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Ecosystem Based Management Tools

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DISCLAIMER

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1. Definition

Ecosystem-Based Management (EBM) can be defined as: "*Ecosystem-based approach (to management), an 'ecosystem-based approach' or 'ecosystem-based management' is an integrated approach to management of human activities that considers the entire ecosystem including humans"* (European Commission Staff Working Document, 2020). The goal with EBM is 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. It is a spatial approach that builds around a) acknowledging connections, b) cumulative impacts and c) multiple objectives*" (European Commission Staff Working Document, 2020)[1].

Other variants of the EBM term in available literature include the Ecosystem Approach (EA or EcAp) or the Ecosystem-Based Approach.

There are various EBM methods/tools available that link to the EBM phases of planning, implementation, reviewing and evaluation. A summary of the different EBM tools is provided in Section 3 of this paper.

2. EBM and EBM tools

The Ecosystem Approach was first developed by the UN Convention for Biological Diversity (CBD, 2000, 2004) as a set of 12 principles (CBD, 1992). Annex 1 of this document lists the 12 principles. Long *et al*. (2015) started from the 12 CBD principles and undertook a literature review of EBM principles (up to 2010, across marine and terrestrial environments) and selected the 15 more important/commonly cited principles from a list of 26 principles. The Fifteen Key Principles were identified (in descending frequency of appearance in the literature): **Consider Ecosystem Connections**, **Appropriate Spatial and Temporal Scales, Adaptive Management, Use of Scientific Knowledge**, **Integrated Management**, **Stakeholder Involvement**, **Account for Dynamic Nature of Ecosystems**; **Ecological Integrity and Biodiversity**; **Sustainability**, **Recognise Coupled Social-Ecological Systems**; **Decisions reflect Societal Choice**, **Distinct Boundaries**, **Interdisciplinarity**, **Appropriate Monitoring**, and **Acknowledge Uncertainty**.

EBM implementation it is not a 'one size fits all'. Therefore, the operationalisation of EBM approaches can be diversely shaped, including, from local to global scale, and in view of levels of uncertainty, knowledge available, diversity of human pressures and stakeholder engagement. Examples of EBM implementation/application include, for example, within The CBD, regional seas conventions and associated strategies, assessments, action plans e.g., Oslo-Paris Convention, The Barcelona Convention, and Integrated Ecosystem Assessments (Levin, 2009; 2014).

There are several scientific tools/methods that have been developed to date for EBM. EBM tools include software and methods that can be used by decision-makers/marine managers to support the operational implementation of EBM, including conceptual models, spatial mapping tools, species models, and assessment indices.

EBM tools vary in terms of focussing on a specific part of a marine ecosystem, or taking a whole ecosystem view, or may involve EBM applied in a specific context e.g., marine spatial planning or commercial fisheries management.

[1] Definition also highlighted in the GES4SEA project Marine Strategy Framework Directive Terminology Definitions and Lists (Smith *et al*. 2022).

The Good Environmental Status for Seas (GES4SEAS) project that is a 'sister project' to Marine SABRES, undertook a process to identify EBM components that align with the GES4SEAS project needs and subsequently identified and reported a range of EBM methodological approaches/tool groups. A narrative of each method/approach/tool was produced within the various tools. Given the comprehensive nature of the existing review, the tools lists and information have been adapted for the purposes of this Marine SABRES briefing paper.

The EBM tools in this briefing paper have not been grouped into a hierarchy but are set out roughly in order from more qualitative approaches (e.g., conceptual models) to more complex quantitative modelling (e.g., ecosystem models) as well as marine spatial planning tools. It is recognised that several of these EBM tools are linked and they may be used in concert to pursue EBM objectives.

3. EBM tools summary

Conceptual models

Description: Conceptual models are graphical representations or models that are abstract and aim to represent a system and components. Examples of conceptual models include argument mapping, mind-mapping, 'horrendograms' and organograms.

Application: Conceptual models are usually created using drawing packages or using software packages for computer-aided argument mapping, e.g., KUMU analytics and visualisation platform to create relationships maps. Conceptual models have been used in a variety of marine environmental management studies to date. Notably, in the Marine SABRES there are the creation of the governance 'horrendograms' for each Demonstration Area, the DAPSI(W)R(M) framework and use of Kumu software. These are described in Marine SABRES Briefing Papers 1, 2 and 8.

Knowledge Graphs

Description: A knowledge graph is a structured representation of knowledge that encapsulates information on entities, their attributes, and the relationships between them. It consists of 'nodes' (representing entities) and 'edges' (representing the relationships between them). A knowledge graph can be visualized as a network or a graph.

Application: Knowledge graphs can be used for integrating data, analytics and sharing information. For example, Fotopoulou *et al*. (2022) conceptualised and developed a knowledge graph to track information related to the progress towards achievement of targets defined in the United Nations Sustainable Development Goals (SDGs), at both national and regional levels. The high-level map from Fotopoulou *et al*. (2022) is shown in Figure 1.

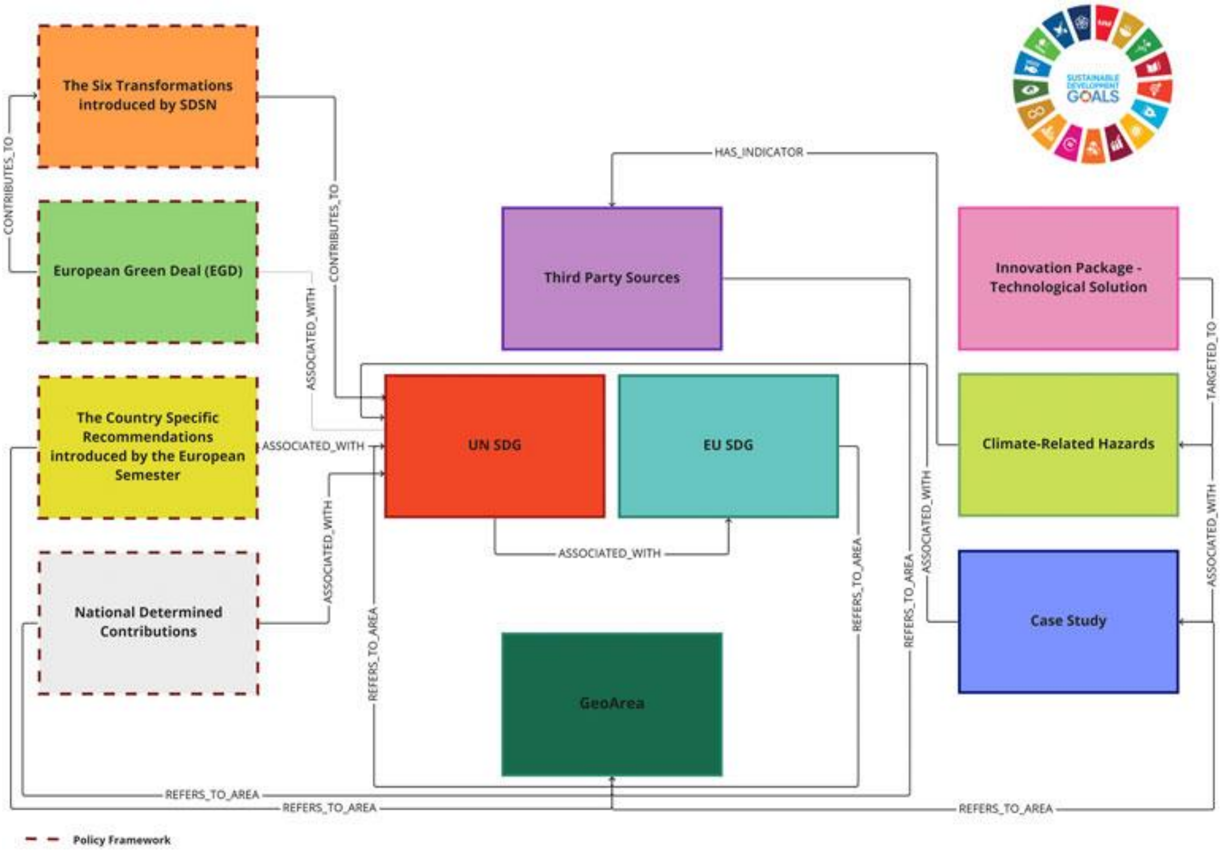

Figure 1: High level view of the SustainGraph, sourced from Fotopoulou et al. (2022).

Bayesian Belief Networks

Description: Bayesian Belief Networks (BBNs) are models that graphically and probabilistically represent correlative and causal relationships among variables and which account for uncertainty (McCann *et al*. 2006). BBN nodes or vertices represent variables which can include observed or unobserved quantities, expert opinion, model outputs, or unknown parameters. There are links or edges joining parent nodes to child nodes[2]. In this way, BBNs can incorporate both empirical, quantitative data and narrative evidence, providing a way to link across the natural and social sciences.

Application: BBNs have been used in a variety of studies on marine and coastal environmental management and fisheries management studies. For example, considering management of coral reefs (e.g., Carriger *et al*. 2019), and extracted figure shown in Figure 2 example; management of fishery interventions (e.g., Underwood *et al*., 2016); support tool for marine spatial planning (e.g., Stelzenmüller *et al*. 2010), and linking natural capital to maritime activities (e.g., Gacutan *et al*. 2019), among others.

[2] Bayesian Belief Networks | IPBES secretariat

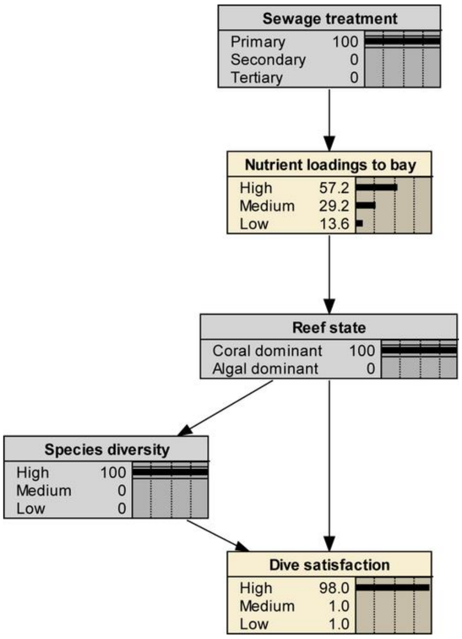

Figure 2: Bayesian network displaying probability distributions for dive satisfaction and nutrient loadings given that primary sewage treatment is implemented, the reef state is observed to be dominated by coral, and species diversity is high. Gray nodes indicate that new evidence has been entered into the node's state(s) (e.g., 100% probability of primary sewage treatment). From: Carriger et al. (2019).

Semi-quantitative mental models (e.g., Fuzzy Cognitive Mapping)

Description: Mental models are another name for a conceptual model and consist of a graphical representation of a system e.g., natural ecosystem, socio-economic system, socio-ecological system. In mental models, the linkages are documented, and the direction and strength of interaction can be specified, which allows for simple scenario investigation. An example of a Fuzzy Cognitive Mapping (FCM) tool is Mental Modeler (Gray *et al*., 2012, 2013a, 2013b).

Application: Semi-quantitative models can help with identifying what elements are relevant/should be included/prioritised in an otherwise extremely complex system. It highlights which elements are related to each other and how they are connected. FCM has been used in a variety of marine environmental management studies to date. For example, Olsen *et al*. (2023) used FCM (with stakeholder input), in an Integrated Ecosystem Assessment. This was to help evaluate the present and future status of the marine ecosystems in the sub-regions of the North Sea, due to modelled changes.

Risk-based approaches exposure-effect-hazard-vulnerability (e.g., bow-ties)

Description: Bow-Tie diagrams are a visual tool describing and analysing the pathways of a risk, from hazards to outcomes and reviewing controls (preventative and mitigation/compensation methods, the so-called Programmes of Measures). The approach shows the causes of a problem (to the left of the knot of a bow-tie), the hazard and element of main concern (the knot of a Bow-Tie) and the consequences of a hazard happening (to the right of the knot). Various controls can be placed on the left of the hazard to prevent the hazard from occurring, or on the right to reduce/mitigate/compensate for the magnitude of any consequences (Cormier *et al*., 2019).

Bow-tie diagrams can incorporate multiple causes and consequences of a given event, to analyse existing and possible controls that are used to prevent the causes of the event, both individually and collectively and to mitigate and recover from consequences of the event (Cormier *et al*., 2019).

Bow-ties are an industry-standard ISO-31000 compliant method and an accepted conceptual model for analysing legislation and policies for managing the environmental risks of human activities (Cormier *et al.*, 2019).

Application: Bow-tie analysis has been used in many industrial applications and recently used in relation to fisheries and aquaculture (Elliott *et al.*, 2020b) and offshore windfarms (Burdon *et al.*, 2018). Figure 3 shows an example of a generic bow-tie diagram for marine spatial planning, from the BALTSPACE project[3]. In BALTSPACE, the bow-tie analysis has been used to analyse and evaluate the spatial and temporal management options to either prevent environmental effects, health and safety incidents or user conflicts as well as mitigate the environmental impacts, socio-economic consequences, or legislative repercussion.

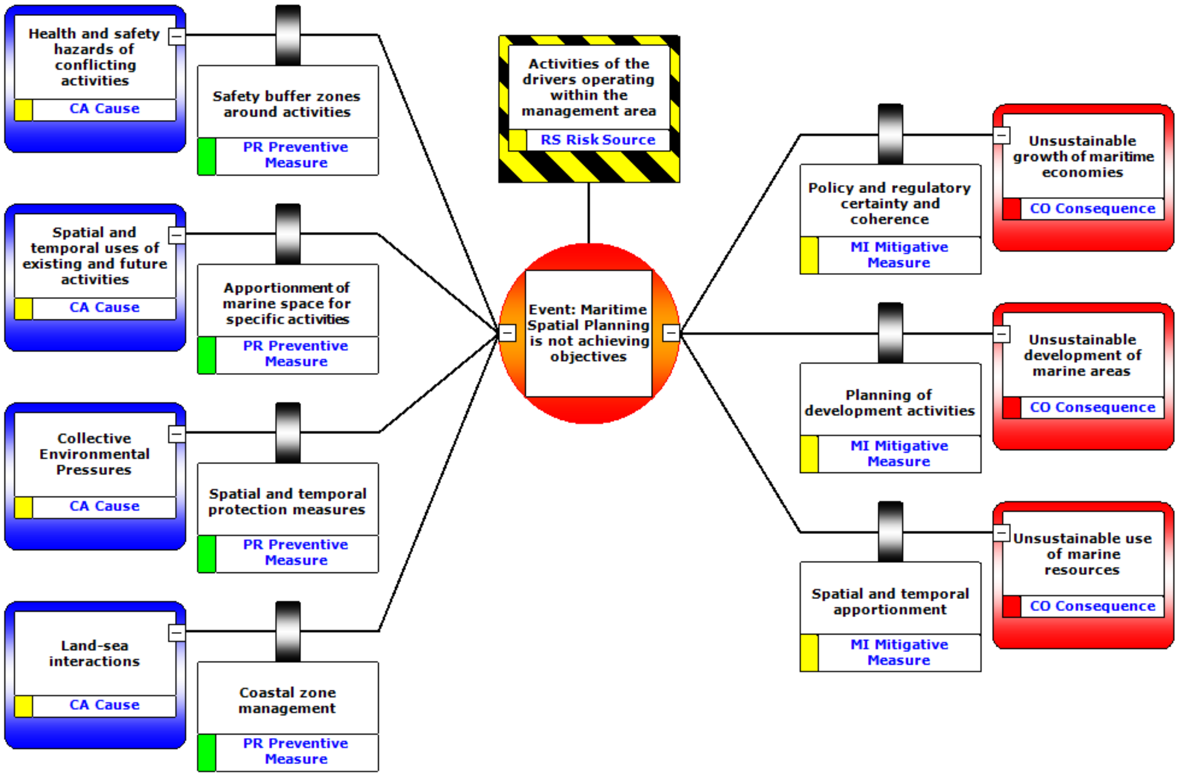

Figure 3: Generic Bow-tie for maritime spatial planning. From: [BALTSPACE - Bow-tie approach](#).

Impact risk ranking through linkage-chain-frameworks

Description: Impact risk ranking through linkage-chain-frameworks can be used as assessment methodology for tracing sector–pressure–ecosystem component pressure pathways. The methods have been developed in the Options for Delivering Ecosystem-Based Marine Management (ODEMM) project and AQUACROSS projects. In general, the approach consists of identifying where linkages exist (mapping in a 'linkage matrix') and then scoring each linkage that does occur for several attributes (e.g., spatial overlap, temporal overlap, degree of impact, resilience or resistance, although there are variations on these).

Application: The methodology has been adapted and evolved, including for use in Ecosystem Overviews produced by the International Council for the Exploration of the Sea (ICES). An example of The Azores Ecosystem Overview is shown in Figure 4.

[3] https://www.baltspace.eu/

Impact risk ranking through linkage-chain-frameworks has been adapted and used, for example, in the Integrated Ecosystem Assessment in the Mission Atlantic project, linking to management objectives such as the EU Marine Strategy Framework Directive descriptors and criteria, and to better account for cumulative impacts (see ICES WGCEAM, ICES 2019a). There are several existing integrated ecosystem assessments, e.g., for four European regional seas (see Knights *et al*., 2015) and for the Irish Sea (see Pedreschi *et al*., 2019).

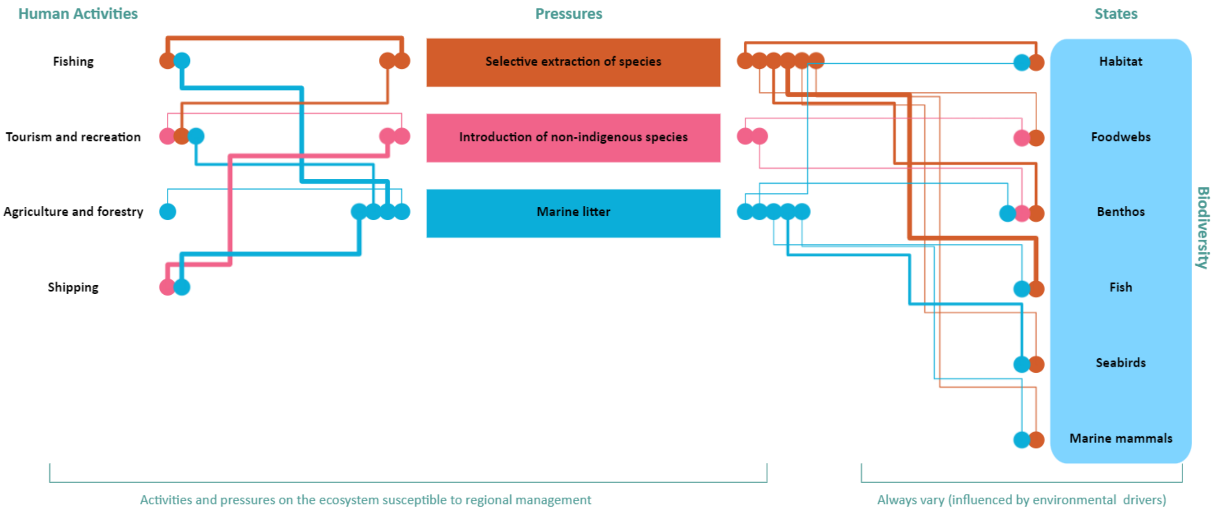

Figure 4: Azores Ecosystem Overview.
From: https://www.ices.dk/advice/ESD/Pages/Azores_ecosystem_overview.aspx?diagramid=48.

Cumulative impact spatial mapping

Description: A method for Cumulative Impact Assessment (CIA) that is based on a geospatial index describing the relative impact of multiple human pressures on the marine environment.
The main features of the global human impact assessment (Halpern *et al*., 2008) are (i) a grid of selected resolution for all the spatial data, (ii) spatial layers of pressures which are quantified and then normalized between 0-1 inside a grid cell, (iii) spatial layers of ecosystem components (e.g., species, species groups, habitats) which are similarly quantified and then normalized between 0-1 inside a grid cell, and (iv) weight scores representing the sensitivity of the ecosystem components to each of the pressures. Depending on the application, the three scores are summed, or a mean of impacted ecosystem components is taken (e.g., Stock and Micheli, 2016). There are also various ways in determining the weight scores (Halpern *et al*., 2007; Korpinen and Andersen, 2016).

Application: Following the first global assessment (Halpern *et al*., 2008), several regional and pan-European development processes were established and published. These include the HELCOM holistic assessment in 2010 (CEA; HELCOM, 2010; Korpinen *et al*., 2012), the Mediterranean and the Black Sea (Micheli *et al*., 2013) and the North Sea (Andersen and Stock, 2013).

Single species models (life cycle, stock assessment)

Description: Single-species models are mathematical representations used to study and understand the dynamics of a particular species within an ecosystem. The models focus on the population size, growth and interactions of a single species, while often considering the species' interactions with its environment and other factors that influence its population dynamics. These models can incorporate limited ecosystem or multispecies information. Examples of types of single-species models are dynamic energy budget models, metapopulation models, dynamic population models and individual-based models (Papadopoulou *et al*. 2023).

Application: Single-species models encompass a large variety of models that differ in the level of complexity and the amount of data required.

Habitat suitability models (species predictive distribution)

Description: Habitat suitability models (HSM) are used to predict the spatial distribution of species based on their observed relationship with environmental conditions. These are also referred to as species distribution models (SDM) or predictive habitat distribution models (Guisan and Zimmermann, 2000).

Application: Examples of applying HSM include use in mapping Essential Fish Habitats for fish and shellfish species, or to identify geographical regions suitable for different cetacean species, seagrass, seabirds, and elasmobranchs. HSM models may also be applied to identify potential important marine areas where to prioritise conservation, restoration or to support spatial planning and project level assessment.

Food web models (e.g., multispecies models, Ecopath with Ecosim)

Description: As described in Papadopoulou *et al*. (2023), Marine Ecosystem Models (MEMs) are of different types and include a variety of assumptions, such as size based, food-web based and individual based processes. Ecosystem models frequently describe the interactions between at least two ecosystem components (e.g., populations, species, functional groups), whereby the interactions are real ecological processes (e.g., predator–prey interactions, mediation, size relationships) and are driven by ecological dynamics, including movement, and perturbations (both natural and anthropogenic). Some of the most frequently used MEMs are food web models, which are often visualized as networks, where nodes denote interacting ecological components, and the causal relationships between them are shown by edges (Geary *et al*., 2020).

Application: Food web models have been applied in a variety of studies, with the use of EwE models to analyse (among others) the ecosystem functioning and the impacts of fisheries; trophic functioning in marine systems; the effects of pollution, aquaculture and Marine Protected Areas on a wide variety of ecosystems (including polar regions and terrestrial systems). Also, to investigate the impacts of climate change or cumulative impacts (Colléter *et al*., 2015; Stock *et al*., 2023). Other applications for food web models include evaluating the trade-offs among alternative fishing strategies (e.g., discard policy); evaluating relative impacts of fisheries and climate effects, evaluation of closed area management, and studying the feasibility for ecosystem-based management.

Biogeochemical models

Description: Biogeochemical models capture two-way interactions between the biology and geochemistry of ecosystems. They are used to simulate how abiotic and biotic variables interact through time and across space and provide a means to explore management scenarios in relation to climate change and change in the flow of nutrients from land into the ocean. Typically, biogeochemical models are used to study nutrient cycling (nitrogen, phosphorus, oxygen, silicon, and iron) and impacts on planktonic communities due to events such as eutrophication and oxygen depletion) (from Papadopoulou *et al*. 2023).

Application: Examples of biogeochemical models include The European Regional Seas Ecosystem Model (ERSEM), which is a plankton functional type model; ECOSMO (ECOSystem MOdel) is a coupled physical-biogeochemical model (Schrum *et al*., 2006a, 2006b), and with the hydrodynamics based on the HAMSOM (HAMburg Shelf Ocean Model, Schrum and Backhaus, 1999). There is also the BALTSEM, the 'Baltic Sea Long-Term Large-Scale Eutrophication Model' (Savchuk *et al*., 2012).

Ecosystem models (e.g., End2End)

Description: As described in Papadopoulou *et al*. (2023), End-to-end (E2E) models are one type of ecosystem models. They are a mathematical representation of an entire ecosystem and a single modelling framework that integrates physico-chemical oceanographic descriptors, and organisms, and links to the marine socio-economic aspects. E2E models are used to describe and understand the current ecosystem and forecast/hindcast scenarios, and often also to make decisions on management actions. They are able to incorporate multiple spatial scales and account for temporally dynamics.

Application: Examples of E2E models are Atlantis and STRATH E2E. Atlantis is an E2E ecosystem model that considers all parts of marine ecosystems, including the biophysical, economic and social systems (Fulton, 2010; Fulton *et al*., 2011). An example of the Baltic Atlantis model–biological structure is shown in Figure 5, from Bossier *et al*. (2018).

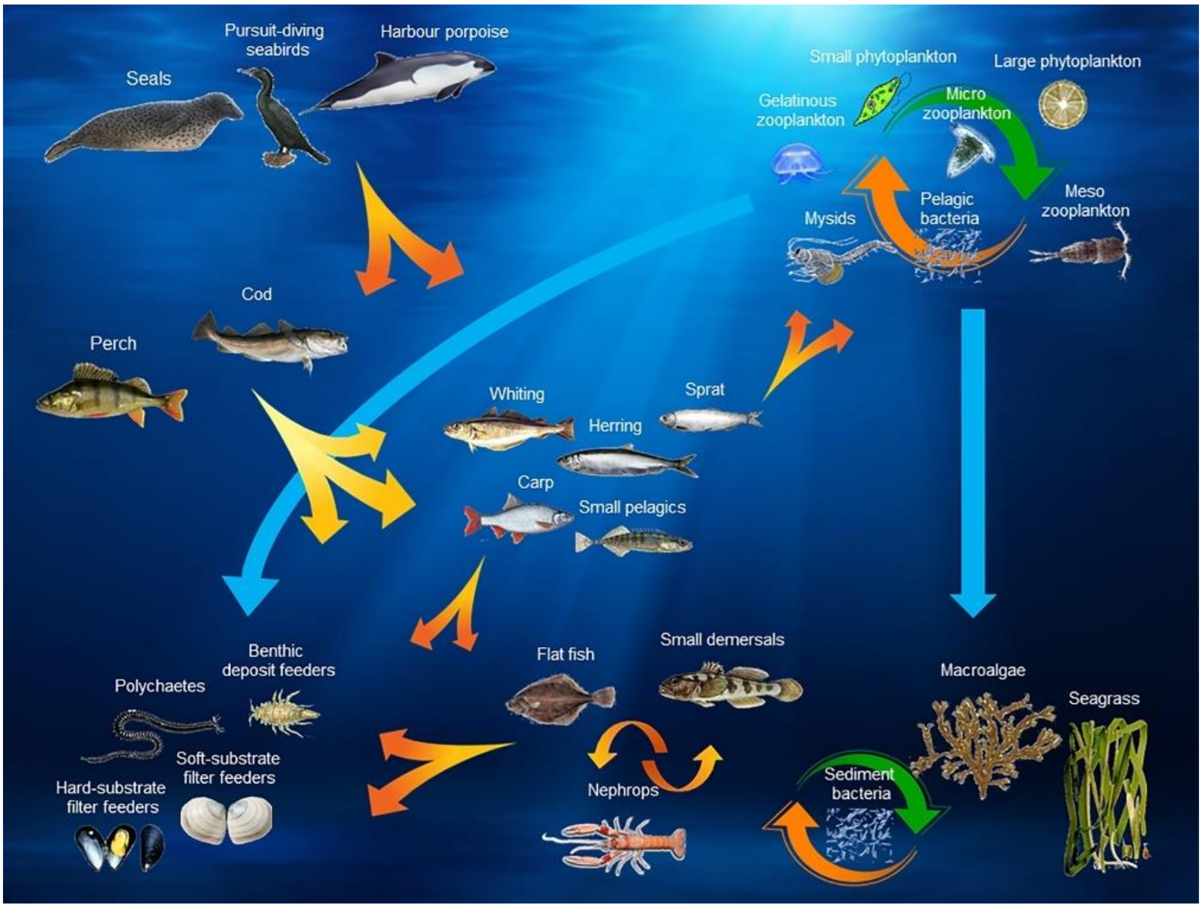

Figure 5: Main interactions focussed upon in the Baltic Atlantis model–biological structure. From: Bossier et al. (2018).

STRATH E2E is geared towards marine ecosystem-based management. STRATH E2E model couples an ecological model with either a fishing fleet model or a fishers' behaviour model and thus creating feedback between ecological state and properties of the fishing fleet. The model is designed for application in the North Sea, West of Scotland, Celtic Sea and English Channel (from Papadopoulou *et al*., 2023).

Natural capital accounting; ecosystem services valuation

Description: Natural capital can be defined as "*another term for the stock of renewable and non-renewable resources (e.g., plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people*"[4]. The natural capital approach to policy and decision-making considers the value of the natural environment for people and the economy. The Natural Capital Approach provides a tool to support the protection and management of the natural environment and to facilitate the engagement of stakeholders into decision making within the marine environment.

Natural capital accounting is an "*umbrella term covering efforts to use of an accounting framework to provide a systematic way to measure and report on stocks and flows of natural capital"*[5]. Natural capital accounting *"covers accounting for individual environmental assets or resources, both biotic and abiotic (such as water, minerals, energy, timber, fish), as well as accounting for ecosystem assets (e.g. forests; wetlands), biodiversity and ecosystem services*"[5].

The United Nations System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) is the "*accepted international standard for environmental-economic accounting, providing a framework for organizing and presenting statistics on the environment and its relationship with the economy*"[5].

Natural capital accounts are developed to assess and monitor the contribution of natural resources to economic activity. Physical accounts tables provide basic information on the state of the environment (the stock and the flows of the natural capital, analogous to ecological structure and functioning) in a specific geographical area. When a condition table is also populated, this information can indicate at what level of the ecosystem an impact of economic activities is occurring. Natural capital accounting provides information that is used in decision support tools to support planning decisions, particularly in bio-economic and socio-economic models (from Papadopoulou *et al*. 2023).

Application: Natural Capital accounts for different geographic areas has been prepared to date (e.g., Northeast Atlantic, for the UK, and for sea basins of the Baltic and Mediterranean Sea *etc*).

Bio-economic models, socio-economic models (cost-benefit analysis), societal goods and benefits valuation

Description: Bio-economic models are integrated economic-ecological models. Cost-benefit analysis (CBA) is a systematic process of calculating the benefits and costs, expressed in monetary units, of policy options and projects. Environmental CBA is the application of CBA to projects or policies that "*have the deliberate aim of environmental improvement or actions that somehow affect the natural environment as an indirect consequence*" (Atkinson and Mourato, 2008). Societal goods and benefits valuation covers consideration of ecological value, economic value, and socio-cultural value. The concept of 'total social value' (covering all these values), can be used to incorporate value preferences of society associated with natural capital into decision making (from Papadopoulou *et al*. 2023).

Application: Bio-economic modelling is applied to resource management and sustainable resource use, such as in fisheries management e.g., anchovy fishery studied in Maravelias *et al*. (2010). A suite of economic valuation methods, including market and non-market approaches, are available which can be applied to value the flow and changes in the flow of ecosystem services. The approach to the monetary valuation of costs and benefits includes assessment based on opportunity costs (defined by the value which reflects the best alternative use a good or service could be put to), and valuation may

[4] Capitals Approach – Capitals Coalition
[5] Natural Capital and Ecosystem Services FAQ | System of Environmental Economic Accounting

include data based on market prices and non-market monetary valuation where market prices are not available. Data on all relevant costs and benefits requires data on a range of variables including those associated with natural capital, health and risks to life (Papadopoulou *et al*., 2023).

Spatial planning tools

Description: Marine spatial planning tools are used to help planners and policymakers make informed decisions about the use of marine space, and coastal and marine resources (examples see UNESCO-IOC/European Commission, 2021). Marine spatial planning models, as an example of tools, are designed to provide insights into the potential impacts of different planning scenarios, and to help identify the most effective strategies for achieving specific planning goals (Stelzenmuller *et al*. 2013). There are several different types of spatial planning models, each of which is suited to different types of planning challenges. Geographic Information Systems (GIS) are computer-based tools used to store, analyse, and visualize spatial or geographic data, and present geographic data in a variety of ways, including as maps, charts, and 3-D models,

Application: GIS-based spatial planning tools have been used in a variety of studies, including applications in marine environmental monitoring and management, fisheries and resource management, development of marine renewable energy projects, and marine environmental emergency responses, among others (e.g., PlanWise4Blue, Kotta *et al*., 2020).

Systematic conservation planning tools

Description: A subset of spatial planning tools, these conservation-specific decision support tools have been developed to facilitate systematic conservation planning, with the most widely used being MARXAN and ZONATION (See Portman, 2016 for further information). These tools tend to include a suite of different applications used together to provide a range of information to underpin planning decisions.

Application: Wider applications of conservation planning tools include use in designing new MPA networks, new MPA sites, zonation within MPAs, prioritise management actions (amongst others). Notably, conservation planning tools are considered relevant for the implementation of the spatial targets of the EU Biodiversity Strategy for 2030.

Other EBM tools include the following: **simple assessment index** (e.g., multimeric index M-AMBI); and **descriptor or theme-specific combination of indices and models** (e.g., HEAT for eutrophication, BEAT for biodiversity, and CHASE for hazardous substances), and **overarching assessment tools** (e.g., Nested Environmental status Assessment Tool and Ocean Health Index (for more details see Borja *et al.* 2016).

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Annex 1 – The 12 CBD Principles

The 12 original principles from the CBD are considered complementary and interlinked [6]:

Principle 1: The objectives of management of land, water and living resources are a matter of societal choices.

Principle 2: Management should be decentralized to the lowest appropriate level.

Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.

Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should:

- *a. Reduce those market distortions that adversely affect biological diversity;*
- *b. Align incentives to promote biodiversity conservation and sustainable use;*
- *c. Internalize costs and benefits in the given ecosystem to the extent feasible.*

Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.

Principle 6: Ecosystem must be managed within the limits of their functioning.

Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.

Principle 8: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.

Principle 9: Management must recognize the change is inevitable.

Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.

Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.

Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

[6] Principles (cbd.int)

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