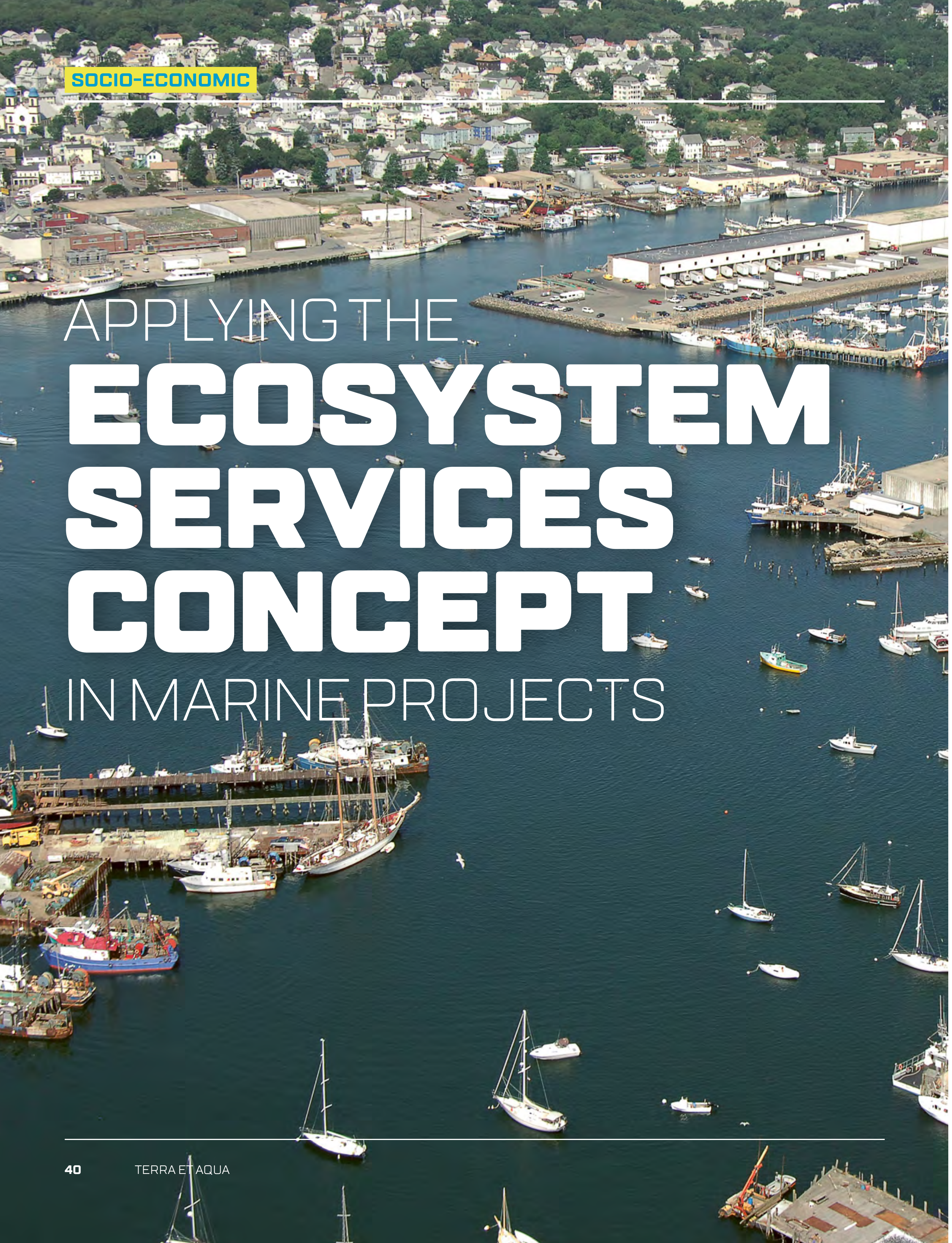


SOCIO-ECONOMIC

APPLYING THE ECOSYSTEM SERVICES CONCEPT IN MARINE PROJECTS

A full consideration of ecosystem services (ES) impacts, interactions and improvements can result in more sustainable and adaptive solutions for dredging and marine construction projects. Furthermore, the benefits can be translated in monetary terms, providing returns on investment and highlighting the links between ecology and economy. For some however, the ES concept is too theoretical. This article seeks to show how the ES concept can actively be applied at any point during a project and the benefits of doing so. Its purpose is to provide a framework for integrated and interdisciplinary thinking throughout the different steps of the project cycle.

The application of the ES concept is based on the idea that nature represents value to humans (through natural capital accounting).

Including ecosystem services (ES) during project development, ensures that, the engineering aspects are developed considering interactions with hydrodynamics, biodiversity, fisheries, recreation, etc. This identifies project dependencies and vulnerabilities, and helps to avoid unintended impacts and achieve broader benefits to society and nature. ES framing can thus identify critical capital and values to be sustained, opportunities for nature-based solutions and win-win scenarios, while serving as a vehicle for stakeholder outreach and communication. The ES concept can help clarify and integrate these considerations into project design and evaluation, enhance sustainability, provide a framework for the integration of disciplines, and play a role in the overall cost-benefit analysis of projects.

The ecosystem services concept

Nature provides processes for human health and well-being, including clean water, air, and food. We use and exploit this natural environment to derive its resources. Given global population and climate change projections, there is a continuing need to provide for growing resource demands in a

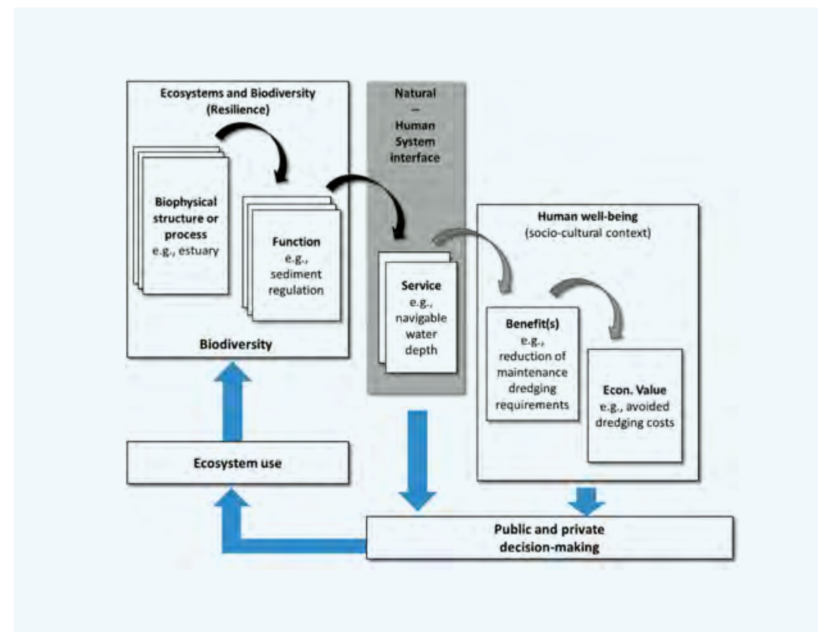


FIGURE 1

The 'cascade model' of ecosystem service generation and valuation highlights the links between biophysical aspects/biodiversity and human well-being (adapted from MEA 2005 and TEEB 2010); as well as the relationship between the understanding of natural systems, socio-cultural systems and decision-making.

TABLE 1

ES classification with a broad ES typology, detailed ES categories and examples of possible links with the dredging and marine construction sector (adapted from the major classifications by TEEB, MEA and CICES).

Classification Ecosystem Services	ES categories	Examples of negative impacts from dredging/marine construction projects	Examples of positive impacts on the ES from dredging and marine construction projects
Provisioning services	Food	Reduction of available fishing grounds and number of fishes.	Creating, maintaining or restoring nursery areas for fish, incorporating aquaculture facilities or supporting facilities into the project design.
	Water	Reducing the access to water by the installation of breakwaters or natural habitat.	Improving the access to water for navigation.
	Raw materials	Destruction of mangrove forests that are used for wood.	Dredged material as a resource.
Regulating and maintenance services	Water purification	Destruction of natural habitats	Dredging and maintenance; projects impact contaminant dynamics; design can optimise this function.
	Air quality regulation	Destruction of natural habitats.	Creating, maintaining or restoring forests (terrestrial or kelp).
	Coastal and riverine protection	Destruction of natural habitats, changes to hydrodynamics and sediment balance.	Coastal development through the use of both hard and soft engineering solutions; riverbank design and maintenance.
	Climate and weather regulation	Destruction of natural habitats.	Enhancing carbon storage through nature restoration (e.g. mangroves, marshes).
	Ocean nourishment	Destruction of natural habitats.	Creating, maintaining or restoring natural habitats.
	Life cycle maintenance	Destruction of natural habitats.	Creating, maintaining or restoring fish nursery areas, e.g. seagrass beds, mangrove areas and salt marches.
	Biological control	Destruction of natural habitats.	Creating, maintaining or restoring marine ecosystems.
	Regulation and maintenance by natural physical structures and processes (air, water, substrate)	Destruction of natural habitats, changes to hydrodynamics and sediment balance.	Navigation; design and infrastructure of waterways/ ports; sediment management (incl. handling of dredged material); nature-based solutions.
Cultural services	Symbolic and aesthetic values	Alteration of historically or culturally valuable landscape or infrastructure.	Design and infrastructure of waterways/ports with symbolic and aesthetic values.
	Recreation and tourism	Alteration of recreational landscape, environment or infrastructure.	Incorporating infrastructure with recreational value into the design of e.g. coastal protection projects.
	Cognitive effects	Loss or damage of stratigraphic or archaeological records.	Sharing of information on the impact of the project through media, information panels, etc.

By framing the costs and benefits of natural resource management, ES concepts can be used to evaluate, justify or optimise management decisions.

changing environment while at the same time minimising environmental damage. Therefore, now more than ever, the use of the environment and the management of our activities must be achieved sustainably. This is particularly critical along already extensively altered and exploited river basins, coasts and estuaries, which must adapt to increasing levels of global, regional, and local stresses and changes (e.g. growing population, global warming, sea-level rise, acidification, eutrophication, pollution and habitat loss).

Ecosystem Services (ES) are defined as the benefits people obtain from ecosystems (MEA, 2005). The application of the ES concept is based on the idea that nature represents value to humans (through natural capital accounting). The links between biophysical aspects/biodiversity and human well-being are represented in the ecosystem services cascade model (Figure 1). The recognition that human well-being and economic development is dependent on the preservation of natural resources is certainly not new, but the ES concept is for evermore a means or even an underlying principle of global environmental policy, legislation and management (Apitz, 2013). By framing the costs and benefits of natural resource management, ES concepts can be used to evaluate, justify, or optimise management decisions.

Ecosystem services can be classified into three broad categories: provisioning, cultural and regulating/maintenance services. Provisioning services are the products that we can harvest from ecosystems, e.g. potable water, commercial fisheries and wood. Cultural ES include the enjoyment of natural landscapes, the use of nature for education and research, and the cultural or religious relevance of species or landscapes that directly contribute to the economy or well-being of many people. Finally, regulating and maintenance ES are a group of functions from which we directly benefit, such as the regulation of climate, hydrological cycles, water and air quality, carbon storage and protection against erosion and storm damage. Table 1 gives some examples of ecosystem services that are essential to or can be impacted by dredging and marine construction works.

Since not all ES are equally relevant for each project, an upfront project-specific identification of priority ES should be carried out. Two categories of priority ES related to a project can be identified: (1) Type I, ES on which the project might have impacts (positive or negative) that may affect communities and (2) Type II, ES on which the project directly or indirectly depends. In the case of dredging and marine construction projects, examples of Type I ES are fisheries or water quality impacts; examples of Type II ES are hydrologic or sedimentation processes within or outside the project that affect the execution method or even the main objectives of a project, e.g. providing access for shipping or coastal protection. ES within these two categories should be included in an ecosystem services assessment; others can be left out. The International Finance Cooperation specifies in its performance standards that scoping to identify priority ES should be carried out via literature reviews and in consultation with affected communities (stakeholders). The consultation of and interaction with stakeholders in this process is an important aspect of the stepwise approach to including ES in impact assessments described by World Resources Institute (WRI 2013).

Benefits of applying the ES concept

The concept of ES adds significantly to the operationalisation of Ecosystem-based Management (EBM, also called Ecosystem Approach), which focuses on the management of human activities and natural resources, taking both natural and societal effects into account. EBM provides a mechanism for making decisions about marine infrastructure and dredging activities with the goal of including and maintaining contiguous ecosystems in a healthy, productive and resilient state. From this perspective, the focus is on the diverse interactions between societal systems and ecosystems, rather than a specific project goal or activity. The drivers and pressures affecting ecosystems are varied and numerous; solutions must be holistic and adaptive to avoid negative impacts and to benefit from an integrated multi-sectoral approach. The focus on ecosystems should not be construed as the elevation of ecosystems over people, nature over jobs or of fish and wildlife over progress. Rather, the focus on ecosystems recognises that humans and their systems are part of ecosystems, and reveals the inherent dependence of people on the services provided by the ecosystem (ES) and its functions (Figure 1). The ES concept has become increasingly important for the dredging and marine construction sector (Boerema et al., 2017a; Laboyrie et al., 2018). However, ES impacts and dependencies are not yet generally considered in project-related cost-benefit analyses due to a lack of standard guidelines and methodologies (PIANC, 2016).

Added values for your projects and business

Including ES concepts in marine construction and dredging projects improves and communicates the understanding of the natural and socio-economic context for such projects. Hence, on the one hand, it articulates project dependencies upon ecosystem functions and services. On the other hand, it identifies (both desirable and undesirable) impacts that the project may have on other local, regional or global services and objectives. As a result, project opportunities, risks and vulnerabilities are identified. The improved understanding and inclusion of ES concepts may have the following, partially overlapping, beneficial consequences:

- Enhancing the positive effects of any project on the surrounding natural and socio-economic environment, such as increasing biodiversity, improving natural functions and societal well-being;
- Reducing the negative impact of any project on the surrounding natural and socio-economic environment, thereby

avoiding mitigation measures and compensation costs;

- Reducing project breakdown risk by identifying project dependencies and vulnerabilities; building resilience against extreme natural events and effects of global and climate change; and improving adaptability of infrastructure and supporting environmental security;
- Contributing to the re-establishment and restoration of degraded ecosystems through applying nature-based solutions (NbS);
- Identifying opportunities to capture/use natural processes to obtain functional benefits, e.g. reduced maintenance dredging; this can identify and optimise opportunities for NbS;
- Better alignment of a project in the societal context instead of considering predominately economic targets (e.g. navigation);
- Reducing societal costs or negative impacts in the societal context of the project;
- Facilitating the consent process and stakeholder dialogue (e.g. mitigation of negative impacts in Environmental Impact Assessments). This may reduce project risks (e.g. not obtaining a license and not requiring re-design processes) and allow for more support/acceptance from the local/regional community;
- Better alignment of a project with international guidelines for sustainable development, which increasingly matters for project financing (green/blue finance; Environmental, social and governance; Principles for responsible investment), such as the World Bank and other international investors; and
- Improving green/blue and societal reputation of a given project and its stakeholders.

Examples of benefits from applying the ES concept

Understanding and optimising the natural processes of the system in which a port or dredging work is planned may reduce costs and increase benefits in the long term. Recognising the dependency of a port on sediment balance and storm protection (which can be artificially maintained or supported by natural ecosystem functions) both identifies potential vulnerabilities (for instance, in the case of climate change) or opportunities for nature-based solutions.

For example, developing habitats that remove sediment from the water column upstream of a harbour may significantly reduce maintenance costs. When the channel must be dredged, the dredged material can be used beneficially for the maintenance of sediment balance, habitat creation or restoration, or storm defence in the vicinity of the port or waterway, rather than being treated as a waste product. Sediment can be re-used for wetland or mangrove restoration in areas nearby that would otherwise suffer from a lack of sediment input due to sink processes in the harbour area or upstream. Such designs reduce maintenance costs and can add to local biological diversity, while also enhancing services, such as carbon and water quality regulation. Habitats created may also include facilities to allow access by the public for recreational uses, thus expanding the social and economic benefits.

These approaches may also help to mitigate the detrimental effects of port construction on the environment, improve legislative consent procedures and enhance acceptance by the local community. The socio-economic benefits of measures and their related effects can be evaluated and communicated to involved project parties by applying the ES concept. Although identifying and designing for such synergies may require more up-front planning and assessment effort (soft costs), such efforts can reduce construction and operational costs. They are beneficial not only for the owners or contractors working on the project but also for various stakeholders indirectly impacted by a project.

Support decision-making

Information garnered from ecosystem service-based assessment (ESA) can be decisive, supporting or informative (Apitz, 2013). Decisive information implies that it can generate critical information for scenario selection. ESA will seek to evaluate or even quantify the extent to which various design alternatives may result in ES gains and losses. Trade-offs can be used to frame the decision-making process. Less strictly, it can also be supporting, providing technical information for ES optimisation or compensation decisions. In such a case, risks or opportunities (such as in NbS) can be identified and ES concepts can be used to mitigate undesirable impacts or seize win-win opportunities. Lastly, it can be informative, used to raise awareness, communicate with and inform stakeholders, providing a framework for discussions, without necessarily requiring the same level of in-depth analysis. In these cases, ES framing may help provide the social license to operate by engaging stakeholders in evaluating how their values might be affected and how a project might fit into broader personal, local or regional objectives.

Understanding and optimising the natural processes of the system in which a port or dredging work is planned may reduce costs and increase benefits in the long run.

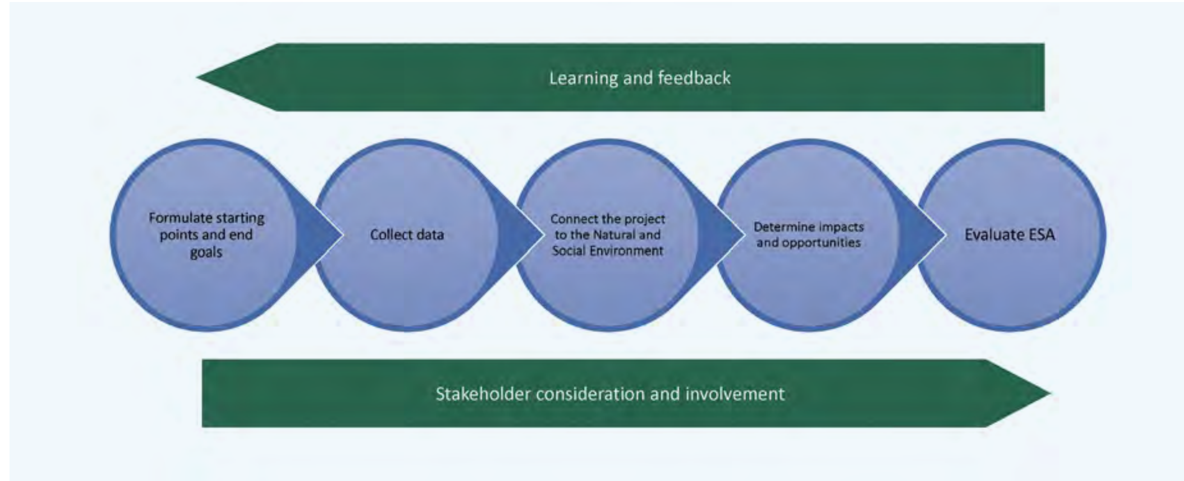


FIGURE 2
Five major steps of the ESA framework. These are underlain by stakeholder consideration and involvement, and may be adaptively optimised using learning and feedback.

ES for which projects?

The ES concept can be applied in many situations, to smaller and larger projects, for private, public and mixed infrastructure investment, in both developed countries as well as countries in transition. To facilitate this, frameworks for the use of ES concept should be (Moore et al., 2017):

- geographically scalable – to allow application to local projects and social/ecological conditions, with limited spheres of influence, as well as to regional problems that may carry national or trans-national implications;
- technically scalable – to allow for efficient allocation of resources (time, money, etc.) in proportion to the consequences of the decision, consideration of cross-scale and cross-sectoral interactions when necessary, or to adapt to the extent and type of data available;
- systematic and transparent – to provide appropriate stakeholder involvement and allow adequate understanding by all stakeholders;
- iterative and based on learning – to inform corrective action and adaptive management through careful consideration of monitoring data and other information; and
- based on a solid understanding of management decisions – to allow for connections between ecological processes, project requirements and human well-being.

In addition to these points, ES should be considered in terms of the wider policy and management contexts within which a project must operate. Each project deals with criteria or guidelines from legislation, regional management plans or sectoral policy reports. Usually, the aims of such regional policies or management plans are to integrate different activities in the region to create benefits for managers and users alike (e.g. improved risk assessment, beneficial reuse of material and integrated design goals).

Although requiring some up-front investment, consideration of ES concepts is expected to pay dividends even for smaller projects and greenfield projects. This demands the inclusion of ES approaches and risk assessment procedures applicable under relatively data-poor circumstances and reduced financial support. Ideally, the financial viability of prospective projects includes (monetised and non-monetised) ES benefits as a separate step in making a business case. This highlights any added value, both in the short and long term, for the project. Examples are beneficial reuse of materials and generation of indirect income through habitat creation (e.g. tourism, fisheries, quality of life, blue carbon). It also demonstrates the project's dependencies on ES (e.g. sediment and water transport, storm protection, water quality).

Ecosystem services assessment (ESA) framework

Steps of the ESA framework

An ES Assessment (ESA) evaluates how a project might affect the environment's capacity to supply various ES, either positively or negatively, compared to the initial portfolio of ES provided (in this case, often the situation prior to a project's execution). Hence, the primary goal of the ESA is to identify the possible or effectuated changes in ES.

The ESA framework consists of five major steps, during which a set of questions needs to be answered to help in decision-making (Figure 2). Table 2 provides the central questions addressed in each step. During all steps, stakeholder consideration and involvement are required. Learning and feedback, which are characteristics of all adaptive and iterative processes, are important: results from earlier steps form the basis for the next steps. If required, the same step may be carried out iteratively.

ESA in the project cycle

Dredging and marine construction projects commonly follow an iterative cycle comprised of a design, an implementation and evaluation/adaptation phase (see Figure 3, blue wheel). This project cycle is used in this article to link the concept of ecosystem services to practice. Throughout the project cycle a series of decisions and actions need to be carried out in order to ensure

TABLE 2

The five generic steps of the ESA framework and the actions that support them.

ESA steps	1. Formulate starting points and end goals	2. Collect data	3. Connect the project to the Natural and Social Environment	4. Determine impacts and opportunities	5. Evaluate ESA
Actions	– Determine the project phase and identify which decisions need to be taken to go to the next phase(s) in the project cycle. – Identify the questions the ESA is to inform (establish assessment objectives). – Determine the major stakeholders who (may) interact with the project (possibly indirectly, e.g. in case of other geographic regions or other generations). – Involve relevant stakeholders in describing the baseline and setting goals. – Identify, describe and communicate end goals of the ESA to be applied.	– Compile relevant project information: technical and operational information, both historical and current data and future goals. – Identify the major ecosystem components of the project's environment and the related processes (habitats-species, abiotic environment, etc.). – Identify the societal environment in which the project is to be realised and identify relevant actors (iterative with Step 1: determine stakeholders). – Determine the regulatory setting. – Collect relevant information from stakeholders (partners involved, local experts, end-users, local government, etc.). – Determine data availability and quality.	– Identify and link causes and effects of project on the environment and societal/economic system. – Check habitats and species a project may affect (or create, in case of habitats). – Look at disrupted flows (e.g. currents) or functions (e.g. light, water temperature) – need to know how this affects ES and function dependencies and interactions. – Identify and describe project aspects that might drive ES impact. – Set priority ES, commonly based on regulations and stakeholders' interests. – Iterate data collection if necessary.	– Perform impact analysis using preferred methods (qualitative, quantitative, valuation). – Identify and enhance opportunities and win-win situations. – Determine whether undesirable interactions can be prevented or mitigated and identify trade-offs (involve stakeholders). – Address uncertainty. – Discuss the methodologies applied and the results with stakeholders. Iterate data collection and analysis if necessary.	– Are the ESA goals achieved as they were identified and agreed in Step 1? – Does the outcome of the ESA sufficiently inform the project decisions? – Does the outcome of the ESA influence project decisions? – What are the lessons learned and what will the follow up plan be in terms of ESA?

that projects are designed to optimally and cost-effectively deliver their primary objective – enabling navigational passage or installation of soft or hard infrastructure in support of, e.g. ports or coastal protection. However, such works and infrastructure can also affect, positively or negatively, other site-specific, regional or regulatory objectives. An ESA as described in Table 2 supports the decision-making process when going from one project cycle stage to the next.

The maximum benefit from using ES concepts can be expected when applied from the beginning of a project. However, even if the ES approach is only applied in later phases of the project, it can still provide significant context and insights. As will be described below, the purpose of the ES framing and the chosen approach may change, depending upon the project stage and phase, and the decisions being made.

Project cycle phases require different levels of resolution and detail and, more importantly, address different questions. Within a project cycle, four types of ES assessment (ESA) types can be defined. As can be seen in Figure 3, each of these ESA types informs decisions and bridges different project cycle phases.

The key features of each ESA type are described below.

Baseline/scoping ESA carried out during plan development and design, aims to answer questions, such as 'What are priority ES?' and 'What is their current status?' This bridges the initial concept phase to the conceptual design phase. Any idea for developing a project goes through a very early step (conception of a plan) in which at a quick-scan or reconnaissance-level decisions need to be made on further development of the plan. In the scoping ESA, a conceptual (i.e. not detailed) description is made of the biophysical environment of the project area and how the plan would interact with this area, illustrating the cause and effect relationships and how these affect ES. This provides an opportunity to think about goals other than the strictly technical project goals that can be achieved. Essential stakeholders should be identified and potential risks and benefits identified. The goal of a project is formulated at this point and discussed with the key stakeholders.

Prospective ESA carried out during the design phase, investigates how ES might be impacted by potential design scenarios. This bridges the conceptual to the technical design phase. Introducing ES during the conceptual design gives the project more freedom to consider ES risks, opportunities and trade-offs when choosing and optimising a design alternative. If ES concepts are introduced in the technical design, the focus will be on what gains can be expected from adapting the design within the already rather fixed technical design specifications. In a Prospective ESA, the extended set of goals (technical goals, ES goals, societal goals) are more quantitatively assessed. This is an assessment based on knowledge of the biophysical state of the project environment, cause and effect relationships between the technical design and the biophysical state, affecting near-field and far-field natural (biotic and abiotic) processes and functions. This results in an overview of trade-offs of ES impacts, their likelihood and extent. A prospective ESA may also consider project vulnerabilities to changing ES provision, due to climate and other changes. This phase should include plans on how to monitor the impacts of the project on the natural (and socio-economic) environment in the context of ES. It should be noted that such a Prospective ESA can be developed even at a relatively low information level, e.g. based on stakeholder interviews or workshops.

Retrospective ESA carried out during and after construction and operation, aims to evaluate whether ES were impacted during the evaluation phase of the project, based upon monitoring data. The reason for doing a retrospective ESA is to learn and adapt.

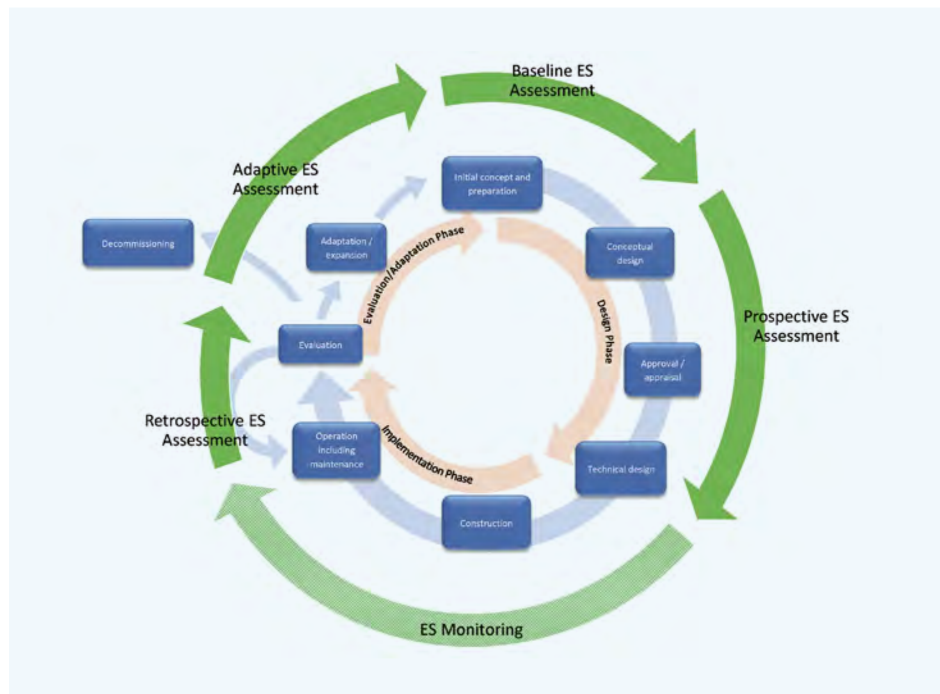


FIGURE 3

Key features of ESA types and monitoring. ES assessment types (shown by the green arrows) provide a bridge between project cycle steps (shown by the blue boxes forming a wheel); monitoring provides the data to bridge between prospective and retrospective assessment.

There are two types of Retrospective ESA: one evaluates data in the absence of a prior Prospective ESA (and thus evaluates monitoring data with an ES framing, but with no prior ES predictions), and the other evaluates monitoring results in the context of ES impacts predicted by the Prospective ESA. If ES impacts are determined to be unacceptable (or if objectives change), potential adaptive strategies are considered and an Adaptive ESA may be carried out. In either case, outcomes should be evaluated in interaction with stakeholders. If all goals are reached (and no new ones have been developed) and the retrospective ESA outcome does not call for further adaptation of the project, the ESA for the project stops here, only to be picked up again when the project is decommissioned (if ever).

ES monitoring provides the data to bridge the gap between the Prospective ESA (which predicts impacts of scenarios) and Retrospective ESA (which assesses whether impacts have occurred). ES monitoring is therefore important to provide input for all types of ESA and throughout the project cycle. ES monitoring is not however, an assessment type and hence not included in the four types mentioned above. If undesirable impacts are deduced, adaptive strategies or measures may be considered. Interaction with stakeholders is necessary to evaluate the outcome of the project, and any necessary adaptation. If adaptation is deemed necessary, an Adaptive ESA may be carried out. If all goals are reached (and no new ones have been developed) and the Retrospective ESA outcome does not call for further adaptation of the project, the ESA for the project stops here, only to be picked up again when the project is decommissioned (if ever).

Adaptive ESA evaluates how ES might be affected by adaptive scenarios. Adaptive ESA also uses prospective (rather than retrospective) assessment however, as it is carried out far into the project cycle, benefits from all previous scoping, assessment and data, and is focused in scope. Ideally, at least one round of ESA has taken place and technical and communication lessons have been learned (e.g. Did we address all stakeholders and how well?). Less ideally, nothing (in the context of ESA) has yet been done; in this case, a focused Retrospective ESA may be needed. In all cases, degrees of

TABLE 3

Eight case studies considering ES in one or more phases of the project cycle.

Case study	Region	Type of project	Environment
Maasvlakte II	Europe – Netherlands	Port extension	Coastal
Western Scheldt	Europe – Belgium	Maintenance dredging, estuary	Estuary
Horseshoe Bend	North America – USA	Maintenance dredging, inland waterways	River
Sigmaplan	Europe – Belgium	Flood management, inland waterways, dam/dyke	Estuary
Nicaragua Canal	Central America – Nicaragua	Construction of navigation channel, inland waterways	River, Lake
Ems estuary	Europe – Germany	Environmental restoration of a port, inland waterways	Estuary
Coffs Harbour	Asia Pacific – Australia	Harbour breakwater upgrade, recreation infrastructure	Coastal
Blue Carbon	North America - USA	Managing port 'blue carbon' coastal ecosystems	Coastal

TABLE 4

List of case studies showing the ES concept applied in several of the project stages.

Case study	Project cycle phases							
	Initial concept and preparation	Conceptual design	Approval/ appraisal	Technical design	Construction	Operation including maintenance	Adaptation/ expansion	Decom- missioning
	Baseline/scoping ESA		Prospective ESA		Retrospective ESA		Adaptive ESA	
1. Maasvlakte II		X	X	X	X	X	X	
2. Western Scheldt	X			X	X		X	
3. Horseshoe Bend						X	X	
4. Sigmaplan	X	X						
5. Nicaragua canal			X	X				
6. Ems estuary	X	X						
7. Coffs Harbour	X	X	X	X	X		X	
8. Blue Carbon	X	X	X	X	X			

freedom and potential benefits of an ESA are smaller than in a full Prospective ESA, however the use of ES in considering adaptations to the project can still be beneficial.

The generic approach of the ESA framework (as described in Figure 2) remains constant throughout the project cycle, no matter which ESA type is undertaken. As one moves through the project cycle, more detailed information (if available) is required; information developed in one stage can be built upon in the next. While the first three steps in the framework are more in the focus during the design phase of the project, the last two steps gain importance in the implementation and evaluation phases of a project. The exact ESA approach will also depend not only upon the phase and stage

Overview of how case studies illustrate potential applications of the ES concept throughout the entire project cycle. >>

Case 2: Western Scheldt

- **Full-cycle (baseline, prospective, monitoring, evaluation, adaptation) selective, non-explicit ESA** to design beneficial, synergistic dredged material disposal and management.
- WwN to enhance habitats and optimise hydrologic function, balancing multiple goals.
- Broader ES consideration, e.g. water quality regulation, could enhance benefits.

Case 4: Sigmaplan

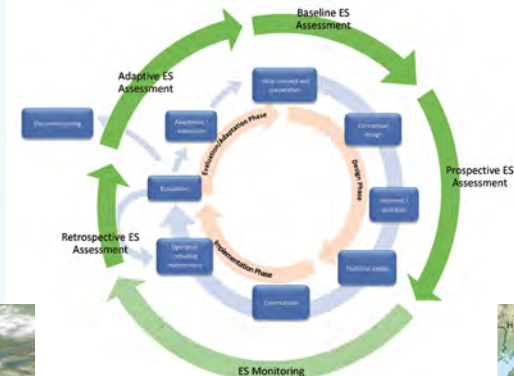
- **Baseline ESA** identified multiple objectives; **prospective ESA** informed conceptual design phase.
- Monetary societal cost-benefit analysis sought highest net benefits, considering flood safety, navigation, agricultural, regulation and cultural services.
- Alternative chosen differed from choice based upon flood control alone, demonstrating benefits of early ES consideration.

Case 6: Ems estuary

- GIS-based **retrospective**, **baseline and prospective ESA** (1930, present, and 2050) evaluating provisioning and regulating ES, and a restoration masterplan.
- Early explicit consideration of ES facilitates communication and future planning.
- A broader range of ES could increase impact.

Case 1: Maasvlakte II

- **Prospective ESA** of design solution trade-offs.
- Legislation-driven inclusion of natural and social values identified opportunities to mitigate or compensate for impacts.
- Early consideration would save time and money; facilitating approval.

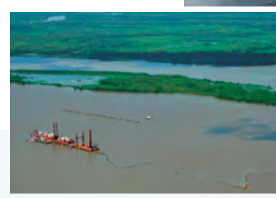


Case 5: Nicaragua Canal

- **Baseline ESA**, then **prospective ESA** examining impacts of selected design to identify mitigation measures.
- Qualitative assessment, as part of ESIA.
- Earlier and explicit consideration of ES in design phase may reduce impacts and the need for mitigation.

Case 3: Atchafalaya

- **Retrospective ESA** identified multiple, serendipitous ES benefits from a mid-channel disposal strategy.
- Channel stabilisation reduced dredging requirement, while providing beneficial habitat for critical species.
- Earlier consideration of ES may identify more such opportunities for future projects.



Case 8: Blue Carbon

- Small-scale pilot **baseline and prospective ESA**; **monitoring plan** focusing on carbon sequestration (climate regulation) and water quality improvement via blue habitat creation.
- Small-scale research focuses on one ES (carbon sequestration), which can be directly translated into an economic benefit.
- Future work, considering broader range of ES, may support port enhancement and mitigation plans.

Case 7: Coffs Harbour

- Prospective, non-explicit ESA informed multi-criteria assessment to balance 'use values'(safety, recreation and economics) of shoreline protection plans.
- Values were gathered through early, multi-disciplinary stakeholder engagement.
- More explicit consideration of potential ES may have broadened criteria.

TABLE 5

Ecosystem Service studied in the case study projects. Assessment types used: qualitative (Ql), quantitative (Qnt) or monetary valuation (M). Effects can be positive (green), negative (red), or neutral or both positive and negative (yellow).

ES classification	ES sub-category	Case studies: Maasvlakte II	Western Scheldt	Horseshoe Bend	Sigmaplan	Nicaragua canal	Ems estuary	Coffs harbour	Blue Carbon
Provisioning services	Food	Qnt			M	Ql / Qnt	Qnt		
	Water					Qnt	Qnt		
	Raw materials				Ql	Qnt			
Regulating and maintenance services	Water purification			Qnt	M	Qnt	Ql / Qnt		
	Air quality regulation			Ql					
	Coastal and riverine protection		Ql		M	Qnt			Ql
	Climate and weather regulation			Qnt	M	Qnt	Qnt		Qnt
	Ocean nourishment			Ql					
	Life cycle maintenance		Ql			Qnt			
	Biological control								
	Regulation and maintenance by natural physical structures and processes			Ql	M	Ql / Qnt	Ql	Ql	
Cultural services	Symbolic and aesthetic values				M	Ql	Ql		
	Recreation and tourism	Qnt		Ql	M		Ql	Qnt	
	Cognitive effects								Ql

in the project cycle, the role the information plays in a decision-making or communications effort but also upon the socio-environmental situation and the priorities put forward.

Lessons learned from case studies

A range of case studies were collected to learn how the ES concept is being applied in practice (Table 3). Some projects have been completed, others are in the process of design or are still at a conceptual stage. The cases may address a part of a total project, illustrating the application of the ES concept in that part or phase. The geographic spread includes areas with countries in transition to indicate that at this level of information and means, the concept of ES may also provide added value to a project.

Examples of applying the ES concept across a project cycle

Overall, we found no dredging/marine construction case study that applied the ES concept across the entire project cycle. Nevertheless, each of the selected case studies demonstrate some aspects of recommended practice (Table 4). In each case study, the ES concept was applied to inform different decision types, ranging from providing better understanding of the natural environment, to facilitating improved stakeholder engagement and/or providing evaluation methods to inform final decisions. The case studies demonstrate that the concept of ES can be applied at various stages of the project cycle and have led to an improved understanding of the possible or actual benefits of using ES in the projects.

Which ES were assessed and how?

Most ES were evaluated in one or more cases and all case studies considered multiple ES (Table 5). The assessment types that were used are qualitative (Ql), quantitative (Qnt) or monetary valuation (M). The cases demonstrate that even qualitative assessment of some ES can add useful information to the overall evaluation of a project. Furthermore, the case studies demonstrate that the impact of a dredging/marine construction project on ES can be either positive or negative and that most projects generate both kinds of impacts. It is important to note that water as an abiotic provisioning service had been considered in only two case studies, the Nicaragua Canal and the Ems estuary. This is in part because of the relatively recent acknowledgement and application of abiotic services (those provided not by ecosystem organisms but by ecosystem biophysical conditions) in the ES concept (Apitz, 2012). Other case studies are less recent and therefore did not yet consider abiotic services in their assessment. The inclusion of all priority ES, including these abiotic ones, are especially important in the context of impact assessments and cost-benefit analysis, which is particularly dependent upon such ES. It should also be noted that not all case studies considered all ES in project design. Some were focused on specific issues and thus the selection of ES across case studies cannot be considered comparable or comprehensive in all cases.

This overview from the case studies clearly shows the diversity of methods possible for ES assessment studies. The different methods (Ql, Qnt and M) require different levels of detail, budget and expertise; each with its own strengths and weaknesses (Boerema et al., 2017b). Below, we briefly describe the three categories of methods. Please check the PIANC working group WG195 report (2021) for more explanation and example references.

Qualitative approaches have lower data requirements than do quantitative, however will not provide the same level of detail. Qualitative methods, such as scores (e.g. -2, -1, 0, +1, +2), can be used for rapid assessment or, in cases of low data availability (e.g. data-scarce regions), may provide an indication of relative (but not absolute) magnitudes of impacts. This should be done together with local experts that have some knowledge to be able to judge if the impacts of a project on each ES will be large or small, and positive or negative. Mapping ecosystem services can be done with qualitative data and is therefore also applicable for data-scarce regions. It should be noted that the outcome gives only a high-level indication of possible effects. After evaluating the impact of the project on each ES, a multi-criteria analysis can be applied to make an integrated evaluation for the multiple ES.

For a smaller set of ES, impacts can be quantified in biophysical units, such as cubic meters of water purified or tons of carbon stored. When a tidal habitat along a river gets lost due to a new infrastructure project, the capacity of the tidal area to, for example, purify water (m^3) or to store carbon (tonnes C/m^2) will be lost. Ideally, primary data (field measurements) are collected or modelled to calculate effects (e.g. using software such as InVEST, ARIES, MIMES, ECOPLAN-SE, MAPURES). Secondary data can be used for a quick calculations or when primary data cannot be generated; however the outcomes are less accurate, as they are not site-specific. Literature data from similar cases can be used, e.g. average tons of carbon stored in temperate marshes. Mapping ES with quantitative data gives a good spatial overview of the effects of a project. After evaluating the impact of a project on each ES, different tools are available to make an integrated evaluation (multi-criteria analysis, cost-effectiveness analysis).

For a smaller subset of ES, monetary and non-monetary valuation is possible. Non-monetary valuation methods allow for the estimation of the value to society for each ES (in terms of appreciation, not in monetary values). Monetary valuation methods allow for the estimation of the economic monetary value of ES. Benefit transfer uses data from other (similar) studies. This results in large uncertainty because the data are not specific for the project and location; however it can be useful as first indication for a quick assessment or if primary data are lacking and cannot be generated. Several meta studies provide global monetary ES values for several biomes. After evaluating the impact of a project on each ES, the monetary values can be calculated in a cost-benefit analysis. This allows for the addition of ecological and societal benefits (or negative effects) into a classical cost-benefit analysis that usually only looks at direct costs and benefits of the project.

It is essential to define system boundaries for a given project, e.g. to define the spatial and temporal boundaries of analysis, the processes to be considered and the appropriate level of data and analytical detail. Furthermore, the level of quantitation possible may be limited by project conditions and resources, but need only be as detailed as required to inform the decision at hand. Often detailed, quantitative assessments are not necessary to provide useful information for communication or decision stages in dredging and marine construction projects. Analyses should be no more complex than needed to identify and distinguish between alternatives. Given that no model, in this case for deriving and generating ES, is more precise than its least precise component, a focus only on parameters that are quantifiable in detail may result in blind spots. Breadth of analysis can be more important than precision in ensuring all environmental, social and economic risks and opportunities of a project are identified and considered. In some projects, a tiered approach, with increasing levels of quantitation or detail, to reduce critical uncertainty or as a project moves through the cycle, may be appropriate.

The maximum benefit from using the ES concept can be expected when applied in each project phase, starting from the very beginning of a project.

Conclusions

ES concepts allow project planners and proponents to put data they have already collected in a different context, identifying risks and opportunities, and supporting engagement. ES thinking supports consideration of project impacts on broader objectives, which may help in stakeholder engagement, as well as enhancing project acceptance and support. In fact, using ES framing to place stakeholders into the centre of the discussion can be one of the keys to success.

Since ES can be used to help place projects within their broader regional, social and economic context, and frame impacts in terms of stakeholders' priorities, considering ES concepts has the most impact if incorporated as early in the process as possible. When addressed in this manner, an ES-framed impact assessment broadens from a consideration of risks alone to one that also looks at the benefits and opportunities of a project, as well as, potentially identifying project vulnerabilities to future changes in ES provision due to climate and other drivers.

To solidify the application of the ES concept in decision-making, there is a need for more demonstration projects in the broader dredging and marine construction sector. This will support growing appreciation by the project owners, developers, operators or managers, public authorities and financers, and result in an increased application. This, in turn, should trigger more legal and regulatory demand and standard setting for the use of ESA (e.g. EU biodiversity strategy). Ultimately, ESA should become a standard component in planning and realisation of dredging and marine construction projects within the broader environment, as such becoming an intrinsic part of development and good governance.

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Summary

Throughout the project cycle, a series of decisions and actions need to be carried out in order to ensure that projects are designed to optimally and cost-effectively deliver their primary objective. Incorporating the ES concept and performing Ecosystem Services Assessments (ESA) supports the project decision-making process in each project cycle stage.

A full consideration of ES impacts, interactions and improvements in marine construction projects can result in more sustainable and adaptive solutions for dredging and marine construction projects, providing returns on investment. ES framing can therefore identify critical capital and values to be sustained, opportunities for nature-based solutions and win-win scenarios, while facilitating the consent process and stakeholder dialogue.

The maximum benefit from using ES concepts can be expected when applied from the beginning of a project. However, even if applied only in later phases of the project, it can still provide significant context and insights. The purpose of this article is to provide a framework for integrated and interdisciplinary thinking throughout the different steps of the project cycle.

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This article is a summary (with slight adaptations) from the PIANC WG 195 report 'An Introduction to Applying Ecosystem Services for Waterborne Transport Infrastructure Projects' (2001) available at https://www.pianc.org/publications/envicom/wg195.

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