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Ecosystem indicators to measure the effectiveness of marine nature-based solutions on society and biodiversity under climate change

Arantza Murillas-Maza[a,*], Stefanie Broszeit[b], Sarai Pouso[a], Juan Bueno-Pardo[c], Ana Ruiz-Frau[d], Jorge Terrados[d], Susanna Jernberg[e], Ane Iriondo[a], Marina Dolbeth[f], Stelios Katsanevakis[g], Paul J. Somerfield[b,†], Jose A. Fernandes-Salvador[a]

[a] *AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Txatxarramendi Ugartea z/g, 48395 Sukarrieta, Spain*
[b] *PML, Plymouth Marine Laboratory, Plymouth PL1 3DH, UK*
[c] *Centro de Investigación Mariña, Universidade de Vigo, Future Oceans Lab, Lagoas-Marcosende, 36310, Vigo, Spain*
[d] *Instituto Mediterráneode Estudios Avanzados, IMEDEA (CSIC-UIB), 07190 Esporles, Spain*
[e] *Finnish Environment Institute (SYKE) / Marine Research Centre, Latokartanonkaari 11, 00790 Helsinki, Finland*
[f] *CIIMAR - Interdisciplinary Centre of Marine and Environmental Research, Novo Edifício do Terminal de Cruzeiros do Porto de Leixões, Avenida General Norton de Matos s/n, 4450-208 Matosinhos, Portugal*
[g] *Department of Marine Sciences, University of the Aegean, 81100 Mytilene, Greece*

A R T I C L E I N F O

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A B S T R A C T

An assessment framework of marine ecosystem services (ES) indicators to quantify the socio-ecological effectiveness of nature-based solutions (NBS) and nature-inclusive harvesting (NIH) under climate-driven changes was developed. It creates a common understanding about the health status of ecosystems, their services (ES), and the impact of implementing NBS&NIH to inform policymakers and the public. The two NBS considered were restoration and conservation which need to be performed considering the sustainable harvesting of marine resources (NIH). The interaction between the biodiversity indicators with the socioeconomic, response and pressure indicators was established using the ES cascade. However, it was also 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). A set of 155 multidisciplinary indicators were identified through a literature review and their effectiveness in measuring ES under changing climate. Biodiversity & environmental as well as Pressure indicators are the most numerous in the list representing 34 % and 23 % of the total respectively, while only 12 % of the used Indicators below to the economic dimension. Socioeconomic indicators considering CC are rarely contemplated, except for a short list redefining output and demand approach indicators to aggregate a carbon footprint valuation. For cultural services economic indicators dominate, whereas sparse for provisioning and regulating. The 70 % of the selected indicators were also empirically verified with 27 European storylines. Storylines have high coverage of biodiversity, environmental indicators, and CC indicators (91 %), lower coverage of economic (71 %) and poorer related to social (31 %) indicators. Harvest, pressure and/or habitats are clearly the groups of indicators majority used when evaluating the ES on marine and coastal ecosystems both in terms of the number of used indicators but also, the frequency of use. Despite the increase of ES research, this study identifies 14 substantial gaps or weaknesses limiting the guidance for NBS&NIH implementation derived from the employment of an unbalanced (between dimensions and key groups) number of quantitative indicators.

* Corresponding author.
E-mail address: amurillas@azti.es (A. Murillas-Maza).

† Paul J. Somerfield passed away while the manuscript was in the second round of revision.

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Acronyms

BIOFIN	biodiversity finance initiative
CBD	convention on biological diversity
CC	climate change
CFP	common fishery policy
CICES	common international classification of ecosystem services
DAPSI(W)R(M)	drivers – activities – pressures – state (change) – impacts on human welfare – response
EBFM	ecosystem-based fisheries management
EC	European Commission
ES	ecosystem services (ES P. provisioning, ES C. cultural, ES R. regulating)
EUROSTAT	European statistical office
GDP	gross domestic product
IPBES	intergovernmental science-policy platform on biodiversity and ecosystem services
IPCC	intergovernmental panel on climate change
MSP	marine/maritime spatial planning
MSFD	(EU) marine strategy framework directive
NBS	nature-based solutions
NIH	nature inclusive harvesting
NIS	non-indigenous species
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	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

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 [1]. 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 [2]. 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 [3,4]. In the literature, several ES classification frameworks can be found (e.g., [3,5]; MEA [6–9]). 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 [10,11]. CC impacts on the marine system include rising temperatures, ocean acidification, deoxygenation, and sea-level rise ([1] and references therein; [10,12]). 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) [13]; Davies et al. [14,15], and Girardin et al. [16], 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. These habitat-forming species 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 CO2 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 [17–19] 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). These 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 [18–20]. Environmental, ecological, and biodiversity indicators measure various aspects of the marine ecosystem and can also measure ES [18,19,21,22]. Balvanera et al. [23] 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 [24]. In addition, indicators can tell us about capacity and flow of ES that need to be considered in the trade-off between supply offered and demand. 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. Being the potential use/flow the capacity, that is, the amount of ecosystem services that can be provided or used in a sustainable way. Those 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 [25].

Here we provide a framework that links indicators from different disciplines, also referred to as dimensions (natural sciences, economy, social sciences, and policy) to twenty ES (based on CICES, [6]) 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 which 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. And (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.

Materials and methods

The work comprised chiefly of three steps (Fig. 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 effective at 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. 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 storylinés explanation 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.

Twenty-seven storylines were involved covering all the NBS&NIH spread across European Seas. 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). Twenty marine ES were addressed, taken from the CICES classification [6]. This classification links ES to functions and therefore similar ES can be listed in several versions, for example, in provisioning ES biomass is split into 18 services, such as reared and wild animals and plants and the function for which they are used (nutrition or materials). While this is important because it helps to quantify each ES, it can make some investigations cumbersome. Therefore, in this manuscript, the 20 ES were reduced to twelve by putting similar CICES ES together (Table 1). This is helpful because it reduces repetition in indicator assessment since indicators may tell us simultaneously about several ES of CICES. The ES chosen for this study were based on their relevance to marine ecosystems but also to ensure coverage of provisioning, regulating and cultural ES. Throughout the rest of the manuscript, 12 ES will be mentioned. 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.

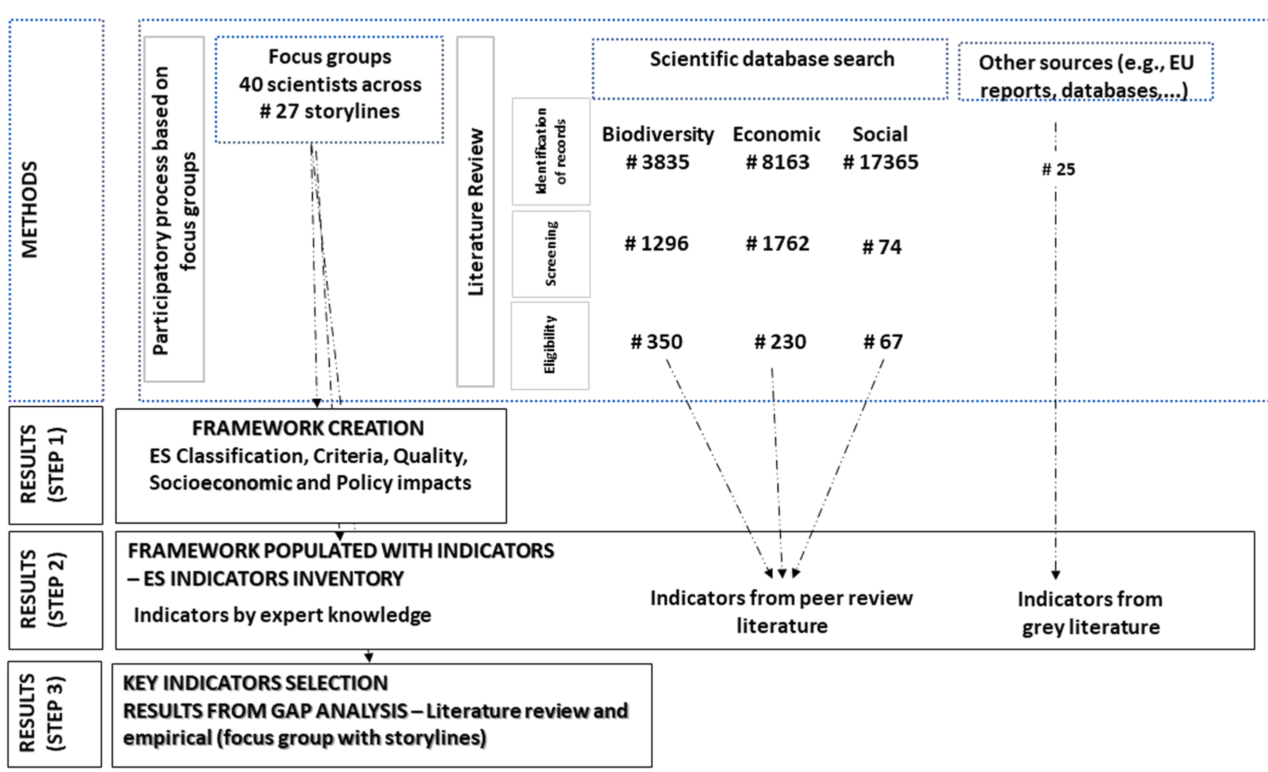

Fig. 1. Work process and results of this study. Scientific search method based on [26].

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

Step 1. Focus groups of 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. Both methods were used to identify criteria for selecting key indicators from the scientific literature and expert knowledge (Table 2). 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. The capacity and flow concept are linked to ecosystem services accounting where capacity is the state of the ecosystem assessed for one ecosystem service and flow is considered the regeneration and absorption rates that - if used within sustainable boundaries – produce each ecosystem service if the ecosystem components remain in the same condition [25]
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 sample?
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)

Step 2: search for suitable indicators based on literature review and classification

The primary question and aim of this work step were 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 (Fig. 1). First, a set of relevant scientific review manuscripts was identified, including Crossman et al. [27]; Queiros et al. [28]; Englund et al. [29]; Muller et al. [30]; Broszeit et al. [18]; Broszeit et al. [31]; Balzan et al. [32], Boyd et al. [33] Czúcz et al. [34]. Second, a scientific literature review was conducted, and databases were searched based on the PRISMA Statement guidelines [26]. 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 (Fig. 2).

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. [18]), 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 Intercessional Correspondence Group on Cumulative Effects). 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 to assess negative changes impacting ES as well. As the potential success of NBS and/ or NIH. Seven categories of pressure indicators were created including: 1) general to capture those indicators that can be applied to several pressures (such as some MSFD indicators to measure anthropogenic impacts); 2) fishing considering any indicator measuring negative effects on the biodiversity through catch and bycatch; 3) physical gathering any pressures exerted on the seafloor be they through trawling or other habitat alterations; 4) nutrients such as eutrophication indicators and excluding other forms of pollution; 5) pollution through chemicals such as oil, or other materials and sewage; 6) non-indigenous species (NIS) pressures; and, 7) 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 (adding 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 being the value GDP Demand equally to the GDP production value at country level. 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. [4]) 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. [37], we adapted the IPBES NCP for the purpose of indicator classification. The IPBES framework (Table A3) 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).

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 discipline. A gap analysis was then performed to identify which further indicator types need to be developed to strengthen ES monitoring. The gap analysis was split into the different dimensions and the general gaps were also identified and relevant goals to address these were described. In addition, scientists working on the 27 storylines were asked to fill in an online questionnaire to assess which of the indicators they use in their respective storylines.

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

Discipline	Search string used Included topics	Excluded topics	Number
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

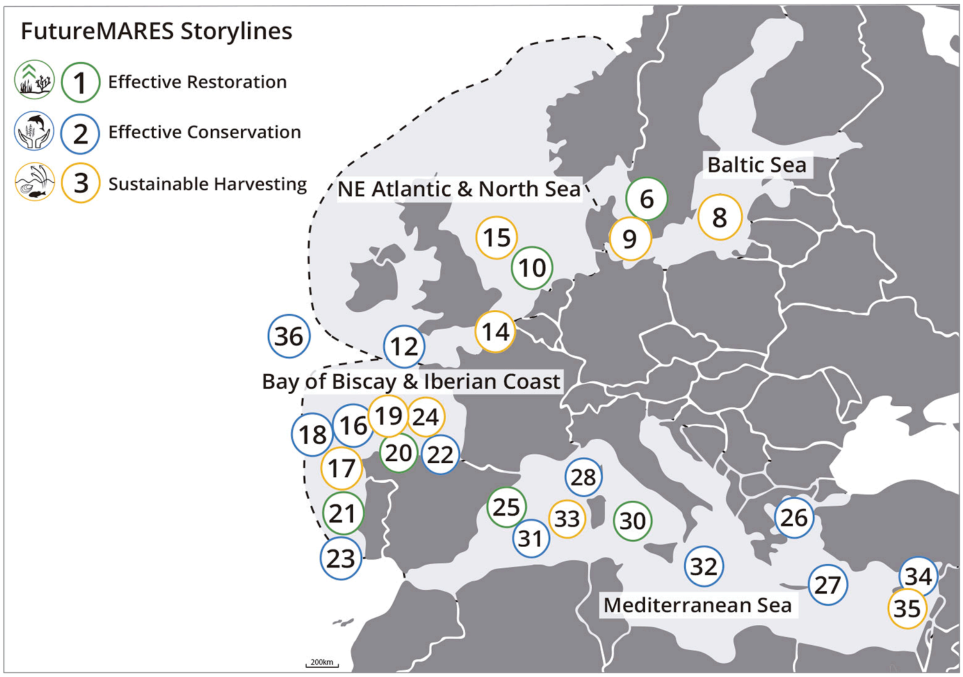

Fig. 2. Storylines engaged in focus groups, workshops, and surveys across the work progress. Note the identified number is not correlative from 1 to 27, because it was originally assigned by FutureMARES project which covers 40 storylines in total.

Results

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, firstly classifying indicator as related to provisioning, cultural or regulating ES, and secondly, identifying these as flow or capacity ES indicators. This link to ES was established despite difficulties in finding exclusive indicators [34] 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 from Nomenclature of Economic Activities), 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. In addition, selected indicators should be easily communicated to policymakers, and to be relevant to management measures to a certain degree. If policy-relevant, the indicator is linked with the most relevant piece of legislation. For example, 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 A2 presents the list of fields included in the framework.

Effective ecosystem services indicators for NBS&NIH under climate change

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 (Fig. 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. [38] 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.

In total, 201 distinct indicators were assessed (Fig. 4), and some are able to measure the effect of more than one NBS&NIH (accounting for a total of 334 indicators, Table 5). 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 supplementary material). 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

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

Dimension	Groups	Description
	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.
Biodiversity and environmental indicators	Assemblages	Based on Cooke, [35]: 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 communities and others.
	Habitat	This included indicators where the habitat was important such as nursery role of a habitat or height and density of forest forming algae.
	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.
	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 ecosystem services such as cultural services. The Number of papers or patents is an example of such an indicator.
	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.
	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).
Economic indicators	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 contribution to CC is 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 consumeŕs need for an ecosystem service. These are estimated following the SNA.
	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 peoplés 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. [36].
	Quantity and quality of NBS area from a people's perspective	Indicators measuring the quantity and quality of the NBS. This can include access, facilities, location, connectivity.
Social indicators	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.
	Economic aspects	Indicators on the relationship between the NBS&NIH and economic aspects.

indicators - while only 12 % of the used indicators below to the economic dimension, 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.

Looking at the indicators per group (Table 5) 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 (23 and 26, respectively of a total number of 201 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 (24 indicators in total). 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. Socioeconomic indicators considering CC are rarely contemplated (4 indicators). The exception is a short list redefining output and demand approach indicators to just estimate a carbon footprint valuation (no indicators for adaptation or mitigation to CC). Some of those indicators are for instance, a 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; and 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).

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. 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. [39]. Biodiversity indicators measure the status of species or the direct functions of species. For example, abundance of cephalopods is an indicator that describes the status of a species 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. Finally, pressure indicators measure pressures exerted on the marine environment such as presence and distribution of alien species. NBS1 and NBS2 targeting conservation and restoration of habitats (NBS1) and habitats, species, and trophic interactions (NBS2) shared some indicators useful to evaluate both NBS. Since NIH improves assemblages and trophic interactions, NIH indicators can be also used for the two NBS, however, the number of shared indicators between the three NBS&NIH is lower. Fig. 4 shows the number of overlapping indicators in a Venn diagram.

In total, 26 indicators measured provisioning services attributed to food provision except one for material provision from algae (Table 6). Thirty-eight indicators are suitable for measuring regulating services. Of these, nine measure climate regulation like carbon sequestration rate and seagrass biomass. A further five measure bioremediation of waste and include indicators such as primary production, or state of benthic

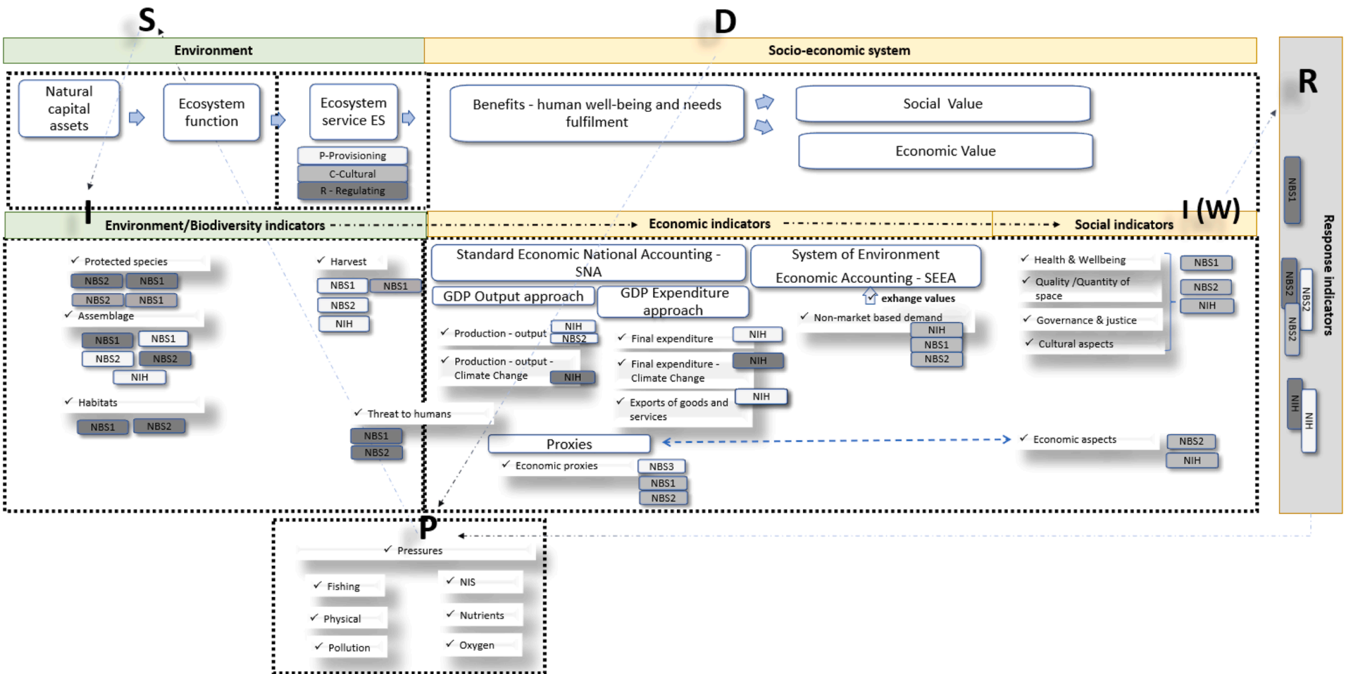

Fig. 3. ES indicators (*P* = provisioning, C = cultural, *R* = regulating) through the ES cascade and DPSI(W)R frameworks linked to SNA/SEEA economic accounting frameworks and IPBES classification. DAPSI(W)R stand for respectively: Driver, Activities, Pressure, State, Impact(Welfare), Response.

communities. Eleven indicators are helpful for measuring disturbance prevention and include indicators, for example bottom vegetation biostabilisation capacity and wind fetch reduction by saltmarshes. Cultural ES are assessed using 13 indicators focused on three types of species. These species types are engineering species (e.g. 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 their 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. 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. 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).

Socioeconomic and response indicators

Economic indicators. In total 24 economic indicators were identified and classified into two groups based on the GDP (Table 5): output indicators, and expenditure or demand indicators. Also, 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, most of the framework indicators are based on SNA to measure production-based indicators (25 % of the total economic indicators), especially for provisioning and cultural ES, revenues, added-value, gross premium written and profits. The framework also considers the CC driver when assessing regulating ES but only through a small number of indicators (17 % of the total economic indicators), most often when providing impact assessments of production as for instance, the ecological footprint indicator, and/or the fishing sector green growth – Environmental and resource productivity – indicator which modifies previous business indicators to consider the C02 emissions associated with the fish production. Economic proxies, which provide measures in physical rather than in monetary terms (Fernández et al. [36], Foley et al. [40]), represents a 25 % of the total number of indicators, measuring among others, potential modification of the density of fishing vessels and employment, but also the associated labour productivity (value produced by engaged fishers), the use of the space. Finally, for migratory fishes the nutrient transportation regulating ES is scarcely being assessed (Morton et al. [41]). This indicator, together with the green growth ones relate to the NIH impact on regulating ES.

The expenditure or demand approach of GDP represent 12 % of the total number of indicators added to the framework, 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. [23]), 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, this is useful in the assessment of 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)

Table 5
Summary of indicators per dimension and group.

Dimension	Group	NBS1	NBS2	NIH	Total	Distinct
	Total	42	49	29	120	69
Biodiversity and Environmental indicators	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
	Total	**8**	**9**	**14**	**31**	**24**
Economic indicators	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
	Total	**27**	**42**	**35**	**104**	**56**
Social indicators	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**

but only for certain cultural ES. In particular, the cultural value of fishing activity is introduced in the framework (Werner et al. [42]), which is mainly covered by scientific publications but not still covered by regulating or other bodies such as the UN.

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. [43]. 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 CO2 emissions. For these two NBS the employment of non-market-based indicators is growing strongly using the willingness to pay to preserve the coastal areas and specifically the cultural ES associated with MPAs [44].

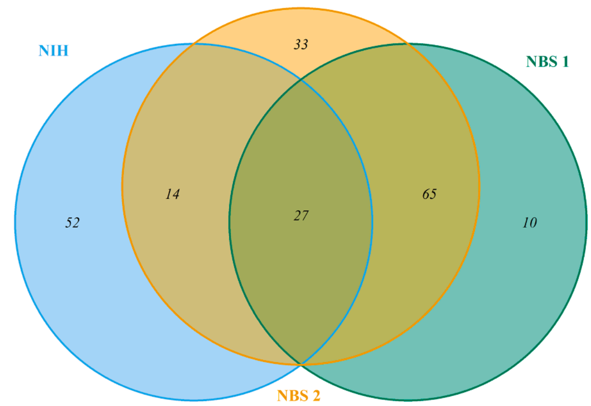

Fig. 4. Number of indicators per NBS&NIH and number of overlapping indicators in a Venn diagram. Total number of distinct indicators: 201.

Response and social indicators. Measuring management responses to ensure sustainable marine-use approaches is also linked to specific indicators in the framework, 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 mainly 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. 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.

Social indicators (Table 5) are divided into five categories adapted from the work of Carmen et al. [37]: 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 Fig. 4A) 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. 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.

Analysis of effectiveness of selected indicators and gap analysis

After removal of the pressure indicators, which are not ES indicators, 155 remained for the analysis. Each of the selected indicators can be

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	NBS1 Capacity	Flow	NBS2 Capacity	Flow	NIH Capacity	Flow	Total
Provisioning	Food provision	1	4	4	5	18	23	55
	Material and energy provision	0	0	0	0	1	0	1
	Section level indicators for provisioning services							**56**
Regulating	Climate regulation	7	5	5	5	0	5	27
	Bioremediation of waste	2	3	2	3	0	0	10
	Disturbance prevention	5	3	6	4	0	0	18
	Protection of habitats and species	10	1	13	1	2	0	27
	Pest control	0	1	0	1	0	0	2
	Section level indicators for regulating services							**84**
Cultural	Cultural heritage	2	5	3	9	3	19	41
	Aesthetic experience	4	0	3	0	2	0	9
	Educational	0	7	0	7	0	4	18
	Leisure and recreation	11	7	15	12	1	5	51
	Existence value	0	1	0	1	0	0	2
	Section level indicators for cultural services							***121***

useful to measure changes in more than one ES section and/or class, and in relation with more than one NBS&NIH (Fig. 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 sections, 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.

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 twelve ES (see column "Description" in Table 6) which represent a good coverage considering these are only related to the three studied NBS&NIH. 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, which 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

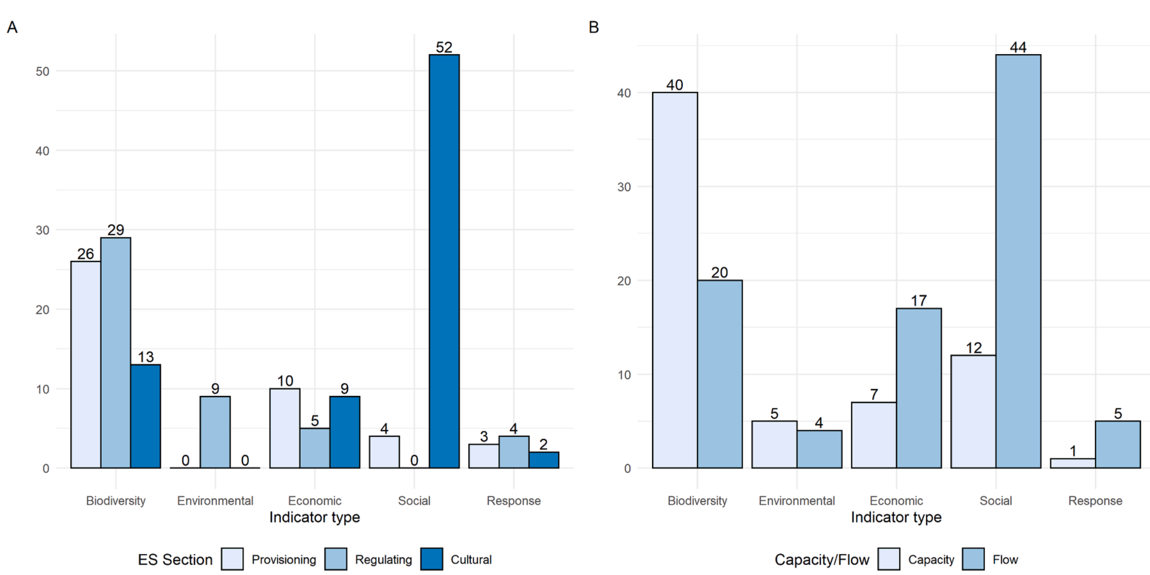

Fig. 5. (A) Number of indicators by type of indicator (biodiversity, environmental, economic, social or response) and ES; (B) Number of indicators by type of indicator (biodiversity, environmental, economic, social or response) and by ecosystem service aspect that they capture (capacity, flow).

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).

Generally, impacts through ES are not assessed following a transdisciplinary perspective, meaning that the used indicators to assess a single ES do not cover the whole ES cascade following the same criteria. For instance, the socioeconomic system is oriented to produce flow indicators in contrast to what happens in the biodiversity and environment system, Fig. 3 (i.e., from capacity to flow). Thus, the 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 (Fig. 4).

The analysis revealed several gaps and goals that need to be achieved to ensure that holistic multidisciplinary ES assessments can be carried out (Table 7). Fourteen gaps were identified, and matching goals described. These ranged from general gaps, to gaps in the criteria, to those around the ES classification and the indicators themselves.

Application of indicators across storylines

Scientists working on 27 storylines (Fig. 2. Storylines engaged in focus groups, workshops, and surveys across the work progress. Note the identified number is not correlative from 1 to 27, because it was originally assigned by FutureMARES project which covers 40 storylines in total) were asked which indicators of the list they are using or are aware of being used in their respective storyline to test the current usage of selected indicators. The study revealed that 70 % of the identified indicators (framework) are applied. However, there are important differences between the dimensions. Storylines used the 85 % of indicators belong to the biodiversity and environment (79 from a total of 92 indicators). A 91 % if indicators considering the CC are included. To a lesser extent, the storylines covered the 71 % of the economic indicators (17 indicators from a total of 24). This contrasts with the social dimension, where only 31 % (18 of 56) of indicators were used, indicating that the framework may either be less effective in this dimension or that more uptake of a variety of indicators should be encouraged. Making emphasis into the non-used indicators across dimensions, empirical 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 impacts in terms of the production value (GDP). Harvest, pressure and/or habitats are clearly the groups of indicators majority used when evaluating the ES on marine and coastal ecosystems both in terms of the number of used indicators but also the frequency. Fig. 6 shows the relative importance of each group based on the number of indicators per typology selected across the 27 storylines. Moreover, it is also very relevant the frequency, here defined as the number of storylines selecting those indicators, which is showed at Fig. 7.

Discussion

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 [17,19] and the effectiveness of conservation and restoration actions. This research highlights that even using huge known frameworks to link natural capital conditions and socioeconomic dimensions, scientific literature, and even more relevant, also some international initiatives such as, IPBES, MSFD trying to reach measurably indicators to state changes [18–20] but also, the storylines applications fail to illustrate a complete assessment of those changes, with key potential implications within the different management contexts. Thus, the potential of those NBS&NIH to provide benefits has not been totally completely assessed and there are concerns over their reliability and cost-effectiveness ([45]; Seddon et al.[46]).

This is the first study that rigorously linked appropriate indicators to measure twelve important marine ES affected by CC. All indicators selected are also considered important in measuring effects of NBS&NIH 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 however, to monitor ES, it is necessary to measure several aspects of the socio-ecological system, for example, bioremediation of waste is carried out by several species and processes ([47]; Broszeit et al. [18,48]). This is also true for other ES such as food provision, and ES provided through many different species, and for which indicators include species abundance and biomass harvested but also their standing stock biomass, among other measurements. The storylines encompass a variety of different habitats and species groups which can and must be measured in a variety of different ways which means that again, this leads to higher number in the biodiversity dimension. Also, ES research is firmly grounded in ecological and biodiversity science with economics and social sciences studies having joined ES research efforts later.

This study also highlighted that pressure indicators do not tell us about ES, but they provide insight on how the ecosystems may be negatively impacted, leading to a reduction in ES and therefore these indicators are valuable in monitoring pressure to indicate how the pressures may lead to changes in ES, depending on the habitat(s) and species affected. Therefore, the common current approach is to carry out an ES assessment, for example by linking ES to the habitats where they derive from (e. g. Potts et al. [49]; Hattam et al. [48,50]) and then carry out an assessment of pressures and their impacts on those habitats in a separate step. Then, the results can be linked together (e. g. Depellegrin et al. [51]). For this approach, the list of indicators created in the current study are useful. This approach is especially relevant in a context of application of the Marine/Maritime Spatial Planning directive (MSPD, 2014/89/EU), which tries to make compatible across borders and sectors of the different human activities at sea. As previous literature states, Galparsoro et al. [52]; Pendlenton et al. [53] the ES concept has emerged as a potential framework supporting MSP. The concept of marine ES is central to the MSPD, aiming to manage maritime activities to avoid conflicts among them allowing for the sustainable exploitation of marine resources but also, marine ES. However, there is not an operational framework well defined to do it and, as those authors state there is still a need to develop and agree upon the appropriate progress in ES development to support MSP. The employment of pressure indicators together with those about ES when developing a fully integrated cost-benefit analysis linked to introducing economic activities at seas – both traditional but also emerging activities or even, new protection areas –, will allow to overcome the existing gap. Highly relevant is the consideration of the three analysed NBS&NIH in this research under the described MSP context.

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

Topic	GAP	Desired goal
General overview	- Even using very well-known frameworks (ES cascade, SNA, SEEA) establishing linkages between nature and socioeconomic dimensions, 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 used 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.
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.
Criteria	- Socioeconomic indicators are rarely used 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
Biodiversity and environmental	- A need to use more earth observation data and essential biodiversity variable and essential ecosystem service variable approaches.	- Ensure that earth observation data is 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) with policy makers. To enhance their transference to final stakeholders. - To introducing exchange values from non-market assessment as part of an operational framework of indicators.
Response	- Covered to a lesser extent	
ES classification	- among provisioning services, food provision was the most assessed one, and in general, solely wild fish for nutrition was considered. 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.

In general, the integration of marine and coastal ES assessment in policy and decision-making still being challenging, although it is becoming required and tried to be applied under the context of international regulations and policies. To this respect, and following a more broadly perspective, this research highly contributes to overcome the ES assessment gap when applying the Marine Strategy Framework Directive (MSFD), an overarching framework which defines environmental objectives to be applied across all European marine regions, ensuring the sustainable use of EU waters and marine resources [54,55]. Article 1 (3) MSFD requires marine strategies to apply an ecosystem-based approach to the management of human activities to maintain ecosystems in a healthy, clean, productive, and resilient condition, so that they can provide humans with the services and goods upon which we depend. The assessments of the environmental state, Article 8(1)(a) and pressures, Article 8(1)(b) MSFD should also be extended to cover socioeconomic drivers and quantification of ES (Article 8(1)(c) MSFD). Article 8 assessment is a powerful instrument to follow up changes in the quality of the marine environment (in relation to activities, pressures, impacts and the state of ecosystem component), however, it is still missing an operational framework to include an initial ES assessment (including a selection of indicators, and methods, among others).

Related to the indicator selection, the major efforts have been orientated to identify direct market-based impacts on production (provisioning ES), usually well identified and relatively easy to measure for economic assessments following SNA. 25 % of the total economic indicators highly used in previous literature (Fernández et al. [36]; Marre et al. [56]; Johns et al. [57]; Hein et al. 2017) and well-covered by international frameworks (AER, CFP, OECD, SNA). 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. [58]; Carrasco De la Cruz [34]) 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 but we are still far away from a generalized application of the SEEA. As Pendlenton et al. [53] remarked much of the economic value of the coast and ocean lies outside of the market, however these non-market values can be used to design management measures, policies for open space, beach-going, shoreline protection, and, for habitat for wildlife. The National Oceanic and Atmospheric Administration (NOAA) serves as an example of an agency that has used non-market values to quantify physical damages to coastal ecosystems.

Going more specifically to the fishing sector and the NIH, the

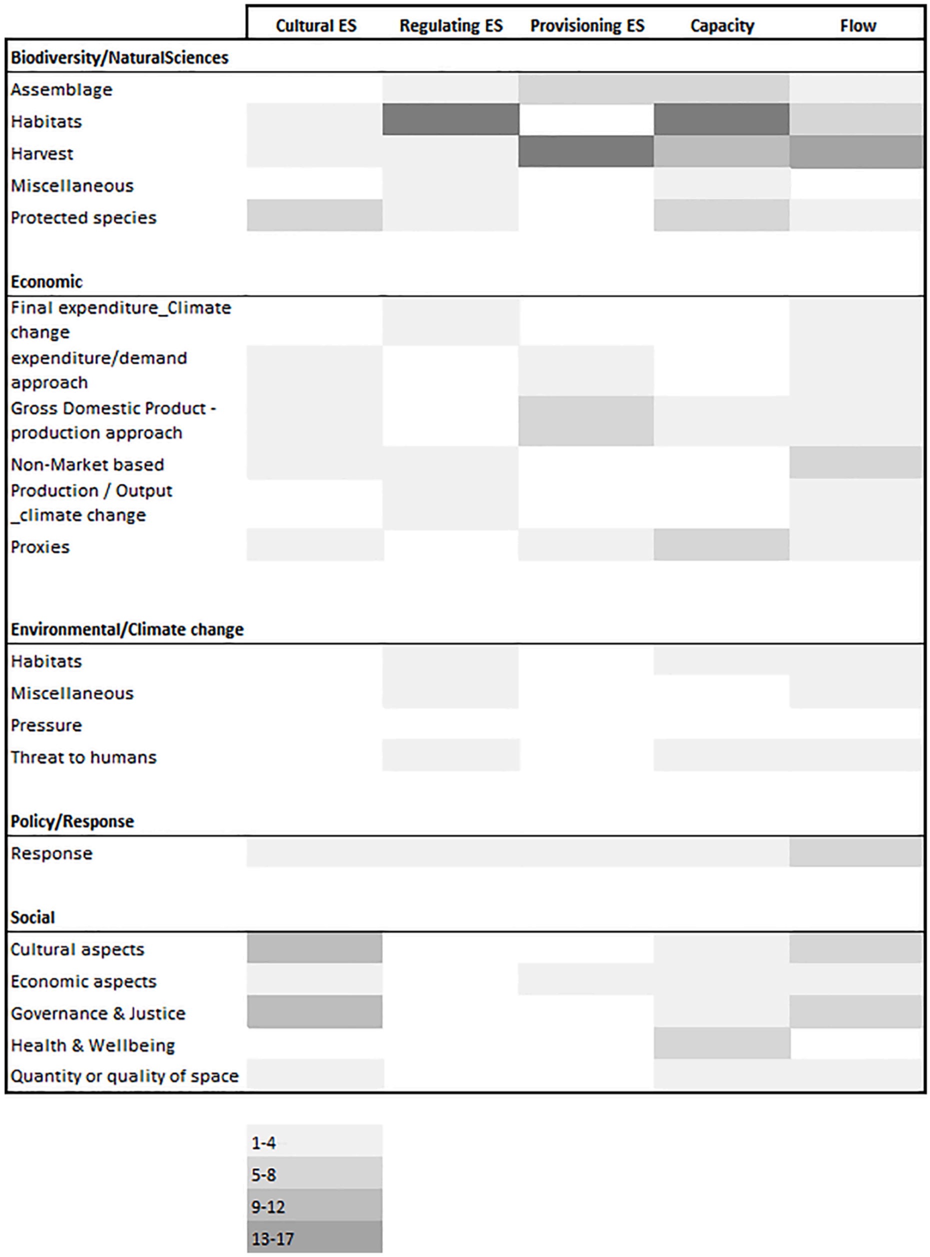

Fig. 6. Empirical approach: indicators selected across 27 storylines.

European Commission (EC) through the Common Fishery Policy also promotes the adoption of an Ecosystem-based fisheries management, EBFM, (EU, 2022) as the holistic way of managing fisheries and marine resources by taking into account the entire ecosystem of the species being managed. The goal of EBFM is to maintain ecosystems in a healthy, productive, and resilient condition ensuring the current and future fish provision. However, its implementation requires to balance the social and economic dimensions with the environmental and biodiversity ones, which cannot be ensure if failing in the assessment of any of those dimensions (as it has been stated at certain degree). EBFM also remarks the key importance of considering the ES humans will receive. Gaps observed in the estimation of the cultural ES value (non-material ES for which there is not a market value) might conduct to have an underestimation of the real NIH impact assessment (mainly considering the impacts on food production ES). Storylines rarely considers bioeconomic models including the WTP (cultural ES) which might represent even a 400 % of the most traditional fish provisioning value of fisheries as it is showed by the storyline about artisanal commercial fisheries in the Bay of Biscay (NIH SL 24). Including more than the traditional provisioning value allows final stakeholders to put in value the real fisheries value, which it is very relevant for their future conservation and, as an input in trade-off analysis under the context of the MSP in the Bay of Biscay. However, 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 [59]) 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 [60,61].

Thus, a major concern is still to reach a complete integration of biophysical, economic, and sociocultural assessment for a broader and comprehensive understanding of the benefits gained from marine ecosystems and the ecological, social, and economic costs due to the potential loss of these benefits. This integration is not an easy task. 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 while flow is mostly measured

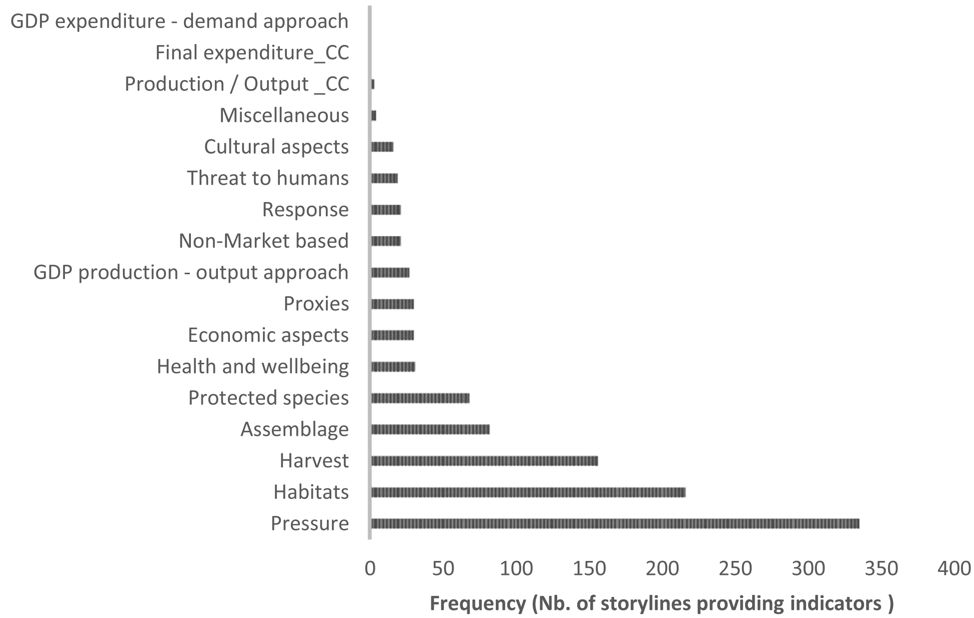

Fig. 7. Empirical approach: frequency of use of each group of indicators by storylines to assess changes to ES attached through NBS&NIH.

by economic and social indicators. The temporal scale also represents a major gap between the socioeconomic and environmental 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). Moreover, considering mainly economic /social flow indicators can have significant implications in management terms, requiring a so-called adaptative management including regular assessment and adjustment of management strategies to ensure they align with periodically assessed economic but also social flow changes.

There are few indicators that link to economics and biodiversity, and poor number of response indicators (which usually are reported at the national level which makes necessary an estimation for its use in the context of a very specific NBS, Buisman et al. [62]; Zableckis et al. [63]). However, there is an abundance of social indicators (104 added in the framework) although the link between NBS and these social aspects is sometimes difficult to establish [64], albeit several examples of potential indicators exist in the literature (e.g., Fongar et al. [65]). In the developed framework, 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, the use of the space, Valenti el. al. [66], 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. The observed gaps in previous literature (Nahuelhual et al. [67]) were precisely due to departures in different individual variables, the lack of consistency of the indicators used, and even the absence of a definition of ES explained this previous literature gap.

A very high effort is emerging when considering regulating ES in social and economic terms, but usually 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 UNEP, OECD and EUROSTAT but not broadly adopted by scientists, although some fisheries carbon footprint examples can be found in previous literature [52,68–70]. 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 into the interaction between CC and ES. Thus, an important gap exists in the socio-economic dimensions to measure regulating services. Socioeconomic indicators are rarely used to assess adaptation or mitigation to CC, and moreover, only 49 % of the found environmental indicators do it. So, win-win impact assessment in terms of CC after NBS&NIH implementation remains understudied having direct management implications. Enhancing inclusion and understanding of those CC additional indictors will help inform policy makers when designing MPA and restauration areas (NBS1 and NBS2) promoting these solutions also as natural climate solutions supported by regulating ES benefits socioeconomic estimation. In addition, this knowledge gap should be soon overcome to fully embed the blue economy into the Green Deal and the recovery strategy, from the EC recently adopted a new approach for a sustainable blue economy in the EU (COM/2021/240 final) which implies, among others, to meet EU's environmental and climate objectives. More specifically related to NBS3, fisheries related indicators to assess adaptation or mitigation to CC need to be necessarily estimated to given answer to the EC communication on the recent Energy Transition of the EU Fisheries and Aquaculture sector (COM 2023).

The framework of indicators for a fully assessment of the ES cannot be exclusively guided by researchers ́s capacities and disciplines but, considering the necessities to support and enhance the analysis of real impacts into public policies. With this objective in mind, Table 7 presented a summary of the discussed gaps which necessarily should be covered in a way. Addressing these gaps is beyond the scope of this study but they may well guide future research initiatives to ensure that the gaps can be closed. Efforts are still needed to advance the research on marine and coastal ES providing policy makers with an operational framework of agreed indicators to implement effective strategies for the sustainable use and management of coastal and marine ecosystems.

Conclusions

To the best of our knowledge this research is the first to develop a complete framework of indicators linking the capacity of marine and coastal habitats to generate ES (ES capacity) with ES use (ES flow), assessing ES from the natural through to the economic and social dimensions. Furthermore, this research combines the most relevant and broadly used frameworks from different disciplines (cascade model, the Standard National Account, and the System of Environment Economic Accounting). This allows, both scientists and managers, to carry out indicator analysis to help understand marine ecosystems and their services under the implementation of NBS&NIH linked to CC and other pressures on ecosystems. Therefore, the framework is designed to be useful to managers and empirically tested with 27 storylines across European waters. Furthermore, this framework covers supply and demand-based groups for economic indicators adding to the traditional Standard National Account system the link of the environment to the socio-economic dimensions including the ES identification and their economic assessment.

The framework focuses on a selection of indicators able to measure the effect of more than one NBS&NIH, also including pressure indicators (334 indicators in total). Biodiversity & environmental as well as Pressure indicators are the most numerous in the list, about three times those belong to the economic dimension, which are mainly related to the output/production approach group. This unbalanced selection of indicators between dimensions and groups is especially relevant when moving into the CC linked indicators. More exacerbated when linking socioeconomic indicators to CC, which are rarely considered, except for a short list of redefining indicators to aggregate a carbon footprint valuation. Consequently, this prevent policymakers to be better informed by science, and most of the considered NBS&NIH interventions for addressing the impacts of CC cannot be fully evaluated. Therefore, trade-offs analysis between CC impacts and other broader biodiversity, social or economic impacts will be very limited unless those identified gaps will be fulfilling. According to the conducted research there are few studies providing an integrated and fully assessment of the NBS&NIH impacts in marine and coastal ES. The pattern is similar here for economic indicators been less applied in the 27 European storylines, and worsened for social indicators (half than economic, and a third of biodiversity and environmental indicators). The storylines did cover neither the demand-side economic indicators nor the contribution to CC indicators, non-market based or even, low social indicators, providing an impact assessment with high frequency oriented towards the estimation of biased impacts (in terms of pressures, harvest and habitats impacts).

In summary, this work provides the strengthened evidence-based framework of indicators needed to build resilience protecting the marine and coastal ES under climate change. A framework which reinforces not only the multidisciplinary nature of the evaluation of NBS&NIH impact on ES but also, the equilibrium between the key groups trying to overcome the current bias towards an assessment mainly based on harvest, habitats, and pressures knowledge.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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ANNEX I

Table A1.

Table A1
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

(*continued on next page*)

Table A1 (*continued*)

Global framework	Weblink / Source
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 A2
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: [71], 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.
Criteria	Scientific basis	C1	YES/NO	Has the indicator been published? Either as ecological/biodiversity or ecosystem service indicator?
	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?

(*continued on next page*)

Table A2 (*continued*)

Block	Field definitions	Acronym	Fill into the field	Notes
	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 A3
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

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nbsj.2023.100085.

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