Marine SABRES Deliverable 3.2 Briefing Paper 4.

Marine Processes and Functioning and Ecosystem Services

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DOCUMENT INFORMATION

Version	Date	Description			
		Responsible	Authors	Reviewed by	Approved by
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Name	Organisation
MARBEFES	MARBEFES - MARine Biodiversity and Ecosystem Functioning leading to Ecosystem Services MARBEFES project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement no 101060937, and the UKRO Grant 10048815
Dr Pamela Woods	MFRI
Dr Bruno Meirelles de Oliveira	AZTI

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This briefing paper was produced under the Marine SABRES Project: Marine Systems Approaches for Biodiversity Resilience and Ecosystem Sustainability. Funded by the European Union's Horizon Europe research and innovation programme under grant agreement no. 101058956 and the UK Research and Innovation Fund, UKRI Project numbers 10050525 and 10040244.

This briefing note is one in a series of documents aimed at supporting the Simple Social-Ecological Guidance. For the complete set of briefing documents, please refer to the accompanying signposting document, which can be found at the following link: [insert link here].

Recommend Citation: *Elliott, M. Burdon, D. Atkins, J. Smith, G. (2023). Marine Processes and Functioning and Ecosystem Services, Deliverable 3.2. Marine SABRES, European Union's Horizon Europe research and innovation programme under grant agreement no. 101058956. and the UKRI Project Numbers 10050525 and 10040244*

UK Research and Innovation

Funded by the European Union

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1. Introduction

The marine system and its relationship with human uses and abuses can be visualised as an integrated model (Figure 1, Elliott 2023) in which a central spine from physico-chemical structure and functioning creates the conditions for ecological structure, biodiversity and functioning and ecosystem services. The latter then lead to societal benefits, including material goods, and wellbeing after adding human capital and assets (see Briefing Paper 5: *Societal Drivers, Benefits, Goods and Wellbeing*). Those natural science aspects (in green in Figure 1) and human aspects (in blue) are then affected by human activities and their resulting pressures (see Briefing paper 3: *Cause-Consequence-Response Chains-DAPSI(W)R(M)*) which can lead to a degraded system (denoted as the grey bar in Figure 1). Adaptive management, restoration, governance and planning are then required to prevent degradation or restore the degraded system as shown by the surrounding side and lower blue boxes in Figure 1.

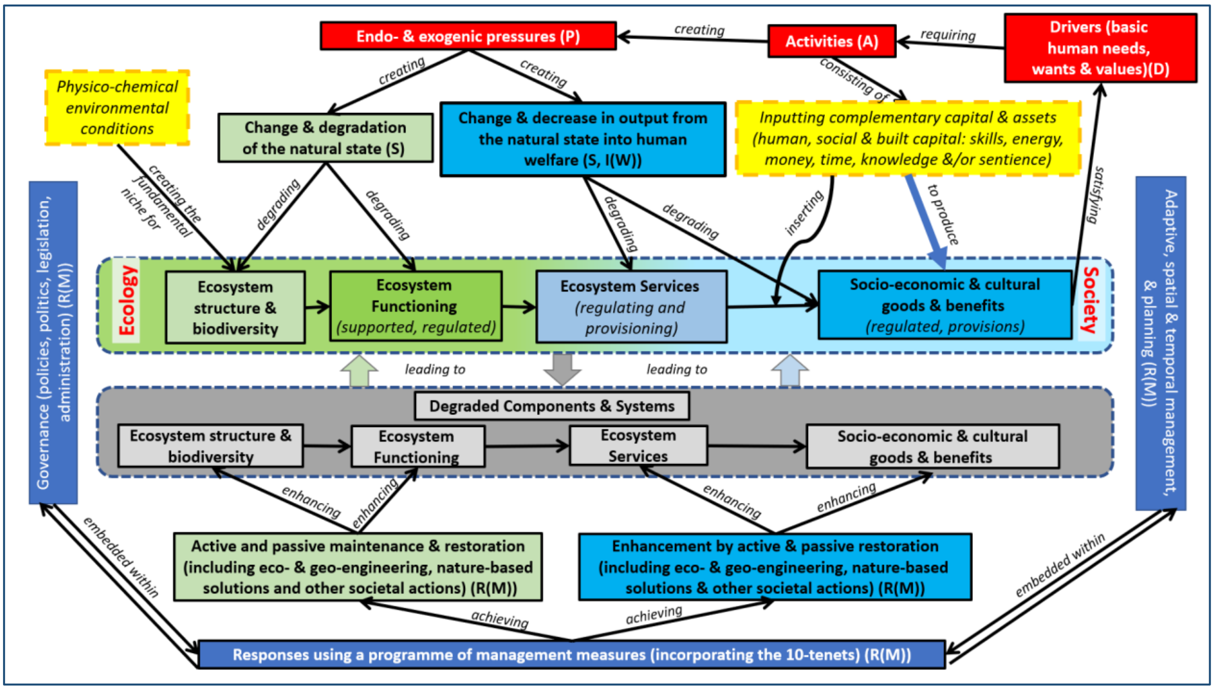

Figure 1 The integrated socio-ecological system aiming to unify the DAPSI(W)R(M) framework, the means of degrading the natural system and recovery management measures, and the ecological structure and functioning to ecosystem services and societal goods and benefits continuum (from Elliott, 2023).

In the Marine SABRES Simple SES approach (Gregory et al., 2023), an understanding of the terms 'marine processes and functioning' and ecosystem services is essential to determining the nature of the State Changes to the natural environment and then the adverse effects on the social system (the Impacts (on human Welfare)) as part of the DAPSI(W)R(M) underpinning framework (Elliott et al., 2017). For this we regard these terms as:

Ecosystem Services - *"functions and products from nature that can be turned into benefits with varying degrees of human input"* (UK Natural Capital Committee, 2019).

Marine Processes and Functioning – *"All the ways in which marine biota and ecosystems control or modify the biotic and abiotic parameters defining the environment of people (i.e. all aspects of the 'ambient' environment)* (Haines-Young and Potschin, 2018). However, in the use here, this should be extended to include the environment for nature as well as people.

2. Marine Processes and Functioning

Determining marine environmental sustainability requires evaluating the way in which human activities affect both the human and natural environment, as well as how the environment impacts society; this requires knowledge of the behaviour of human activities in the area, their footprints together with their pressures- and effects-footprints and the features and behaviour of the natural environment (Gray and Elliott, 2009; Elliott et al., 2020; Elliott and Wither, 2023). Coastal and marine ecosystems are complex and diverse, consisting of a variety of natural components such as habitats, species and ecological processes, all of which are both influence by, and the result of, the physico-chemical structure and processes. These elements form the basis of the natural capital, which provides a wide range of ecosystem services (Stuart and Davison-Smith, 2021; Elliott 2023; Burdon et al., 2024).

The term Natural Capital is defined as *"the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions"* (UK Natural Capital Committee, 2019). This recognises that coastal and marine ecosystems contain a range of components (e.g., habitats and species) and processes (e.g., food webs and ecological dynamics), which are the marine processes and functions from which Ecosystem Services flow (UK Natural Capital Committee, 2019). Understanding and managing this natural capital is essential for ensuring the sustainable use of our oceans and coasts (Stuart and Davison-Smith, 2021).

While it is not the aim of this Briefing Paper to explain the different marine processes and functioning in each habitat and ecosystem studied in the MarineSABRES project, general underlying principles can be given which can then be applied to those different habitats and ecosystems. Ecosystems are formed by the interconnected nature of physico-chemical and biological structural components (where structure equates to the features at one time) which are then modified by key rate processes, the resultant ecosystem functioning (Gray and Elliott, 2009). The Convention on Biological Diversity defines an ecosystem as "*a dynamic complex of plant, animal, and microorganism communities, along with their non-living environment, interacting as a functional unit*" (CBD, 2000). In the context of the marine environment, these critical processes relate to the inter-relationships between the physico-chemical (abiotic) and biological (biotic) attributes, as shown in Table 1 and Figures 1-4. However, natural phenomena and anthropogenic activities will then affect the structure and functioning of these ecosystems by impacting these fundamental processes and functions. Healthy marine environments are necessary to provide the full range of ecosystem services and societal benefits that enhance society's well-being.

The natural marine environment interacts with human systems through fundamental processes; these processes can be broadly categorised into three distinct groups: physico-chemical, ecological, and anthropogenic. The physico-chemical processes can be separated into the water column and the bed processes (respectively left-hand and right-hand sides in Figure 2, from Gray and Elliott 2009). It is emphasised here that such physico-chemical features can be defined as a suite of interlinked regimes and that the ecological structure and function cannot be understood or interrogated without a good understanding of these regimes and features. Figure 2 shows the cascade in those features from global and long-term scales at the top to more local and short-term scales lower in the figure.

Summarised as 'environment-biology interactions', the physico-chemical system creates a habitat, i.e. the fundamental niches in the water column or substrata, colonised by organisms and so creating the community structure, according to the environmental tolerances of the organisms (Gray and Elliott, 2009; Solan and Whiteley, 2016). (There are also interactions between the physico-chemical features – termed the 'environment-environment relationships'.) The organisms then interact with each other at the individual, population and community levels, for example with competition and predator-prey interactions; these constitute the inter- and intra-specific 'biology-biology interactions' that lead to ecological functioning (i.e. rate processes) (Figure 3). Such interactions occur across the trophic levels, from producers to top consumers, in which a lower layer may produce the biomass to support an upper layer and the upper layers act as population controls on the lower trophic levels. There is likely to be competition for available resources within and between such trophic levels and ultimately all biological material will be recycled through detrital food chains and the microbial system.

Following this, the biological components (as levels of biological organisation from the individual and population to communities and ecosystems) can create a feedback mechanism and influence the physico-chemical system, which is then termed the 'biology-environment relationships' (Gray and Elliott, 2009). In essence, the physical system sets up the conditions for relevant colonising organisms, which then modify the system via feedback loops. It is important to note that these natural processes are influenced by anthropogenic processes and features. The impact of these features and processes on the natural environment is a matter of increasing concern as marine processes and functions and the resulting ecosystem services ultimately produce societal benefits (see Briefing Paper 5).

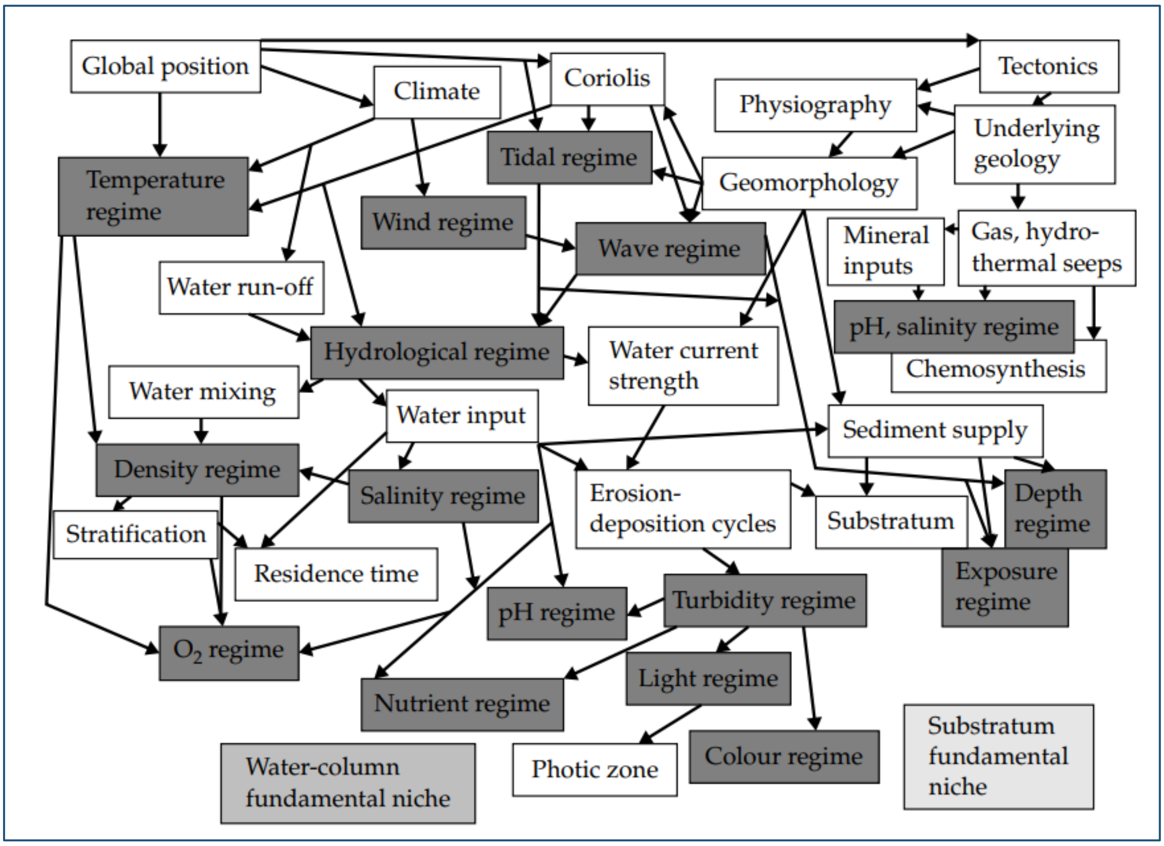

Figure 2 The links between the physico-chemical regimes and features resulting in the two main fundamental and overarching niches, for the water column and substratum; the darkened boxes are the main regimes (from Gray and Elliott, 2009).

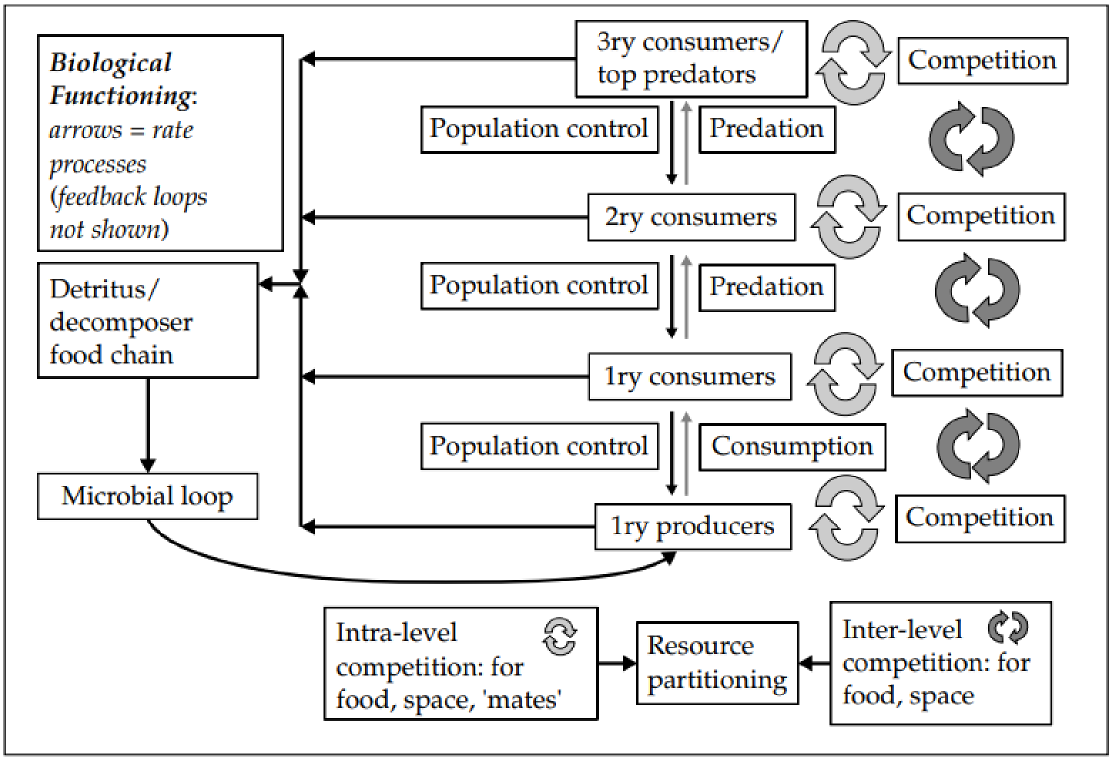

Figure 3 Ecosystem Functioning: the main ecological processes (from Gray and Elliott, 2009).

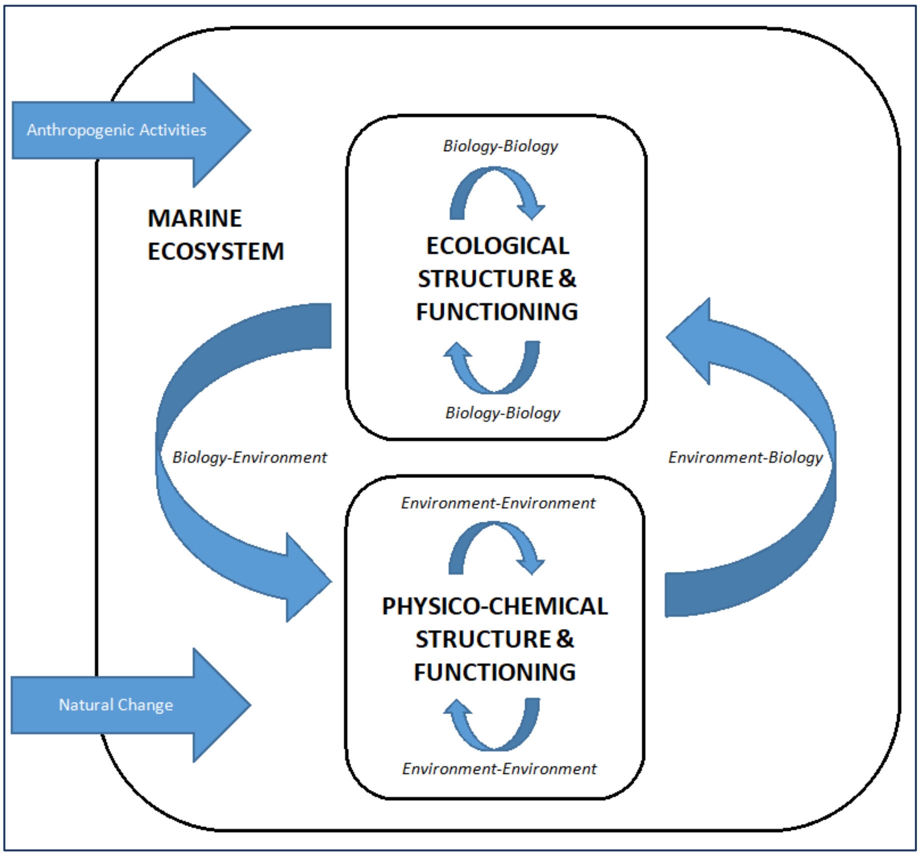

Figure 4: A conceptual model indicating the linking and feedback between abiotic and biotic attributes of the marine ecosystem; the model denotes the main four sets of interrelated processes – 'environment-environment', 'environment-biology', 'biology-biology' and 'biology-environment' (Burdon, 2016; modified from Gray and Elliott, 2009).

Table 1: Estuarine and coastal processes and inter-relationships (Table modified from Burdon, et al., 2024; based upon Atkins et al., 2014 and Gray and Elliott, 2009).

Processes	Meaning	Examples
'Environment–biology'	The physico-chemical system (e.g., salinity, temperature, sediment, geology, hydrography, etc.) creates the fundamental niches for colonisation by organisms, where that colonisation depends on the environmental tolerances of each species.	Reduced water currents will allow the development of muddy substrata which will be colonised by deposit-feeding organisms; biogeographic regimes and physico-chemical oceanographic processes and gradients will thus create the conditions likely to be colonised by organisms.
'Biology–biology'	The resultant community is modified by biological processes and interactions such as predator–prey relationships, competition, and recruitment processes such as propagule supply and settlement.	The mud-dwelling invertebrates then compete with each other for space but also provide food for wading birds and fish.
'Biology–environment'	The biology may influence the physico-chemical system and the import and export of materials into and out of the system.	Benthic invertebrates bioturbate and alter the sedimentary regime, leading to biogeochemical changes; water column oxygen demand is created by a large number of organisms occurring together.
'Environment–environment'	One or more elements of the physicochemical system impact upon other elements of the physico-chemical system.	Changes in the hydrographic regime (e.g., currents, tides, etc.) result in changes to the sediment structure on the seabed.

3. Ecosystem Services and their Interconnectedness with Marine Processes and Functioning

Marine processes and functioning underpin the production of ecosystem services and all of these constitute the natural domain and interact with the human domain. As indicated above, marine processes and functioning provide the fundamental physico-chemical and biological conditions that create and sustain diverse ecosystems which deliver a range of ecosystem services. After inputting human capital and assets, these services contribute significantly to human well-being and the economic vitality of coastal and marine communities (see Briefing Paper 5: *Societal Drivers, Benefits, Goods and Wellbeing*). However, it is important to manage and mitigate the impacts of human activities on these natural processes to ensure the sustainability, resistance and resilience of both the marine environment and the human benefits derived from it.

The concept of ecosystem services has been presented and debated for several decades (e.g. Daily, 1997; Constanza, et al., 1997; De Groot, et al., 2002). Despite this, there is no consensus on the definition of Ecosystem Services and the term is often both conflated and confused with the term Societal Benefits (Burdon et al., 2024; Elliott, 2023). Figures 5 and 6 illustrate this link between the natural environment and the human domain, which is explained below and especially in the Briefing paper 5: *Societal Drivers, Benefits, Goods and Wellbeing*).

In the context of identifying, defining and quantifying goods and services provided by marine biodiversity alone, the UN 2005 Millennium Ecosystem Assessment (MEA 2005) described four types of ecosystem services:

- Production services which involve products and services obtained from the ecosystem;
- Regulating services which are the benefits obtained from the regulation of ecosystem processes;
- Cultural services which are the non-material benefits people obtain from ecosystems;
- Supporting services which are those that are necessary for the production of all other ecosystem services, but do not yield direct benefits to humans.

Beaumont et al. (2007) then introduced a further category of 'Option use values which are associated with safeguarding the option to use the ecosystem in an uncertain future'. As a successive iteration, the generic term 'goods and services' was more recently been modified to indicate that a fully functioning ecosystem maintains a set of ecosystem services and that these are separated into fundamental services or characteristics (the physico-chemical environment) and final services (the biological elements and processes resulting from the fundamental services which will lead to the benefits for society) (Potschin et al., 2016). That fundamental structure (the natural capital and the ecosystem structure and functioning) and final ecosystem services then produce societal benefits although these require the introduction of human capital and assets to be obtained (see Briefing Paper 5: *Societal Drivers, Benefits, Goods and Wellbeing*). The societal benefits, and material goods, can then be valued both as TEV (Total Economic Value) and TSV (Total System Value) in which the latter may include components for which it is difficult to derive a monetary value (use/non-use, tangible/non-tangible, material/non-material and 'feel-good' values) (Elliott et al., 2017).

For example, the natural system can maintain the hydrographic processes which create the conditions for invertebrates as food for fishes and then harvesting the fishes requires boats and harbours, and the skills to use those fish. As another example, the natural processes can deliver marine sands and gravels but these become marine aggregates for construction when the vessels and infrastructure are created to exploit them. As a further example, the natural system can produce a blue whale but human capital is required for society to confer a greater value to that animal than just if it was yet another animal.

While there are various iterations of this model, the most recent versions (see Elliott and Wither, 2023; Burdon et al., 2024), modify this ecosystem services classification and further emphasise the separation of the marine system into the natural and human domains (Figures 5 and 6). These emphasise that the term ecosystem services only refers to the central part of the model and should always be distinguished from societal benefits, including material goods. Secondly, the model suggests that supporting services are no different from ecosystem structure and functioning and so the term has been dropped. Thirdly, Figure 5 maintains the classification of regulating, provisioning and cultural services, whereas Figure 6 emphasises only provisioning aspects and regulating processes occur and suggests that the term cultural services is a misnomer as the natural environment does not recognise 'culture' which is a human construct. Both figures indicate that the left-hand side of the models relates to the natural domain whereas the right-hand sides relate to the human domain. Finally, these recent models further indicate that ecosystem services are an intermediate step giving flows from ecosystem structure and functioning (natural capital) to societal benefits.

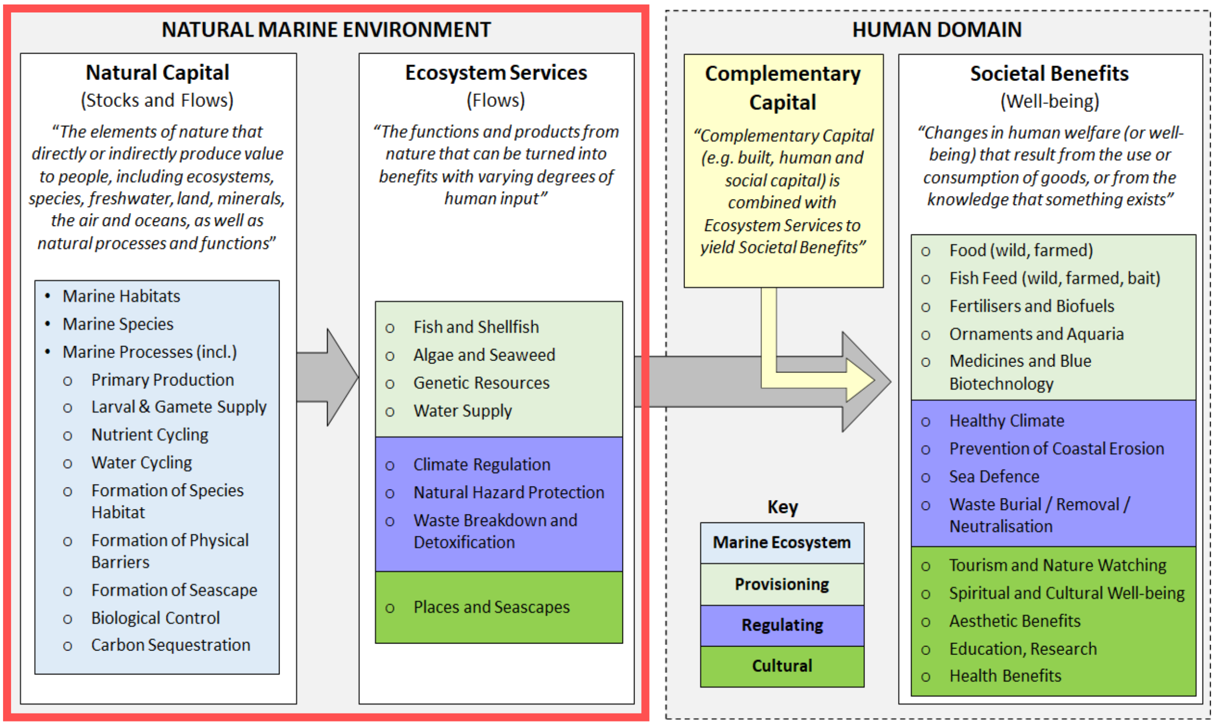

Figure 5: The Ecosystem Services and Societal Benefits Model with the Natural domain (Marine Processes and Functioning and Ecosystem Services) highlighted by a red box (Burdon et al., 2024).

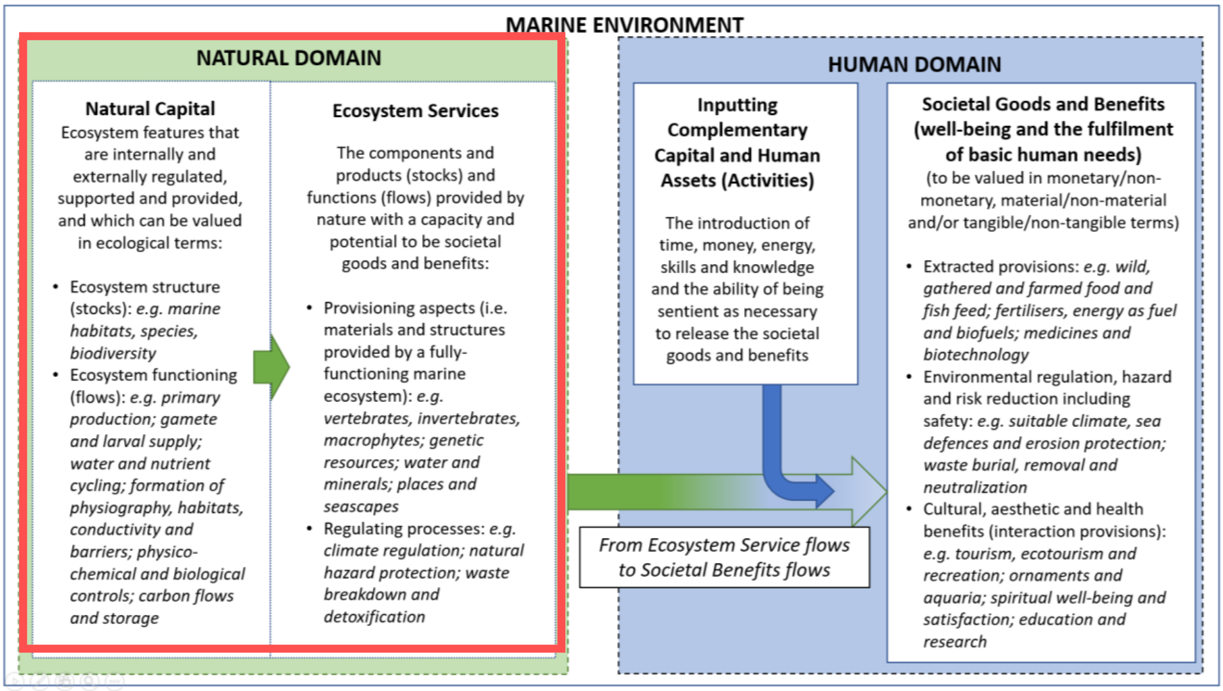

Figure 6 The revised Ecosystem Services and Societal Goods and Benefits Model (from Elliott 2023)

4. References and Further reading

Atkins, J.P., Burdon, D., Elliott, M., Gregory, A.J., 2011. Management of the Marine Environment: Integrating Ecosystem Services and Societal Benefits with the DPSIR Framework in a Systems Approach. Marine Pollution Bulletin, 62(2): 215-226.

Atkins, J.P., Burdon, D., Elliott, M., Schaafsma, M. and Turner, R.K. (2014). Coastal and marine Ecosystem Services. *Environmental Scientist*, 23(4), pp. 26-30.

Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., Van Ierland, E., Marboe, A.H., Starkey, D.J., Townsend, M., Zarzycki, T., 2007. Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. Marine Pollution Bulletin, 54(3), pp. 253-265.

Burdon, D., 2016. An interdisciplinary approach to marine management: Bridging the divide between natural and social sciences research. PhD by published work, University of Hull, UK.

Burdon, D., Atkins, J.P., Potts, T. (2024). Classification of Estuarine and Coastal Ecosystem Services. In D. Baird and M. Elliott, (Eds.) *Treatise on Estuarine and Coastal Science, 2nd Edition*. Elsevier.

CBD (2000). Convention on Biological Diversity. http://69.90.183.227/doc/legal/cbd-un-en.pdf.

Costanza, R., D'Arge, R., de Groot, R.S., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neil, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and Belt, M.V.D. (1997). The value of the world's Ecosystem Services and natural capital. *Nature*, 387, pp. 253-260.

Daily, G.C. (1997) Introduction: What Are Ecosystem Services? In: Daily, G.C., Ed., Nature's Services: Societal Dependence on Natural Ecosystems, Island Press, Washington DC, 1-10.

De Groot, R.S., Wilson, M.A. and Boumans, R.M.J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41(3), pp. 393-408.

Elliott, M. (2023). Marine Ecosystem Services and Integrated Management: "*There's a crack, a crack in everything, that's how the light gets in*"!. Marine Pollution Bulletin. 193. 115177. https://doi.org/10.1016/j.marpolbul.2023.115177

Elliott, M., Borja, A., Cormier, R. (2020). Activity-footprints, pressures-footprints and effects-footprints – walking the pathway to determining and managing human impacts in the sea. Marine Pollution Bulletin, 155: 111201; https://doi.org/10.1016/j.marpolbul.2020.111201.

Elliott, M., Borja, A., Cormier, R., 2020. Managing marine resources sustainably: a proposed integrated systems analysis approach. Ocean & Coastal Management, 197, 105315, https://doi.org/10.1016/j.ocecoaman.2020.105315

Elliott, M., Burdon, D., Atkins, J.P., Borja, A., Cormier, R., de Jonge, V.N., Turner, R.K., 2017. "*And DPSIR begat DAPSI(W)R(M)!*" - a unifying framework for marine environmental management. *Marine Pollution Bulle*tin, 118 (1-2): 27-40. http://dx.doi.org/10.1016/j.marpolbul.2017.03.049

Elliott, M., Hemingway, K.L., (Eds.), 2002. Fishes in Estuaries. Blackwell Science, Oxford, pp636.

Elliott, M., Wither, A., (Eds.) (2023). Environmental Consequences and Management of Coastal Industries: Terms and Concepts. Elsevier, Amsterdam, Paperback ISBN: 9780443137525, eBook ISBN: 9780443137532

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68(3).

Gray, J.S., Elliott, M., 2009. Ecology of Marine Sediments: science to management. OUP, Oxford, 260pp.

Gregory, A.J., Atkins, J.P., Smith, G., Elliott, M. (2023). Simple Social-Ecological Systems Guidance, Deliverable 3.1. Marine SABRES, European Union's Horizon Europe research and innovation programme under grant agreement no. 101058956. and the UKRI Project Number 10050525

Haines-Young, R.H. and Potschin, M.B. (2010). The links between biodiversity, Ecosystem Services and human well-being. Chapter 6 In: Raffaelli, D. and Frid, C. (Eds.): *Ecosystem Ecology: a new synthesis.* BES ecological reviews series, Cambridge University Press, Cambridge (31 pp).

Haines-Young, R.H. and Potschin, M.B. (2018). Common International Classification of Ecosystem Services (CICES) V5.1. Guidance on the Application of the Revised Structure. Available online. https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf

MEA (2005). UN 2005 Millennium Ecosystem Assessment (https://www.millenniumassessment.org/en/index.html):

O'Higgins, T.G., Lago, M., DeWitt, T.H., (Eds.), 2020. Ecosystem-Based Management and Ecosystem Services: Theory, tools and practice. Springer, Amsterdam. ISBN 978-3-030-45842-3, ISBN 978-3-030-45843-0 (eBook); https://doi.org/10.1007/978-3-030-45843-0

Potschin, M., Haines-Young, R., Fish, R., Turner, R.K., 2016. Routledge Handbook of Ecosystem Services. Routledge, Abingdon, UK. ISBN 978-1-138-02508-0, pp629.

Solan, M., Whiteley, N., (Eds.), 2016. Stressors in the marine environment: physiological and ecological responses: societal implications. OUP, Oxford, Hardback ISBN 9780198718826.

Stewart, K., & Davison-Smith, H. (2021). Marine and Coastal Natural Capital Review. Yorkshire Marine Nature Partnership. https://yorkshiremarinenaturepartnership.org.uk/wp-content/uploads/2022/05/21-07-01-Marine-Natural-Capital-Review-FINAL.pdf

Turner, R.K., Schaafsma, M., (Eds.), 2015. Coastal zones ecosystem services: from science to values and decision making. Springer Ecological Economic Series, Springer Internat. Publ. Switzerland, ISBN 978-3-319-17213-2

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