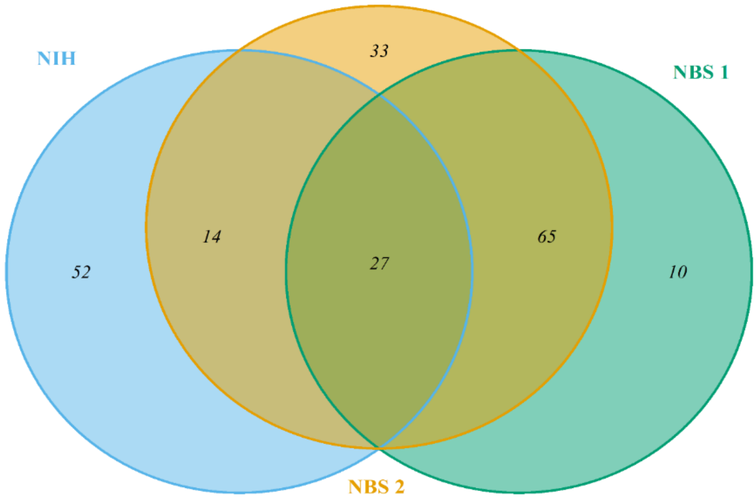

Figure 4. Number of indicators per NBS1, NBS2 and NIH and the number of overlapping indicators in a Venn diagram. Total number of distinct indicators: 201.

Looking at the indicators per group reveals further gaps and differences in how indicators are used across dimensions. Most frequently, harvest and habitats groups are assessed through a very high number of indicators. In terms of the economic indicators, output, and demand approaches, but also non-market-based indicators, are balanced but their number is, in general, very low. However, except for the output-based indicators, the remaining groups are rarely adopted in the literature, with only demand indicators being considered by organizations such as the OECD and the Word Bank.

For socioeconomic indicators, CC indicators are rarely considered, except for a short list redefining output and demand approach indicators to aggregate a carbon footprint valuation. This aggregation allows the assessment of the economic sector's contribution to CC, although no indicators for adaptation or mitigation to CC were identified (i.e., Fishing sector green Growth for NIH (*food provision based on CO2 emissions); Greenhouse gas emissions induced by household recreational and cultural consumption for NBS1&NBS2; Greenhouse gas emissions induced by household fish food consumption for NIH)*. In the biodiversity and environmental dimension, 22% of the number of indicators are not related to (describe) CC adaptation or mitigation (i.e., *SFD-D10C3 - Ingested plastic, MSFD-D10C4 - Number of individuals adversely affected by litter such as entanglement).*

Table 5. *Summary of indicators per dimension and group*

Dimension	Group	NBS1	NBS2	NIH	Total	Distinct
Biodiversity and Environmental indicators	**Total**	**42**	**49**	**29**	**120**	**69**
	Assemblages	2	4	5	11	6
	Habitats	26	24	1	51	26
	Harvest	5	7	22	34	23
	Protected species	5	8	1	14	8
	Threat to humans	2	4	0	6	4
	Miscellaneous	2	2	0	4	2
	Pressure indicators	**24**	**36**	**12**	**72**	**46**
	General	8	11	6	25	12
	Fishing	0	0	4	4	4
	NIS	2	5	1	8	5
	Pollution	0	9	0	9	9
	Nutrients	7	4	0	11	7
	Oxygen	2	2	0	4	2
	Physical	5	5	1	11	7
Economic indicators	**Total**	**8**	**9**	**14**	**31**	**24**
	GDP production – output approach	1	1	5	7	6
	Production – output CC	1	1	1	3	2
	GDP expenditure – demand approach	1	2	2	5	3
	Final expenditure CC	1	1	1	3	2
	Non-market based	2	2	2	6	5
	Proxies	2	2	3	7	6
Social indicators	**Total**	**27**	**42**	**35**	**104**	**56**
	Cultural aspects	5	9	7	21	10
	Economic aspects	0	1	5	6	5
	Health & Wellbeing	15	23	11	49	29
	Quality/Quantity of space	3	3	3	9	3
	Governance & justice	4	6	9	19	9
Response indicators	------------	1	3	3	7	6
	Total	**102**	**139**	**93**	**334**	**201**

3.2.1 Biodiversity, environmental and pressure indicators

Environmental indicators were defined as measures of abiotic factors such as *sea surface temperature, oxygen concentrations or wave energy and coastal flooding*. Indicators in this category can be used to assess the effectiveness of NBS1 or NBS2 or both, for example *estimates of coastline change* or *wind fetch reduction by salt marshes*. Nine of the environmental indicators were derived from SEBI (Streamlined European Biodiversity Indicators) and twelve are listed as MSFD indicator categories. Other indicators were selected from a variety of scientific publications and one indicator (carbon sequestration) was listed by Maes et al. (2016).

Biodiversity indicators measure the status of species or the direct functions of species. For example, a*bundance of cephalopods* is an indicator that describes the status of the cephalopod population in each area. *Primary production* measures an ecological function, as it measures the biomass or energy accumulation per area and time unit through carbon sequestration by photosynthetic organisms such as seaweeds and seagrass. These indicators, therefore, allow ES to be measured (Broszeit et al., 2017; Hattam et al., 2015). Finally, pressure indicators measure pressures exerted on the marine environment such as *presence and distribution of alien species*. There was overlap between NBS1 and NBS2 for biodiversity indicators with less overlap with NIH. This is due to NBS1 and NBS2 targeting conservation and restoration to habitats (NBS1) and habitats, species, and trophic interactions (NBS2). NIH also aims to improve assemblages and trophic interactions and, therefore, indicators can be used for those two NBS or for NIH as well.

In total, 26 indicators measured provisioning services, and all are attributed to food provision, and one for material provision from algae (Table 6). Thirty-eight indicators are suitable for measuring regulating services. Of these, nine are able to measure climate regulation and examples include *carbon sequestration rate* and *seagrass biomass*. A further five can measure bioremediation of waste and include indicators such as *primary production*, or *state of benthic communities*. Eleven indicators are helpful for measuring disturbance prevention and include indicators such as *bottom vegetation biostabilisation capacity* and *wind fetch reduction by saltmarshes*. Cultural ES can be assessed using 13 indicators. These are either concerned with macrophytes (such as depth limit of spermatophytes), iconic species (such as presence of iconic/endangered species) or species targeted by recreational fisheries (e.g., distributional pattern within the distributional range of demersal elasmobranchs).

Pressure indicators were grouped separately within the biodiversity and environmental indicator groups because links to specific ecosystem services and NBS and/or NIH were not established. By their definition (based on JNCC, https://jncc.gov.uk/our-work/marine-activities-and-pressures-evidence/, accessed 23/08/2022) 'the mechanism by which an activity or natural event affects the ecosystem', they can negatively affect any ecosystem service and NBS (and NIH) and do not measure the effectiveness of NBS and/or NIH on maintaining or increasing ES provision.

Seven categories of pressure indicators were created. These included *general:* to capture those indicators that can be applied to any pressure (such as some MSFD indicators); *fishing*: any indicator measuring negative effects on the biodiversity through catch and bycatch, *physical:* any pressures exerted on the seafloor be they through trawling or other habitat alterations; *nutrients*: any eutrophication indicators and excluding other forms of pollution; *pollution*: pollution through chemicals such as oil, or other materials and sewage; *NIS*: any pressure created by non-indigenous species; *oxygen*: oxygen is usually measured to assess hypoxic or anoxic conditions rather than measuring the state of the ecosystem and so this indicator was included as a pressure indicator.

Of the 72 pressure indicators (46 without duplication), 53 (32) were biodiversity indicators and 19 (14) were environmental. The 53 biodiversity pressure indicators were linked to the pressure types of *NIS, nutrients, fishing* and *general*. The environmental indicators were linked to five pressure categories: *general, pollution, nutrients, oxygen* and *physical*. Pressure indicators are valuable in that they can help assess negative changes to the NBS&NIH, ecosystem and/or ecosystem services (e.g., MSFD indicators measuring *plastic ingested by wildlife*) and therefore remain in the framework. They are also used to measure the pressures themselves (e.g., MSFD category on *composition, amount, and distribution of litter on the coastline*).

Within pressure indicators, CC indicators are particularly important in addressing the research question, that is, ecological, social, and economic indicators of ecosystem services in relation to policy targets and climate change and their link to NBS&NIH. These CC indicators include those measuring *pH in coastal waters, oxygen concentrations* and *sea surface temperature*.

3.2.2 Socioeconomic and response indicators

3.2.2.1 Economic indicators

Economic indicators were classified into two groups based on the GDP: output indicators, and expenditure or demand indicators. A third group, the so-called non-market-based demand indicators, originate from the most recent SEEA framework. Specifically, introducing NIH will prevent the unsustainable exploitation of many fish populations, by altering the sustainable economic growth of the fishing sector and the fish provisioning ES. Therefore, previously published literature used SNA to measure production-based indicators (representing the 25% of the total economic indicators), especially for assessing provisioning and cultural ES, *revenues, added-value, gross premium written* and *profits* (Fernández *et. al.* 2015, Marre *et. al.* 2016, Johns *et. al.,* 2014, Hein et al 2017). These economic indicators are well-covered by international frameworks (AER, CFP, OECD, SNA). The CC driver is considered in assessing regulating ES by only a small number of indicators (8% of the total), most often when providing impact assessments of production. Previous literature considers the consideration of the CC in a very general way, using the *ecological footprint* indicator (UNEP), although the OECD specifies that it is better to provide the fishing sector green growth - *Environmental and resource productivity* – indicator which modifies previous business indicators to consider the $C0_2$ emissions associated with the fish production. Parker and Tyedmers (2015), Parker et. al. (2018) and Greer et. al. (2019) use different metrics for the indicator but follow a similar conceptual approach. Economic proxies are gaining in importance in assessments of both provisioning and cultural ES, being 25% of total indicators (terminology from Fernández et. al. 2015, Foley et. al., 2011). Proxies are well considered to identify indicator measures in physical rather than monetary terms are also needed to assess the potential modification of the *density of fishing vessels* and *employment* (AER, CFP), but also the associated labor productivity (value produced by engaged fishers), the *use of the space* (Valenti el. al. 2018) and trends in certified sustainable fisheries (UNEP) due to the NIH implementation are key examples.

Specifically, for migratory fishes the nutrient transportation regulating ES is scarcely being assessed (Morton et. al. 2017). This indicator, together with the green growth ones relate to the NIH impact on regulating ES, while the rest are provisioning ES.

The expenditure or demand approach of GDP represent 12% of the total number of indicators, used to a lesser extent than the output approach indicators to assess both cultural and provisioning ES. For example, the demand for fish as food, has increased with the growth of the human population (Balvanera et. al. 2022), a reason why it is also important to quantify the impacts of NIH on locally affected demand. However, only statistical bodies such as EUROSTAT identify this demand indicator through the *environmental expenditure – household expenditure on consumption categories (fish as food).* Also, following the previous production-approach, the indicator *greenhouse gas emissions induced by household food consumption* is adopted to incorporate the CC driver, useful to assess regulating ES. Exports of food fish are also included by the Institute of Fisheries Management (UK) as an additional indicator to complete the expenditure approach of GDP, being indicators related to the food provisioning ES, except for the greenhouse gas emissions attached to regulating ES. More recently, the SEEA is progressing by placing greater importance on other, non-market based economic assessments (21% of the indicators) but only for certain cultural ES. In particular, the *cultural value of fishing activity* is introduced in the framework (Werner et. al., 2014.), which is mainly covered by scientific publications but not still covered by regulating or other bodies such as the UN. However, only the so-called *exchange values* (i.e., the value at which goods, services and assets are exchanged regardless of the prevailing market conditions (Obst et. al., 2016)) should be integrated as part of the SEEA. This integration was not yet found in the literature (0% of indicators), remaining a missing topic only covered for terrestrial ecosystems (Caparros et al., 2017; Campos et. al. 2021).

In a similar way, the economic indicators for NBS1 and NBS2 are also obtained. The change in numbers of visitors and recreational vessels associated with improved natural habitats is very relevant, as remarked in Pinto et. al. (2014). These are related to cultural ES in contrast to the proxies in NIH usually linked to the provisioning ES. The output approach indicators are mainly used (although to a lesser extent) to assess the degree to which the recreational sectors at coastal areas and/or MPAs act as drivers of business improvements. These are, again, related to cultural ES in contrast to the employment or business indicators for NIH related to provisioning ES. OECD also promotes the estimation of the associated indicator to assess the NBS1 and NBS2 in terms of regulating ES, *Coastal tourism green Growth - Environmental and resource productivity - good and services provision based on* CO_2 *emissions.* For these two NBS the employment of non-market-based indicators is growing strongly. Indicators more generally covered by previous literature in relation to both NBS1 and NBS2 are limited to the estimation of the willingness to pay to preserve the coastal areas and specifically the cultural ES associated with MPAs (Austen et al., 2019).

3.2.2.2 Response indicators

In this study, response indicators were defined as those that measure management responses to ensure sustainable marine-use approaches, e.g., conservation status of habitats under the EU Habitats Directive or level of environmental related subsidies (Linked to CC). The type of response indicators is less specific and usually broadly used by the different organizations (covered in a lesser extent in previous literature), which may sometimes prevent their use in a very specific NBS context. More indicators are generally used for NBS2 and NIH in contrast to NBS1. OECD remarks that the level of fishing sector subsidies and the public cost of fisheries management (control, management, and enforcement) are key indicators. However, these are generally provided at the national level which makes necessary an estimation for its use in the context of a very specific NBS (Buisman et. al. 2009; Zableckis et. al. 2009). The investment in energy in the fishing sector (World Bank) may help the NIH to mitigate CC impacts of fishing. In addition, this indicator is to be used for NBS1 and NBS2. The OECD also promote the use of the indicator economic opportunities and policy response-expenditure in marine protected areas to preserve the three ES in NBS2.

3.2.2.3 Social indicators

Social indicators are divided into five categories adapted from the work of Carmen et al. (2020): 1) quantity and quality of NBS area from a people's perspective, 2) cultural aspects, 3) economic aspects, 4) health and wellbeing, and 5) governance and justice. The specific search on social indicators related to NBS and/or NIH, ES and CC retrieved a relatively low number of indicators (16 indicators). However, during the search, a considerable number of indicators related to NBS on urban and green spaces was detected. After careful consideration and review of the land-based indicators, those which could be applicable within the context of the marine NBS and/or NIH and CC (40 indicators) were included. In total, 30% of the indicators was found in marine and coastal peer-reviewed literature, while the rest originated from EU reports on the implementation of NBS in urban and green spaces. In total, 104 social indicators (56 without duplication, see Figure 4.A) were included in the framework. The distribution of indicators across the different IPBES categories was as follows: most indicators (52%) related to the health & wellbeing of people in relation to the implementation and presence of NBS, followed by indicators on cultural aspects (18%), governance & justice (16%), the quality & quality of the NBS area (5%) and economic aspects (9%).

The groups of "cultural aspects" and “governance and justice” indicators were more closely related to ES on the "characteristics of a living system that are resonant in terms of culture and heritage" as they are focused on heritage, bequest, identity, and justice. The link between NBS and these social aspects is sometimes difficult to establish (Dumitru et al., 2020), albeit several examples of potential indicators exist in the literature (e.g., Fongar et al., 2019). Moreover, the five indicators classified as “economic aspects" were related to the provisioning ES "wild animals used for nutritional purposes". These indicators (i.e., fisheries dependence, fishing sector employment) are only related to NIH as this is directly linked to the commercial exploitation of seafood. These are used both by social and economic research works.

3.3 Changes in ES due to effectiveness of NBS&NIH: Analysis of appropriateness of selected indicators

After removal of the pressure indicators, 155 remained for the analysis. Each of the selected indicators can be useful to measure changes in more than one ES section and/or class, and in relation with more than one NBS and NIH (Figure 5).

The number of indicators was higher for NBS2 (139 indicators) than for NBS1 (102) or NIH (93). Generally, the number of biodiversity and environmental indicators is higher than for the remaining types. A single biodiversity indicator was found for NIH (Status of marine fish and shellfish stocks in European seas), and a unique response indicator for NBS1 (Investments in coastal restoration funded by public bodies). The biodiversity and environmental indicators related to regulating services (75, 38 without duplication) are more abundant than indicators for the other two ES types, provisioning (41, 26 without duplication) and cultural (20, 13 without duplication) ES. However, indicators of regulating services are the most numerous (and measuring the status of ecosystem functions), these do not later translate to the socio-economic system. Thus, only 7 economic (5 without duplication) and 5 response indicators (4 without duplication) measure changes in regulating services.

The opposite happens with the provisioning and cultural ES: provisioning services are covered by 11 economic indicators (10 without duplication), 4 social (4 without duplication) and 3 response indicators (3 without duplication), while cultural ES are covered by 100 social (52 without duplication), 13 economic (9 without duplication) and 2 response indicators (2 without duplication). Some cultural ES are also measured through biodiversity indicators (13 indicators without duplication), mainly related to measures of protected species and habitats groups, such as Abundance of marine birds, cephalopods, or presence of iconic/endangered species. The increase in economic assessment of cultural ecosystem services was reflected by the presence of 9 specific economic indicators. Most of them used traditional market-based indicators (GDP expenditure demand approach) such as Environmental expenditure - Household expenditure on consumption categories (recreational and culture), but also, non-market-based indicators as the cultural value of fishing activities, or (Willingness to Pay) for biodiversity preservation through MPAs, value as a reservoir of biodiversity.

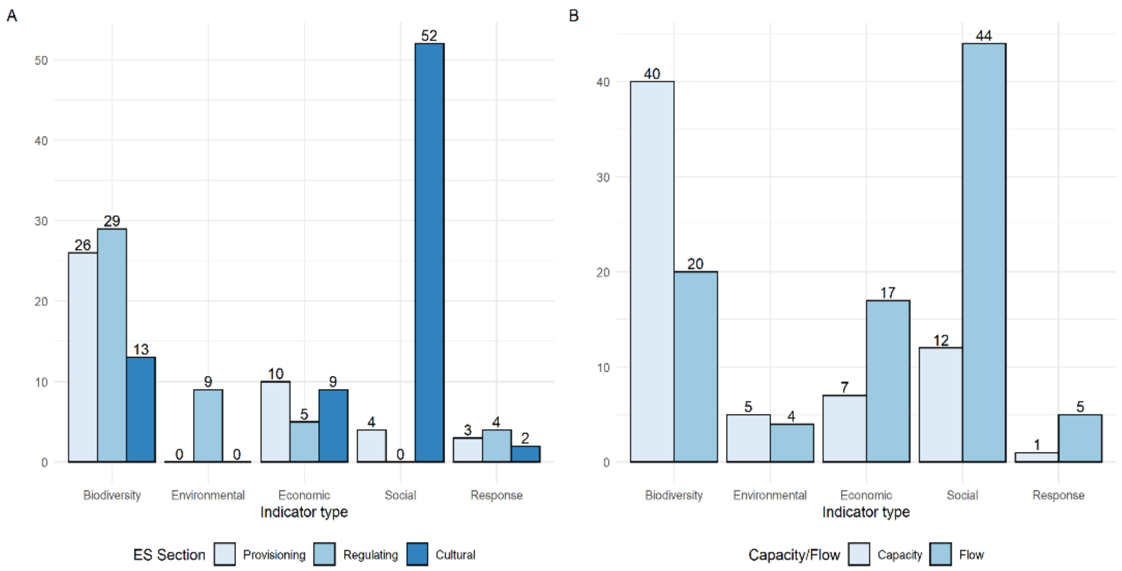

Figure 5. (A) Number of indicators by type of indicator (biodiversity, environmental, economic, social or response) and ES section; **(B)** Number of indicators by type of indicator (biodiversity, environmental, economic, social or response) and by ecosystem service aspect that they capture (capacity, flow).

From the 48 ES class categories included in the Marine CICES 5.1 (considering both biotic and abiotic components), this literature review found indicators for 20 ES (see column “Description” in Table 6) which represent a good coverage considering these are only related to NBS1, NBS2 and NIH examined in FutureMARES. However, in many cases, it was not possible to classify each indicator at ES class level and, therefore, some of them were aggregated according to their thematic coverage. This corresponds with the column “short ES name” in Table 6. For example, “food provision” aggregates four ES CICES 5.1 classes: wild animals, wild plants, reared aquatic animals and cultivated aquatic plants used for nutritional purposes. In other cases, it was only possible to classify the indicator at section level (provision, regulating or cultural); and those indicators have been included in Table 6 as “section level indicators”. It is also important to note that a single indicator may be relevant for more than one NBS&NIH or ES, and therefore, numbers in Table 6 are higher than the total number of unique indicators (155).

To a greater or lesser extent, the NBS&NIH are linked to indicators covering the three ES types (i.e., provisioning, regulating, and cultural) although, depending on the NBS/NIH, the number of indicators for each ES type varies. Thus, for NBS1 and NBS2, the highest number of indicators are for regulating services, while for NIH most indicators are linked to provisioning services (Table 6).

For provisioning services, ES related to nutrition or “food provision” are the most common, while for material provision only one indicator was found. Food provision indicators are especially abundant for NIH (41), compared with NBS1 (4) and NBS2 (9). Among regulating services, “protection of habitats and species” and “climate regulation” are the ones with higher number of indicators. For all the regulating services analysed, there is a better indicator coverage for NBS1 (39 indicators) and NBS2 (43 indicators) than for NIH (7 indicators). For cultural ecosystem services of “leisure and recreation” 38 indicators available, compared to the remaining 5 categories, for which only 18 indicators are available. In some cases, indicators could only be classified to “section” level (5 provisioning, 5 regulating, 2 cultural) due to the low specificity (Table 6).

Table 6. *ES for which indicators have been found, classified, and described based on CICES 5.1. The number of available indicators has been classified according to the two nature-based solutions (NBS) and one nature-inclusive harvesting (NIH) and type of indicator (capacity or flow). Note that one indicator may be relevant for more than one NBS/NIH or ES. Pressure indicators are not included here.*

Ecosystem service section	**Ecosystem service**	**Description**	**Short ES name**	**NBS1**		**NBS2**		**NIH**		**Total**
				Capacity	**Flow**	**Capacit y**	**Flow**	**Capacity**	**Flow**	
Provisioning	Wild animals (terrestrial and aquatic) for nutrition,	Wild animals used for nutritional purposes	Food provision	1	4	4	5	18	23	55
	Wild plants (terrestrial and aquatic) for nutrition	Wild plants used for nutrition								
	Reared aquatic animals for nutrition	Animals reared for nutritional purposes, e.g., through aquaculture such as fish, shellfish								
	Cultivated aquatic plants for nutrition	Cultivated plants grown for nutritional purposes, e.g., plants through aquaculture								
	Wild and cultivated aquatic plants for materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	Material and energy provision	0	0	0	0	1	0	1
		Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy								
		Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)								
		Plants cultivated by in- situ aquaculture grown as an energy source								
	Wild and reared animals for materials or energy	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)								
		Wild animals (terrestrial and aquatic) used as a source of energy								
		Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)								
		Animals reared by in-situ aquaculture as an energy source								
	***Section level indicators* for provisioning services**									**56**
Regulating	Regulation of chemical composition of atmosphere and oceans	Regulation of climate by sequestration and storage of carbon dioxide and other green-house gases	Climate regulation	7	5	5	5	0	5	27
	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bioremediation by micro-organisms, algae, plants, and animals	Bioremediatio n of waste	2	3	2	3	0	0	10
		Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals								
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection),	Disturbance prevention	5	3	6	4	0	0	18

Ecosystem service section	Ecosystem service	Description	Short ES name	NBS1		NBS2		NIH		Total
				Capacity	Flow	Capacity	Flow	Capacity	Flow	
		Control of erosion rates								
	Lifecycle maintenance, habitat, and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	Protection of habitats and species	10	1	13	1	2	0	27
		Seed dispersal								
		Maintaining nursery populations and habitats (Including gene pool protection)								
	Pest and disease control	Pest control (including invasive species)	Pest control	0	1	0	1	0	0	2
	Section level indicators **for regulating services**									**84**
Cultural	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	Cultural heritage	2	5	3	9	3	19	41
		Characteristics of living systems that enable aesthetic experiences, e.g., Seaview	Aesthetic experience	4	0	3	0	2	0	9
		Characteristics of living systems that enable education and training	Educational	0	7	0	7	0	4	18
	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation, or enjoyment through passive or observational interactions, e. g. wildlife watching	Leisure and recreation	11	7	15	12	1	5	51
		Characteristics of living systems that enable activities promoting health, recuperation, or enjoyment through active or immersive interactions, e. g. snorkelling, SCUBA diving								
	Biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	Existence value	0	1	0	1	0	0	2
	Section level indicators **for cultural services**									**121**

Generally, impacts through ES are not assessed following an interdisciplinary perspective, meaning that the used indicators to assess a single ES do not cover the whole ES cascade following the same criteria. The socioeconomic system is oriented to produce flow indicators in contrast to what happens in the biodiversity and environment system, Figure 3 (i.e., from capacity to flow). Thus, the ES cascade model allows to measure biodiversity capacity and socioeconomic flow imbalances. 45 Biodiversity and environmental indicators are covering the impacts of NBS&NIH on ES capacity of this system vs. 24 socio-economic indicators capturing ES flow (Figure 4.B).

3.3.1 FutureMARES empirical evidence: indicators to assess changes in ES due to effectiveness of NBS&NIH

Usefulness of selected indicators (from the review of literature presented in previous sections) was also analysed through a set of FutureMARES Storylines (so called empirical evidence). Empirical evidence was caught through the FutureMARES 27 Storylines. As a result of a set of working groups organized in the context of the Task 1.3 it was stated that Storylines used a 70% of the identified indicators. However, going through the dimensions, 85% of used indicators belong to the biodiversity and environment dimensions going up to 91% for those considering the CC which push the impact assessment to be oriented to evaluate the NBS impacts in terms of capacity. In a lesser extent, the Storylines covered the 71% of the economic indicators (17 indicators from a total of 24 were used). However, very low usefulness of the framework was demonstrated when moving to the social dimension where Storylines only used 18 from 56 potential indicators. It is relevant to confirm the highest number of pressure indicators followed by habitats and harvest indicators, and in a lesser extent by assemblage and protected species. Very relevant is the consideration of non-market based economic indicators.

Making emphasis into the non-used indicators across dimensions, Storylines did cover neither the demand-side economic indicators nor the contribution to CC indicators, providing an impact assessment with high frequency oriented towards the estimation of the economic impacts in terms of the Gross Domestic Product (flow assessment rather than capacity). Together with a very low coverage of the social indicators. See frequency of indicators use in Figure 6.

Thus, in general FutureMARES will do a good coverage of the framework of indicators obtained from the literature review process showing a similar coverage of indicators across dimensions and groups withing those dimensions than the coverage provided by the previous literature review. Highly oriented to flow indicators within economic and social dimension while oriented to capacity indicators in the biodiversity and environmental dimensions. Covering all the ES considered: cultural, regulating and provisioning as it can be seen at Figure 7.

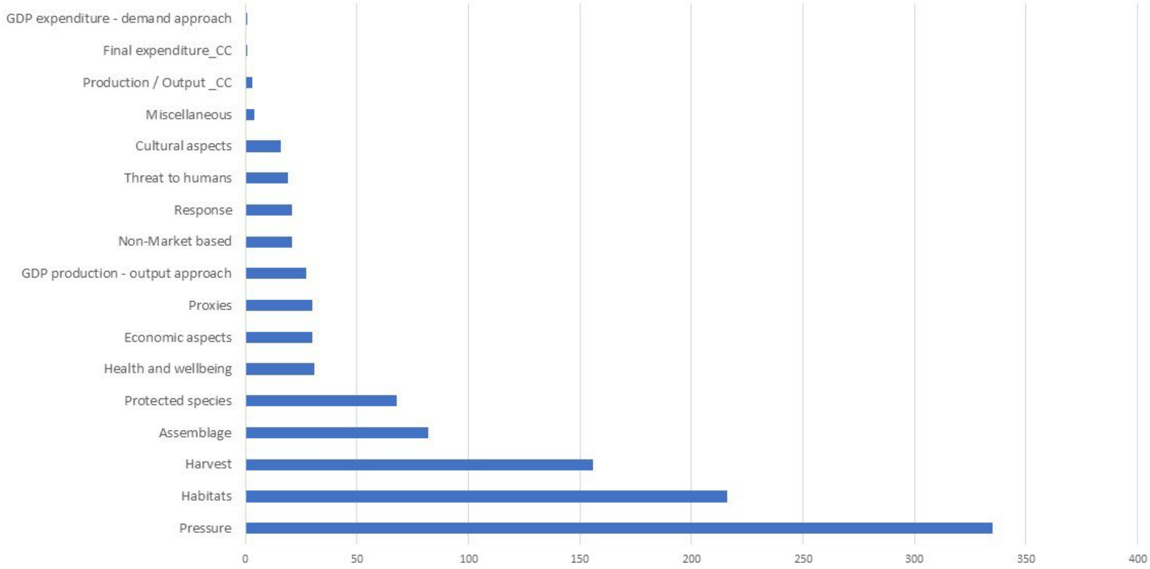

Figure 6. Empirical approach: frequency of use by FutureMARES storylines of the different indicator groups indicator when assessing impacts on ES provided by NBS&NIH.

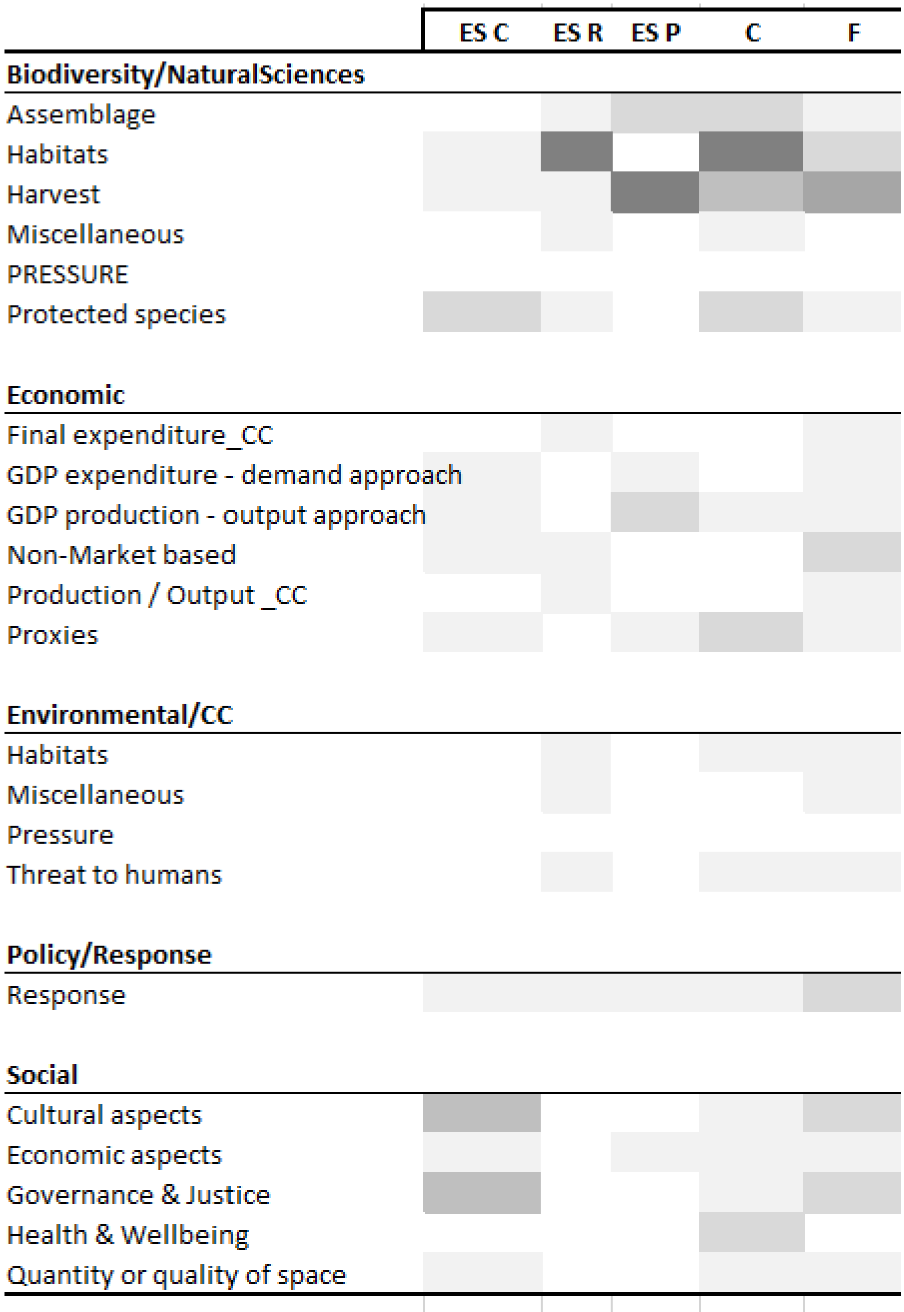

Figure 7. Empirical approach: frequency of coverage by FutureMARES storylines of the different ES (ES C - cultural, ES P - provisioning and ES R - regulating) and indicator type (F-flow or C-capacity)

4 Discussion

This is the first study that rigorously linked appropriate indicators to measure 20 important marine ES that will be affected by CC. All indicators selected are also considered important in measuring effects of NBS on the selected ES. The use of the ES cascade model helped identify gaps where specific ES cannot be assessed across the entire model. Most indicators were derived from biodiversity and ecological research. This may have several reasons. To monitor ES, it is necessary to measure several aspects of the natural system, for example, bioremediation of waste is carried out by several species and processes (Watson et al., 2016, Broszeit et al., 2016, Broszeit et al., 2017). This is also true for other ES such as food provision, an ES provided through many different species, and for which indicators include species abundance and biomass harvested but also their standing stock biomass, or other measurements. This leads to a greater number of indicators than economic or social indicators. The Storylines used encompass a variety of different habitats and species groups which can and must be measured in a variety of different ways. Also, ES research is firmly grounded in ecological and biodiversity science with economics and social sciences studies joining ES research efforts later.

With regards to economic assessments, direct market-based impacts on production are usually well identified and relatively easy to measure, other areas, such as the direct market-based impacts on demand or non-market-based indicators, are still in development and provide limited or no information to support decision making towards implementing NBS&NIH. The amount of scientific literature covering non-market-based assessment (estimating so-called willingness to pay) confirms this gap. Some authors (Fishers et. al. 2008, Carrasco De la Cruz, 2018) state the inability to capture these values. Although, this research has highlighted that the economic value information for fish (particularly salmonids and Protected Endangered Threatened Species) or coastal areas has been improved, both in terms of species studied and the types of willingness to pay estimates being generated. These can potentially be used in policy applications (Lee, 2015) but we are still far away from a generalized application of the SEEA.

A key result of this study was the distinction between capacity and flow indicators which sit firmly within different dimensions. Capacity is mostly measured through biodiversity indicators and flow is mostly measured by economic and social indicators.

While there is an abundance of social indicators, there are few that link to economics and biodiversity. For instance, the Revenues per landing effort, categorised as a social indicator (social dependency group), may also be used in economic studies (output indicator) and even in environmental studies. Likewise, economic proxies (number of fishermen, number of visitors, vessels, etc.), are commonly also adopted as social indicators (social procedure, social education). Thus, a common, multidisciplinary approach is compulsory to avoid redundancies even though the interpretation might vary depending on the discipline.

Pressure indicators do not tell us about ES, but they provide insight on how all the ecosystems may be negatively impacted. Habitat indicators also do not automatically tell us about ES. To gain that information, further details are needed such as the type and condition of the habitat. For example, mudflat habitats provide ES that differ from seagrass habitats.
The temporal scale also represents a major gap between the systems. The transition from mostly capacity-based indicators in the environmental system to the flow-based socio-economic assessment and policy response requires additional analysis usually missing when evaluating NBS&NIH. In which way these flows from the socio-economic system are exceeding the environmental capacity is usually missing particularly since socio-economic indicators do not capture the full potential service assessment (i.e., fish provisioning considering the fish population).

With regards to ES types, provisioning and cultural ES are better covered than regulating ES in social and economic terms, the latter being reduced to climate regulation assessment by introducing the carbon footprint measure for both output and demand-based indicators. These are mainly identified by organizations such as OECD and EUROSTAT but not generally adopted by scientists, except for some fisheries carbon footprint examples (Parker and Tyedmers, 2014; Parker et. al., 2018; Greer et. al., 2019). The assessment of the maritime activities carbon footprint helps to gain knowledge on the trade-offs between the provisioning and the regulating ES, which provides insights on the interaction between CC and ES. Thus, an important gap exists in the socio-economic dimensions to measure regulating services. Socioeconomic indicators are rarely useful to assess adaptation or mitigation to CC - only 20% of the environmental indicators do this. So, a win-win impact assessment in terms of CC after NBS1, NBS2 and/or NIH implementation remains to be conducted.

This research highlights that even using very well-known frameworks (ES cascade, SNA, SEEA) linking natural and socioeconomic dimensions, stakeholders are usually oriented to some of these groups in isolation, operating at different temporal and spatial scales and avoiding cross-comparisons between dimensions and groups for the same NBS&NIH.

Overall, the suggested holistic framework of indicators is needed to conduct a complete and necessary operational impact assessment of the NBS&NIH on ES both in terms of transdisciplinary flows and capacity over the short-term and long-term under CC.

Table 7. *Gap analysis summary: current gap, desired goal*

Topic	GAP	Desired Goal
Biodiversity and environmental	- A need to use more Earth observation data and essential biodiversity variables and essential ecosystem service variables approaches.	- Ensure that earth observation data are compatible with and used in environmental and biodiversity assessments
Social, economic and Policy	- Non balanced indicators, with the majority oriented towards biodiversity and environmental dimensions - Indicators not linked to a complete array of relevant overarching policies . - Inability to estimate the value of non-marketed ES. Non – market - based indicators (mainly economic and social) are not responsible to policy management. These are not easy to evaluate or communicate to final stakeholders who do not consider these in decision making. - Non-market-based indicators only found in previous scientific research but not used by organizations in an operational way. No exchange values are obtained for any marine related research	- Update the number of indicators used in a way of providing more coverage to all relevant environmental policies. - To transfer non-market-based indicators (social and economic) to policy makers. To enhance their transference to final stakeholders. - To introduce exchange values from non-market assessment as part of an operational framework of indicators
Response	- In general, covered in a broadly way (not for very specific NBS&NIH) which prevents its use - Covered in a lesser extent	
ES Classification	- Among provisioning services, food provision was the more commonly assessed one, and in general, solely considered wild fish for nutrition. This overlooks the role of the fish as part of the ecosystems. - Capacity aspects of regulating ES assessment are better covered than flow aspects. For some regulating ES few indicators were found. - Among cultural ecosystem services, leisure and recreation is the most assessed one. - Few social and economic capacity indicators. Almost all are categorised as flow indicators. - Social and economic aspects for provisioning and cultural ES are better covered than for regulating ES.	- To assess other provisioning services apart from nutritional outputs, to enhance other material contributions of marine ecosystems. - To develop better indicators to assess all regulating ES. To enhance the comprehensiveness of regulating ES to improve the establishment of socio-economic new indicators. - To develop better indicators to assess non-recreational cultural ecosystem services. - To measure capacity aspects (e.g., anthropogenic contribution) using economic and social indicators. Capacity indicators will be integrated in future environmental economic accounting in contrast to the flow indicators. - To enhance the assessment of ES demand which represents the society´s preferences for specific ES attributes such as biophysical characteristics – this is larger than other business economic flow indicators. - To improve the way to measure economic and social aspects for regulating ES.
Criteria	- Socioeconomic indicators are rarely useful to assess adaptation or mitigation to CC, and moreover, only 20% of the found environmental indicators do it. So, win-win impact assessment in terms of CC after NBS&NIH implementation remains understudied	- To enhance the assessment of the socio-economic impact of CC
Multidisciplinary overview	- More multidisciplinary work is needed. Some indicators are shared between social and economic dimension (e.g., Added Value might be a dependence social indicator but also an economic indicator) providing different societal benefits	- An inter and transdisciplinary approach should be followed when evaluating NBS&NIH impacts on ES
General overview	- Even using very well-known frameworks (ES cascade, SNA, SEEA) establishing linkages between nature and socioeconomic, each group might be useful at different temporal and spatial scales. i.e., Regulating indicators from environmental system rarely reach the socio-economic system. - Indicators usually conduct to assess the socioeconomic impacts mainly over the short-term in contrast to a long-term oriented approach	- Overall, the suggested holistic framework of indicators is needed to conduct a complete and necessary operational impact assessment of the NBS&NIH on ES both in terms of transdisciplinary flows and capacity over the short-term and long-term under CC.

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Annex

Table A 1. *Grey literature*

Global framework	**Weblink / Source**
Strategic Plan for Biodiversity 2011-2020	https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-28-en.pdf https://www.cbd.int/development/doc/biodiversity-2030-agenda-technical-note-en.pdf
Biodiversity Indicators Partnership (BIP)	https://www.bipindicators.net/
IPBES	https://www.ipbes.net/indicators-data-ipbes-assessments; login required to access indicator lists
UNSC SDG Indicators List	https://unstats.un.org/sdgs/indicators/indicators-list/ https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/
UNCCD	http://www2.unccd.int/sites/default/files/inline-files/ICCD_COP%2813%29_L.18-1716078E.pdf https://knowledge.unccd.int/sites/default/files/inline-files/Decision22-COP11.pdf
UNFCCC	http://unfccc.int/resource/docs/2009/sb/eng/04.pdf
UNECE SEEA Climate Indicators	https://www.unece.org/statistics/networks-of-experts/task-force-on-a-set-of-key-climate-change-related-statistics-using-seea.html
Ramsar	https://www.ramsar.org/document/sc31-15-ecological-outcome-oriented-indicators-for-assessing-the-implementation https://www.cbd.int/doc/meetings/ind/emind-02/official/emind-02-08d-en.pdf https://www.cbd.int/doc/meetings/sbstta/sbstta-18/information/sbstta-18-inf-18-en.pdf https://www.ramsar.org/document/national-report-form-for-cop13-offline-version
SENDAI	https://www.preventionweb.net/drr-framework/sendai-framework-monitor/indicators https://www.preventionweb.net/files/45466_indicatorspaperaugust2015final.pdf
Global Biodiversity Outlook (GBO)	http://science.sciencemag.org/content/346/6206/241.full?sid=cc96265a-2269-4f7c-bf6e-96c8d505241e
EU Biodiversity Strategy 2020	https://biodiversity.europa.eu/topics/sebi-indicators
PEI (Poverty-Environment Indicators)	http://www.unpei.org/poverty-environment-indicators http://www.unescap.org/sites/default/files/06_SEEA_applications_Poverty-Environment_Accounting_Framework.pdf
EU 7th Environment Action Programme (EAP)	https://www.eea.europa.eu/publications/environmental-indicator-report-2017
Global Environmental Outlook	https://www.unenvironment.org/resources/global-environment-outlook
Partnership for Action on Green Economy (PAGE)	http://www.un-page.org/guidance-manual-green-economy-indicators
BIOFIN	http://www.biodiversityfinance.net/biofin-around-world https://unstats.un.org/unsd/envaccounting/ceea/meetings/twelfth_meeting/Methodological%20alignment-biodiversity%20accounting%20Final.pdf
World Bank	https://data.worldbank.org/indicator
Inclusive Wealth Accounts	http://www.ihdp.unu.edu/docs/Publications/Secretariat/Reports/SDMs/IWR_SDM_2014.pdf
OECD	https://www.oecd-ilibrary.org/sites/9789264268586-20-en/index.html?itemId=/content/component/9789264268586-20-en
EUROSTAT	http://ec.europa.eu/eurostat/web/environment/environmental-indicator-catalogue
Valuation and Accounting of Natural Capital for Green Economy (VANTAGE)	https://www.unenvironment.org/explore-topics/ecosystems/what-we-do/accounting-ecosystems
Green Growth (OECD)	http://www.oecd.org/greengrowth/green-growth-indicators/
EU SDG Indicator Set	http://ec.europa.eu/eurostat/documents/276524/7736915/EU-SDG-indicator-set-with-cover-note-170531.pdf
MSFD indicators	
NOAA TOOL	https://www.st.nmfs.noaa.gov/data-and-tools/social-indicators/

Table A 2. *Framework and criteria selection for indicators*

Block	Field definitions	Acronym	Fill into the field	Notes
Background	**Number of the entry**	**Nb**	**Introduce a consecutive number**	To list the indicators to be introduced
	Type	**Type**	**choose: Biodiversity/Economic/Social/Policy responses**	Open field, may not be easy to differentiate
	Name	**B1**	**open field**	Title of indicator as per source
	Origin (DEVOTES, MSFD, HELCOM, ...) or Adapted from these origins	**B2**	**open field (but see examples in "origin" sheet)**	Source of the indicator (there may be several). At the "origin" sheet you can find a selection. You can add more if needed. Choose the most relevant.
	Brief description	**B3**	**open field**	To explain briefly what the indicator is doing
	Measurement unit/process	**B4**	**open field**	As described in the source
	Availability of data	**B5**	**YES/NO**	Further info can be provided at the end of the framework
	Data in form of time series	**B6**	**YES/NO**	
Link to FutureMARES	**NBS/Story lines # in Futuremares**	**#**	**choose from the FutureMARES list**	can it be linked to the NBS/story lines or is it suggested by one of these?
	NBS	**NBS1/ NBS2/ NBS3**	**choose NBS1, NBS2 or NBS3**	can it be linked to the NBS/story lines or is it suggested by one of these?
ES Classification	**ES Section (provisioning, cultural, regulating)**	**ES1**	select between Provisioning, P, Cultural, C and Regulating, R ecosystem services **choose: P, C, R**	The definition of the ecosystem service is introduced following the structure of the Common International Classification of Ecosystem Services (CICES 5.1). Ecosystem services as defined as the direct contributions of ecosystems to human wellbeing. link with the other frameworks (MA, TEEB, MAES, IPBES) will be done outside.
	Assesses stock (capacity) or flow?	**ES2**	**Choose F (FLOW) or C (CAPITAL)**	Distinguish the kind of indicator between USE OR FLOW (F) and capacity (C). **USE OR FLOW:** is the use of the ecosystem service by the different economic units. The actual flow may be higher (overuse), equal or lower (underuse) than the potential flow. **POTENTIAL USE/FLOW OR CAPACITY**: amount of ecosystem service that can be provided or used in a sustainable way Source: (Villamagna et al., 2013), La Notte *et al.*, 2017
Social benefits	**SB selection**	**SB**	**Choose from the list**	A complete list of social benefits has been already produced. To select the most relevant
Economic benefits	**Economic sectors**	**Class**	**Choose from the list**	The EU official list of economic sectors is included as list. To select one of the list, the most relevant.
	Scientific basis	**C1**	**YES/NO**	Has the indicator been published? Either as ecological/biodiversity or ecosystem service indicator?

Block	Field definitions	Acronym	Fill into the field	Notes
Criteria	Ecosystem service relevance	C2	YES/NO	Based on ES indicator lists/publications
	Responsive to CC (one or all: hypoxia, increase of temperature, decrease of pH)	C3	YES/NO	Based on literature where available
	Scale of response in time and space	C4	YES/NO	
	Possibility to set targets	C5	YES/NO	This will help in restoration efforts
	Can it measure tipping points?	C6	YES/NO	
Quality	Cost-effective	Q1	YES/NO	Is there good return for the sampling? Need to assess how to measure and judge this consistently!
	Ease of sampling	Q2	YES/NO	Easy measurements are less prone to failure to return accurate, precise and otherwise useful data
	Accurate	Q2	YES/NO	How close to the actual value do we measure?
	Precise	Q3	YES/NO	How reproducible are the measurements?
Societal Uses	Time series (years)	SU1		When was it started? How long was it collected if stopped?
	Policy relevance	SU2	if YES choose from the close list (MSFD, EU Biodiversity, CFP, …)	Which policy needs MAY it address? A List of potential policies is provided
	Easy to communicate to managers, policy makers and stakeholders?	SU4	YES/NO	Use graphical display to ease understanding, but how easy is it to explain the measurement, indexes may be harder to grasp than indicators
	Socially relevant	SU5	YES/NO	Yes: if it is possible to define a relevant range of coverage (people, wellbeing, ...)
	Responsive to management measures	SU6	YES/NO	
	Does it measure mitigation or adaptation?	SU7	choose M, A	Distinguish the kind of indicator between Mitigation (M) or Adaptation (A)
Data location	Website/Link	DL1	Open field	This will be useful when locating data to test the indicators
	Data owner	DL2	Open field	Any info to contact the owner
	Publication	DL3	Open field	Fill in the reference of the publication
	Further references	DL4	open field	

Table A 3. *IPBES classification. Theme classification of the social indicators following an IPBES approach.*

Dimension	Indicator class / theme	Aspects captured by the indicator
Society	Cultural aspects	Stewardship
		Identity, sense of place
		Heritage values
	Health and wellbeing	Social relations
		Physical and mental health
		Education and knowledge
		Safety and security
	Governance and justice	Procedural justice
		Distributional justice
	Economic aspects	Jobs created
		Profits for business
		Value of properties
Contributions	Regulation contributions	Regulation of water quality, climate, ocean acidification, hazards, extreme events
		Habitat creation and maintenance
		Dispersal of propagules
		Erosion protection
	Material contributions	Energy
		Food and feed
		Materials
		Medicinal, biochemical and genetic resources
	Non-material contributions	Physical and psychological experiences including learning and inspiration
		Supporting identities
Nature	Nature	Nature itself
	Quantity/quality	Quality
		Quantity
		Accessibility

Table A 4. *Listing ecosystem services indicators*

Biodiversity

Abundance of cephalopods

Abundance of seagrass associated fish

Abundance of selected (coastal) fish species

Algae morphotype and height

Amount (spatial extent, gear type, intensity) of fishing effort within vulnerable habitats

Biomass of (survived) hake recruits

Blue Carbon stocks

Bottom vegetation biostabilization capacity

Carbon fixation in benthic organisms and sediment

Carbon sequestration

Carbon sequestration rate

Changes in fish distributions in European seas

Chlorophyll in transitional, coastal, and marine waters

Conservation status of species under the EU Habitats Directive

Depth limit of Fucus spp

Depth limit of macrophytes

Depth limit of spermatophytes

Dissolved organic carbon purification amount by benthic organisms.

Distribution shifts of marine species

Distributional pattern within the distributional range of cephalopds

Distributional pattern within the distributional range of demersal elasmobranches

Distributional pattern within the distributional range of demersal fish

Distributional pattern within the distributional range of sea-turtles

Distributional range of cephalopods

Estuarine and Lagoon Fish Index - ELFI

Extent and height of the forest forming algae

Habitat nursery role

Harvests (algae, plants, or animals)

Lost Potential Yield of a fish stock (species level, in a region) after Sacharina latissima farming, based on biomass, LPYb

Mammals: consumed biomass of invasive species

Management performance to achieve sustainability, MPS

Marine Bird Abundance

Marine bird breeding success/failure

Marine Stewardship Council engaged fisheries

Marine Trophic Index

Mean length of fish in the community

MSFD-D10C3 - Ingested plastic

MSFD-D10C4 - Number of individuals adversely affected by litter such as entanglement

MSFD-D11C1 - Anthropogenic impulsive sound in water

MSFD-D1C1 Mortality rate through Bycatch

MSFD-D1C2 - Anthropogenic

MSFD-D1C3

MSFD-D1C3

MSFD-D1C4

MSFD-D1C5

MSFD-D1C6

MSFD-D2C1

MSFD-D2C2

MSFD-D2C3

MSFD-D3C1

MSFD-D3C2

MSFD-D3C3

MSFD-D4C1

MSFD-D4C2

MSFD-D4C3

MSFD-D4C4

MSFD-D5C3

MSFD-D5C6

MSFD-D5C7

MSFD-D6C1

MSFD-D6C2

MSFD-D6C3

MSFD-D6C4

MSFD-D6C5

MSFD-D8C2

MSFD-D8C4

MSFD-D9C1

Percentage cover of algae and its configuration (e.g., fragmented, dense...)

Percentage of nitrogen load remove through denitrification

Potential spawning habitat; Potential nursery habitat

Presence and Distribution of alien species

Presence of iconic/endangered species

Primary production

Proportion of fish stocks within safe biological limits

Proportion of predatory fish

Proportion of threatened species for which mortality rate due to fisheries is decreasing

Seagrass biomass

Seagrass cover

Seagrass grazing marine megafauna distribution (e.g., green sea turtle & dugong)

Seagrass shoot density

Seal abundance and distribution

Soil seedbank

State of benthic communities

Status of marine fish and shellfish stocks in European seas

Surplus production, SP

Sustainability of the exploitation of the food provisioning capacity, SFP

Total catch. Trophic level of catch

Trends in marine non-indigenous species

Trends in population of non-target species affected by fisheries

Yield from artisanal fishing activities

Yield from hunting activities

Yield from mechanical clam harvesting activities

Yield from recreational fishing activities

Choose Biodiversity, Economic, Social, Response (policy, private)

Economic

Amount of expenditure associated to the recreational/tourism activities (NON-MARKET BASED)

Assessed fish stocks exceeding fishing mortality at maximum sustainable yield (Fmsy)

Business indicator by coastal tourism related economic sectors (MARKET BASED). Different options: Added Value, Turnover or gross premium written, profits

Business indicator of fishing sector (MARKET BASED). Different options: Added Value, Turnover or gross premium written, profits

Coastal tourism green Growth - Environmental and resource productivity - good and services provision based on CO_2 emissions

Cultural value (non-market based) of fishing activity

Environmental expenditure - Household expenditure on consumption categories (food)

Environmental expenditure - Household expenditure on consumption categories (recreational and culture)

Export of goods and services

Fishing sector green Growth - Environmental and resource productivity - food provision based on CO_2 emissions

Greenhouse gas emissions induced by household food consumption, per Euro spent

Greenhouse gas emissions induced by household recreational and cultural consumption, per Euro spent

Labour productivity

LPUE Landings per unit effort

Mammals: number of people interacting through whale watching etc

MSC certified catch

Number of fishermen

Number of vessels

Number of visitors

Nutrient cycling economic assessment

Recreation visitors (divers, sailing, recreational fishermen)

Use of space

Value (Willingness to Pay) for biodiversity preservation through MPAs, value as a reservoir of biodiversity (non-market based)

Value (Willingness to Pay) or biodiversity preservation through coastal areas restauration (non-market based)

Environmental

Coastal protection capacity

Coastal protection supply

Estimates of coastline change

Extreme sea levels and coastal flooding

Global and European sea level rise

MSFD-D10C1

MSFD-D10C2

MSFD-D11C2

MSFD-D5C4

MSFD-D5C5

MSFD-D7C1

MSFD-D7C2

MSFD-D8C1

MSFD-D8C3

Nutrient load to coast

Nutrients in transitional, coastal, and marine waters

Ocean acidification

Oxygen concentrations in European coastal and marine waters

Primary production. Nutrients retention in sediments

Sea surface temperature

Wave energy reduction ratio

Wave run-up height ratio of run-up height to top of seawall

Wind fetch reduction by saltmarshes

Response

Conservation status of habitats under the EU Habitats Directive

Economic opportunities and policy responses - expenditure in environment protection - MPA

Investments in coastal restoration funded by public bodies

Investments in energy, fishing sector, funded by Gross Exploited Excedent or public bodies

Level of environmental related subsidies (Linked to CC)

The public cost of fisheries management (enforcement, research, management)

Social

Connection to nature

Environmental education

fisheries dependence

Fishing sector Employment

Landings per Unit Effort (LPUE)

Local identities

Number of boat trips - leisure boats

Number of visitors for the purpose of recreation

Number of visitors for the purposes of environmental education

Positive well-being

Recreation activities linked to a protected area

Recreation Opportunity Spectrum (ROS)

Recreation Potential indicator (RPI)

Revenue per Unit Effort (RPUE)

Wellbeing/ perceived wellbeing

Wellbeing

Exploratory behaviour in children

Place attachment, sense of place, place identity

Connectedness to nature

Perceived quality of blue spaces

Recreational value of public blue space

Encouraging a healthy lifestyle

Cultural Heritage protection

Mindfulness

Traditional knowledge and uses reclamation

Traditional events organised in NBS areas

Observed physical activity level within NBS

Quality of life

Natural and cultural sites made available

Historical and cultural meaning

Cultural value of blue spaces (NBS)

Self-reported mental health and wellbeing

General wellbeing and happiness

Level of chronic stress (perceived stress)

Level of outdoor physical activity

Bridging – quality of interactions within and between social groups

Bonding – quality of interactions within and between social groups

Inclusion of different social groups in NBS projects

Solidarity among neighbours

Quantity and quality of social interaction

Perceived social cohesion

Perceived ownership of space and sense of belonging to the community

Proportion of target group reached by an NBS project

Opportunities for tourism

Scenic sites and landmarks created

Scenic paths created

Citizen involvement in environmental education activities

Social learning regarding ecosystems and their functions/services

Active engagement of citizens in decision-making

Children involved in environmental educational activities

Engagement with NBS sites/projects

Community involvement in NBS planning

Community involvement in NBS implementation

Positive environmental attitudes motivated by contact with NBS

Involvement of citizens from traditionally underrepresented groups

Sense of empowerment: perceived control and influence over decision-making