Journal of Environmental Management 130 (2013) 135–145

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Typology and indicators of ecosystem services for marine spatial planning and management

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ARTICLE INFO

Article history:
Received 19 October 2012
Received in revised form
19 June 2013
Accepted 10 August 2013
Available online 26 September 2013

Keywords:
Ecosystem approach
Ecosystem-based management
Marine ecosystem services typology
Indicators
Marine Strategy Framework Directive
Marine spatial planning

ABSTRACT

The ecosystem services concept provides both an analytical and communicative tool to identify and quantify the link between human welfare and the environment, and thus to evaluate the ramifications of management interventions. Marine spatial planning (MSP) and Ecosystem-based Management (EBM) are a form of management intervention that has become increasingly popular and important globally. The ecosystem service concept is rarely applied in marine planning and management to date which we argue is due to the lack of a well-structured, systematic classification and assessment of marine ecosystem services. In this paper we not only develop such a typology but also provide guidance to select appropriate indicators for all relevant ecosystem services. We apply this marine-specific ecosystem service typology to MSP and EBM. We thus provide not only a novel theoretical construct but also show how the ecosystem services concept can be used in marine planning and management.

1. Introduction

The increasing human pressure on marine resources, and the failure to date of single-sector marine policies to achieve sustainable resource use, has resulted in recent policy shifts towards the adoption of ecosystem-based management (EBM). This adoption of EBM intends to facilitate protection, recovery, and sustainable use of marine environments (Directive, 2008/56/EC of the European Parliament and of the Council, The White House Council on Environmental Quality, 2010; The White House Office of the Press Secretary, 2010). Worldwide, EBM examples can be found. Australia, for instance, has focused on multiple use management since 1997 (Sainsbury et al., 1997) and, as of 2006, created a revised National Oceans Act and Policy to implement EBM for protection and sustainable development of Australia's Exclusive Economic Zone (ACF and NELA, 2006). Similarly, Canada adopted EBM and has developed a suite of objectives and indicators to meet the principles of sustainable development and integrated management of ocean resources (Canadian Science Advisory Secretariat, 2001). Likewise, the USA adopted the National Oceans Policy in 2010, which emphasizes the EBM approach in its coastal and marine zones (The White House Council on Environmental Quality, 2010; The White House Office of the Press Secretary, 2010).

The European Union (EU) has also developed a comprehensive Maritime Policy, which includes the Marine Strategy Framework Directive (MSFD) (Directive, 2008/56/EC of the European Parliament and of the Council, 2008) and the recently proposed Maritime Spatial Planning Directive (pMSPD) (European Commission, 2013). This Maritime Policy adopts EBM to support environmentally and socially sustainable development, in addition to improving the quality of Europe's regional sea (Directive, 2000/60/EC of the European Parliament and of the Council, European Commission, 2006, 2007; Directive, 2008/56/EC of the European Parliament and of the Council). Moreover, the co-existence of conflicting marine sector activities must be facilitated (European Commission, 2013). Both MSFD and pMSPD explicitly link marine

Abbreviations: EEZ, Exclusive Economic Zone; ES, ecosystem service; EBM, ecosystem-based management; GES, good environmental status; MSFD, marine strategy framework directive; MSP, marine spatial planning; pMSPD, proposed Marine Spatial Planning Directive; TEEB, the economics of ecosystems and biodiversity.

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http://dx.doi.org/10.1016/j.jenvman.2013.08.027

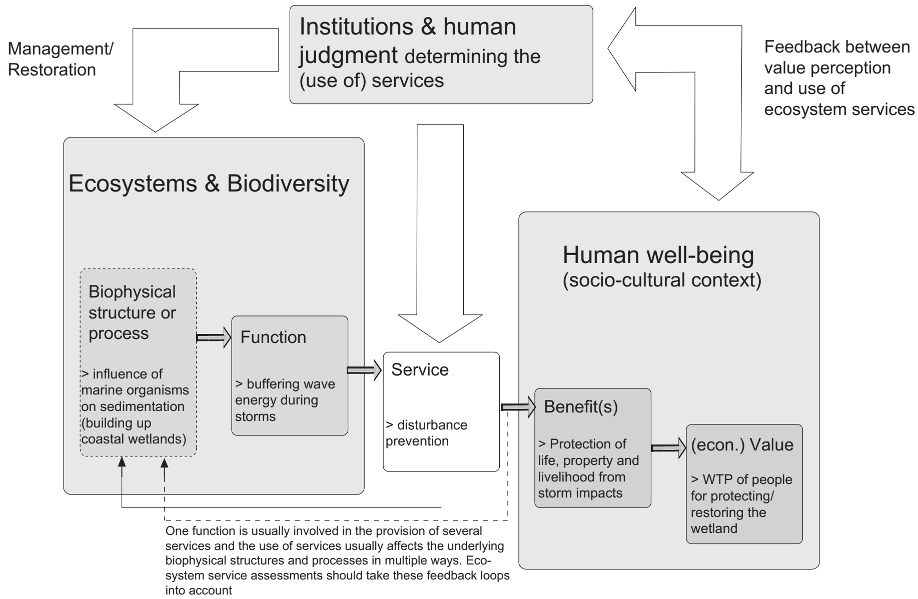

Fig. 1. Linking ecosystem structure and processes to human well-being applying the example of the service *Disturbance Prevention or Moderation* in the marine environment (adapted from De Groot et al. (2010), based on Haines-Young and Potschin 2010).

planning and management with the ecosystem services[1] (ES) concept. According to the MSFD, the marine strategies adopted by the EU member states in the future must enable the sustainable use of ESs (Article 1). The MSFD emphasizes the importance of healthy ecosystems as a prerequisite for ESs to be provided (Directive, 2008/56/EC of the European Parliament and of the Council). Similarly, the pMSPD aims to "halt the (…) degradation of ecosystem services" (Article 5) and requires member states to consider ESs in their coastal management strategies (Article 8).

This illustrates the importance of the ES concept for marine planning and management. This connection, unfortunately, has not gained much attention as yet in the literature. For instance, while several publications identify and discuss required advances in MSP (Ehler and Douvere, 2010; Flannery and Ó Cinnéide, 2012; Halpern et al., 2012; Jay et al., 2012), the integration of ESs in assisting the MSP process is largely unexplored. This lacking consideration of ESs in marine management and planning to date may be contributing to the continued absence of an integrative approach in marine management. Consequently, single sector development plans are still dominating which involves largely unresolved conflicts among different coastal user groups, and continued unsustainable resources use (European Commission, 2011).

We argue that the ES concept can be embedded in the application of MSP and EBM in order to facilitate the consideration of multiple uses and impacts, as well as the analysis of use conflicts and trade-offs implied by different management and development options. This way, the integration of ESs can advance EBM and MSP beyond commonly used single sector management. The assessment of ESs helps to bridge the conceptual gap between the natural and social sciences (i.e. between marine ecosystems and human preferences) by linking the state of ecosystems (i.e. their processes and functions) with human well-being and activities, even (or perhaps especially) when formal markets are incapable of doing so (MA, 2005; TEEB, 2010). This potential of the ES concept is important given that there is a tendency within decision-making to ignore social welfare changes that are not directly quantified through market-based measures, and that humanity's ultimate reliance is on well-functioning ecosystems (Brown et al., 2007; Beaumont et al., 2008; Boyd, 2008).

This paper aims to make the potential of the ES concept for marine planning and management accessible, by:

1. Providing a clearly structured, internally consistent and operational ES typology that is adapted for use in marine ecosystems and associated management approaches, for example, EBM and MSP.
2. Providing guidance on the application of the typology by (i) linking the typology to a set of possible indicators to quantify the provision of ESs; (ii) identifying related benefits; (iii) identifying services which can be enjoyed directly and those which require other forms of capital before they can be enjoyed.
3. Discussing and illustrating the application of the typology in MSP and EBM.

To address these aims, this paper is organized as follows: In Section 2, we present an overview of extant ES classifications and use the extant literature as a starting point to define our requirements for a new EBM/MSP oriented ES typology. In Section 3, we both present and elaborate on our novel marine-focused ES typology and in Section 4 provide guidance for operationalizing the ES typology (through indicators, required capital input and the identification of benefits). In Section 5, it is explained how the ES typology and related outcomes of this paper can be applied for EBM. Together, the various components of this paper illustrate the need for a new marine ES typology that identifies and addresses the gap in the ES field and its application in MSP and EBM.

2. Existing terrestrial and marine ecosystem services classifications

Early comprehensive classifications of ESs and their applications originate in the 1990's (de Groot, 1992; Costanza et al., 1997; Daily, 1997) where they provided guidance to classify natural ecosystems'

[1] See Section 3 for the definition of ecosystem services adopted by the authors of this paper.

contributions to human well-being. These early typologies allowed ES research to diversify, generating several different ES classifications (e.g., MA, 2005; Farber et al., 2006; Beaumont et al., 2007; Boyd and Banzhaf, 2007; Wallace, 2007; De Groot et al., 2010; Atkins et al., 2011).

The existing typologies have been reviewed against the following criteria:

a) **ES definition:** Does the applied definition distinguish between ecosystem processes, ecosystem services, related benefits and values? This is important because this cascade allows to translate a change in ecosystem state (as induced, for instance, by planning or management) into related implications for human well-being.
b) **ES categories**: Which categories (e.g., provisioning or supporting services) of ES are applied?
c) **Specific ESs considered.** Which service types are included and are these capable of reflecting changes in ecosystem state? The latter question is crucial for applying this typology in EBM or MSP, where different management options or spatial scenarios influence the state of an ecosystem.

The review against the above criteria yielded the following results:

2.1. ES definitions in existing typologies

Recent typologies present definitional limitations wherein ESs are frequently defined to be *the benefits people obtain from ecosystems* (MA, 2005; Farber et al., 2006; Beaumont et al., 2007; Wallace, 2007). Although this definition is generally accepted, De Groot et al. (2010), Boyd and Banzhaf (2007) and Atkins et al. (2011) point out that benefits and services need to be independently distinguished, stressing that one service can deliver multiple benefits, which can be economically valued. ES definitions, which confuse different levels of the ES cascade (i.e. processes – functions – services – benefits – values; see Fig. 1), are considered inappropriate here because they interrupt this cascade and thus impede the smooth translation of ecosystem state changes (as introduced, for instance, through marine planning and management) into implications for human well-being.

This applies also for the two existing marine-focused ES typologies. Beaumont et al. (2007), for example, considered ES to be synonymous with benefits, while Atkins et al. (2011) equated ES with ecosystem processes. This implies that the existing marine ES typologies are based on problematic definitions because they fail to make appropriate distinctions between processes, which provide the services, and the magnitude of the benefits derived from the services.

2.2. Classification of ES in existing typologies into ES categories

The majority of ES typologies mentioned above (MA, 2005; Farber et al., 2006; Beaumont et al., 2007; Wallace, 2007; De Groot et al., 2010; Atkins et al., 2011) aim to contribute to EBM-focused decision-making and all include the provisioning, regulating, and cultural services categories. However, five of them also include the supporting service category[2] (termed *fundamental services* in one case) within the typology itself. Although this category was introduced by the Millennium Ecosystem Assessment (MA, 2005), its inclusion in a typology intended for application in a context where economic trade-offs must be analysed is problematic because it substantially increases the risk of double counting when aggregating valuations across service categories.[3] As was the case with the ES definitional issues, the two explicitly marine focused typologies identified (Beaumont et al., 2007; Atkins et al., 2011) include the supporting (or fundamental) service category. This limits their suitability for economic valuation.

2.3. Specific ES included in existing typologies

For applying the ES concept within MSP or EBM, the specific ESs included within typologies and the specific service definitions used are also important to consider. For instance, Farber et al. (2006) define the service *Raw Material* as “building and manufacturing, fuel and energy, soil and fertilizer”. This definition suggests that both wind energy and non-renewable energy would be considered to be an ES within this particular typology. This, in turn, limits the ability of this service to reflect changes in ecosystem state. Indeed, only the examples reveal the biological focus of this service while the typology itself is not explicit about this issue – a feature of this typology that undermines its usability in the context of EBM and MSP.

Individual ES definitions can also be problematic if they fail to maintain the aforementioned distinctions between services, benefits, and values. Beaumont et al. (2007) include as a service type *Option Use Value*, with the corresponding specific service of *Future Unknown and Speculative Benefits*. However, in the often used Total Economic Value framework,[4] *value types* (such as option value) are not considered to be separate services, but are instead considered to be subsets of the Total Economic Value of an ecosystem service that, in turn, *reflects the importance* of services to people. This is a key distinction to make – between services and humankind's perception of their importance. We agree that the option use value of ecosystem services deserves attention in decision-making, but its inclusion as a separate *service* is problematic and can both confuse and undermine the valuation process.

The above analysis of ES typologies reveals the weaknesses of existing marine-focused typologies. This suggests that their application is problematic in the context of EBM and MSP and it implies that in the absence of an improved marine-specific typology the terrestrially-focused typologies must be adapted for use in marine systems on a case-by-case basis. In turn, this may have a number of consequences that undermine the effectiveness of MSP or EBM-focused measures. For example, different marine management initiatives or spatial planning units rather likely use different, and potentially fundamentally contradictory, service definitions. Consequently, this may cause inconsistencies between different

[2] Other than the ES definition applied by these typologies (i.e. *benefits people obtain from ecosystems*) suggests, supporting services are not directly beneficial to people. They are rather a prerequisite for other services being provided and that way *support* these actual services.

[3] Double counting occurs when the value of an ecosystem service is counted more than once which causes distortions in the valuation results. Double counting can be caused, for instance, by insufficiently delineated services or by valuing a service and additionally its underlying processes (as such included in the supporting services category). For example, if all marine organisms extracted from the sea are valued (including those used as fodder in aquaculture) and additionally, aquaculture products themselves are valued as well, this involves double counting the portion of marine organisms used as fodder because the value of the final aquaculture product contains/subsumes the value of the inputs, including that of the fodder. In an application-oriented ecosystem service typology – i.e. one that can be used for monetary valuation in EBM or MSP processes – double counting must be avoided. For the purpose of the typology proposed here, therefore, the supporting services category is considered not appropriate.

[4] For more details on the Total Economic Value framework see, for instance, (Unai et al., 2010). The economics of valuing ecosystem services and biodiversity. 5 In: P. Kumar, The Economics of Ecosystems and Biodiversity (TEEB): Ecological and Economic Foundations, pp. 183–256. London, Washington: Earthscan.

(neighbouring) planning or management units. Additionally, using different and inconsistent ES typologies would likely complicate comparisons between different EBM approaches and MSP case studies. This would inhibit the transfer of experiences and lessons learnt between different case study sites. A third issue that could arise from case-by-case adapted terrestrially-focused typologies relates to the economic valuation of ESs via the benefit transfer[5] approach. Where different valuation studies use different ES definitions, the ability of the analyst to justify transferring value estimates from one case study to another is severely undermined.

2.4. Synthesis

Considering the extant ES classifications, there are three main reasons for developing a new typology specific to EBM and Spatial Planning for a marine context: (i) ES typologies developed with a terrestrial focus cannot be smoothly transferred to applications in marine ecosystems; (ii) the use of extant typologies is problematic for economic valuation; and (iii) several specific ES types and definitions found within existing typologies are not capable of reflecting changes in the state of the marine ecosystem. Given the absence in the literature of a typology that meets all these requirements, we propose in the following section an innovative marine ecosystem services typology.

3. Typology of marine ecosystem services for ecosystem-based management and marine spatial planning

The typology presented in this paper addresses the issues raised above while being consistent with **T**he **E**conomics of **E**cosystems and **B**iodiversity framework (TEEB, 2010). This framework distinguishes between ecosystem processes, services, benefits and values (Fig. 1). In the context of MSP and EBM, this separation of the different ES cascade levels is critical and recognizes that the ES definition and/or typology needs to facilitate the analysis of trade-offs implied by human actions and environmental management strategies.

In the TEEB framework, biophysical structures and processes interact and generate ecological functions. In turn, these ecological functions generate ESs that are definable and measurable entities. Humans derive benefits from these services. These are the social preferences, which may be quantified and explicitly included in economic analyses for decision-making (see Fig. 1). In the case of coastal wetlands, for example, the TEEB framework recognizes that coastal wetlands are formed by *biophysical processes* that enhance sedimentation. Therefore, the wetlands *function* ecologically as natural buffers during storms. This function is described as providing the *ecosystem service* of *Disturbance Prevention* where human infrastructure is protected from naturally occurring impacts such as wave surges or storms originating from the ocean. The individuals to whom this service is provided *benefit* from this service.[6] Depending on their understanding of their relationship to the marine ecosystem and their personal preferences,[7] these individuals may or may not *value* the benefit derived from the service.

3.1. Definition of ES within the proposed typology

In order to facilitate the separation of the different levels of the ES cascade (Fig. 1) we use the following definition of ESs (De Groot et al., 2010):[8] "*ecosystem services are the direct and indirect contributions of ecosystems to human well-being*".

In addition to maintaining this type of separation between functions, processes, services, benefits, and values, our typology strives to be internally consistent, meaning that there is consistency between the generic definition of 'ES' used and the specific descriptions, definitions, and examples of the specific services provided in the typology. The proposed typology therefore addresses one of the main critiques of existing ES typologies as described in section 2, and should help to alleviate one of the major constraints to the adoption and operational use of the ES typologies published to date (Boyd and Banzhaf, 2007). An internally consistent typology facilitates the consideration of explicit links between the ecological processes that are responsible for *providing* ES and the economic valuation of the *benefits* that those services provide (Chapman, 2008; Fisher et al., 2009). Hence, this will be crucial for the utility of ES assessments in the context of trying to improve marine management.

In order to achieve internal consistency, each ES was assessed for compliance to the generic service definition (shown above) prior to inclusion in the typology (Table 1). Additionally, every ES that was defined and included within the typology was explicitly constrained in terms of scope so as to avoid overlap with the other ES identified. Creating the typology in this way required a combination of both minor, largely semantic adjustments to existing service characterizations (for example, include the following: 'Food' is adapted and restricted to *Sea Food*, *Erosion Prevention* is restricted to *Coastal Erosion Prevention*, and *Biological Control* is redefined to focus on marine pest and disease control), as well as, more substantively, the creation of specific *definitions* for each service included in the typology. These are included in sufficient detail to make the boundaries between each of the services explicit and therefore to facilitate its application in management or spatial planning.

3.2. The proposed ES typology in context of MSP and EBM

In this context it is noteworthy that consistently defined and explicitly delineated ESs are still interdependent (i.e. in that the use of one may affect the provision of others) because they are the products of complex ecological systems. These interdependencies are important to consider, for instance, in EBM or MSP when assessing trade-offs or other implications of management measures or planning alternatives. They are multifaceted and depend on site-specific characteristics (see Box 1 for a subset of possible examples and Supplementary Material 1 for examples for each ES considered in this typology) and may reflect both positive and negative feedback loops.

[5] Valuation studies on ecosystem services can be quite time and money consuming. A quicker and cheaper option is the benefit transfer approach because it is based on data available from existing valuation studies. These original value estimates are transferred to value ecosystem services in a new study area.

[6] As their lives, property and livelihoods would experience increased threats in the absence of the services.

[7] Value may, for example, be expressed through actions designed to protect the relevant ecosystem. Failing to value the ecosystem service may result in decisions that undermine the provision of the service and increase risk to life and property, which may, in this example, result in people incurring damage and replacement costs after storms/extreme events.

[8] This definition implies that ecosystem services contribute to human welfare through the creation of benefits which people may/may not recognize and value. In our interpretation of this definition, by 'direct,' we mean that the services generate benefits for humanity directly and without needing to be paired with other forms of capital. By 'indirect,' we mean that the services generate benefits through their pairing with other forms of capital. 'Direct' and 'indirect' should not, therefore, be construed as being equivalent to the label of 'final' or 'intermediate,' respectively, when it comes to describing services (for examples see Table 2).

Table 1
Typology of marine ecosystem services.

	Ecosystem service	Description	Example
Provisioning Services	1 Sea Food	All available marine fauna and flora extracted from coastal/marine environments for the specific purpose of human consumption as food (i.e. excluding for consumption as supplements)[a]	Fish, shell fish, seaweed
	2 Sea Water	Marine water in oceans, seas and inland seas that is extracted for use in human industry and economic activity	Seawater used in shipping, industrial cooling, desalinization
	3 Raw Materials	The extraction of any material from coastal/ marine environments, excluding which is covered by service 6	Algae (non-food), sand, salt
	4 Genetic Resources	The provision/extraction of genetic material from marine flora and fauna for use in non-marine, non-medicinal contexts, excluding the research value on Genetic Resources which is covered by service 20.	The use of marine flora/fauna-derived genetic material to improve crop resistance to saline conditions
	5 Medicinal Resources	Any material that is extracted from the coastal/ marine environment for its ability to provide medicinal benefits, excluding the research value on Medicinal Resources which is covered by service 20.	Marine-derived pharmaceuticals; marine/ coastal-derived salt-water used for health purposes
	6 Ornamental Resources	Any material extracted for use in decoration, fashion, handicrafts, souvenirs, etc.	Shells, aquarium fish, pearls, coral
Regulating Services	7 Air Purification	Air Purification provided by a coastal/marine ecosystem	The removal from the air of pollutants like fine dust and particular matter, sulphur dioxide, carbon dioxide, etc.
	8 Climate Regulation	The contribution of the biotic elements of a coastal/marine ecosystem to the maintenance of a favourable climate via their impact on the hydrological cycle and their contribution to the climate-influencing substances in the atmosphere	The production, consumption and use by marine organisms of gases such as carbon dioxide, water vapour, nitrous oxides, methane, and dimethyl sulphide;
	9 Disturbance Prevention or Moderation	The contribution of marine ecosystem structures to the dampening of the intensity of environmental disturbances such as storm floods, tsunamis, and hurricanes	The reduction in the intensity of and/or damage caused by environmental disturbances resulting directly from marine ecosystem structures like salt marshes, sea grass beds, and mangroves
	10 Regulation of Water Flows	The contribution of marine and coastal ecosystems to the maintenance of localized coastal current structures	The effect of macro algae on localized current intensity; The maintenance of deep channels by coastal currents which are for shipping
	11 Waste Treatment	The removal by coastal/marine ecosystems of pollutants added to coastal/marine environments by humans through processes such as storage, burial, and biochemical recycling	The breakdown of chemical pollutants by marine microorganisms; The filtering of coastal water by shell fish
	12 Coastal Erosion Prevention	The contribution of coastal/marine ecosystems to Coastal Erosion Prevention, excluding what is covered by service 10 (i.e. transportation or deposition of sediments by coastal currents)	The maintenance of coastal dunes by coastal vegetation; The reduction in scouring potential that results from near-shore macro-algae forests
	13 Biological Control	The contribution of marine/coastal ecosystems to the maintenance of natural healthy population dynamics to support ecosystem resilience through maintaining food web structure and flows.	The support of reef ecosystems by herbivorous fish that keep algae populations in check; the role that top predators play in limiting the population sizes of opportunistic species like jelly fish and squid
Habitat Services	14 Lifecycle Maintenance	The contribution of a particular habitat to migratory species' populations through the provision of essential habitat for reproduction and juvenile maturation	The reproduction habitat of commercially valuable species that are harvested elsewhere
	15 Gene Pool Protection	The contribution of marine habitats to the maintenance of viable gene pools through natural selection/evolutionary processes	Inter- and Intra-specific genetic diversity that is supported by marine ecosystems which enhances adaptability of species to environmental changes
Cultural & Amenity Services	16 Recreation and Leisure	The provision of opportunities for Recreation and Leisure that depend on a particular state of marine/coastal ecosystems	bird/whale/…-watching, beachcombing, sailing, recreational fishing, SCUBA diving, etc.
	17 Aesthetic Information	The contribution that a coastal/marine ecosystem makes to the existence of a surface or subsurface landscape that generates a noticeable emotional response within the individual observer. This includes informal Spiritual Experiences but excludes that which is covered by services 16, 18, 19, and 21.	The particular visual facets of a 'sea-scape' (like open 'blue' water), a 'reef-scape' (with abundant and colourful marine life), a 'beach-scape' (with open sand), etc. that emotionally resonate with individual observers

(*continued on next page*)

Table 1 (*continued*)

Ecosystem service	Description	Example
18 Inspiration for Culture, Art and Design	The contribution that a coastal/marine ecosystem makes to the existence of environmental features that inspire elements of culture, art, and/or design. This excludes that which is covered by services 6, 16, 17, and 21.	The use of a marine landscape as a motif in paintings; The use of marine environmental features (like waves) in jewellery; The construction of buildings according to a marine-inspired theme; the use of marine organisms or marine ecosystems in films (including Jaws and Finding Nemo)
19 Spiritual Experience	The contribution that a coastal/marine ecosystem makes to formal religious experiences. This excludes that which is covered by services 17 and 21)	Several Greek and Roman gods were connected to the sea; A prominent Christian symbol is the fish; Marine organisms (such as whales and salmon) sometimes play important roles in various indigenous communities' religion
20 Information for Cognitive Development	The contribution that a coastal/marine ecosystem makes to education, research, etc. This includes the contribution that a coastal/marine ecosystem makes to bionic design and biomimetics and to research on applications of marine Genetic Resources and pharmaceuticals.	The environmental education of children and adults; The development of surfaces to reduce marine biofouling based on similar surfaces found in marine environments; the application of hydrodynamic flow analysis to marine animals for ship design; Utilization of marine animal swimming mechanisms in engineering design[b]
21 Cultural Heritage and Identity	The contribution that a coastal/marine ecosystem makes to Cultural Heritage and Identity (excluding aesthetic and formal religious experiences). This includes the importance of marine/coastal environments in cultural traditions and folklore. This covers the appreciation of a coastal community for local coastal/marine environments and ecosystems (e.g. for a particular coast line or cliff formation) as well as the global importance that may be associated with a particular marine landscape.	The Wadden Sea is listed as UNESCO World Heritage site

[a] The marine fauna referred to here may come from both capture fisheries and aquaculture operations.

[b] For example see the AirPenguin, AirJelly, and Air_ray created by Festo Robotics (Deutschland). Available at: http://www.festo.com/cms/de_corp/9780.htm, http://www.festo.com/cms/de_corp/9647.htm, and http://www.festo.com/cms/de_corp/9789.htm.

Source: Adapted from De Groot, Wilson and Boumans (2002), Beaumont et al. (2006), (De Groot et al., 2010).

Box 1

Examples of relationships where changes in ESs drive changes in other ESs within the typology.

The ***Sea Water*** quality can influence the services *Sea Food, Recreation and Leisure, Aesthetic Information*: if as a consequence of water extraction (e.g., for ballast water) invasive species were brought to a new location, this could change 1) availability of *Sea Food* 2) suitability for recreational activities (impact of occurrence of jelly fish on beach tourism) 3) *Aesthetic Information* of a location.

Carbon Sequestration in oceans is driving research and education (*Information for Cognitive Development*) and can also influence on *Sea Food* provision: Ocean acidification due to uptake of atmospheric CO_2 may influence the availability of *Sea Food* like shell fish, especially in the future.

Lifecycle Maintenance can influence on *Sea Food* provision, *Biological Control*, and *Recreation and Leisure*: Changes to nurseries can impact on the availability of *Sea Food* harvestable in an area, on the food web, and on recreational activities related to observation of nurseries.

The ***Aesthetic Information*** of an area might influence services related to human perception of an area, such as *Recreation and Leisure, Inspiration for Culture, Art and Design*, and *Spiritual Experience*. The interdependency with *Cultural Heritage & Identity* may be connected to the aesthetics of a place because changes in *Aesthetic Information* can influence the sense of place feeling.

Another key feature of the proposed typology is the ability of each ES within the typology to reflect ecosystem state changes driven by changes in management or spatial planning. Both management and spatial planning target the state of an ecosystem, that is, its processes and functions, and therefore the ecological characteristics that ultimately provide ESs and the associated benefits for human well-being.

Although the treatment of ESs as being ecosystem state-dependent means explicitly excluding from the typology any uses of marine ecosystems that are independent of ecosystem state (e.g., oil and gas, renewable energy, transportation/shipping), this does not mean that such related activities should be neglected in EBM and MSP. They are, or course, important drivers of marine change (Halpern et al., 2008) and carry a value to people. Rather, distinguishing between state-dependent ESs and state-independent activities means that trade-offs between the pursuit of those activities and environmental protection can be more easily assessed.

A third issue crucial in this context is to consider the direct or indirect nature of ES. Prior to benefits being realized, some ESs need to be coupled with other forms of capital, i.e. they contribute indirectly to human well-being (e.g., in the case of *Sea Food*, fishing gear, vessel, and fuel is required to catch fish; moreover, specific knowledge is needed, for instance, which *Sea Food* can be harvested where and when). The nature of *Ornamental Resources* and *Recreation and Leisure* is context-specific in this regard. Table 2 illustrates this link between services and benefits by specifying for each ES those required other capital forms and by identifying services which can be directly enjoyed.

Table 2
Operationalizing the marine ecosystem service typology: indicators, required capital input and human benefits.

ES	Indicators [a]	Other capital input required? Yes / No / depends	Direct benefits: Examples
Sea Food	Amount of fish landed [b] (Beaumont et al. 2006, Lange and Jiddawi 2009, Hunsicker et al. 2010) Amount of Sea Food harvested/year [b] (Kasperski and Wieland 2009, O'Higgins et al. 2010) Amount of fish harvested/km^2/year [b] (Cesar (1996); Ruijgrok et al. (2006) use unit ha/year)	e.g. fishing gear, fishing vessel, fuel	Nutrition, protein source, livelihood, pleasure: enjoy the taste
Sea Water	Number of days sea water is of insufficient quality for desired application Amount of Sea Water extracted per year per area [c]	e.g. desalinization plant, ship	Drinking water, health, safety (ballast water for shipping, cooling water for nuclear power plants), relaxation (recreation, leisure)
Raw Materials	Amount of fuel wood and amount of timer used from mangroves [b] (kg/household/year) (Hussain and Badola 2008) Amount of raw material extracted [b] (Beaumont et al. (2006); Ruijgrok et al. (2006) use unit m^3/year) Amount of seaweed grown per year [c] (Lange and Jiddawi 2009)	e.g. labor, dredger, other extraction gear	Inputs to industrial processes, construction material for infrastructure, employment,
Genetic Resources	# of Genes utilized per year per area [b]	e.g. genetic engineering lab/facility	Industry products, nutrition, livelihood,
Medicinal Resources	# of undiscovered oncological drugs (Erwin, López-Legentil and Schuhmann 2010)	e.g. lab, facilities to process pharmaceuticals	Health
Ornamental Resources	Amount of Ornamental Resources (tons) used per year per area [b]	for personal use: directly beneficial, for commercial use indirect: labour, extraction gear, transportation	Pleasure (interior decoration – symbolic or other, use for fashion, jewellery), livelihood
Air Purification	Amount of fine dust/NOx or SO2 captured (kg/ha/year) (Ruijgrok et al. 2006)		health (via clean air)
Climate Regulation	Amount of CO_2 sequestered (Beaumont et al. 2006, Ruijgrok et al. 2006, Jialin et al. 2009, Wang et al. 2010)		Favourable living conditions, health and wellbeing
Disturbance Prevention or Moderation	# of freshwater wells or amount of drinking water protected from tsunami impacts (Sanford 2009)		Safety (protection of human life, coastal infrastructure, property, livelihood), (mental) health and wellbeing of coastal citizens
Regulation of Water Flows	Amount of sediment prevented from sedimentation in natural channels used for shipping (m^3/year) (Ruijgrok et al. 2006)		Maintenance of natural shipping lanes, Safety, livelihood (shipping sector)
Waste Treatment	Biochemical degradation capacity of COD (g/m^3/day) (Wang et al. 2010) Amount of N and P stored kg/ha/year (Souza and Ramos e Silva 2011)		Health (via clean Sea Water)
Coastal Erosion Prevention	Length of natural coast line (Wang et al. 2010) Amount of sediment prevented from erosion per ha of an ecosystem per year (Ruijgrok et al. 2006)		Protection of property and land (e.g. used for recreation, coastal protection, agriculture, industry), protection of land/ seascape, mental and physical health and wellbeing of coastal citizens
Biological Control	# of species (Species richness) (Beaumont et al. 2006)		Mental and physical health
Lifecycle Maintenance	Amount of fish caught outside an area [b] (Hussain and Badola 2008)	e.g. fishing gear, labour, fishing vessel	Nutrition (via Sea Food), health, livelihood, Warm glow (existence value satisfaction)
Gene Pool Protection	Genetic diversity per population		Warm glow (representing the existence value)
Recreation and Leisure	*For most frequently used indicators please refer to section 4* # of visits of an area [c] (Dehghani et al. 2010) # of trips per site per year [c] (Gao and Hailu 2011) # of days used for particular activity per person [c] (Tapsuwan and Asafu-Adjaye 2008) # of day trips per year and # of overnight stays [c] (Ruijgrok et al. 2006) # of hotel rooms in a region [c] (Lange and Jiddawi 2009) Square feet of beach/beach day[d] (Bell 1986) Amount or Catch rate of target fish species (Cameron and James 1987, Bockstael, McConnell and Strand 1989) # of visitors per season [c]; # of boats involved in trips [c]; # of dive operators offering trips [c] (Dicken 2010)	Depends: e.g. SCUBA diving vs. beach recreation	Feelings of relaxation, pleasure and enjoyment, health and wellbeing, happiness, rejuvenation, employment
	Annual access days [c] (Cameron 1988)		
Aesthetic Information	Square feet of beach/beach day[b] (Bell 1986) Beach day [c,b] (Bell and Leeworthy 1986)		Pleasure, feelings of stimulation, relaxation, rejuvenation, and enjoyment.
Inspiration for Culture, Art and Design	Amount of time (# or person days) dedicated to creation of culture, art and design per area per year [c]		Inspiration and the promotion of creativity, enjoyment, satisfaction, livelihood
Spiritual Experience	Amount of time (# of person days) dedicated for formal religious ceremonies that involve coastal/marine environments per area per year [c]		Feelings of spirituality, the ability to perform religious ceremonies
Information for Cognitive Development	Amount of time (# of person days) spent in education about, research regarding, or individual learning about an ecosystem/species/ etc. per area per year [c]	e.g. any tools to study marine organisms	Intellectual inspiration to pursue knowledge, satisfaction of curiosity, education
Cultural Heritage and Identity	# of households that consider an area or aspects of an area as cultural heritage [c] (Ruijgrok et al. 2006)		Cultural practices which define the heritage, sense of community, sense of place, belonging, health and wellbeing.

[a] Cells shaded grey: no indicator could be obtained from literature; indicators proposed here are considered to represent the ecosystem service in question as good as possible. However, depending on data availability for specific case studies these indicators may need to be adjusted.
[b] This indicator is directly linked with the state of the ecosystem. However, due to the indirect nature of this service, a change in human effort of using it may disguise these ecosystem state changes. For instance, increasing fishing effort can mask a reduction of fish stocks.
[c] This indicator is not or indirectly linked with the state of the ecosystem and rather reflects human activities.
[d] This Study assessed bundled services *Coastal Erosion Prevention, Recreation and Leisure, Aesthetic Information.*

The aspect of direct and indirect services is relevant to spatial planning, management and decision-making where the implications of different management measures are evaluated. In case of a management measure resulting in changes of ecosystem service provision, these changes are experienced directly in case of the directly enjoyed services. However, in case of the indirectly enjoyed services, these changes are moderated through the other types of capital required which can obscure the actual changes in service provision. For example, if due to a certain management measure the availability of *Sea Food* is reduced, an increase in fishing intensity can mask this reduction (by increasing the amount of other capital required). In contrast, a reduction in *Air Purification* is perceived directly by people who are affected by reduced air quality.

Consideration of these aspects can assist in trade-off analyses. Understanding the direct and indirect effects of changes in ES provision also has implications for the ES value perception by related economic sectors as well as consumers. For instance, a decrease of an indirect service (like *Sea Food*) may be perceived differently (especially if subsidies compensate for the required increase of other capital forms) than a decrease in a direct service (like *Air Purification*) where the losses cannot be mitigated by technical measures.

A further aspect relevant for applying the ES concept in the context of spatial planning is to distinguish the scale (and location) at which ESs are provided and the scale (and location) at which benefits are enjoyed. It is important to consider that these scales very much depend on site specific conditions and that they can exceed the actual scale of a planning area. Hein et al. (2006), for instance, explore this issue in more detail. An illustrative example of this issue in the marine context is *Sea Food*. While a spawning habitat of a species may be situated in one country's Exclusive Economic Zone (EEZ), its nursery area may be located in a second country and finally this species may be caught in a range of different countries' EEZs. The fisheries in these different countries however, consciously or unconsciously, heavily depend on the situation and ecosystem state in the spawning and nursery areas. In contrast to this, the service *Disturbance Prevention or Moderation* is rather 'stationary' with regard to the location of service provision and related beneficiaries. At a coast where, for instance, sea grass meadows buffer wave energy, thus mitigating storm impacts, only residents located at the coast adjacent to this ecosystem are benefiting. An "export" of benefits (as seen in case of *Sea Food*) is rather unlikely for this service.

The proposed typology facilitates to identify the spatial scale of ES provision and the scale of benefit enjoyment for each service. Changes in ecosystem state impact on the capacity of ecosystems to provide services. Since the proposed typology is sensitive to ecosystem state changes, this facilitates linking the scale and location of ecosystem state changes with scale and location of ES provision changes. For linking the ESs of this typology with the scale at which benefits are enjoyed, Table 2 lists relevant benefits for each ES. Subsequently, the spatial scale of these benefits can be determined individually for case study specific conditions.

4. Operationalizing the marine ecosystem services typology: indicators, human benefits and required capital input

4.1. Quantifying ES through indicators

This paper links the marine typology shown in Table 1 to a number of indicators that can be used to *quantify* service provision (see Table 2). This quantification is an important step in the consideration of ESs in EBM and MSP because it can provide a first indication of the service importance in an area and it constitutes an important reference point for the monetary value of a marine ES which can be affected by planning and management.

The indicators presented here were derived from an extensive literature review of marine valuation studies. This literature review used valuation and ecosystem service-focused keyword searches in the *ISI Web of Knowledge* database through the end of 2011 and yielded more than 145 studies of note. For some services there seems to be a consensus on the indicator to use (such as is the case with *Sea Food*, *Raw Materials*, and *Climate Regulation*), for other services the measures applied to date appear rather diverse, (as is the case, for example, with *Waste Treatment* and *Coastal Erosion Prevention*). Studies on *Recreation and Leisure* have generated the greatest variety of indicators. The most frequently used measures are *number of trips* (e.g., angling, diving, boating and beach visit) (Agnello, 1989; Curtis, 2003; Blackwell, 2007; Rees et al., 2010; Souza and Ramos e Silva, 2011), *number of tourists in an area* (involved with particular activity, such as whale watching) (Beaumont et al., 2006; Ruijgrok et al., 2006; Ovetz, 2007; Lange and Jiddawi, 2009; Souza and Ramos e Silva, 2011) and *number of beach days or tourist days*[9] (Bell and Leeworthy, 1986; Brandolini, 2006; Moksness et al., 2011). Other measures included number of hotel rooms, catch rate of target fish species (for recreational fishing) or annual access days.

In order to apply this typology in the context of EBM and MSP, the importance of reflecting ecosystem state has been emphasized earlier. However, these above examples reveal that not all indicators used in the extant literature are actually sensitive to changes in ecosystem state but rather refer only to human activities that, in turn, may have some lag in their sensitivity to ecosystem state change. For example, decline in the marine fauna observed by divers, or the fish species targeted by anglers may not be noticed by people immediately, but instead may only be noticed after several years (at which point a decline in target species would influence the number of trips taken). This means it is possible for there to be a temporal disconnect between preferences, human behaviour and state change. Similarly, in the case of beach recreation (number of beach days), it is unclear whether this indicator is linked to ecosystem state at all unless it is possible to explain what visitors appreciate during their visits. This can be either the physical characteristics only (sand, waves, water) or biological features (e.g., collecting sea shells) and the opportunity to spot marine fauna or the cleanliness of water (without algal or jelly fish blooms) as well. These observations based on recreation and leisure indicators apply to other cultural services as well and have been indicated in Table 2 since it may be crucial to be aware of this issue when applying indicators of this type.

Indicators were lacking in the reviewed literature for eight ecosystem services including: *Sea Water*, *Genetic Resources*, *Ornamental Resources*, *Biological Control*, *Inspiration for Culture, Art and Design*, *Spiritual Experience*, *Information for Cognitive Development*. To address this gap, possible units are proposed here (Table 2). The identification of appropriate biophysical units of measure for each ES included in our typology is an important contribution to the usability of this typology.

The reviewed literature interestingly revealed that several studies, which valued ESs in monetary terms, described ESs qualitatively but did not apply respective indicators and were not explicit on the amount of a service provided (and valued). Without this quantification, an important reference point for the monetary value of an ES is missing and changes in ecosystem state cannot be (smoothly) translated into changes of benefits and values.

[9] Bell and Leeworthy (1986) assessed bundled services *Coastal Erosion Prevention, Recreation and Leisure, Aesthetic Information.*

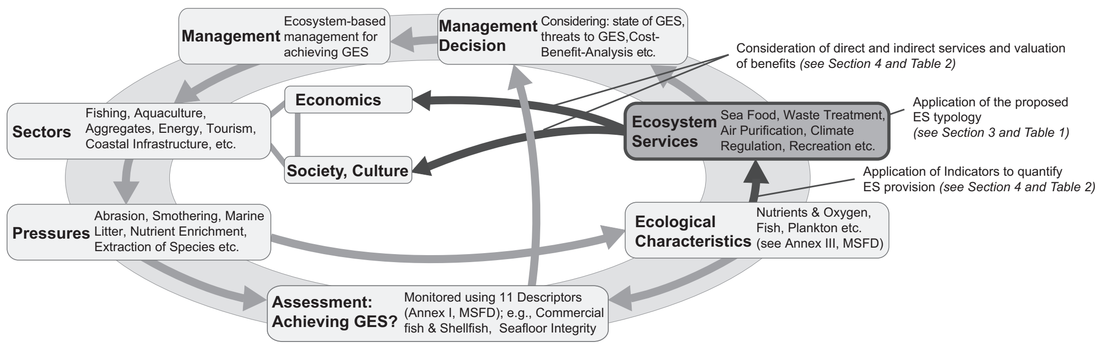

Fig. 2. ES assessments (dark grey box and arrows) within the management cycle for implementing the MSFD (Figure adapted from Koss et al. (2011)).

Additionally, this complicates the use of such monetary values for benefit transfer. We address this gap in several ways: (i) Designing the typology, only those ESs have been included whose provision is sensitive to ecosystem state (Section 2). (ii) For measuring changes in ESs, suitable indicators have been compiled (Table 2). (iii) For facilitating to identify further indicators, crucial issues are highlighted above (i.e., ecosystem state sensitivity, possible time lag in responding to ecosystem state).

This assists in linking ecosystem state changes with implications for human well-being and enables valuation study results for benefit transfer.

4.2. Linking ecosystem functions, ES and related benefits

The analyses presented in Sections 2 and 3 have been integrated into one comprehensive table (Table 2). This table provides for each ES the details essential to apply the proposed typology in EBM and MSP contexts (and beyond) and links consistently three different levels of the ESs cascade (Fig. 1), i.e. functions, services and benefits.

Starting at the function level, the indicators compiled (Table 2) assist in assessing the linkages between the ecosystem functions and services, and therefore between functions and quantity of ESs provided. For EBM and MSP contexts, these indicators help to translate the expected or observed changes in ecosystem state into changes in ES quantity and consequently, to estimate the impacts on human well-being (see Fig. 2).

The benefits derived from the ESs are identified in a further column of Table 2. This reveals that one ES can be associated with several related benefits which in turn can be valued. In the case of *Sea Food*, the benefits comprise for instance, nutrition, livelihood and the pleasure when enjoying its taste.

5. The application of the ecosystem services typology in ecosystem-based management and marine spatial planning

As discussed in Section 1, global marine policies are adopting EBM in order to achieve the improvement, restoration, or protection of coastal and marine ecosystems and their resources. This management approach often legislates for substantial ecological data collection and monitoring, and evaluates the achievement of environmental improvement in the context of ecological indicators. Simultaneously, the *feasibility* of individual management options, new policies, or other forms of human intervention in the environment is evaluated in relation to the financial input required and its impact on human welfare. This dichotomy often results in a fundamental disconnect between the overall goals of this type of legislation (i.e. environmental improvement/protection as assessed via ecological indicators) and the way in which individual efforts aiming to contribute to these goals are evaluated (i.e. through economic assessments of social welfare).

An illustrative example of this type of legislation is the EU's MSFD (Directive, 2008/56/EC of the European Parliament and of the Council) (for an example of a management cycle according to the MSFD see Fig. 2). Its objective is measured by the achievement of Good Environmental Status (GES) in Europe's regional seas for 11 high-level qualitative descriptors and measured by 17 ecological characteristics and 18 pressures and impacts (see Annexes I and III of Directive, 2008/56/EC). This in turn must be evaluated (and monitored) according to a series of criteria, indicators, and attributes (European Commission, 2010). The actions required to achieve ecologically-defined GES are largely left to member states to determine, but the MSFD mandates that proposed actions be subject to social and economic analysis. This legislation therefore demands dual decision-making based on both ecological and socio-economic analysis without giving clear priority to either, or based on an explicit link between them. The integration of ecosystem services in the MSFD implementation process can provide this link (see Fig. 2). As ecosystem services are grounded in ecology, they can be defined and measured using ecologically relevant units (see, for example, Luck et al. (2009) and Kontogianni et al. (2010)), and the proposed indicators in Table 2. The impact of sustainable management measures can be traced via changes in the ecological characteristics used for the assessment of GES through accompanying changes in the provision of ecosystem services as ecological entities. ESs are however also inherently economic in nature where changes in the ecological delivery of the ESs influences the benefits (i.e. welfare) received by society.

The marine ES typology specifically proposed in this paper is a tool that facilitates several steps within this management cycle (Fig. 2, dark grey box and arrows). Therefore, it facilitates the dual decision-making required to assist in achieving marine EBM and in implementing the MSFD in EU Member States.

6. Discussion and conclusions

The field of marine ESs is currently rapidly emerging. Our brief review of existing ES classifications (Section 2) reveals that an appropriately designed and marine-focused typology is lacking.

This paper highlights several aspects crucial for its application in EBM and MSP: The ESs considered here are clearly defined and delineated for being applicable and they are sensitive to ecosystem state for allowing any meaningful assessment in context of EBM and MSP (section 2 and 3). When applying our proposed typology, attention must be paid on the direct and indirect nature of ESs since this may mask ongoing changes in ecosystem state (section 3). Last, ESs are, just like different components of ecosystems, interconnected. These interdependencies (Box 1, Supplementary Material 1) are important to consider in ES assessments.

A further pre-requisite to marine ESs being effectively utilized in EBM and MSP-based decision-making is the quantification and valuation of marine ESs via a set of indicators that relates to human benefits. Our analysis found that the extant literature is patchy in this regard. Further research is therefore needed to better understand the nature of those ES that have so far received little formal attention by researchers. Absent this, it will be difficult to better forecast impacts on human well-being due to changes in ecosystem state.

Of interest is the review of several studies that valued ES in monetary terms without being explicit about *how much* of a particular service has been valued. Without this quantification, an important reference point for monetary value of a marine ES is missing, and the linkages between ecosystems and ESs are broken. Consequently, changes in ecosystem quality cannot be translated into changes of benefits and values, something that complicates the use of such monetary values for benefit transfer. Hence, identifying and testing suitable ES indicators, as well as their consistent application in valuation studies, requires attention in future marine ES research.

While some consider a comprehensive typology inappropriate, and instead favour individually created, context sensitive typologies (Fisher et al., 2009), we believe a common and comprehensive typology as proposed in this paper is both beneficial for, and appropriate in the context of EBM and MSP. A comprehensive typology can be seen as a reference list from which services relevant in an area can be selected for further assessment in MSP. A common typology can also facilitate comparisons between different EBM approaches and MSP case studies to improve the transferability of experiences and lessons learnt. Similarly, a common typology will also facilitate the primary economic valuation of ESs, and by extension, the improved valuation of ESs using the benefits transfer approach. In turn, this is important as benefits transfer is frequently applied in practice and is especially valuable when time and/or money are scarce. Additionally, policy makers often prefer benefits transfer over primary valuation due of resource constraints. In the absence of a common marine ES typology, each project developing its own typology with individual service definitions creates a situation in which benefits transfer is complicated or even unfeasible. Based on this rationale, the application of a common and agreed typology, with uniform ES definitions, is essential for large-scale EBM and MSP. This allows for consistency in the management and planning approaches across all involved nations and regions and reducing inconsistencies across the borders of different planning units.

The applications of integrated ecosystem assessments are increasing, specifically for countries where legislation stipulates the implementation of EBM to the management of marine ecosystems to mitigate degradation to our oceans and seas. As the field of ES research continues to grow and facilitate the link between the natural science, social and economics, governments are starting to recognize the importance and benefits of integrating ES in spatial planning and national environmental and economic accounting. This requires a consistent marine ES typology, indicators and tools for assessment at different spatial scales.

The typology proposed in this paper is comprehensive, consistent and application-oriented, and can serve as a framework for marine EBM and MSP (c.f. Section 3 and 5).

Acknowledgements

This typology has been developed as a contribution to the EU FP7 project ODEMM (Options for Delivering Ecosystem-based Marine Management, Grant agreement no. 244273; for more information see: http://www.liv.ac.uk/odemm/). The authors acknowledge the comments received from Leonie A. Robinson on Fig. 2 and from Elyse Walker regarding this typology and from the two anonymous reviewers on an earlier version of the manuscript.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2013.08.027.

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