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.

**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.
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).

### Provisioning services

<table>
<thead>
<tr>
<th>ES categories</th>
<th>Examples of negative impacts from dredging/marine construction projects</th>
<th>Examples of positive impacts on the ES from dredging and marine construction projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Reduction of available fishing grounds and number of fishes</td>
<td>Drawing, maintaining or restoring nursery areas for fish, incorporating aquaculture facilities or supporting facilities into the project design.</td>
</tr>
<tr>
<td>Water</td>
<td>Reducing the access to water by the installation of breewaters or natural habitat.</td>
<td>Improving the access to water for navigation.</td>
</tr>
<tr>
<td>Raw materials</td>
<td>Destruction of mangrove forests that are used for wood.</td>
<td>Dredged material as a resource.</td>
</tr>
</tbody>
</table>

### Regulating and maintenance services

<table>
<thead>
<tr>
<th>ES categories</th>
<th>Examples of negative impacts from dredging/marine construction projects</th>
<th>Examples of positive impacts on the ES from dredging and marine construction projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water purification</td>
<td>Dredging and maintenance projects impact contaminant dynamics; design can optimise this function.</td>
<td>Dredging and maintenance projects improve water quality; design can minimise adverse impacts.</td>
</tr>
<tr>
<td>Air quality regulation</td>
<td>Dredging of natural habitats (terrestrial or water).</td>
<td>Dredging of natural habitats (terrestrial or water).</td>
</tr>
<tr>
<td>Coastal and riverine protection</td>
<td>Destruction of natural habitats; changes to hydrodynamics and sediment balance.</td>
<td>Coastal development through the use of both hard and soft engineering solutions; riverbank design and maintenance.</td>
</tr>
<tr>
<td>Climate and weather regulation</td>
<td>Sudden changes in temperature, rainfall, wind.</td>
<td>Enhancing carbon storage through natural restoration; e.g. mangroves, marshes.</td>
</tr>
<tr>
<td>Life cycle maintenance</td>
<td>Dredging of natural habitats; changes to hydrodynamics and sediment balance.</td>
<td>Dredging of natural habitats; changes to hydrodynamics and sediment balance.</td>
</tr>
<tr>
<td>Biological control</td>
<td>Dredging and maintenance projects impact contaminant dynamics; design can optimise this function.</td>
<td>Dredging and maintenance projects improve water quality; design can minimise adverse impacts.</td>
</tr>
</tbody>
</table>

### Cultural services

<table>
<thead>
<tr>
<th>ES categories</th>
<th>Examples of negative impacts from dredging/marine construction projects</th>
<th>Examples of positive impacts on the ES from dredging and marine construction projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbolic and aesthetic values</td>
<td>Alteration of historically or culturally valuable landscape or infrastructure.</td>
<td>Design and infrastructure of waterways/ports; sediment management (incl. handling of dredged material); nature-based solutions.</td>
</tr>
<tr>
<td>Recreation and tourism</td>
<td>Alteration of recreational landscape; environmental change.</td>
<td>Incorporating infrastructure with recreational value into the design of e.g. coastal protection projects.</td>
</tr>
<tr>
<td>Cognitive effects</td>
<td>Loss or damage of stratigraphic or archaeological records.</td>
<td>Sharing of information on the impact of the project through media, information panels, etc.</td>
</tr>
</tbody>
</table>

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

### By framing the costs and benefits of natural resource management

- **Ecosystem Services (ES):**
  - **Provisioning services:**
    - Food
    - Water
    - Raw materials
  - **Regulating and maintenance services:**
    - Water purification
    - Air quality regulation
    - Coastal and riverine protection
    - Climate and weather regulation
    - Ocean nourishment
    - Life cycle maintenance
    - Biological control
  - **Cultural services:**
    - Symbolic and aesthetic values
    - Recreation and tourism
    - Cognitive effects

### Benefits of applying the ES concept

- **Environmental:**
  - Enhancing the positive effects of any project on the surrounding natural and socio-economic environment, such as increasing biodiversity and improving natural systems and services.
- **Socio-economic:**
  - Enhancing the positive effects of any project on the surrounding natural and socio-economic environment, thereby improving the socio-economic well-being of many people.

### Added values for your projects and business

- Including ES concepts in marine construction
- By framing the costs and benefits of natural resource management, ES concepts can be used to evaluate, justify or optimise management decisions.
avoiding mitigation measures and comparison costs. Reducing project breakdown risk by identifying project dependencies and vulnerabilities, building resilience against extreme natural events and effects of global climate change, and improving adaptability of infrastructure and supporting environmental security. Contributing to 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 ex-design processes) and allow for more support/acceptance from the local/regional community.

Support decision-making

Information garnered from ecosystem service-based assessment (ESA) can be decisive, supporting or informative (Apillit, 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 supportive, 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 information for 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 licence to operate by engaging stakeholders in evaluating how their values might be affected and how a project might fit into broader local, personal or regional objectives.

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 in itself attenuate local coastal biodiversity, 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.

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 and cost-effective 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, 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 1 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. The 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
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 a port 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 early planning phases to inform decisions, assess project cost-benefit, and identify preliminary ES-related issues. It provides the data to bridge the initial conceptual design phase to the conceptual design phase. Any idea for developing a project goes through a very early stage (conceptual design) 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 primary 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 design phase, investigating 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 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 reality, 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 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 so is that a retrospective ESA is to learn and adapt.

There are two types of Retrospective ESA one evaluates ES data in the absence of a prior Prospective ESA (and thus evaluates monitoring data with a ES framing, but with no ES predictions) and the other evaluates monitoring results in the context of ES impacts predicted by the Prospective ESA. If ES side effects have been 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 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).

A 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 an important tool to provide input for all types of ES 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 instead. 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). 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) adaptive scenarios. However, as it is carried out far into the project’s cycle, benefits from all previous scoping, assessment and data is focused is 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? Least 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
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 generic, 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 generic, 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 generic, 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 generic, 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 generic, the use of ES in considering adaptations to the project can still be beneficial.
illustrating the application of the ES concept in practice (Table 3). Some projects have added value to a project. Examples of applying the ES concept were collected to 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 (April, 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 those 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 (and with each own strengths and weaknesses) (Blanco et al., 2017b). Below we briefly describe the three categories of methods. Please check the PIANC working group W2195 report (2023) for more explanation and example references.

Quality 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 for specific 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 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 physical 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 area to, for example, purify water (m³) or to store carbon (tonnes C/yr) will be lost. Ideally, primary data (fast measurements) are collected or modeled to calculate effects (e.g. using software such as INFES, ARIEES, MIEMES, ECOPLAN-SE, MAPURES). Secondary data can be used for a quick calculation or when primary data cannot be generated however the outcomes are less accurate, especially when it comprises specific literature data from similar cases can be used. e.g. a rough estimate of carbon stored in temperate marshes. Mapping ES with qualitative 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).

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.
objectives, which may help in stakeholder engagement, as well as announcing 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 financiers, 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.

### Annelies Boerema

Annelies specialises in ecosystem services research combining a biophysical and economic evaluation of ecosystem management practices. Her background is in economics and environmental science. In 2018, she obtained a PhD in Environmental Science at the Ecosystem Management group at the University of Antwerp in Belgium. Since 2020, she works as an advisor at JMC, an international engineering and consultancy company in the field of natural waters.

### Sabine E. Apitz

Sabine specialises in developing various conceptual tools, including ecosystem services, sustainability and other ecosystems-based framings, to link what we can measure as scientists to what we want to achieve in society, to support environmental management, policy and decision-making. With a BSc in chemistry (CSUF 1983) and a PhD in Oceanography/Marine Geochemistry (UCSD 1993), she worked for 10 years as a senior marine environmental scientist for the US Navy. For the last 20 years, she has been the Director of SEA Environmental Decisions, an independent consultancy.

### Jochen Hack

Jochen is Professor for Ecological Engineering at the Institute for Applied Geosciences and Leader of the interdisciplinary research group SEE-URBAN-WATER at Technical University (TU) Darmstadt, Germany, since 2018. He is an expert in environmental modeling of nature-based solutions, the study of Green Infrastructure and Ecosystem Services. Jochen holds a PhD in Environmental Engineering and a diploma in Civil Engineering from TU Darmstadt, one of the leading technical universities of Germany.

### Arjen Boon

Arjen is a marine ecologist. He has over 25 years of experience in ecological research and advice. He specialises in integrated ecosystem analyses, monitoring systems and natural resource management. He is currently lecturer of environmental sciences at Aarhus University of Applied Science in Brøndby, the Netherlands.

### References


Pianc (2018) Opportunities to apply the concept of ecosystem services (ES) to the waterborne transport infrastructure (WIT) sector. Pianc Report.


### 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 a better return 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.

### Acknowledgments

This article is a summary (with slight adaptations) from the PIANC W195 report An Introduction to Applying Ecosystem Services for Waterborne Transport Infrastructure Projects (2020) available at https://www.pianc.org/publications/enviscom/ w195.