Part III

Assessment of Major Ecosystem Services from the Marine Environment (Other than Provisioning Services)

Chapter 3. Scientific Understanding of Ecosystem Services

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1. Introduction to the concept of ecosystem services from oceans

Humanity has always drawn sustenance from the ocean through fishing, harvesting and trade. Today 44 per cent of the world's population lives on or within 150 kilometres from the coast (United Nations Atlas of Oceans). However this fundamental connection between nature and people has only very recently been incorporated into trans-disciplinary thinking on how we manage and account for the human benefits we get from nature. Today, when a product taken from an ecosystem[1], for example, fibres, timber or fish, enters the economic cycle (i.e., a part of the human system), it receives a monetary value that accounts at least for the costs associated with its extraction and mobilization. If that natural product is the result of cultivation, as in the case of agriculture, forestry and aquaculture, the monetary value also includes the production costs. However, the extraction of natural products and other human benefits from ecosystems has implicit costs of production and other ancillary costs associated with preserving the integrity of the natural production system itself. Traditionally these benefits and costs have been hidden within the "natural system," and are not accounted for financially; such hidden costs and benefits are considered "externalities" by neoclassical economists. While the neoclassical economic toolbox includes non-market valuation approaches, an ecosystem services approach emphasizes that 'price' is not equal to "value" and highlights human well-being, as a normative goal. The emergence and evolution of the ecosystem services concept offers an explicit attempt to better capture and reflect these hidden or unaccounted benefits and associated costs when the natural "production" system is negatively affected by human activities. The ecosystem services approach has proven to be very useful in the management of multi-sector processes and already informs many management and regulatory processes around the world (e.g. United Kingdom National Ecosystem Assessment, 2011).

Ecosystems, including marine ecosystems, provide services to people, which are life-sustaining and contribute to human health and well-being (Millennium Ecosystem

[1] Synonyms for 'ecosystems' in the literature are: natural systems, natural capital, nature, natural assets, ecological resources, natural resources, ecological infrastructure.

Assessment, 2005; de Groot, 2011). The Millennium Ecosystem Assessment defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" and goes on to define ecosystem services as "the benefits that humans obtain from ecosystems" (p. 27). This definition encompasses both the benefits people perceive and those benefits that are not perceived (van den Belt et al., 2011b). In other words, a benefit from ecosystems does not need to be explicitly perceived (or empirically quantified) to be considered relevant in an ecosystem services approach. Similarly, ecosystems and their processes and functions can be described in biophysical (and other) relationships whether or not humans benefit from them. Ecosystem services reflect the influence of these processes on society's wellbeing; including people's physical and mental well-being. While ecosystems provide services not only to people, the evaluations of services are, by definition anthropocentric.

The deliberate interlinking between human and natural systems is not new, but over the past few decades interest in "ecosystem services" as a concept has surged, with research and activities involving natural and social scientists, governments and businesses alike (Costanza et al., 1997; Daily, 1997; Braat and de Groot, 2012). This interest is in part driven by the growing recognition that the collective impact of humans on the earth is pushing against the biophysical limits of many ecosystems to sustain the well-being of humankind. Such pressures are well recognized (e.g., Halpern et al., 2008; Rockstrom et al., 2009) and are felt by pelagic, coastal, and intertidal ecosystems.

The human system – comprising built, human and social capital[2] –ultimately is fully dependent on natural capital. Ecosystems can exist without humans in them, but humans cannot survive without ecosystems. Therefore, the human system can usefully be considered as a sub-system of natural capital. An ecosystem services approach then becomes an organizing principle to make visible the relative contribution of natural capital toward the goal of human well-being. The use of such an organizing principle can be the basis for investments to maintain and enhance natural capital to ensure a flow of ecosystem services (Costanza et al., 2014).

Natural capital is the natural equivalent of the human-made agricultural and aquaculture production systems mentioned above (Daly and Cobb, 1989). In essence, natural capital refers to ecosystems (i.e., coastal shelves, kelp forests, mangroves, coral reefs and wetlands) as a network of natural production systems in the most fundamental sense. Humans with our many production systems are part of this natural capital and collectively have much to gain or lose from maintaining or neglecting, respectively, its sustainability.

The normative goal underpinning the ecosystem services concept is to maintain long-term sustainability, as well as local and immediate enhancement of human well-being within the carrying capacity of the biophysical system. To continue

[2] Built Capital refers to human-made infrastructure. Human Capital refers to the ability to deal with complex societal challenges, including education, institutions and health. Social Capital refers to the networks of relationships among people who live and work in a particular society, enabling that society to function effectively.

receiving a sustainable flow of ecosystem services, it is crucial to manage the scale of the human system relative to its natural capital base (Rockstrom et al., 2009). The ecosystem services approach acknowledges natural capital as the paradigm in which the human subsystem exists, highlighting (but not limiting to) the anthropocentric aspect of this concept (Costanza et al., 2014). At the same time the ecosystem services approach draws into decision-making the less visible aspects of sustainable development, such as supporting, regulating and cultural services. Through an ecosystem services approach, people, governments and businesses are increasingly using this approach as an organizing principle for finding new ways to invest their human, social and built capital in this common goal (Döring and Egelkraut, 2008).

The magnitude of human pressures on the earth's natural systems and acknowledgement of the interconnectedness between ecosystems and human sub-systems has revealed a need to transition from an emphasis on single-species or single-sector management to multi-sector, ecosystem-based management (TEEB, 2010a; Kelble et al., 2013) across multiple geographic (Costanza, 2008) and temporal (Shaw and Wlodarz, 2013) dimensions. Intensification of use of natural capital increases interactions between sectors and production systems that in turn increase the number of mutual impacts (i.e., externalities). This requires accountability among tradeoffs in a way that was, perhaps, not as necessary when the use of natural capital was less intense. On land, negative impacts can be partially managed or contained in space. However, in the ocean, due to its fluid nature, impacts may broadcast far from their site of origin and are more difficult to contain and manage. For example, there is only one Ocean when considering its role in climate change through the ecosystem service of "gas regulation".

An ecosystem services approach supports assessment and decision-making across land and seascapes; i.e., to consider benefits from ecosystems in natural, urban, rural, agricultural, coastal and marine environments in an integrated way, and ultimately to understand the potential and nature of tradeoffs among services given different management actions. An example derived from Food and Agriculture Organization (FAO) states that 50 billion United States dollars is lost annually from global income derived from marine fisheries, compared to a more sustainable fishing, due to fish stocks over-exploitation, when viewed through an ecosystem services lens (FAO, 2012).

Principles for sustainable governance of oceans[3] are straightforward (Costanza et al., 1998; Crowder et al., 2008,), but use of an ecosystem services approach has the potential to provide a basis for collaborative investments (in monetary or governance efforts), based on common ground and shared values. In other words,

[3] 'Lisbon' Principles for Sustainable Development of Oceans: 1) Responsibility: ability to respond to social and ecological goals. 2) Scale-matching: ensuring flow of ecological and social information allows for timely and appropriate action across scales. 3) Precaution: in the face of uncertainty about potentially irreversible ecological impacts, decisions about natural capital err on the side of precaution. The burden of proof shifts to those whose activities potentially damage natural capital. 4) Adaptive management: decision-makers collect and integrate socio-cultural-economic-ecological information, adapting their decisions accordingly. 5) Full-cost accounting: where appropriate, external costs allow markets to reflect full costs.6) Participation: foster stakeholder awareness and collaboration.

the ecosystem services approach has the potential to provide a new "currency" or organizing principle to consider multi-scale and cross-sectoral synergies and tradeoffs.

Several recently developed and evolving frameworks outline an ecosystem services approach and its underlying connection between natural and human systems. Although the essence of the ecosystem services concept is the dependence of human well-being on ecosystems, there are diverse definitions of the concept, reflecting differing worldviews on how human systems relate to ecosystems. For example, ecological economists emphasize that human societies are a sub-set of ecosystems and as a consequence assume limited substitutability between built/manufactured and natural capital (Daly and Farley, 2004; van den Belt 2011a; Braat and de Groot, 2012; Farley, 2012). Some definitions of ecosystem services emphasize the functional aspects of ecosystems from which people derive benefits (Costanza et al., 1997; Daily, 1997) and others put more exphasis on their utilitarian aspects and seek conformity with economic accounting (Boyd and Banzhaf, 2007; United Nations Statistics Division, 2013). Still others emphasize human health and well-being (Fisher et al., 2009) and values (TEEB, 2010a).

The ecosystem services approach aims to address and make explicit the inherent complexity of the coupling between biophysical and human systems. For example, it allows regulating ecosystem services at a global scale, such as climate regulation and sea level rise, to be integrated into local decision-making (Berry and Bendor, 2015). An important point here is that though climate change is perceived as a broadly global phenomenon, its impacts will be local, depending on a host of local/regional drivers that will interact with global climate changes. This means that assessments of natural capital and ecosystem services are best done at multiple scales. At the same time, integration across and between regions is essential to ensure shared best practices, agreed protocols and data-access policies, etc. This is an important function for governance at the global level.

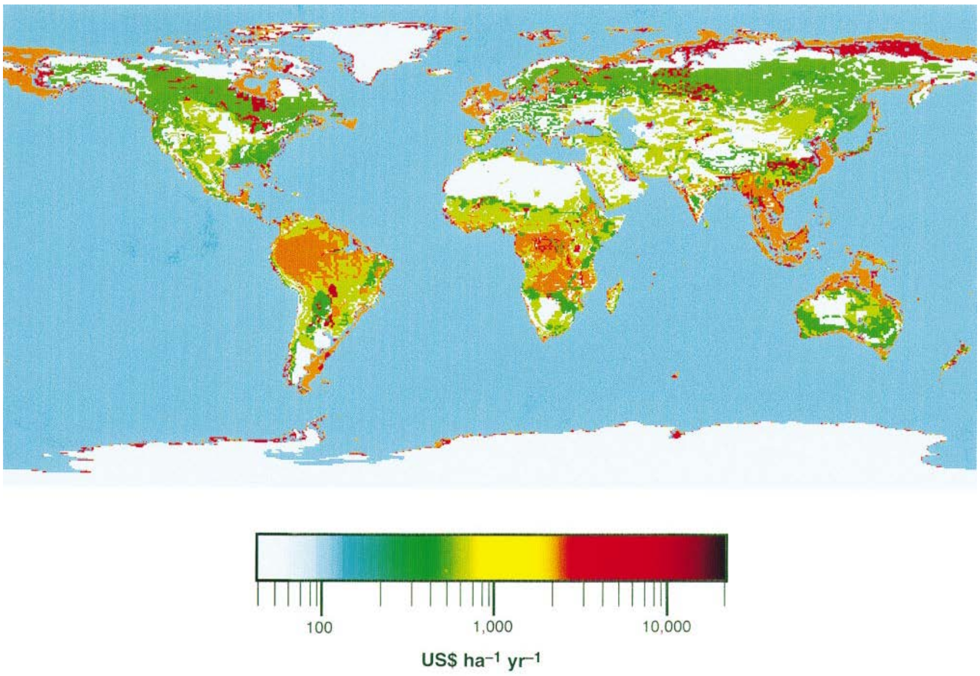
The ecosystem services approach has been embraced by different fields and perspectives. For example, those concerned with biodiversity (e.g., TEEB, 2009; TEEB, 2010a; TEEB, 2010b; TEEB, 2010c; Intergovernmental Panel for Biodiversity and Ecosystem Services-IPBES) and climate change (e.g., Intergovernmental Panel for Climate Change-IPCC) have generally aligned themselves with this approach. Many international organizations (e.g., United Nations, World Bank, the Organization for Economic Cooperation and Development (OECD), The Nature Conservancy, International Union for the Conservation of Nature(IUCN), FAO), governments (e.g., European Union, United Kingdom, United States of America), and increasingly companies (e.g., Dow Chemical and potentially those connected to the World Oceans Council) are collaborating to explore the potential for efficient and effective decision-making offered by an ecosystem services approach. An example of intergovernmental collaboration on ecosystem services is the Group on Earth Observations (GEO)[4] and particularly GEO's Biodiversity Network (GEO BON), a voluntary partnership among intergovernmental, non-governmental and governmental organizations (www.earthobservations.org/geobon). The

[4] GEO, the Group on Earth Observations has today 89 member states and the European Commission.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) enhances this integration effort at sub-regional, regional and global levels (Larigauderie and Mooney, 2010; www.ipbes.net).

Although the concept has achieved broad acceptance, caution is needed in implementing ecosystem services approaches to avoid a simplistic or biased commodification of ecosystems that prioritizes some elements of nature that are economically useful to the detriment of overall ongoing preservation of those ecosystems for their intrinsic value. An unbalanced approach focused primarily on assigning monetary values can exacerbate power asymmetries and increase socio-ecological conflicts (e.g., Beymer-Farris and Bassett, 2012). Giving equal focus to non-market/non-use services within the ecosystem services framework is both a desirable approach and a strength of this method for decision-making (Chan et al., 2012). When ecosystem services are approached as an organizing principle, this includes the development of common units of measurement for decision support, beyond application of existing tools in the natural and social science toolboxes. It needs to be acknowledged that we don't, and may never, fully understand social-ecological systems to the point that people can confidently predict changes and impact or 'optimize' these systems. A precautionary stance regarding management and governance for maintenance of resilience of social-ecological systems is highlighted (Bigagli, 2015).

The ecosystem services approach gained momentum in the late 1990s, when monetary values associated with ecosystem services from natural capital were conservatively estimated (at a rate double that of global Gross Domestic Product (GDP) to highlight the potential economic and societal value of previously unvalued ecosystem services (Costanza et al., 1997). These values were globally expressed with a single spatial dimension, a snapshot of which is shown in Figure 1. These values only provided a starting point of a necessary debate, as they relied on many and generally conservative assumptions about how to, in a broader sense, value services globally. Although they expressed these services in monetary values, the authors did not claim that these services were suitable for exchange in the market system (Costanza et al., 1997). A recent re-assessment of these global values indicated that the values of global ecosystem services have increased with additional studies on ecosystem services, but these values simultaneously have decreased where natural capital has been converted to other types of capital (Costanza et al., 2014).



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1. Global map of values of estimated ecosystem services in 1997. Source: Costanza et al., 1997.

An ecosystem services approach certainly isn’t without controversy and critique is offered by neoclassical economists and ecologists (McCauley, 2006), albeit for different reasons. Some critiques of an ecosystem services approach are highlighting the utilitarian manner in which this approach has been implemented (Wegner and Pascual, 2011; Bscher et al., 2012). Ecosystem services, or "nature's benefits" provide a strengths-based, organizing principle to more deliberately and systematically consider the contributions biophysical communities (including biodiversity and habitat) provide to human well-being (including health). A weak application of an ecosystem services approach builds on traditional natural resource management tools by considering a broader appreciation of the advantages provided by natural systems to include social, economic, health and ecological benefits. This approach is then used to analyze, in more detail, aspects of ecosystem services currently considered externalities and builds upon natural resource management strategies of the 20th century. This may incrementally expand the quality and quantity of relevant indicators considered when making decisions about tradeoffs. In a strong application of an ecosystem services approach, it can be used to synthesize systemic aspects of managing the human sub-system *within* an ecosystem. A strong application of an ecosystem services approach requires the design of tools and skill sets suitable to support multi-faceted management and governance strategies fit for the 21st century.

The Millennium Ecosystem Assessment (2005) classified ecosystem services as: provisioning services (e.g., food – including food traded in formal markets and subsistence trade and barter -, pharmaceutical compounds, building material); regulating services (e.g., climate regulation, moderation of extreme events, waste treatment, erosion protection, maintaining populations of species); supporting services (e.g., nutrient cycling, primary production) and cultural services (e.g., spiritual experience, recreation, information for cognitive development, aesthetics).

Supporting services are often considered at an ‘intermediate’ level as support functions toward “final ecosystem services” (Landers and Nahlik, 2013). While the intermediate nature of supporting services makes accounting more challenging, i.e. avoiding double counting, it is also important to acknowledge the “unaccountable”’ characteristics of ecosystems for three reasons. First, the complexity of ecosystems is such that applying accounting practices modelled in accordance with traditional economic accounting is often both impossible and inappropriate. In other words, while economic activities can be aggregated to a certain extent[5], attributes of ecosystems and their functions do not lend themselves well to aggregation. Second, supporting services or support functions underlie all other services (e.g., provisioning and cultural services are made available in part by supporting services). Third, supporting services are often considered to be most important from cultural and spiritual perspectives, which have their own specific value (Chan et al 2012).

Scientific publications concerning ecosystem services have grown exponentially since the late 1990s. As shown in Figure 2, the marine and coastal ecosystem services (MCES) literature is no exception. Liquete et al. (2013) recently categorized 145 articles on the current status of MCES.

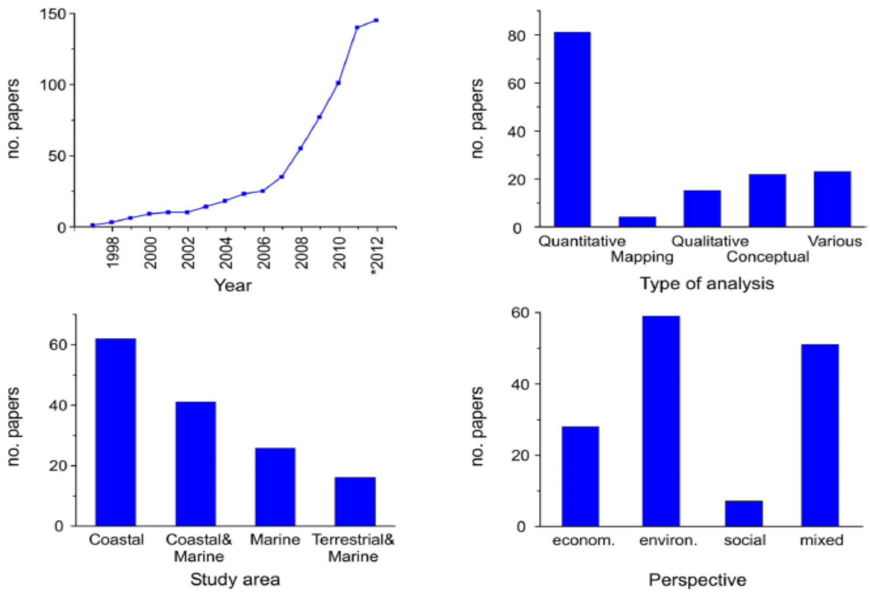


Figure 2. Data and analysis from 145 MCES assessments by Liquete et al. (2013). A. Number of publications per year. *The year 2012 covers 1 January to 4 April. B. Number of studies per type of analysis. C. Number of papers per type of environment analyzed. D. Number of publications per scientific discipline.

The analysis by Liquete et al. (2013) found that most of the MCES case studies they reviewed: 1) were concentrated in Europe and North America; 2) did not cover the

[5] The System of National Accounts does not account for everything either.

area beyond the continental shelf edge, with benthic habitats generally lacking, and 3) focused on mangroves for supporting and provisioning services and on coastal wetlands for regulating and supporting services. A primary focus on local or regional geographic location raises a concern for MCES, as biophysical events and conditions are generated further afield. For example, patterns of upwelling and migratory species will be influenced by benthic and oceanic conditions that might occur at some distance from the affected region and thus will be difficult to predict. As in other domains, decision-makers have to make decisions under conditions of high uncertainty with limited ability to conclusively consider all risks. An ecosystem services approach has the advantage of making visible the non-linear behaviour[6] of ecosystems and draw attention in decision-making to fundamentally different alternatives (Barbier et al., 2008). Such alternatives may lead to synergies (i.e., shared values across sectors as a basis for social-ecological enterprises and poverty alleviation) or to difficult trade-offs between different uses or user groups. A valuation spectrum should include "all that is important to people", whether the people themselves perceive this or not (van den Belt et al., 2011b) and regardless of whether the value is monetary, spiritual, cultural, or otherwise.

2. Evolving ecosystem services frameworks, principles and methods

An overview follows of accepted typologies, principles and methods currently used for assessing and measuring ecosystem services in the rapidly growing international literature. Although concepts and methodologies show a consistent pattern in local applications, no generally accepted classification of ecosystem goods and services for global accounting purposes exists (Haines-Young and Potschin, 2010; Böhnke-Henrichs et al., 2013). The complexity of such a task requires a pluralistic approach across temporal and spatial scales to make ecosystem services visible in decision-making processes and to decision-makers. Capabilities for temporal and spatial analyses are evolving rapidly (e.g. Altman et al., 2014). These now enable decision support and the use of an ecosystem services approach at local, regional, national and global scales (e.g. Zurlini et al., 2014). However, consistency across scales and across terrestrial and marine environments has not been achieved. This is often highlighted as a research, policy and management priority (Braat and de Groot, 2012). For example, the Ecosystem Service Partnership (ESP) (www.es-partnership.org) attracts scientists and practitioners working with the ecosystem services concept in a self-organizing manner. The ESP website allows the assessment of ecosystem services through the various themes, geographic locations and biomes. The themes (Table 1) provide a good overview of the variety of methods and tools and required skills through which the ecosystem services concept can be viewed. Associated with ESP, the Marine Ecosystem Services Partnership (http://marineecosystemservices.org/) features a library of valuation-oriented literature, organized by ecosystem, on the delivery of ecosystem services and offering interconnection with other databases (see Appendix 2 for an overview of

[6] Non-linear behaviour refers to the characteristic of complex systems where effects are not proportional to their causes.

relevant databases). Currently organized by country, further analyses of scale addressed by the valuation studies included may help progress toward a multi-scale approach. For example, completion of Table 1 for marine ecosystem services could be very useful for a future second United Nations World Ocean Assessment.

Table 1. Overview of thematic working groups of the Ecosystem Service Partnership (ESP), which would be useful to complete for a subsequent World Oceans Assessment.

Thematic working groups of ESP	**Biomes**	**Scale**
1. Ecosystem services assessment frameworks and typologies		
2. Biodiversity and ecosystem services		
3. Ecosystem service indicators		
4. Mapping ecosystem services		
5. Modeling ecosystem services		
6. Valuation of ecosystem services 6A. Cultural services and values 6B. Ecosystem services and public health 6C. Economic and monetary valuation 6D. Value integration		
7. Ecosystem services in trade-off analysis and project evaluation		
8. Ecosystem services and disaster-risk reduction		
9. Application of ecosystem services in planning and management 9A. Restoring ecosystems and their services		
10. Co-investment and reward mechanisms for ecosystem services 10A. Ecosystem services and poverty alleviation		
11. Ecosystem service accounting and greening the economy		
12. Governance and institutional aspects		

The Economics of Ecosystems and Biodiversity (TEEB) started as a UNEP project (2007 – 2010) initiated by the G8. This resulted in the promotion of steps toward the management of values that people derive from ecosystems (Figure 3). In essence, the TEEB framework clusters and links the ESP themes into a process suitable for decision support for projects, governments and businesses (TEEB, 2010b). This process is then ideally implemented systemically, with appropriate feedback mechanisms for on-going assessments of all aspects involved at multiple scales.

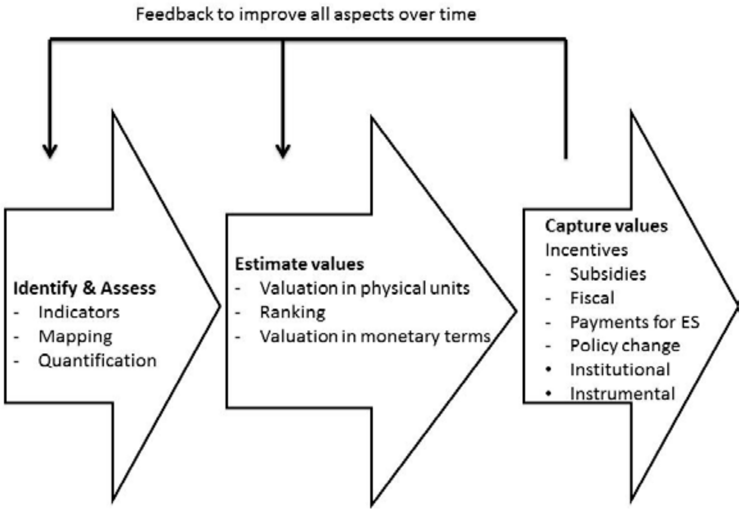


Figure 3. Process of ecosystem service assessments based on TEEB, redrawn after Hendriks et al., 2012.

2.1 The flow of ecosystem services

For this introductory chapter on ecosystem services, however, we elaborate on the cascading Haines-Young and Potschin (2010) framework. This framework is relevant because of its close alignment with the evolving United Nations System of Environmental-Economic Accounting (United Nations Statistics Division, 2013) and its effort to seek a consistent classification system and set of accounting principles (Boyd and Banzhaf, 2007; Landers and Nahlik, 2013).

Conceptual models, such as the Common International Classification of Ecosystem Goods and Services (CICES) (Haines-Young and Potschin, 2010), enable practitioners to differentiate between natural capital, i.e., the natural resources or ecological infrastructure, and the services that are derived from that infrastructure. This is presented in a framework cascading from biome to function/process, service, benefit and value (Figure 4). This framework is influenced by two perspectives: 1) the desire to account for ecosystem services and avoid double counting by economists and 2) an opportunity for natural scientists to rapidly communicate the value of particular ecological structures and processes. When applying this framework, supporting and cultural ecosystem services are easily ignored, as non-market[7] values are at best considered at the end of the cascade and more often are not considered at all; and the flow of ecosystem services is portrayed as linear or unidirectional, mimicking a production chain, and implies a “trickling down” from natural capital to value for people, whose task it is to perceive this value. Appreciated for its simplicity, this framework relies, in theory, on coherent and collective policy action to correct cumulative pressures when values are perceived. This feedback requires active

[7] In a weak application of an ecosystem services approach, cultural services are often limited to a monetary equivalent of 'recreation'. In a stronger application of this approach spiritual connections, sense of place and mental well-being are recognized. Social sciences contribute a myriad of tools to appreciate such values (e.g. (Pike et al.,, 2014).

management to allow natural capital to function and provide essential services and benefits, whether people perceive such values or not. This framework shows similarities to the DPSIR (Driver-Pressure-State-Impact-Response[8]) framework. In comparison, the U.S. EPA draft classification system for Final Ecosystem Goods and Services (FEGS-CS) attempts to provide a categorization of beneficiaries and assist in tracking changes in ecosystem services upon those beneficiaries (Landers and Nahlik, 2013).

Economists often use the term 'ecosystem goods and services', in part to seek comparability and consistency with the System of National Accounting (United Nations Statistics Division, 2013). It is important to recognize that the provision of ecosystem goods and services relies on the integrity of ecosystem processes and functions, referred to as regulating and supporting ecosystem services, with characteristics that make them less than suitable for rigorous accounting (Farley, 2012). Disparate disciplinary perspectives occur in the context of applying an ecosystem services approach; e.g., economists appreciate an ability to account for outputs and optimization of the 'production process', whether it is human- or nature-made, whereas ecologists tend to resist such a linear accounting of ecosystems as inaccurate because ecosystems are 'complex systems', with highly non-linear behaviours, and simplifying these complexities can lead to misrepresentation of management needs required to maintain valued services.

Following the steps of this cascading framework, marine ecological infrastructure includes (but are not limited to) biophysical structures, e.g., the open ocean, continental shelves, coral reefs, kelp forests, seagrass beds, mangroves, salt marshes, rocky intertidal and subtidal zones, sand dunes and beaches. These are ecological systems and the associated structures created by biological and physical processes, e.g., primary production, wave generation, and decomposition of organic matter. Ecosystem functions and processes emphasize the potential capacity of natural capital to deliver an ecosystem service, which includes resource functions (e.g., mineral deposits and deep-sea fish), sink capacity (e.g., the ability to absorb, dilute or keep out of sight unwanted by-products) and service functions (e.g., habitat to support biodiversity, wave attenuation, degradation of organic matter). [9]

This flow from biophysical structures to functions and processes to ecosystem services is labelled the "supply of ecosystem services" (Figure 4). Ecosystem services also provide benefits (such as, air to breathe, water to drink, fish to eat, sustenance of marine life, energy to harness from wave/wind/tidal/thermal power, health, safety and increased human well-being). Because these benefits are essential for

[8] DPSIR: Drivers-Pressures-State-Impact-Response generally focusses on impacts as in costs rather than on the benefits people derive from ecosystems. Another difference is that the 'State' in DPSIR has a biophysical focus, whereas in the ES framework, the 'State' of the human dimension is equally important. (Kelble et al., 2013).

[9] Some scholars (e.g., Aronson et al., 2007) separate natural capital into renewable natural capital (living species and ecosystems); non-renewable natural capital (subsoil assets, e.g., petroleum, coal, diamonds); replenishable natural capital (e.g., the atmosphere); and cultivated natural capital (e.g., aquaculture).

human well-being, a market or non-market value[10] can, in some cases, be placed on these ecosystem services. This is part of the cascade labelled 'demand for ecosystem services'.

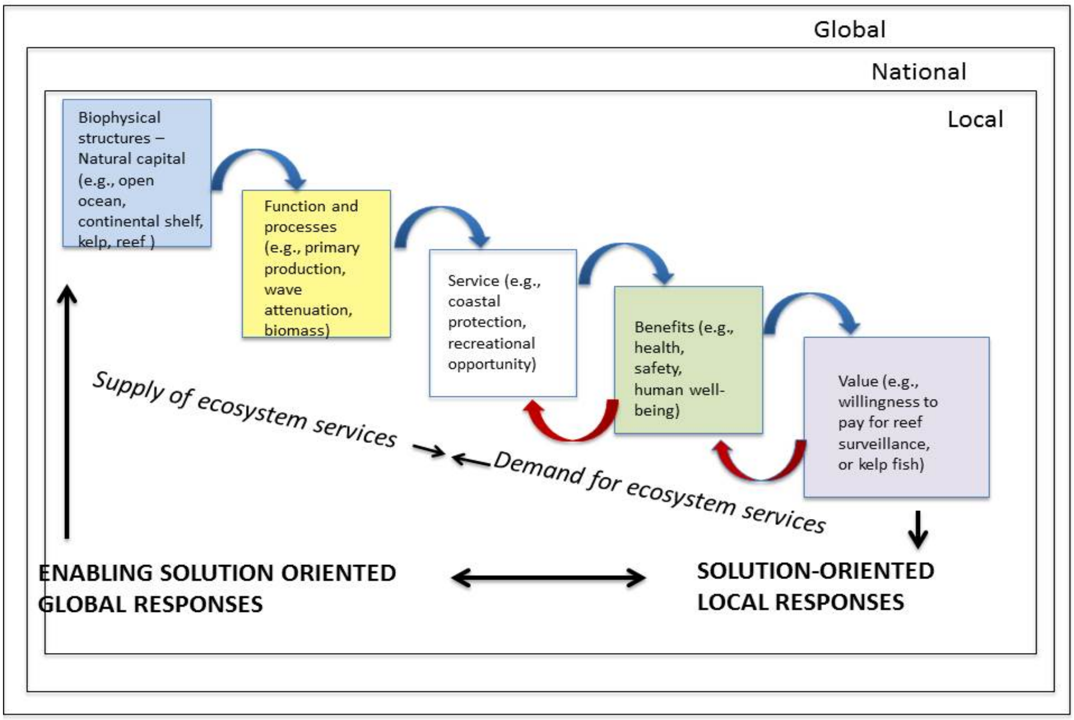


Figure 4. The flow of ecosystem services at multiple scales. Adapted from Haines-Young and Potschin (2010. While not a part of the original model, we added and highlight the 'supply of and demand for ecosystem services' and the gap between 'supply and demand', signalling a shortage or abundance of ecosystem services. This is one basis for establishing 'value' in a broader sense.

In essence, the flow diagram has two fundamental purposes: (1) identifying the ecological processes required to attain ecosystem services; and (2) developing the ability to account more rigorously for this natural 'production system', particularly at a global level. At this analytical level, the ecosystem services concept effectively reveals and communicates the 'invisible' biophysical processes and functions and thereby broadens, guides and informs local decision alternatives and scenarios. This is not a uni-directional flow - the 'cascading production chain' (as shown in Figure 4) also requires attention for reverse processes taking 'values' in a broad pluralistic sense, as a starting point, to collectively develop solutions (Haines-Young and Potschin, 2010; van den Belt, 2014; Maes et al., 2012; Tallis et al., 2012). Understanding this flow of ecosystem services at multiple scales, top-down and bottom-up, facilitates practical local solution-oriented responses, enabled by global guidance.

Sometimes a limited set of ecosystem services can be locally managed for short-term benefits, whereas other ecosystem services have globalized characteristics and/or

[10] Market and non-market values are sometimes also referred to as use or non-use values or as instrumental and intrinsic values.

have longer-term benefits. Therefore, this approach has the potential to effectively connect mutual or competing interests at local to global scales and facilitate cohesive decision support. Given that the ecosystem services approach is an inherently anthropocentric concept and is context-dependent, any value attributed to ecosystem services is not absolute and depends on the supply of (i.e., how much of a service is available, if it is limiting) and demand for the service (i.e., how much people need or want a service). A 'gap' between supply and demand of ecosystem services indicates a shortage or abundance (Figure 4). The gap varies temporally and spatially, per societal sector, and by the political scale of the perspective (i.e., local, regional, or global). When an abundant supply of ecosystem services exists relative to demand, the governance or management requirement is primarily one of monitoring. A shortage of supply of ecosystem services, relative to demand, makes the necessity of effective governance and management more acute (see also 'time preference' below) - quality and efficiency of delivery of ecosystem service need to be considered. Supply and demand are dynamically interconnected and therefore employment of methodologies beyond market-based theories is crucial.

2.2 Biophysical supply of ecosystem services

Any assessment of ecosystem services must begin with natural capital. The natural system encompasses species present, the flows of matter and energy to which these species contribute, their functional attributes, and the interactions with the physical environment that serve to enhance or dampen the functional attributes and processes. This may require principles and practical guidelines codifying simplification schemes (e.g., Townsend et al., 2011), as science will not be able to provide all of the answers in the time needed to develop management responses. An assessment of natural capital in marine systems should include the distribution and level of ecosystem services in relation to space and time, so that changes in ecosystem services may be better understood following different management practices and proximity to tipping points of marine ecosystems (MacDiarmid et al, 2013; Townsend and Thrush, 2010).

Assessing the supply of ecosystem services in practice requires a process similar to the generic TEEB approach highlighted in Figure 3. First, one must define, as specifically as possible, how an ecosystem function or process of interest connects to specific human benefits of interest and exactly which aspects of a species or ecosystem structure are connected to that function. Developing such a conceptual model following ecological principles (Foley et al., 2010) is important because, for example, a single species can provide more than one function, and different attributes or processes of the species may be more or less important for (a) particular service(s) of interest. For example, mangrove forests provide coastal protection, carbon storage, nursery habitat, and wood, among other services, and these services are provided primarily by the density of above-ground biomass, below-ground biomass, submerged root structures, and the absolute amount of above-water/ground biomass, respectively. Mangroves can provide bundles of ecosystem services, which are inter-related to each other. Measurements require knowledge of such bundles and how they occur at multiple spatial scales over which their benefits are conferred (Costanza, 2008).

The second step is to develop a model describing how the biophysical system produces or inhibits production of the metric of interest, and which key drivers modify that production. This step corresponds to step 1 in Figure 3. In the mangrove example above, if we are interested in the coastal protection function of mangrove forests and thus the above-ground density of the woody biomass, we ideally would have or develop a mangrove growth model that could predict how wave height and intensity, sunlight, rainfall, sedimentation, etc., affect production, and especially the inter-plant density, of the woody biomass. In order to do this modelling, for all potential functions (and services) of interest, one can draw on or develop species-specific population models coupled with ecosystem dynamics models, although the parameters of the model may vary spatially and temporally. Once in place, these models then permit relatively simple sensitivity analyses that identify key drivers of change in the metric of interest.

Such models are always challenged by the availability of data, particularly in many developing countries. Thus, model development must proceed hand-in-hand with data discovery and, where possible, data-gap filling, so that models are tailored to the scale, resolution, and complexity of the data available for a region (Figure 5). Typically useful data include physical data on sea level, pH, temperature and wave height and intensity, and biological data on the demographics, densities, dispersal, and trophic dynamics of species. Although the data needs are similar at a global level across the major oceans, these data will vary by locale and temporally (sometimes seasonally). Availability of data and scientific understanding to properly paramatize such models in particular, depends on scale and differs between regions. Local/regional data for marine ecosystem services assessments are generally much more available for counties including, but not limited to Europe, North America, Australia/New Zealand, and Japan, and are very poor in most of Africa, Asia, and Latin America. A complete world assessment of ecosystem services is beyond the scope of this Assessment, but would ideally be undertaken for a future assessment.

The final step in the process of assessing the supply of ecosystem services is to map and monitor the modelled or empirically derived values for the metrics of interest (step 2 in Figure 3) and the communication thereof (step 3 in Figure 3). Mapping and modelling are inherently constrained by the spatial resolution of the input data for the models described above. Without such maps, one cannot say from *where* within a region of interest the supply of and demand for the service is actually coming, and thus managers are left to make decisions about how to maintain or improve the supply, in order to meet demand, at the coarsest scale of assessment (for example, for an entire country). Such coarse-scale decision-making may be appropriate, and in fact is often all that is needed for many decision contexts that occur at a scoping level. Scoping is the process used to identify the key issues of concern at an early stage in any planning process. Scoping should be carried out at an early stage to facilitate strategic planning and reporting. However, when management is using an ecosystem services framework to make smaller-scale decisions, such as designation of Marine Protected Areas, issuing permits for offshore mining, oil or wind-energy installations, and offshore aquaculture installations, then more detailed maps of service supply are critical.

Numerous examples of both types of decision-making exist. On the one hand is the more general, coarse-scale, often data-poor heuristic assessment, where decision-makers are primarily interested in whether service supply will go up, stay constant, or decline under a given management action. For example, model-building, including indigenous stakeholders, can be used to scope for changes over time in ecosystem service values in a non-spatial manner (van den Belt et al., 2012). On the other hand, more specific, finer-scale, often data-rich quantitative scenario development requires detailed assessments of who wins and loses under a given management action, and by how much, when and where. Examples include decisions on wave energy (Kim et al., 2012) and offshore aquaculture facility locations (Buck et al., 2004), considering specific tradeoffs.

At local and regional scales, often considerable but incomplete data are available, to make visible the biophysical supply of ecosystem services. Fundamental to such efforts are sufficient data to map the location and interaction of key biophysical attributes (such as wave energy, ocean temperature, species density and composition, quality and health of those species, etc.), and for some places around the world such data exist. However, for many regions of the world such data do not exist or are extremely limited, constraining the ability to produce precise global, regional and local estimates of the supply of and demand for ecosystem services. A detailed assessment of the most limiting data gaps between regions is a highly desirable study to be conducted before a second United Nations World Ocean Assessment. The ability to map and monitor key areas for ecosystem service supply is crucial for the development of scenarios and strategies to ensure future supply (Burkhard et al., 2012; Maes et al., 2012a; Maes et al., 2012b; Martinez-Harms and Balvanera, 2012). Furthermore, more complete data sets can be achieved through complementary strategies including baseline assessments in key ecosystems and/or in-depth pilot research efforts that can support model development for extrapolation to similar habitats/ecosystems.

The provisioning of ecosystem services depends not only on the presence of biophysical structure and processes, but the condition (intact vs. degraded) and, in some cases, temporal variability (e.g., seasonal variability in the density or height of seagrasses or kelps, or variability in storm-driven waves). To determine the quantity of an ecosystem service, one must identify the spatial scale (local, regional, global) and temporal scale (short- to long-term) of both supply and demand (also illustrated in Figure 4). A mismatch often exists between the data available on supply *versus* demand due to the variability in spatial provisioning and jurisdictional disconnects between supply and demand and the corresponding data available. For example, global studies often draw on low-resolution, remotely sensed data on a global scale, whereas local studies draw on higher-resolution data on a smaller spatial scale. This difference in data quality and spatial extent can lead to different conclusions on the quantity and quality of service provisioning available and the need to handle differences and uncertainty with care. Nevertheless, considering this 'mismatch' of data and information available to assess a gap between supply and demand of ecosystem services is an important move toward broadening the notion of value away from narrow commodification of ecosystem services.

Of particular importance is the multi-scale aspect of the ecosystem services approach, as it provides an invitation to consider a connection between local and global scales at different temporal/seasonal intervals (Costanza, 2008). Some ecosystem services are produced and consumed *in situ* (e.g., coastal protection), whereas others have clear global aspects (e.g., carbon sequestration, climate regulation, biodiversity, global fisheries and mineral extraction). Certain services are primarily seasonal (e.g., coastal protection), and others are provided or utilized year-round (e.g., food provision).

2.3 Demand for ecosystem services

The 'Benefits' and "Value' steps in the cascading framework (Figure 4) represent the 'demand for ecosystem services' and indicate where drivers of management and decision-making can be incorporated. The perception of values and benefits sets the context when determining the 'supply of ecosystem services'. Therefore, it is important to consider demand for ecosystem services through at least two lenses: (1) demand, as identified by market-based, economic sectors (as defined in the United Nations System of National Accounts); and (2) demand from non-market sectors or societal groups, including 'needs' and 'wants', whether perceived by people or not. Therefore, value statements, if perceived, are bi-directional and can be viewed as "trickling down" through Total Economic Values and/or "trickling up" through participatory involvement of local communities.

Although the biophysical knowledge of the *supply of ecosystems services* is progressing, the understanding and visibility of socio-cultural-health-economic benefits from ecosystems (i.e., the understanding of the *demand for ecosystem benefits*) remain fragmented and are lagging behind, especially for oceans. One difficulty in profiling demand is partly due to the vast geographic scope and overall *invisibility* of supporting and regulating ecosystem services. Demand for ecosystem services is frequently assessed based on diverse rationales, such as risk reduction, revealed preferences, direct use or consumption of goods and services (Wolff et al, 2015). Also, the relative importance of these ecosystem services is often locally perceived by non-market sectors, especially through diverse cultural perspectives. As a result, management and decision-making frequently prioritize quantifiable ecosystem services (e.g., provisioning services). This prioritization of provisioning services often occurs to the exclusion or detriment of supporting and regulating services. On the other hand, cultural services are frequently highlighted together with provisioning services, as indigenous livelihoods are often tightly coupled to provisioning services as part of cultural services.

As a consequence, in any comprehensive process of ecosystem services valuation, it will be necessary to utilize both monetary and non-monetary valuations, as befits the spatial and temporal characteristics of each ecosystem service. When classical economic theory addresses "market failures", it resorts to the following distinctions:

- A *rival good* declines in abundance as it is consumed or used, e.g., when one fishing boat catches a fish, the same fish cannot be caught be another boat.

- *Non-rival goods* can be used by many without being 'used up', e.g., one and the same fish can be admired by multiple divers, or clean coastal waters can be available.
- A good is *excludable* if the use of it can be prevented, e.g., one needs permission to drill for minerals in the Exclusive Economic Zone.
- A *non-excludable good* is freely accessible to all, e.g. Storm protection provided by mangroves, seagrasses and reefs and dunes.

Most provisioning goods are 'rival and excludable' and therefore more suitable for valuation through markets, (e.g., fisheries in an Exclusive Economic Zone). However, some provisioning services are 'rival but non-excludable' (e.g., fisheries outside of Exclusive Economic Zones). Depending on place, some non-rival, excludable goods can be enjoyed by those who can afford them; these include some recreational and research services. Most regulatory and cultural services are non-rival and non-excludable, such as the existence of diverse marine life or practically, whale-watching from shores. Based on these characteristics, it is generally inappropriate and unconventional to value non-rival and/or non-excludable ecosystem services using market mechanisms. Even non-market valuation approaches have severe limitations in this realm, which requires socio-political and institutional considerations. Hence, processes to support "trickling up" of local demand for ecosystem services become increasingly important, preferably supported by appropriate data and an ability to integrate and make these data visible.

Some basic global data is available that can be used for the socio-economic component of assessments based on ecosystem services, such as revenue from coastal and marine related economic sectors. Jobs related to coastal and marine related economic sectors - and cultural values related to culturally important species - may be available at regional level in some places, but are less available in other places. Until the multiple ecosystem services, their interconnections and tradeoffs between different sectors are more accurately recognized and at least semi-quantified in the decision-making sphere, full inclusion of all available global databases is beyond the scope of this first assessment. However, the distinction between markets and other interests, resolution, geographic spread and ease of access are important characteristics of any evolving framework of data sets. 'Scale' sets the direct context for any situation where an ecosystem services approach is envisioned, used and under improvement. The ecosystem services approach has the ability to effectively communicate land-sea connectivity and tradeoffs associated with a variety of ocean- and land-based human uses, economic sectors, stakeholders and governance (Butler et al., 2013). In such an analysis, costs (e.g., due to a loss of ecosystem services, often expressed in indirect values) and benefits (e.g., due to a monetary or non-monetary gain in direct or indirect values) are incurred by different groups over different time scales.

Data on ecosystem services and their valuation for specific case studies are often re-used for similar case studies in different locations, because local data collection and analysis are expensive and require specific skills in non-market analysis. Such 'benefits transfer' approaches to valuation can be controversial because they require assumptions about similarities among regions that are often inaccurate, but they remain a powerful and necessary approach to filling data gaps, when used with caution. Table 2 provides a *sample* of references to local case studies of ecosystem services and their values associated with a *sample* of particular marine ecosystems. The development of such matrices is often referred to as a 'rapid ecosystem service assessment (RESA)' to identify where ecosystem services and valuation data are available and where data gaps exist. The 17 per cent of boxes that are grey and have no studies referenced represent ecosystem services provided by a particular ecosystem for which insufficient studies have been conducted.

Table 2. Each marine ecosystem provides a suite of ecosystem services, a subset of which are identified; policy and management decisions result in tradeoffs among ecosystem services. * Open ocean may include benthic and pelagic systems. Grey boxes indicate services provided by the ecosystem on the left. Numbers are examples of studies of the ecosystem service in that particular ecosystem. The numbers in table 2 correspond to the case studies listed in Appendix 1. (expanded from Granek et al. 2010).

Selected ecosystem services / Marine ecosystems	**Aquaculture production**	**Carbon sequestration, climate regulation**	**Fisheries production**	**Pharmaceuticals**	**Pollution buffering and water quality**	**Protection against storm surges, wind damage**	**Recreation and Tourism**	**Shoreline stabilization, Erosion control**
Rocky intertidal							13,45, 50	
Salt marshes		12,36, 37						22,29,62
Mangrove forests	15,39,48	3,20,33	16,17, 41		4,23, 47	6,30, 61		10,49,61
Seagrass beds		16,17, 19, 27, 41	16,17, 41		1,34, 52	6,30		
Coral reefs		21,28, 42	9,16, 17,41	9,61		6,30, 61	9,11, 13,25	61
Kelp forests		32,54	24,43, 55,56			30	2,38, 62	
Sand dunes							13,51, 57	5,35, 40
Open ocean*	7,8,26	18,31, 59	44,53, 60				14,46, 58	

Because it is both essential and expensive to initiate studies of local ecosystem services, various databases have been developed to extract relevant information from site-specific case studies and 'transfer' such knowledge to similar sites. The 'benefit transfer' approach also comes with severe limitations and risk of propagation of errors (Liu et al., 2011). Appendix 2 provides a limited overview of publicly searchable databases that can assist decision-makers in populating matrices suitable to their region, following the exemplified structure of Table 2. The selection of data bases in Appendix 2 was based on explicit reference to an 'ecosystem services' approach, and does not provide an exhaustive list of databases that could be used when applying an ecosystem services approach.

2.4 Managing gaps, tradeoffs, and values across multiple spatial scales

Managing tradeoffs, for example between prioritizing fish-protein production from coastal waters *versus* coastal protection (Maes et al., 2012b), recreational use (Ghermandi et al., 2011) or cultural considerations (Chan et al., 2012), can lead to difficult decisions for managers and policy-makers. Fairness of distribution and environmental justice beyond direct costs and benefits for user groups need to be considered. The supply of ecosystem services is affected by decision-making that may favour production or provisioning of one service over others. For example, if kelp harvest is a favoured service that is managed, associated *"costs"* may be a reduction in fish protein, as fish habitat is reduced, and/or a reduction in recreational diving, as the kelp forest is extracted from the ocean (Menzel et al., 2013). Poor decision-making often results in benefits to some users (i.e., those who harvest kelp) and costs to other users (i.e., those who fish for animals that live in kelp, recreational divers, etc.). To achieve equitable distributions via policy-making, it is necessary to consider who wins (i.e., gains, benefits) and who loses (i.e., suffers a cost or loss), directly and indirectly as well as now and in the future. In the absence of regulation or when decision-making fails to consider the suite of services provided by an ecosystem and the range of users of those services, decisions on how best to manage a marine ecosystem may lead to unintended consequences (e.g., costs to recreational divers and fishing communities).

In decision making, stakeholders or managers often choose a set of possible actions to take and then assess the tradeoffs that exist among the identified options. One strength of an inclusive ecosystem services assessment is that it allows exploration of a broader set of possible actions and outcomes and distributive impacts, often identifying and highlighting true 'win-win' solutions (e.g., Lester et al., 2012; White et al., 2012).

Decision-makers are faced with the challenge of considering the spatial and temporal distribution of these services, which directly affects the flow of services. Certain services may be provisioned in close proximity to local communities, but utilized by both local users and others that live far from the location of provisioning. For example, coral reefs may provide protein and coastal protection to local community members on an island, and recreational opportunities, as well as some protein, to outsiders who visit the location as tourists. Even within the local community, individuals residing along the coast may prioritize the coastal protection service of the reefs or mangroves, whereas residents who live inland or upland may prioritize the provisioning of marine protein. The ecosystem services framework, when systematically applied, allows for considerations of multiple ecosystems services over time and space and thus, in this example, highlighting regulating and supporting services, such as habitat needed for spawning to ensure long term provisioning of protein.

Decisions on how best to manage marine resources frequently require consideration of the tradeoffs among a suite of possible scenarios. These tradeoffs generally entail values gained or lost with each scenario. Most commonly such values assigned are monetary. Historically, this has led to consideration of values that can be given a monetary worth, whereas services that are difficult to measure and value are often excluded from the decision-making process (TEEB, 2010a). Rodriguez et al. (2006) found that provisioning, regulating, cultural and supporting services are generally traded off in this respective order. This approach results in a focus on one or a few ecosystem services and in decisions that have an unequal distribution of costs and benefits across sectors of the population. Failure to include supporting and cultural services, specifically on par with provisioning services, may have unintended consequences.

In other words, understanding the flow of production (i.e., supply) and consumption (i.e., demand) of ecosystem services is complex, leaves room for cultural interpretation (Chan et al., 2012), and has distributive implications (Rodríguez et al., 2006; Halpern et al., 2011). However, tools are available - ranging from simple (for scoping purposes or in the face of poor data) to complex (for management purposes and when adequate data are available) - to assist in the development of scenarios and decision-support for this purpose.

2.5 Time preferences

Just as spatial analysis at multiple scales is crucial in understanding the supply of ecosystem services, the understanding of time scales and time preferences are important in assessing tradeoffs, especially with regard to the demand for ecosystem services. The perception of time is often culturally defined. Indigenous peoples often think in terms of multiple generations and time can have a spiritual element. For a market-oriented investor or government, time is captured in a ‘discount rate’. In essence, a high discount rate reflects a desire to consume resources now rather than later. From an economic perspective, this choice also determines how quickly an investment returns a profit. Long-term planning to safeguard the benefits of less visible, non-provisioning ecosystem services requires low or even negative discount rates (Carpenter et al., 2007). For investments in natural capital and for people to receive ecosystem services and benefits, multiple discount rates are required. Such ecological discount rates may be place-based (e.g., when considering *in situ* ecosystem services) or universal (e.g., when ecological infrastructure is providing global ecosystem services) and should also reflect the (often slow) recovery time of ecosystems. This would apply to most supporting, regulatory and cultural services, as they are ‘non-rival, non-excludable’ services. In addition, certain ecosystem services may be provisioned (e.g., coastal protection when seagrass beds are dense enough to attenuate waves) or utilized (intertidal or inshore fisheries during seasons when ocean conditions do not permit offshore fishery) seasonally, highlighting the importance of managing for time frames that reflect seasonal availability of or access to a service (TEEB, 2010a).

2.6 The challenge of multi-scale integrated assessments for ecosystem services

There are indicators that allow us to reflect on the health of oceans, e.g., the Ocean Health Index (Halpern et al., 2012) and retrospectively how ocean health is changing. A general indicator for ecosystem services from oceans is not available, nor may it be desirable as one indicator. Such an indicator would require integration across biophysical and human dimensions, with relevance across multiple scales and developing a transparent ability to consider tradeoffs with a forward perspective. This requires the gathering of data at local, regional, national and global scales, and in principle with three dimensions: space, time and values. Although not unique to the ecosystem services concept, the need to connect local to global scales through bottom-up and top-down governance is paramount.

Database management and modeling capacity are increasingly important to support decision-making at multiple levels of scale. This capacity needs to be 'fit for purpose' (i.e., it needs to answer specific questions by decision-makers in a timely fashion), as well as contribute to the development of knowledge across scales (i.e., be relevant beyond the boundary of an individual decision-maker). Currently several tools are available, each emphasizing particular strengths, such as the ability to: (1) communicate effectively with local stakeholders (e.g., Rapid Ecosystem Service Assessments (RESA), Seasketch (McClintock et al., 2012); (2) illustrate spatial aspects (e.g., InVEST (Lester et al., 2012; White et al., 2012); and (3) consider scenarios and changes over time, e.g., Mediated Modeling at the scoping (van den Belt et al., 2012), research, and MIMES/MIDAS (Altman et al., 2014) at management levels. Table 3 illustrates some tools with differing strengths and weaknesses. A comprehensive overview of all tools is beyond the scope of this assessment.

Table 3. A subset of tools that can be included in an ecosystem services valuation 'toolbox'. The tools range from crude conversation starters (e.g. RESA) to spatially dynamic decision support frameworks (e.g. MIMES).

	Dimension	**Rapid Ecosystem Service Assessment (RESA)**	**SeaSketch**	**InVEST**	**Mediated Modeling**	**MIMES**
Context	**Social / values**	Possible	Yes	Yes	Yes	Yes
Content	**Spatial**	Limited	Yes	Yes	No	Yes
	Dynamic/ changes over time	No	No	No	Yes	Yes
	Ecological	Yes	Yes	Yes	Yes	Yes
	Economic	Yes	Limited	Yes, where benefits are perceived	Yes, where benefits are not perceived	Yes, where benefits are not perceived
Process	**Adaptive**	Scoping	Scoping	Research	Scoping	Management

These tools draw on local 'small data' and global 'big data' to various extents. Each case study has the potential to be used in education and add to the collective building of knowledge on ecosystem services. As discussed, multiple databases on ecosystem services and their values are already available (Appendix 1), many of which feature ecosystem-based management tools (e.g., http://ebmtoolsdatabase.org). Newly initiated local case studies, as well as the output from modelling tools and applications of TEEB-like processes, add to this body of knowledge, and draw on 'big data' sets. Bringing together the various databases, tools and knowledge gained from various applications is a top priority for multiple stakeholders, such as policy makers, industry and non-governmental organizations. The iMarine infrastructure is one example of an emerging "Community Cloud" platform which offers Virtual Research Environments that integrate a broad range of data services with scientific data and advanced analysis. Such scenarios then result in new datasets. This could be expanded to include protocols for an ecosystem services approach. Figure 5 illustrates a connection between: (1) 'big data', primarily spatial information relevant to the supply of ecosystem service and (2) 'small data', the transferable insights that can be gained from local case studies. These data are brought together in (modeling) tools, evolving (1) from scoping to management level and (2) from static to dynamic tools. In the same way, but with a much more "bottom-up" and integrated emphasis, the European Marine Biodiversity Observation System (EMBOS: http://www.embos.eu/) offers the advantages of scale and expert identification of relevant organisms (taxonomy). This holistic approach is important since marine biodiversity provides many ecosystem services. However, biodiversity is undergoing profound changes, due to anthropogenic pressures, climatic warming and natural variation. Proper understanding of biodiversity patterns and ongoing changes is needed to assess consequences for ecosystem integrity, in order to be in a position to manage the natural resources.

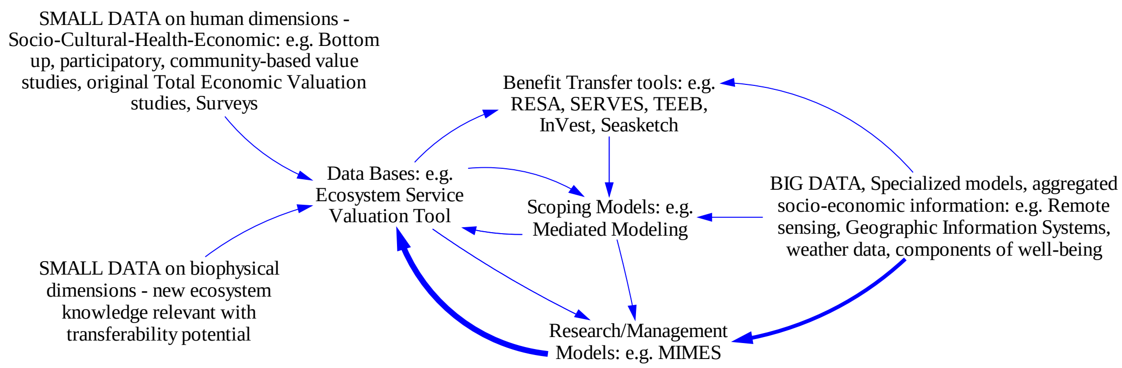


Figure 5. Evolution of ecosystem services knowledge. Adapted from van den Belt et al., 2013.

Appropriate application of an ecosystem services approach as an organizing principle in a consistent manner across multiple scales (space, time and values), requires capacity development.

3. Capacity-building and knowledge gaps

This section highlights knowledge gaps regarding the application of ecosystem services and discusses opportunities for capacity development. This concerns ‘human capital’, often interpreted as the ‘ability to deal with complex societal challenges’. In the context of marine ecosystem services, this is reflected in the capacity to collect and use available data to make visible ‘the benefits that people derive from ecosystems’ relevant for effective decision-making at multiple scales. This includes effective global policies and agreements, education and awareness programmes. Assessing governance and institutional changes that are required at multiple scales is beyond the scope of this chapter, although it should be noted that a feedback to this effect is included in all of the ecosystem services frameworks.

There is a gap in social sciences and economics’ ability to support ecosystem-based science. Application of an ecosystem services approach emphasizes the need for human dimensions of well-being, bridging natural and social sciences. Such integrative approach requires capability building in skills beyond existing disciplines. Generic skills that are needed to work within an ES framework, include: technical (e.g. modellers) and specialists (including scientists in specific disciplines), integrators (to make links between the parts), translators (to change policy questions into assumptions) and interpreters (who can communicate complex issues in simple terms).

The multi-scale and process-oriented aspects of an ecosystem services approach provide both a challenge and an opportunity for capacity development in understanding and capturing value regarding the supply of and demand for ecosystem services. Table 4 attempts to relate the scale of the demand for and supply of ecosystem services with data gaps and capacity to interlink/disseminate data for decision-support.

Table 4. Gaps regarding data and ability to interlink data for decision-support at multiple scales, coherent across marine and terrestrial systems.

	Local	National	Global
Supply of ecosystem services	**Need** = high resolution data and ability to interlink data for decision-support in the short term. **Available** = Mixed data and multiple tools; sufficient for scoping purposes in developed countries. Insufficient for management in developed countries. Insufficient for scoping or management in developing countries.	**Need** = mixed resolution data and ability to interlink data for decision-support in the short and long term. **Available** = Multiple databases often organized per country and multiple tools.	**Need** = low resolution data and high ability to interlink and disseminate data for decision-support in the long term. **Available** = Sufficient data for scoping, insufficient ability to interlink.

Demand for ecosystem services	**Need** = high ability for recognizing market and non-market sectors in managing tradeoffs. **Available** = Market-based information often available through the system of national accounting. Non-market-based information depends on local governance and community involvement.	**Need** = ability for recognizing market and supporting non-market sectors in managing tradeoffs in the short and long term. **Available** = market-based information and some socio-cultural information depending on country.	**Need** = ability to support all sectors with understanding of global ecosystem services and humanity's long-term, collective needs. **Available** = market-based information and some socio-cultural information.
Gap	Matching data between supply and demand of ecosystem services and ability to interconnect with regional/global scales.	Examples of ecosystem services supply; demand-side lagging. Interconnections among ecosystem services and between local and global scales elusive.	Shortage in some global ecosystem services. Interlinkages among global ecosystem services elusive.

The following are important capacity-development needs:

Data availability and resolution at different scales and geographic spread: Here the most important action item will be to map key areas, identify existing gaps and put in place mechanisms for filling those gaps in a coordinated and strategic way. For example, in the developing world data gaps complicate even rapid ecosystem service assessments at the scoping level. Although other areas have access to data for scoping purposes, crucial knowledge is lacking to use such data through an ecosystem services approach for management purposes.

The ability to use data in an integrated manner, both for 'trickling down' accounting, as well as for "trickling up" community empowerment and participatory purposes: This is exacerbated by the severe lack of local empowerment and understanding of the ecosystem services concept and by the fact that it is a multi-factoral and trans-regional, trans-national issue. This can be addressed by coordinated knowledge transfer and information exchange at the global level, for example, in coordination with IPBES.

Capabilities to undertake heuristic/participatory processes: Once again, this should be approached in a regional to global dimension, albeit for enhancement of specific purposes at each level. Heuristics approaches to problem solving can be used in the domains of natural science and social science and refers to 'operating under less than perfect circumstances to arrive at a way forward'. Perhaps most important will be to encourage, facilitate, collate and promote understanding of regional differences in valuation of ecosystem services according to culture and history. The first step in capacity-building and filling in knowledge gaps will be to empower local stakeholder communities and enable them to understand the impact that ecosystem services have on their lives and well-being. Empowerment and enablement are key concepts in the social sciences and if we are to improve and develop an ecosystem services approach, it will be vital to equip communities, from the bottom up, to develop a stronger sense of ownership and responsibility for the protection and sustainability of their local and global ecosystems and resultant services. However, collectively, it is crucial for people to understand that ecosystem services do not respect national and international boundaries, necessitating an integrated approach and a trading off with adjacent regions. If not accomplished in a transparent manner, this approach is likely to exacerbate regional conflicts. A simple example is the need for an understanding of ecosystem life-processes by the community at large and the interdependence and cascading links between individual ecosystem services. Furthermore, it is vital to understand how this varies region-to-region and culture-to-culture.

Relevance and capacity for different regions, specifically for marine ecosystem services:

Human capacity-building (e.g. technology training/education) and the associated physical infrastructure (e.g., coastal marine laboratories and institutes, marine observatories/observations, oceanographic fleets, together with appropriate and robust technology/instrumentation) are important to understand marine biomes as natural capital. This is expensive infrastructure and it is often lacking or operating at a low level in developing countries. Marine research stations are scattered worldwide, are often long established, and can act as important focal points for community-wide understanding and appreciation of marine/coastal ecosystem services. However, they lack capacity to recognize and value ecosystem services or use this approach as an organizing principle. Yet, these infrastructures have the potential to underpin the ecosystem services approach and facilitate gap-filling, e.g., by collecting data relevant to different sea-users and providing avenues to educate local communities. Improvement in these domains requires appropriate national policies in science and significant institutional strengthening. Education and training are vital to share best practices, data and experience and to create a truly global approach. Good examples of the human capital that is available but is, as yet, fragmented, in terms of supporting the development and understanding of ecosystem services, are the various networks of marine infrastructures exemplified by MARS (http://www.marsnetwork.org) in Europe and NAML (http://www.naml.org/) in the USA, together with smaller Japanese and Australian counterparts. Recently a global initiative has been launched with the help of the Intergovernmental Oceanographic Commission, i.e., the World Association of Marine Stations (WAMS) (http://www.marsnetwork.org/world-association-marine-stations-wams), with the mission to unite and integrate their strategies from training, education, and outreach to best practice and shared research agendas. New initiatives emerging from the EMBRC consortium (http://www.embrc.eu) and Euromarine (www.euromarinenetwork.eu) are acting as vibrant platforms bringing together all actors in the marine sphere. An important development recently available is The European Marine Training Portal (http://www.marinetraining.eu/). The European Marine Training portal is a centralized access point for education and training in the field of marine sciences. It will help European scientists, technicians and other stakeholders to navigate in the jungle of courses and training opportunities. Marinetraining.eu offers a variety of services to both training organizers and trainees.

Databases and tools available to Marine Stations and Meteorological Centres need to integrate and share data/tools/strategy. Time series are vital for biological/chemical/physical/geological datasets.

As original local studies of ecosystem services are expensive, guidance is needed for local stakeholders and decision-makers to progress from scoping to management tools. This includes a continuum of multiple discount rates relevant to the various ecosystem services (TEEB, 2010a). The network of existing marine research stations and institutes can play a central and coordinating role in providing relevant information and assist in preparation of options to consider bundles of ecosystem services. Many marine stations have historical data sets that, if properly digitized and shared, could help to fill gaps. Many are still locally collecting biogeochemical, biophysical and biodiversity data and recording their changes. These are powerful tools but tend to be restricted to local or regional databases. Although generally not private, they are often not widely known; this is where the United Nations Member States could come together to identify all sources and repositories of knowledge and data and bring them together to benefit the global community. Indeed this is one of the key missions of WAMS, supported by UNESCO-IOC. Whereas this is well recognized in Europe, North America and Australia, for example, an urgent need exists to embrace and empower other less well-supported regions, including but not limited to Africa, South America, the Caribbean, and the Polar regions.

4. Conclusion

Many fundamental Earth system processes are approaching or have crossed safe boundaries for their continued sustainability. Oceans play a crucial role in these Earth systems. After two decades of development, the ecosystem services approach has made good progress in making more visible the benefits people derive from ecosystems, which are often taken for granted. The ecosystem services approach outlined above provides an organizing methodology to assess and analyze the supply of and demand for ecosystem services and to connect across multiple geographic and temporal scales. However, this chapter does not fully outline the necessary steps to determine the potential supply and tradeoffs of ecosystem services for a region. The trans-disciplinary nature of an ecosystem services approach is complex and goes well beyond a mechanical application of both natural and social science, including decision making. The definitions of ecosystem services are multiple and broad and leave room for interpretation. A strong application of the ecosystem services concept can have a transformational impact, shift paradigms and provide new organizing principles advancing sustainability. A weak application of this concept may provide justification for business-as-usual. For example, a robust and strategic application has the potential to create a collaborative space to address fundamental challenges facing humanity; a weak application may address scattered local challenges at best or justify undesirable outcomes at worst.

Establishing principles, approaches and consistent terminology and guidelines for use of marine ecosystem services are needed. Linkages to people are often missing and more data and knowledge on attitudes, perceptions and beliefs of resource users and resource dependents is key. Several networks (e.g., MEA, GEO-BON, IPBES, TEEB, Lisbon Principles) have developed and are further developing such principles and guides. A significant development in Europe is EMBOS (http://www.embos.eu/). This has a focus on observation systems for marine biodiversity. This represents a significant challenge since biodiversity varies over large scales of time and space, and requires research strategies beyond the tradition and capabilities of classic research. Research that covers these scales requires a permanent international network of observation stations with an optimized and standardized methodology. In this way, we recognize that it is increasingly important to develop 'frameworks of frameworks' and understand the underlying purpose and worldview of each contributing framework in order to unify instead of divide the potential support for an ecosystem services approach, especially for oceans. Developing overarching principles, creating consistency in reporting, and generating relevant shared data and information, as well as the capacity to use such information, are creating an exciting opportunity for the United Nations and its members.

The ecosystem services approach has the potential to support a variety of management frameworks, including Marine Spatial Planning and tools for coordinating national and international sustainable marine resource management. Marine laboratories and fleets provide much of the needed data and human capital to better understand the supply of ecosystem services. Opportunities to fill data gaps exist (especially in developing countries), as well as developing capability to make available data suitable for use in ecosystem services approaches. These opportunities should be identified and acted upon with some urgency.

An increasing amount of spatial data/information is readily available/accessible. However, global data are often too coarse in resolution to make accurate estimates for certain regions and the capacity to access and use global data is limited and often lacking in developing countries and even developed countries. In addition, local or fine resolution spatial data and information are often unavailable and expensive. Also, nomenclatures and protocols should be standardized to enable meaningful integration, comparison and shared analyses.

Perhaps the most important gap in knowledge is understanding and integration of an ecosystem services ethos. This can be remedied by initiating a global approach with coordinated knowledge and education transfer amongst both developed and developing nations. Marine ecosystems exist regardless of the status of development of nations, but their integrity is certainly dependent on anthropogenic effects of all kinds under the influence of cultures around the globe. Thus, the ecosystem services approach must be multi-scalar in all facets. A thematic link with IPBES for oceans could address this.

Numerous methodologies have been developed to guide the ecosystem services approach; these range from scoping to highly advanced research and management approaches. Some methodologies provide static 'snapshots,' and others provide a spatially dynamic framework highlighting inter-linkages between bundles of ecosystem services and their changes over time.

The top-down progression of the cascading model (Figure 4) reflects steps involved in scoping the provision and value of ecosystem services. Inclusive, participatory approaches are important if we are to enhance ecosystem service models with bottom-up considerations to incorporate non-market and monetary values. The incorporation of local or bottom-up perspectives provides the opportunity to better integrate the distribution of costs and benefits and thereby enhance the fairness of decision-making.

When a participatory, bottom-up approach to ecosystem service valuation is taken, the 'gap' between 'supply of' and 'demand for' ecosystem services can more accurately define and measure 'value'; either there is an abundance, a sufficiency, or a shortage in time and space, applying both market and non-market perspectives. Mapping such gaps and how they change over time and space can be used to identify 'hotspots' for prioritization of management actions at multiple scales. Increasingly, marine ecosystem services are used in marine spatial planning (White et al., 2012; Altman et al., 2014).

It is important that the ecosystem services approach is used to influence beyond the immediate jurisdiction of those undertaking or sponsoring an ecosystem services assessment. Marine ecosystems function independently of national boundaries and Exclusive Economic Zones and so require an integrated global approach, if humanity wants to receive ecosystem services. When local biophysical data are not available, more heuristic methods can still guide conversations among multiple stakeholders to consider options to govern, manage and sustain the 'benefits people derive from ecosystems'.

At a global level, assessment of slow-moving biophysical processes (e.g., climate regulation, ocean acidification) need to be interpreted in terms of ecosystem services for their relevance to and impact on bundles of local ecosystem service in case studies.

In order to facilitate and enable the use of an ecosystem services approach, agreement on a global nomenclature and resulting classification would be useful. However, such a classification ought to be flexible enough to allow for local variability in applications. Therefore, the design of nomenclature, principles, and data management needs to be transparent and display characteristics appropriate to scale and purpose.

In addition to multiple scales, comparability between locations and case studies and over time is important. Some databases go to great lengths to encourage long-term comparability, e.g., Marine Ecosystem Service Partnership and Ecosystem Valuation Tool at Earth Economics. Comparability and transferability apply not only to data-gathering and -formatting, but also to the human component of socializing; using/interlinking such data is equally important (e.g., exchanges and collaborative opportunities).

The available ecosystem services frameworks emphasize that this is an iterative, evolving process and therefore needs an adaptive programme of strategic assessment.

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