MARITIME SOLUTIONS FOR A CHANGING WORLD

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TERRA ET AQUA

WORKING WITH LIMITED DATA
Balancing project progress and limited system knowledge in Amatique Bay

CARBON FOOTPRINT
Study to assess greenhouse gas emissions during ripening of dredged marine sediment

ADDED VALUE
Benefits of applying the Ecosystem Services concept across a project cycle

IADC SAFETY AWARDS 2021

RECOGNISING SAFETY INNOVATIONS IN THE DREDGING INDUSTRY

IADC SAFETY AWARDS 2021

AFFIRMING THE IMPORTANCE OF SAFETY

IADC conceived its Safety Award to encourage the development of safety skills on the job and reward individuals and companies demonstrating diligence in safety awareness in the performance of their profession. The award is a recognition of the exceptional safety performance demonstrated by a particular project, product, ship, team or employee(s).

As of this year, two Safety Awards will be granted: one to a dredging contractor (also non-IADC members) and one to a supply chain organisation active in the dredging industry. This concerns subcontractors and suppliers of goods and services. IADC's Safety Committee received 15 submissions in the running for the 2021 Safety Awards. Each one is assessed on five different categories; sustainability; level of impact on the industry; simplicity in use; effectiveness; and level of innovation. Read the full list of contenders on page 30.


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SPEEDING UP THE FIGHT AGAINST CLIMATE CHANGE

Frank Verhoeven
President, IADC

The searing heat that scorched western Canada and the US this summer was 'virtually impossible' without climate change, say scientists. All across the region, multiple cities hit new records far above 40C. Beating the previous national high temperature by more than 4C, as happened in Canada at the beginning of July, is unprecedented.

In the same month, the deluge in central Europe raised fears that human-caused climate disruption is making extreme weather even worse than predicted. Starting on 13 July, historic rainfall caused devastating flooding across North-western Europe, swelling rivers that then washed away houses and triggered massive landslides, and claimed the lives of hundreds of people.

These extreme downpours are one of the most visible signs that the climate is changing as a result of warming caused by greenhouse gas emissions. A warmer atmosphere can hold more moisture, generating more, and more powerful, rainfall. The floods that cut a wide path of destruction devastating towns across western Germany and Belgium, as well as in Austria, parts of the Netherlands, Switzerland and Luxembourg, make the importance of water management clearer than ever.

'We have to speed up the fight against climate change,' said German Chancellor Angela Merkel when she visited the stricken town of Adenau, Germany.

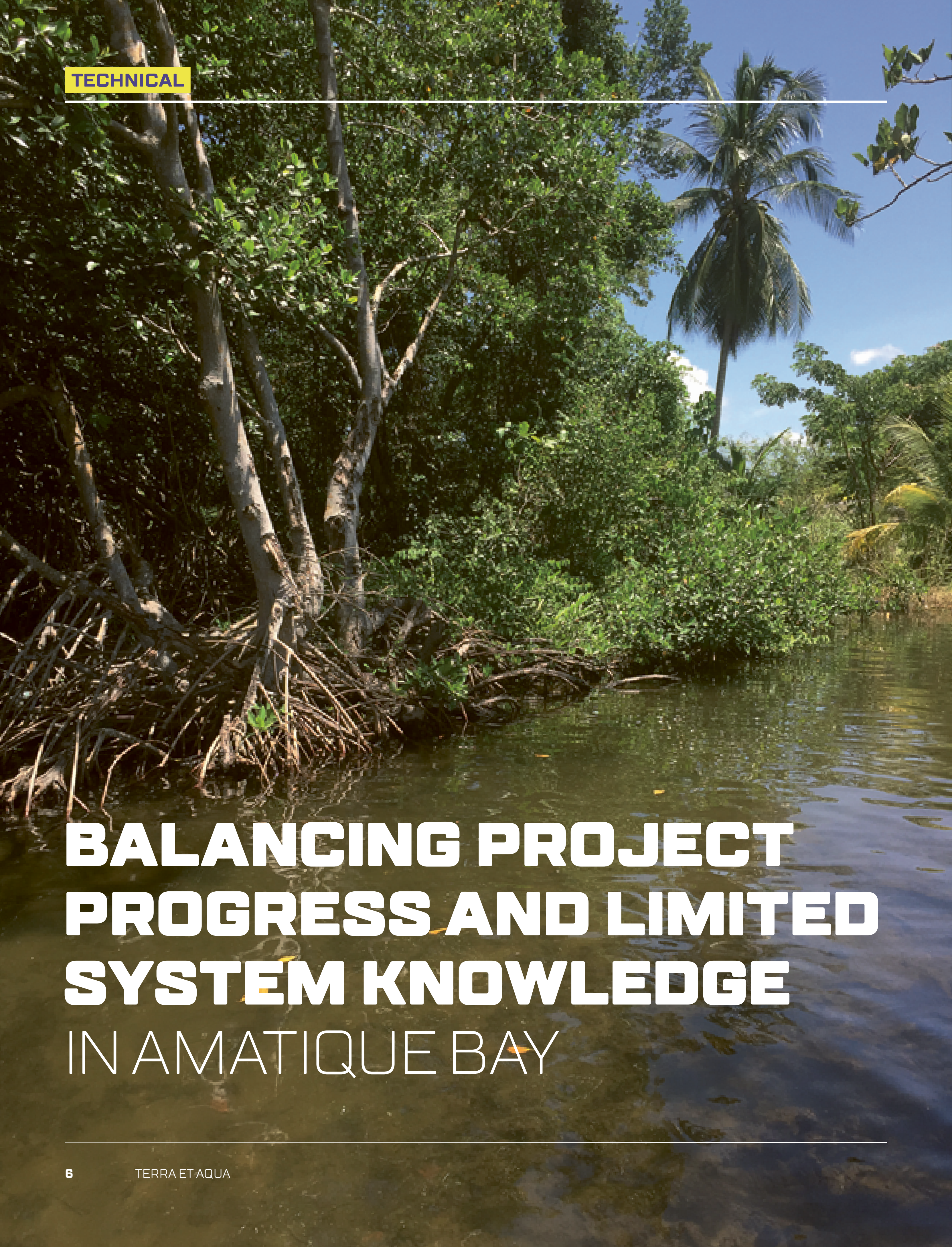
Flooding is a major issue all around the world; the intense rainfall in Kerala, India (2018) and the swollen Yangtze River in China (2020) caused untold damages. The costs – both human and economic – are staggering.

It takes a commitment from many key players to make sustainable marine infrastructure a reality. If clients, contractors and stakeholders make choices that support this commitment, then water infrastructure can be sustainable. IADC and CEDA's joint study to explore the role that investors can play in sustainable waterborne infrastructure projects will be launched during CEDA's Dredging Days, 28–29 September 2021. The report, Financing Sustainable Marine and Freshwater Infrastructure, explores private financing of green coastal, river and port projects. There is no alternative to green infrastructure if we want to tackle the challenges of climate adaptation and reduce the occurrence of the recent devastating events.

As increasing greenhouse gas (GHG) emissions contribute to global warming, it is becoming more important to consider the carbon footprint of hydraulic engineering projects. A study of greenhouse gas emissions during ripening of dredged marine sediment in the article on page 20 does exactly that.

Also in this issue, read the full list of submissions in the running for IADC's Safety Awards 2021, the benefits of applying the Ecosystems Services approach throughout a project cycle, and how a method was developed to assess impacts and risks in Guatemala while having limited data at hand.

The floods that cut a wide path of destruction, make the importance of water management clearer than ever.



BALANCING PROJECT PROGRESS AND LIMITED SYSTEM KNOWLEDGE IN AMATIQUE BAY

The development of a new marine project demands a system approach in which all aspects, including technical, economic, environmental and social, are considered and integrated equally and at an early stage. While insufficient information may be available to make informed decisions, choices need to be made to progress a project, assess impacts and risks, and engage stakeholders. This article explores the case of a new port terminal in Amatique Bay, Guatemala. A method was developed to assess, at an early stage, the potential negative impacts on seagrass habitats from the disposal of dredged material at different locations, while having limited real-time and location-specific information at hand.

The challenge is determining the optimal disposal site in relation to dredging method, seagrass beds to be protected and potentially large disposal plumes.

The development

Amatique terminal is a new port in a greenfield location along the Caribbean coast in the bay of Amatique, north of Puerto Barrios, in Guatemala (Figure 1). The terminal is designed for handling containers, general cargo and liquid bulk. The development consists of a port basin (dig-in), storage and handling areas. A new navigation channel will be dredged over a length of 4.3 kilometres (km) and will connect the existing navigation channel to the ports of Santo Tomás and Puerto Barrios with the Amatique terminal.

Amatique Bay is locally rich in biodiversity, especially in the shallow coastal areas where there are habitats of mangrove and seagrass, important for various marine wildlife including the manatee. These coastal areas are, for a large part, protected by Guatemalan Law (Decreto 4-89). Just north of the proposed terminal is the Punta de Manabique Wildlife Refuge, which is also recognised as a 'Wetland of International Importance' under the Ramsar Convention (www.ramsar.org). Information on habitats and species is scarce.

The bay is no longer a pristine natural system, as human activities have a negative effect on the habitat. The towns of Puerto Barrios and Santo Tomás, with their ports (and access channel), industrial activities and urban population concentrations generate wastewater that drains into the bay. There are cargo and passenger sea vessel movements, as well as commercial and artisanal fishing activities ongoing in the bay. In addition, mangrove habitats are often affected by recreational and agricultural practices. Hence the fact that the bay is only locally rich in biodiversity.

Port location and design

Different locations and designs were considered to develop the best alternative matching the requirements for the port and the value of the environment. Amatique terminal is proposed to be located north of Puerto Barrios (Figure 1). Here, the terminal will be protected from waves, with a good connection to hinterland infrastructure and away from various protected areas as much as possible.

A choice was made for a compact inland (dig-in) port, which reduces the visual impact of the port and integrates the terminal in the natural land- and seascape. The effect on the wildlife refuge would be reduced by limiting the permanent intrusion of the protected area and providing an opportunity to dig a large part of the port in a contained area, reducing plume extension and risks of spills. The downside of this choice is that the volume of earthworks is relatively large.

FIGURE 1

Location of the proposed terminal.

Dredging works

By dredging the navigation channel and the inner basin, a total volume of around 10 million m^3 of dredged material will be generated. It is expected that the dredging operation will last between 12–15 months.

Reuse of the dredged material has been considered for fill material and the creation of an artificial island. Disposal on land was also considered. However, the dredged material appeared not suitable for reuse and no land was available for disposal purposes. Bringing the spoil to a marine disposal site appeared to be the only feasible option.

The proposed dredging equipment is largely determined by the minimum water depth required by the dredgers. At a water depth of less than 7 metres, a Backhoe Dredger (BHD) or Cutter Suction Dredger (CSD) can be used. In deeper sections of the access channel, a Trailing Suction Hopper Dredger (TSHD) is preferred. The different types of dredgers are shown in Figure 2.

The challenge

The map in Figure 3 shows the different aspects related to the dredging and disposal activities for Amatique terminal in its environment, showing the challenge of this project. Alternative dredge spoil disposal sites have been identified which have to be analysed for the environmental effects, resulting from the use of each site. Navigational charts of the bay showed two designated disposal sites (C and D) relatively close to the dredging location. The actual regulations regarding these disposal sites could not be confirmed with the authorities in Guatemala. Next to these designated sites, a potential disposal site E has been proposed, outside the protected area and large enough to accommodate all dredge spoil. The map also shows the location of the seagrass meadows and the ecologically sensitive areas in Amatique Bay. The relevant ecological conditions are elaborated on later in this article.

The challenge is to determine the most optimal disposal site in relation to the dredging equipment and method, seagrass beds to be protected and the fine soil, potentially resulting in large dredging and disposal plumes of high turbidity. All this in an environment with little data available and low (and therefore difficult to predict) dynamics in the bay. On the other hand, the project developers wanted to understand the feasibility of the project, inform relevant stakeholders and start the approval process with the local authorities.

FIGURE 2

Different types of dredging equipment (source Boskalis, 2018). (A) Backhoe Dredger (BHD). (B) Cutter Suction Dredger (CSD). (C) Trailing Suction Hopper Dredger (TSHD).

Extensive survey campaigns were not opportune at this stage, forcing us to develop a practical and effective approach to select the optimal disposal site.

FIGURE 3

Overview of the Amatique terminal development and its environment.

The sensitivity of the observed seagrass species to increased sedimentation and turbidity levels was based on literature review.

To predict the suspended sediment concentrations (SSC), which will affect the overall turbidity levels and the sedimentation of the released dredge spoil, a schematised numerical plume model was set up. As input to the model, a source term (elaborated on later in this article) is required. By combining soil conditions, the proposed dredge and disposal locations and the type of dredging equipment to be deployed, source terms were determined.

Extensive survey campaigns were not opportune at this stage, forcing us to develop a practical, integrated and effective approach for selecting the disposal site.

Approach

Our approach is presented in Figure 4 and follows a number of steps. We began by obtaining an in-depth insight into the baseline situation, both for physical and ecological parameters. Most relevant for the physical environment are the hydrodynamic and soil conditions in Amatique Bay. The ecological baseline consists of the presence and extent of seagrass, and its sensitivity to increased sedimentation and turbidity levels due to the dredging and disposal activities.

Physical parameters were derived from analysis of vibrocores and basic flow and turbidity measurements. The seagrass extent was determined by a drone survey and scuba diving for verification at specific locations.

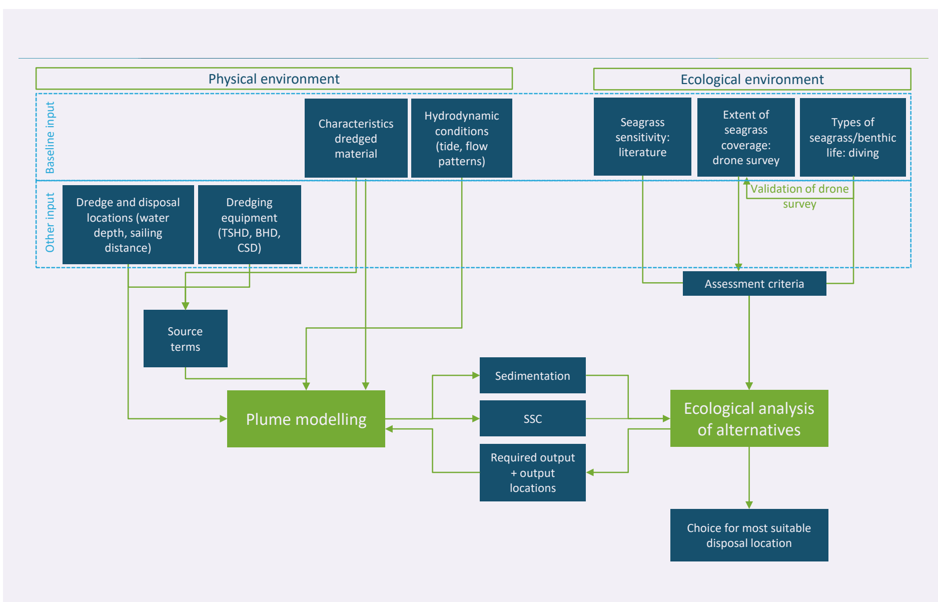


FIGURE 4

Steps of the approach.

Drone surveys for the extent of the seagrass beds were confirmed by diving surveys to determine species and their condition.

In this article, we will focus on the impact of disposal of dredge spoil at the different proposed disposal sites and the selection of the optimal disposal site. The impact of the dredging itself was added to the disposal impact when applicable. With the sensitivity criteria of the seagrass and the outcomes of the plume modelling, the effects of using the alternative disposal sites were compared to select the preferred one.

Baseline

Physical conditions

The bay is characterised by limited tidal difference and weak currents. At the dredging location, the soil material is very fine. Limited data on tidal currents, turbidity and soil characteristics in the bay were readily available.

According to the Admiralty Tide Tables, the tidal variation is limited: MLLW–MHHW range at Livingstone (about 20 km northwest of the project location), is only 0.5 m and the MLHW–MHLW range is 0.3 m.

The project location, in the south-western area of the bay, is sheltered against waves from the Caribbean Sea. The waves are locally generated and therefore low and short. Waves have therefore been ignored in the plume model.

As knowledge of the local currents is essential for a plume dispersion assessment, basic current measurements were conducted with a hand-held instrument in three, regularly alternating locations near the project area. The measurements were

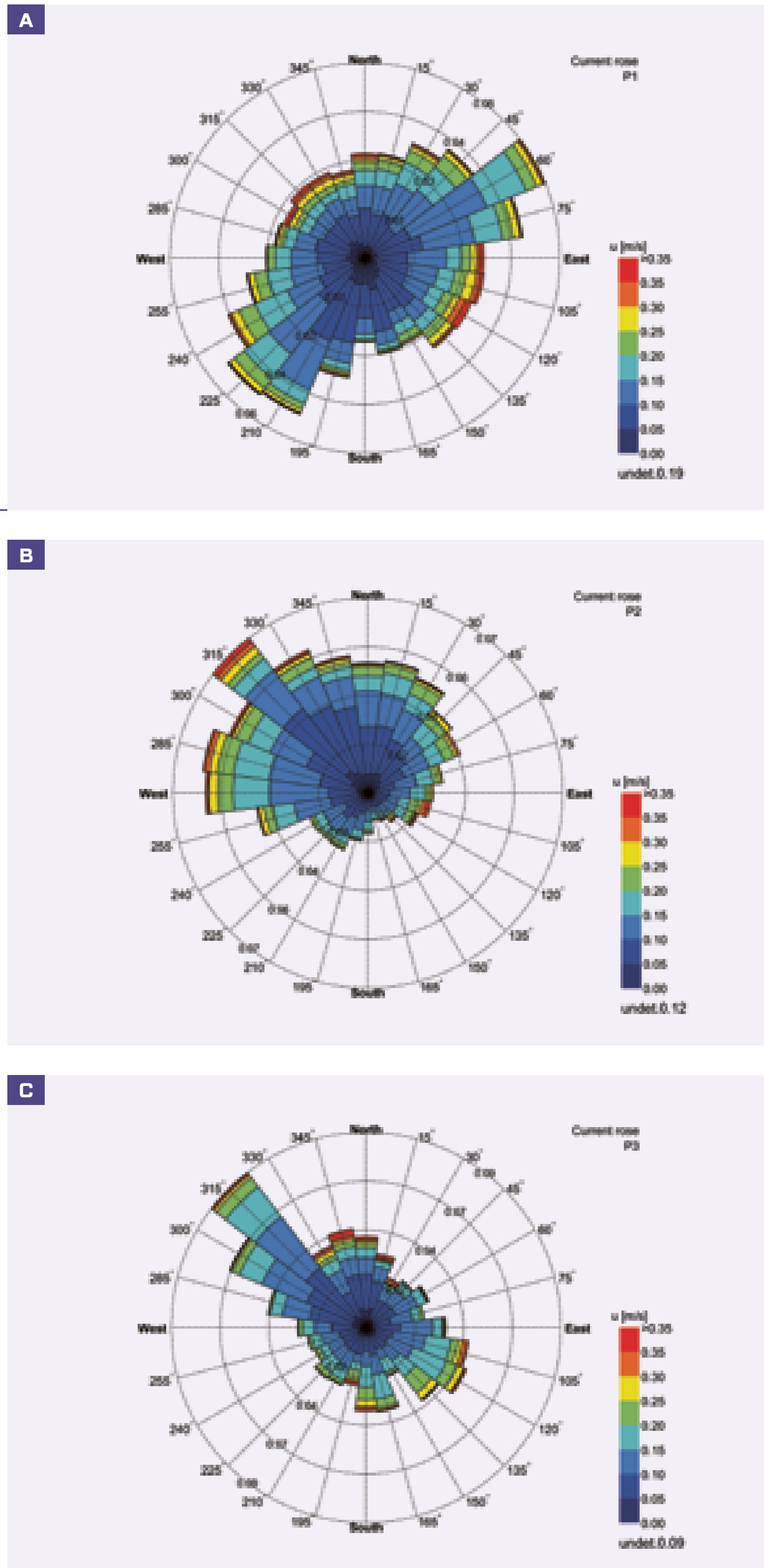


FIGURE 5

Current roses of the three survey locations P1 (A), P2 (B) and P3 (C), collected in the period April to June 2018. Current directions defined relative to north.

FIGURE 6

Schematisation of the measured current conditions as used in the plume dispersion study.

conducted in the period April–June 2018, just before the start of the wet season. The results are shown as current roses in Figure 5. For 95% of the time the velocities were smaller than 0.3 m/s.

Current directions measured with a hand-held instrument in a low-velocity environment are usually inherently inaccurate. Nonetheless, the measured current directions in the three survey locations do show evidence of a circulation pattern along the western shore of Amatique Bay, although variation in the direction is large. Figure 6 shows the measurement locations and our interpretation of the measured current conditions as used in the schematised plume model.

The current in Amatique Bay is likely a combination of tidal filling and emptying, large-scale wind-induced circulation patterns and small-scale disturbances due to bathymetry, topography and local wind variation. The currents are the sum of several subtle processes, whilst the relevant importance of each process will vary in both time and space. Such low-dynamic, complex systems are extremely difficult to simulate accurately with a numerical flow model.

Together with the current measurements, turbidity levels were also measured. Except for occasional peak values of up to 50 NTU (Nephelometric Turbidity Unit), the turbidity levels were generally low resulting in average turbidity levels of around 1 NTU. The turbidity measurements were conducted in the same period as the current measurements. The few rain showers that occurred did not result in increased turbidity levels. Turbidity levels during the wet season may be higher than measured in the dry season, due to more sediments entering the bay with the run-off.

Water samples were collected to establish a correlation between NTU and actual suspended sediment concentrations (SSC) under natural conditions, but unfortunately, no useful correlation could be derived: although NTU values varied substantially, SSC values remained in a very narrow range. An explanation could be locally occurring tannins dissolved in the waters of the bay. These tannins cause strong water discoloration and can significantly influence turbidity without appreciably altering SSC values (Czuba et al., 2011; Fink, 2005). The drone survey images confirmed the dense mangrove forests and associated channels to be the sources of tannins in the system (Figure 7A). The extent of tannins in the system varied along the coastline and occasionally made the observation of seagrass difficult (see following section and Figure 7B).

In March 2018, several vibrocores in the bay were taken of which a selection was analysed on physical characteristics. The percentage of fines (<63 µm) ranged between 70–99% with an average value of 82%. The median grain size d50 was correspondingly small with values between 1.6–22.0 µm, being in the range of clay and medium silt. The in-situ wet density was estimated to be 1,400 kg/m^3.

Distribution of seagrass beds

Seagrass beds are highly productive ecosystems, which play an important role in preventing coastal erosion, siltation of coral reefs and enhancing fish productivity. In Amatique Bay, the seagrass beds are an important food source for manatees. Based on local observations, manatees were known to gather in the area north of Punta de Pichillingo. However, no manatees were observed during the drone surveys. Sightings are rare, as the animals are elusive by nature and difficult to see. However, local fishermen indicated that they see the manatees regularly.

A first drone survey was executed in August 2018 to determine the extent of seagrass beds. With the Map Plus application (iOS), the targeted sections/areas of investigation were preloaded into the base-map. These sections consisted of tracks parallel and perpendicular to the coast using georeferenced waypoints for the drone flights (Figure 8). The planned drone tracks and actual flight coordinates were merged with the recorded videos. These drone surveys were augmented with dive surveys in specific locations to verify assessed species, maximum extent of seagrass beds and local conditions. The drone survey footage was analysed by detailed viewing and notes taken for each transect flown. From these notes, an overall summary assessment was made on the extent of seagrass beds and patterns identified.

A

B

FIGURE 7

(A) Tannins (plant extracts dissolved in water) released by mangroves and channels result in strong water discoloration along the coast.
(B) Tannin-rich waters make assessing seagrass bed presence at depth difficult. In the shallows however, the distribution of tannins visualise the effect of seagrass on water movements.

Based on the drone and dive surveys, two species of seagrass were identified. These are *Thalassia testudinum*, also known as turtle grass, and *Syringodium filiforme*, known as manatee grass. *Thalassia testudinum* is most abundant. Both species of seagrass are classified as of 'least concern' on the IUCN Red List of Threatened Species (www.iucnredlist.org). Other species were not observed during the surveys, but if they do occur in the bay, they exist in much lower abundance. Green algae and possibly *Halimeda* species were observed during the drone surveys.

The surveys show that the seagrass grows close to the coastline and extends approximately 200 m into the bay. The seagrass is found up to an approximate water depth of 6 m. On the south-western coastline near Punta de Palma, patches of seagrass have also been observed (Figure 3).

A second drone survey was executed in September 2018 to determine the extent of the seagrass along the western coastline near Punta de Palma. During this survey, only parts of the coastline were surveyed. The footage shows that the seagrass beds have a patchy distribution along all coastlines. The drone survey showed that seagrass was present all along the surveyed coast, with highest densities observed in very shallow waters (Figure 9). When seagrass was not visible, it was assessed that this was most likely due to local turbidity and/or discoloration of the water due to plant extracts (tannins) coming from the mangrove coast.

Plume modelling

Source terms

One of the most important parameters to be considered when assessing environmental impact of dredging is the generated turbidity. Source terms, being the mass of fines released per second, are needed as input for turbidity modelling. Source terms can be calculated as peak source terms or cycle average source terms. Peak source terms are calculated for

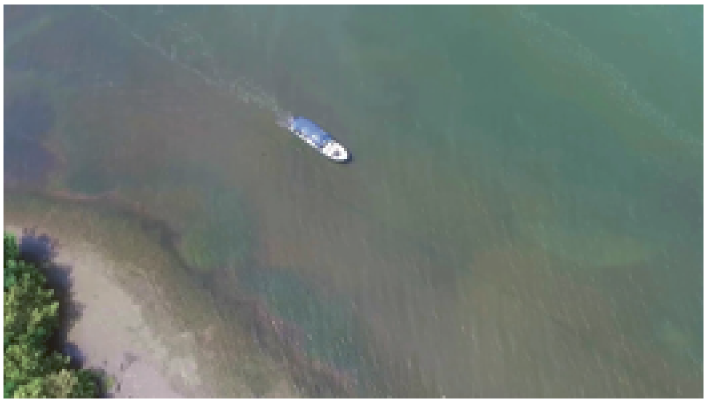


FIGURE 8

Drone flights along the coast, launched from a small boat, aided in surveying the presence and extent of seagrass beds and patches.

FIGURE 9

Seagrass was present all long the surveyed coast, with highest densities observed in very shallow waters.

the duration of the activity that is causing the turbidity, e.g. dredging or overflowing. Cycle average source terms average the mobilised mass of fines over the entire dredging cycle, consisting of dredging, sailing to disposal location, disposing and sailing back to dredge location. Such a dredge cycle is typically related to dredging with a TSHD. CSD or BHD dredging is more or less a continuous process for which there is no distinction between the peak and cycle average source term, whilst disposing by means of barges is intermittent, just like TSHD dredging.

The source terms are calculated with the method put forward in CEDA/IADC (2018). The magnitude of the source terms of dredging operations depends on the type of dredger, the dredger's production rate, percentage of fines in the bed, in-situ density and the far-field factor, being the fraction of the dredged fines that will form the sediment plume. In this study, the source terms have been calculated deterministically, although the input parameters involved are variable and uncertain.

As various disposal locations are reviewed with different water depths, as well as different types of equipment, multiple situations have been considered in the source term determination (see Table 1). Four types of equipment have been examined. Disposal takes place at locations C, D or E and dredge spoil will be disposed by either of the equipment types. As the CSD is deployed in combination with non-overflowing barges, the CSD disposal source term is relatively small due to the large volumes of process water in the barges. The TSHD can be loaded most efficiently, hence the relatively large disposal source term. Note that the peak source terms of the two BHDs are equal but the cycle time differs with a factor of approximately two, because of which the two BDHs will have different impacts.

TABLE 1

Source terms for various work methods and disposal locations.

Equipment	Location	Depth [m]	Source term [kg/s]	Cycle
CSD	C	6	25.6	Intermittent
BHD A	C	6	95.3	Intermittent
BHD B	C	6	95.3	Intermittent
TSHD	D	10	131.1	Intermittent
	E	9	131.1	Intermittent

Plume spreading

Following the determination of the source terms, the spreading and associated sedimentation of fines is determined. The current pattern in Amatique Bay is complex and difficult to reproduce with a numerical model, especially due to the absence of accurate bathymetric data, spatially and temporally varying wind fields and more accurate current and water level measurements. We therefore chose an approach using a schematised Delft3D model rather than a model of the actual bay.

The schematised numerical model was based on uniform representative depths and schematised flow patterns (Figure 6). This enabled us to isolate the influence of parameters and processes and provide valuable insight into the model sensitivities.

In the schematised model, the tidal flow is strictly bi-directional, ensured by imposing water levels at one end and flow velocities at the other end of the domain. Boundary conditions are imposed in such a way that the average current velocity represents the measured current velocities of approximately 0.2 m/s. Wind-driven currents are neglected. The model domain has a length of 20 km in the direction of the flow and a width of 5 km perpendicular to the tidal axis, with a grid resolution of 50 m in both directions. A 3D modelling approach was adopted to accurately simulate the slowly settling fines, resulting in a variation in concentration over the water column. Ten vertical layers were used over the water column, each containing 10% of the water depth. The seabed level is uniform but may vary for the considered locations, resulting in water depths ranging between 5–10 m.

The release of fines during the different disposal activities was simulated by adding the source terms in the middle of the model domain. A far-field situation was considered so the sediment source term was divided equally over the ten vertical layers. The discharged spoil typically has a particle size (d_{50}) of 10 μm, with an associated settling velocity of 0.08 mm/s. For each location, a schematised model was set up and the appropriate source term was imposed representing the different dredging methods and cycle times.

The numerical model predicts the variation of suspended sediment concentrations and sedimentation layer thickness, both in time and space. Due to the recurring tidal flow pattern, the released fines flow back and forth while slowly settling to the seabed. This symmetric pattern in the sediment plume can clearly be seen in the maximum (or average) concentration of suspended fines over a period of 4 days (Figure 10) for disposal at site E with the TSHD. It should be noted that the maximum (or average) values shown here do not occur simultaneously. The concentrations and sedimentation thickness are highest close to the dredging location and quickly decrease in the flow direction (Figures 10A and 10B). At a distance of 2 km, the maximum concentration has decreased to 66 mg/l.

Table 2 summarises the results of the sediment plume dispersion model. For all simulations, the maximum and mean suspended sediment concentration (SSC_{max} and SSC_{mean}) in 4 days is given for locations at 2 km and 3.5 km away from the disposal location. These distances have been chosen to provide a general overview of the results of the different simulations and to support the ecological assessment. In addition, the mean and maximum lengths (Lp) and the widths (Wp) of the SSC plume have been listed, where the edge of the plume is assumed to be at a suspended sediment concentration of 1 mg/l. Furthermore, the average sedimentation thickness (over the entire area where sedimentation occurs) was calculated (D_{mean}). Only the average sedimentation thickness

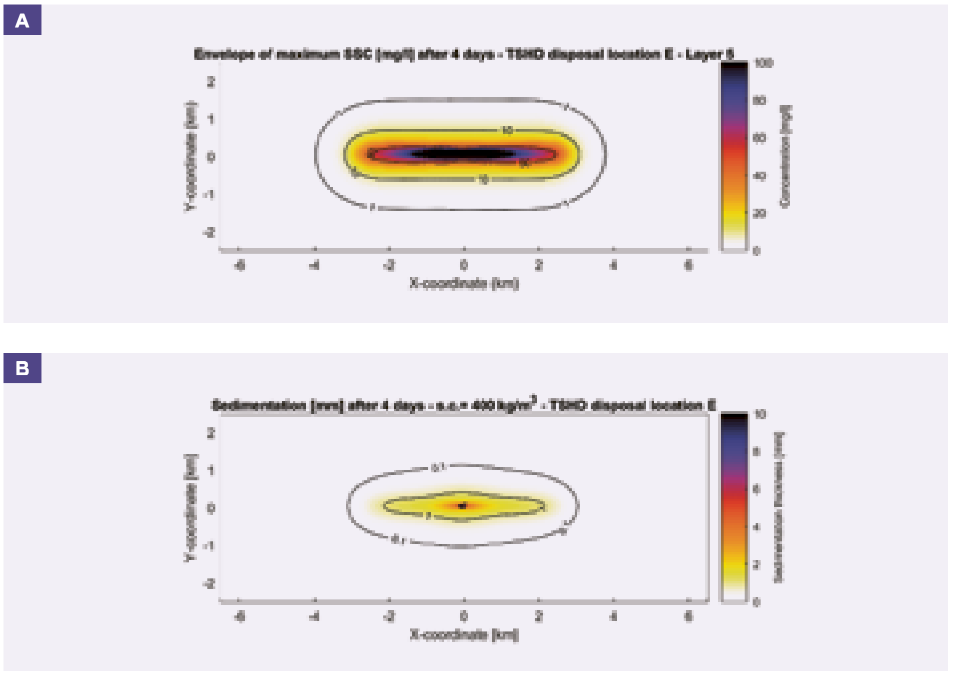


FIGURE 10

(A) Maximum suspended sediment concentrations half-way the water column following disposal activities with the TSHD. (B) Sedimentation on the seabed from disposal activities with the TSHD.

is presented, because this fine material, once on the bottom, spreads out easily and becomes an almost flat area. Note that the SSC are excess SSC and that for the total SSC the ambient SSC should be added.

In this way, the effects of the different disposal methods and locations are compared (Table 2). The suspended sediment concentration at 2 km is highest for the BHD A. At 3.5 km it is highest for the TSHD. The sedimentation is also larger for the TSHD and BHD A. For the disposal activities, there is some variation in the length of the plume. It should be noted that not only does the magnitude of the source term play a role in the SSC and sedimentation patterns, but also the dredging operation cycle time and depth.

In this assessment, the sensitivity of the plume dispersion and deposition to flow velocity, sediment particle size, dry density of deposited sediment and assumptions in the source term determination were assessed, in order to account for natural variations in the system. For example, the maximum measured flow velocity of 0.3 m/s results in a longer but more diluted sediment plume. When the disposed sediment is finer, the sediment plume is significantly larger in extent, both due to advective and diffusive processes. When determining the source term, the percentage of fines reaching the far field (i.e. the far-field factor) needs to be estimated, but this estimate can have a large effect on the plume extent.

The schematised model results were transformed into impact maps (Figure 10 and 11) using the interpretation of the measured current conditions (Figure 6). These maps show the 1, 10 and 50 mg/l contour line of the mean suspended sediment concentration, based on disposal either in the centre or at the edge of the disposal location.

In these maps, the general flow direction is considered as well: the plume extent was rotated in such a way aligning it with the dominant flow direction, following the circulation pattern in the bay as shown in Figure 6. As disposal can in principle take place anywhere within the boundaries of the disposal site, an impact area around the edges of the disposal site was indicated, covering the area of the disposal site and the maximum extent of the plume around it.

TABLE 2

Suspended sediment concentrations and sedimentation at different distances from the source location.

Equipment	Location	SSC_{max} (mg/l) in layer 5		$W_{p,max}$ (km)	$L_{p,max}$ (km)	SSC_{mean} (mg/l) in layer 5		$W_{p,mean}$ (km)	$L_{p,mean}$ (km)	D_{mean} (mm)
		2 km	3.5 km			2 km	3.5 km			
CSD	C	45	1.4	2.4	3.5	13	0.3	2.3	3.0	0.5
BHD A	C	80	1.9	2.5	3.6	18	0.4	2.3	3.0	0.6
BHD B	C	56	0.8	2.0	3.4	3.2	0.1	1.9	2.7	0.4
TSHD	D	61	3.6	3.0	3.9	17	0.7	2.9	3.3	0.6
TSHD	E	66	3.7	2.9	3.9	18	0.7	2.8	3.3	0.6

Impact on seagrass beds

Methodology

The tolerance of seagrass to increased turbidity and additional sedimentation is species and location specific. Larger, slow-growing species with substantial carbohydrate reserves show greater resilience to such events than smaller opportunistic species of seagrass. However, the latter display much faster post-dredging recovery when water quality conditions return to their original state (Erftemijer and Lewis, 2006). The species present in Amatique Bay, *Thalassia testudinum* and *Syringodium filiforme,* belong to the larger, slow-growing species. Literature, for example Erftemeijer and Lewis (2006), was reviewed to determine the tolerance of these species to dredging activities.

The actual impact of dredging and disposal activities on seagrass depends on multiple factors, such as ambient levels and changes to light availability, turbidity levels and sedimentation rate. Not only are the levels of these different parameters important but also the duration at which the seagrass species is exposed to increased levels of turbidity and sedimentation. Temporary exposure to high turbidity levels may not be fatal while long-term exposure can cause degradation of seagrass beds. Seagrass can tolerate sediment plumes (and therefore elevated turbidity levels) for relatively long periods. Tolerance levels vary between species based on their growth strategy and morphology (i.e. amount of starch reserves in the roots). However, most species are less tolerant to increased sedimentation, with only the fastest-growing species capable of outpacing sedimentation rates for a limited period before eventually exhausting their resources. Based on the literature reviewed, the tolerance of the species to increased levels of turbidity and sedimentation showed a large range and differed per location. No studies were found specifically on the tolerance of seagrass in Amatique Bay.

The exact requirements for the seagrass species in Amatique Bay and the water quality parameters (including seasonal changes) within which the species occur were unclear as there was only limited data on natural turbidity levels and light availability. Ideally, critical thresholds should be determined in terms of light availability close to the seabed (% SI) and suspended sediment concentrations (SSC).

TABLE 3

Table showing the overlap of the plume with the seagrass areas in km^2 for different disposal scenarios.

Disposal site	Equipment	Flow velocity	Settling velocity	Overlap maximum extent plume with seagrass
C	CSD	0.2 m/s	0.08 mm/s	3.4 km^2
D	TSHD	0.2 m/s	0.08 mm/s	2.0 km^2
E	TSHD	0.2 m/s	0.08 mm/s	1.3 km^2

Without robust survey data, a critical threshold could not be determined to assist in the selection of the disposal locations. Therefore, to enable an assessment, the impact of disposal activities on the seagrass was based on the total area of seagrass exposed to both the maximum extent of the sediment plume and the extent of the sediment plume with an average increase of SSC levels of 1, 10 and 50 mg/l over a period of 4 days. These levels were chosen based on a practical basis, with 1 mg/l dictating the 'maximum plume extent', 10 mg/l indicating an 'area of influence' and 50 mg/l indicating an 'area with potential for impacts'.

Selection of the optimal disposal site

At first, disposal sites were compared based on the total area exposed to the maximum extent of the sediment plume. The maximum extent is the maximum area that could have raised SSC levels (of at least 1 mg/l) at one point in time during the dredging and/or disposal activities. The extent of the plume was based on the equipment that was most likely to be used at the disposal site. For disposal site E and D, the TSHD is proposed, while for disposal site C, the CSD is suitable due to the location's shallower water depth.

Figure 11 shows an example map of the maximum extent of the sediment plume at disposal site E with different concentration levels.

Table 3 shows the maximum area of seagrass, which could have SSC levels of at least 1 mg/l at one point in time during disposal activities.

Site E was selected as the most favourable disposal site for the following reasons:

Site C:
- Shows the highest potential overlap (3.4 km^2) of the sediment plume with the seagrass area;
- Suspended sediment concentrations and sedimentation from disposal accumulate with those from dredging in the navigation channel (NC); and
- Effort of maintenance dredging increases as the navigation channel crosses this disposal site.

Site D:
- Generates a substantial area (2.0 km^2) of seagrass to be exposed to the sediment plume;
- Is located within the Punta de Manabique Wildlife Refuge; and
- May create exposure of known feeding areas of manatees to the sediment plume.

Site E:
- Shows the smallest area of seagrass exposed to the sediment plume (1.3 km^2);
- Is located outside Punta de Manabique Wildlife Refuge and further away from Ox Tongue (a known manatee area); and
- This site is further away from the dredging site than the other sites.

Sensitivity analysis

The imposed source terms that were used in the model were based on multiple assumptions, such as the amount of material reaching the far field and the settling velocity of the spoil. A sensitivity analysis was performed to show the effects of the choices in (input) parameters on the suspended sediment concentrations and the amount of sedimentation.

In addition, the location where the dredge spoil is disposed within the area of the disposal site

FIGURE 11

Extent plume disposal site E using TSHD.

FIGURE 12

Extent of the sediment plume when disposing at the corner of disposal site E, based on the assumption that 5% of fines reach the far field, a current velocity of 0.2 m/s and a settling velocity of 0.08 mm/s.

(either in the centre or at the edge of the disposal site) can have a significant effect on the extent of the dredging plume.

Table 4 shows the difference in maximum extent of the sediment plumes with a variety in source terms, settling velocity and disposal in the centre or at the edge of site E. The maximum extent of the sediment plume increases slightly if the current is increased from 0.2 m/s to 0.3 m/s and if the percentage of fines in the far field increases from 5% to 25%. When applying the 5% source term, after 4 days, the disposal plume does not overlap with the seagrass beds when disposing in the centre of the site. However, when disposal near the edge is modelled, a small area of seagrass is potentially affected.

TABLE 4

Overlap of the plume with seagrass areas in km^2 at disposal site E for TSHD with different input parameters.

Flow velocity	Far-field factor (for source term determination)	Settling velocity	Maximum extent
0.2 m/s	5%	0.08 mm/s	1.3 km^2
0.2 m/s	10%	0.08 mm/s	1.9 km^2
0.2 m/s	25%	0.08 mm/s	2.6 km^2
0.2 m/s	5%	0.2 mm/s	0.6 km^2
0.3 m/s	5%	0.08 mm/s	4.4 km^2

Based on the plume modelling results, we cannot rule out the possibility that during the 12–15 months of disposal, some areas of the seagrass might be exposed to increased SSC levels of more than 1 mg/l when the disposal would be undertaken near the edge of the disposal site (Table 4). Based on our analysis, a maximum area of 0.1 km^2 of seagrass will be exposed to these increased levels of SSC. However, the seagrass will not be exposed for a significant amount of time because the actual disposal location will vary over the dredging period. It can be concluded that the seagrass will experience minimal exposure to any appreciable elevated turbidity and sedimentation levels for longer periods.

Lessons learned

By sharing some lessons learned from this case of the Amatique terminal, we hope to provide insight to all stakeholders involved in similar projects around the world.

Multi-disciplinary team involved at an early stage

One of the most important lessons learned was the need for a multi-disciplinary team in a very early stage of the assessment. Experts in port

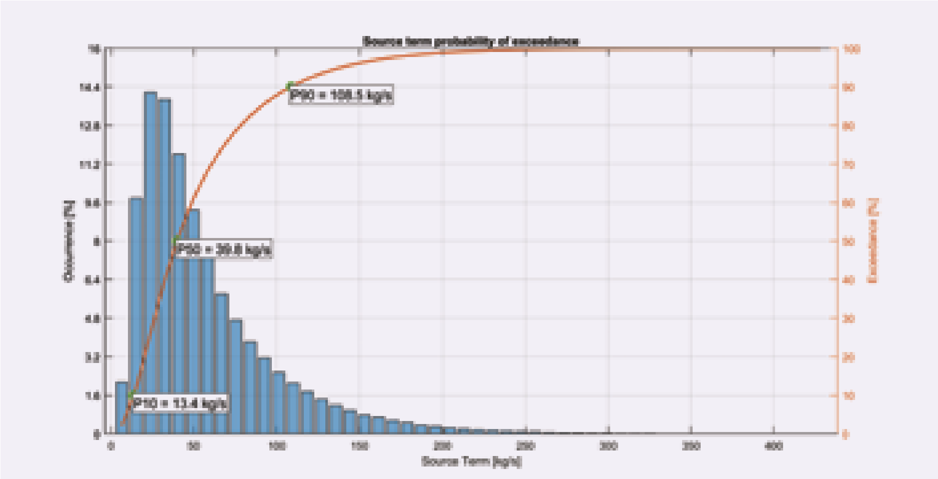


FIGURE 13

Example of a source term probability of exceedance curve.

The set up of a realistic model of Amatique Bay is only feasible and of added value when extensive data sets are collected for model set up, calibration and validation. At minimum, detailed bathymetric data of the entire bay, spatial wind fields, water levels, water depth, flow data and turbidity data at various locations are required. Gathering this data would entail an extensive survey campaign, which was not feasible in this stage of project development.

design, dredging methods, ecology, coastal hydrodynamics and morphology need to be involved at the same time. An integrated system approach should be developed together.

Source term determination using a Monte Carlo approach

The source terms as input in the plume dispersion model were, in this case, calculated in a deterministic manner, which is one source term for each unique combination of dredger type, production and soil conditions. However, the parameters determining the source term are uncertain, vary in time and space and/or have limited accuracy. A probabilistic source term calculation does more justice to the uncertainty in these parameters.

A way to do this is to apply a Monte Carlo simulation, in which a large number of random samples are drawn from a pre-defined range of parameter values with an associated distribution (e.g. uniform or triangular). The result is a source term probability of exceedance curve. A typical example of which is shown in Figure 13.

With symmetrical distributions around the mean values of each parameter, the median (P50) source term is equal to the mean source term and to the deterministic source term. The added value arises from a quantification of the spreading in the source term, typically expressed in P10 and P90 values (values exceeded 90% and 10% of the time respectively). Depending on, among others, the purpose of the study and the need for a cautionary principle, the user can select one or more appropriate values for the source term.

Key considerations of the drone survey method

The drone survey provides some important opportunities. Drones can cover large areas in a relatively short timeframe with minimal interference in the natural environment. The results include a valuable ecological and morphological database, useful for the whole project cycle.

However, there are also some important considerations and limitations to make. Drone flights require in-situ validation of observed or assumed species, densities and other metrics. Satellite images can also support the outcomes of the drone survey. The principle of lateral continuation can help to interpolate the seagrass presence/absence, even if it appears to be absent due to low visibility for example.

Optical factors, such as weather, air quality, water depth, water quality and coloration, optics, sunlight reflection and waves, influence the quality of the video footage considerably. This demands careful planning and preparation.

Application of the plume model

The advantage of a schematised model approach as used here is the efficient testing of model sensitivities, providing valuable insight in possible bandwidths of results. Furthermore, setting up a realistic model in a data-poor environment such as Amatique Bay is complex and requires an enormous effort. Improvements to the schematised model can be made if more detailed field data, such as flow velocity, water level and turbidity, at locations of interest is available, enabling verification of the model results.

Seagrass sensitivities in baseline conditions

There is a lack of information on the current levels of exposure and sensitivity of seagrass to turbidity and sedimentation levels within the bay. A key question remains whether the seagrass is naturally adapted to the already high turbidity levels, making them resilient to transitory plumes from the operations or if they are already near or at their maximum ecological threshold, in which case any added perturbation may trigger visible impacts. This made it difficult to determine the added impact of the dredging operation for the Amatique terminal. To determine thresholds values, above which measures are required to protect the seagrass, data of (the variation in) current ambient levels are required. To provide a robust assessment, a precautionary approach had to be adopted. When more information would have been available, a more realistic scenario could have been assessed.

Moving forward

The results of this study have been included in the Environmental Impact Assessment and when the dredging operation starts on the Amatique terminal, an adaptive management approach will be applied. Adaptive management ensures that the effects of the dredging activities will remain within environmental boundary conditions with the aim to limit, if not prevent, any negative impacts to the seagrass beds. This is done by adapting the operation based upon the monitored ecosystem's actual health, particularly of sensitive receivers such as the seagrass beds.

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Summary

In present times, the development of a new marine project demands a system approach, in which all aspects from technical, economic, environmental and social are considered and integrated equally and at an early stage. The process from a first project idea to actual implementation is complex, iterative and time-consuming with many (unknown) variables. For some aspects, there may not be sufficient information available (yet) to make a fully informed decision to feed the project development process. However, choices need to be made to progress the project, assess impacts and risks, and engage stakeholders. This is a dilemma common to those working in marine project development.

This article explores the case of the greenfield development of a new port terminal in Amatique Bay, Guatemala. We developed a method to assess, at an early stage, the potential negative impacts on seagrass habitats from the disposal of dredged material at different locations, while having limited real-time and location-specific information at hand. This method relied on basic surveying and the application of a schematised numerical plume dispersion model. We hope to inspire readers to think about similar cases and share these, so we can learn from each other and enhance our projects, contributing to sustainable development locally and globally.

REFERENCES

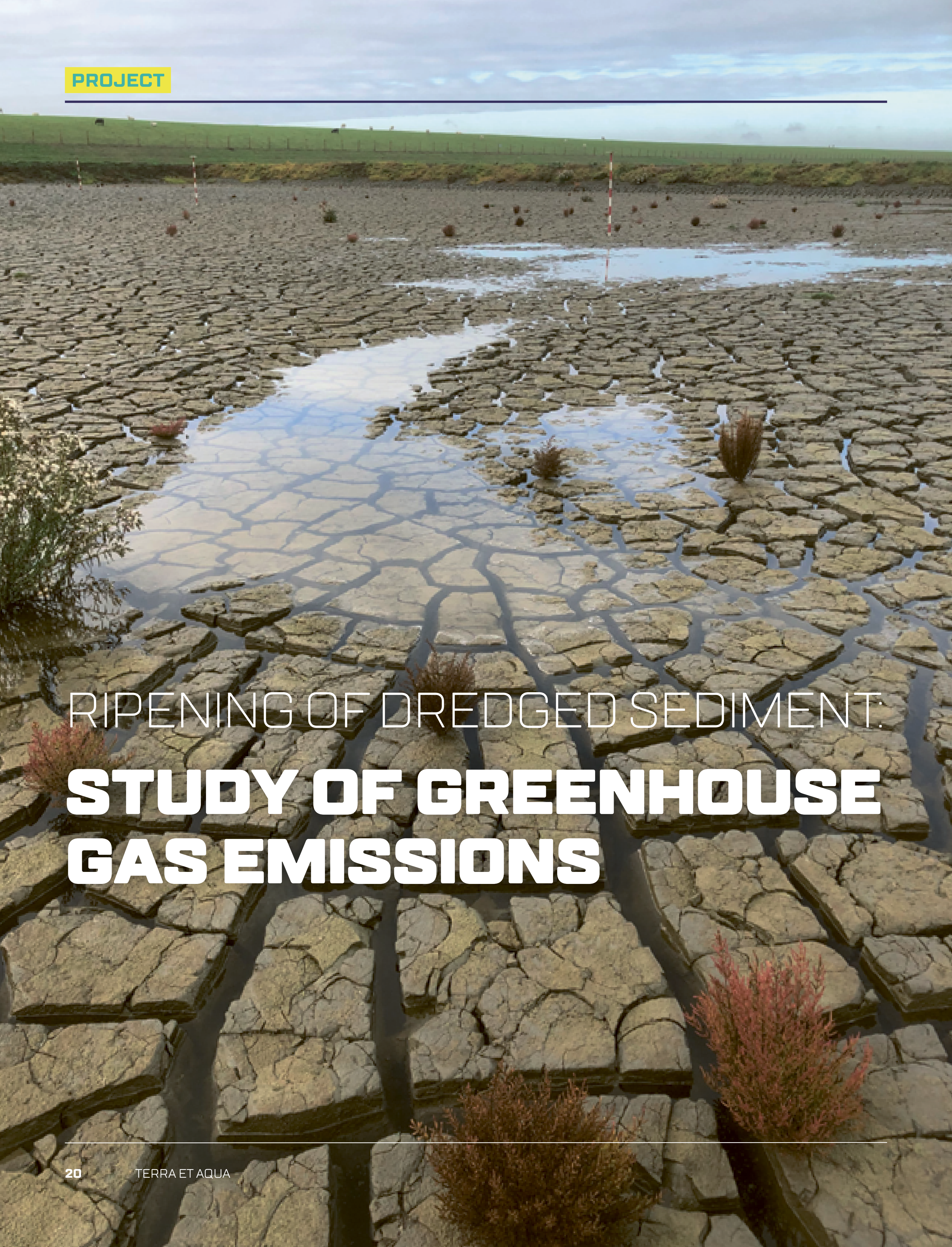
Admiralty Tide Tables, Volume 2 (2017)
No 2422 Rio Dulce Entrance (15°50'N 88°45'W near Livingstone, approximately 20 km NW of project area).

CEDA/IADC (2018)
Dredging for sustainable infrastructure. CEDA/IADC, The Hague, the Netherlands.

Czuba J. A., Magirl C. S., Czuba C. R., Grossman E. E., Curran C. A., Gendaszek A. S. and Dinicola R. S. (2011)
Comparability of suspended-sediment concentration and total suspended solids data sediment load from major rivers into Puget Sound and its adjacent waters. USGS fact sheet 2011–3083. Tacoma, WA: U.S. Geological Survey.

Erftemeijer P. L. and Lewis III R. R. R. (2006)
Environmental impacts of dredging on seagrasses: A review. *Marine pollution bulletin*, *52*(12):1553–1572.

Fink J. C. (2005)
'Establishing a relationship between sediment concentrations and turbidity' in The effects of urbanization on Baird Creek, Green Bay, WI (Thesis). http://www.uwgb.edu/watershed/fink/Fink_Thesis_Chap4.pdf



RIPENING OF DREDGED SEDIMENT: STUDY OF GREENHOUSE GAS EMISSIONS

Two clay ripening pilots were constructed in the province of Groningen: Delfzijl and Kwelder, established in 2018 and 2020 respectively.

As increasing greenhouse gas (GHG) emissions contribute to global warming, it is becoming more important to consider the carbon footprint of hydraulic engineering projects. This carbon footprint is more complex than previously thought however, as it can also include the carbon dynamics of the sediments from which projects are built. The purpose of this study was to provide a first approximation from sediment-related GHG emissions of dredged sediments. Using the case study of the clay ripening pilot project ('Kleirijperij') in Groningen, the Netherlands, one phase of sediment processing was examined: the ripening of dredged sediments for use as a clay material in dyke construction.

When calculating GHG emissions from dredging and dyke infrastructure developments, the focus is on the emissions arising from operations and transport (e.g. fossil fuel combustion). However, the carbon stock concealed in ecosystem sediments, has the potential to be released as GHGs by dredging, drying, processing and further use. To date, these sediment-related GHG emissions arising from disturbance are often not accounted for in life cycle analysis (LCA) of hydraulic engineering projects. It also not known how much of the stored carbon is released via GHG emissions upon disturbance.

Clay ripening pilot project ('Kleirijperij'): a win-win

The aim of the clay ripening pilot project ('Kleirijperij') is to study innovative methods to transform locally dredged soft sediments into clay soil suitable for dyke construction. The pilot project monitored a range of physical and chemical characteristics over 2 years and assessed the suitability of the clay product for dyke construction. Two clay ripening pilots were constructed in the province of Groningen: Delfzijl and Kwelder, established in 2018 and 2020 respectively (Figure 1). Both pilot projects consisted of multiple test beds to test whether the conditions, such as the deposition layer thickness, the ploughing frequency and the presence of plants, aid the ripening process and eventually the clay quality. Ultimately, the finished ripened clay product will be used for the construction of the 'Brede Groene Dijk' (The Wide Green Dyke). Clay ripening from soft sediment is a form of beneficial use of dredged sediment. The Eems-Dollard estuary has to be dredged annually for transport purposes (mainly for the harbours of Delfzijl and Eemshaven) as well as ecological purposes. The high turbidity of the estuary is an ecological concern. Structurally removing approximately 1 million tonnes of sediment per year can have significant effects on this turbidity (Van Maren, 2016), which is a driver for larger scale future dredging. To evaluate large-scale use on land of dredged Eems-Dollard sediment in the future, several pilots are being conducted within the Eems-Dollard 2050 programme. The clay ripening pilot is one of them (Sittoni, 2019) and is executed by the Province of Groningen, Groninger Landschap foundation, Groningen Seaports, Rijkswaterstaat North Netherlands, water authority Hunze en Aa's and the EcoShape foundation.

Ripening soft sediment to clay for dyke construction

The large quantities of dredged sediment can be beneficially used in a number of ways. One is the use of clay for dyke construction. In the Netherlands, there is a great need for high-quality clay to reinforce and raise dykes, in order to adapt to the challenges of climate change. Due to the demand, foreign clay is often imported. Costs of dyke clay and transport, in terms of market value, ecological degradation and the carbon footprint from foreign clay extraction and transport, suggests locally produced dredge spoils provide a promising alternative.

In order to be suitable for use as dyke clay, the estuarine soft sediment from the Eems-Dollard estuary (i.e. the sediment trap Delfzijl harbour for the clay ripening pilot Delfzijl and soft sediment deposits in polder Breebaart, deposited over the past 20 years) has to undergo maturation or ripening. This involves

FIGURE 1

Location and overview of the clay ripening pilot projects in the Netherlands. (A) Delfzijl and (B) Kwelder (showing the salt marsh before sediment filling.

dewatering, desalinisation and degradation of organic matter. Desired targets are a pore water chloride content below 2.4 g L^{-1} and an organic matter content of below 5% (dry matter basis). To efficiently reach this composition, various strategies that may improve aeration and availability of labile organic matter were tested, such as aeration of the sediment through ploughing, flushing with freshwater prior to deposition in the test bed, and stimulating biological factors (i.e. plants and worms).

FIGURE 2

Schematic drawing (not scaled) of the test beds at 'Kleirijperij Kwelder' (K1-K10). Schematic overview (not scaled) showing placement of the respiration chambers in test bed K1 and K8. SK = Dewatering cistern. The photo on the right shows cylindrical respiration chambers for sampling greenhouse gases in the field, prior to placement.

How ripening can result in GHG emissions

Coastal estuarine sediments are carbon sinks (Macreadie et al., 2019). Multiple conditions in the coastal estuary, including anaerobic (oxygen-free) conditions in sediments, result in this long-term storage. Dredging activities in the coastal estuary disturb processes both in these ecosystems and in the dredged material. This can result in the release of the stored carbon in the form of GHG emissions. GHG emissions are likely to vary depending on the dredging method, approaches to deposition and the composition of the dredged material. Oxygen is the key element that, when available, facilitates fast microbial degradation of organic carbon stored in the fine sediment. This results in loss of organic carbon as GHG carbon dioxide (CO_2).

During and after dredging, GHGs escape from the dredged material as a result of microbial degradation of organic matter. Following dredging, increased availability of oxygen to the sediment speeds up the degradation process, resulting in the reduction of organic carbon content through increased CO_2 emissions. There is a growing awareness that this source of GHG emissions might be significant for hydraulic engineering infrastructure projects (dykes, harbours, aquaculture, etc.) (Fiselier et al., 2018). However, few reliable measurements or assessments of GHG emissions due to ecosystem-derived carbon losses in hydraulic engineering projects are available.

In this study, we made a preliminary assessment of the carbon loss and resulting GHG emissions from dredged sediments during the clay ripening phase of a hydraulic engineering pilot project. Our goals were to illustrate an approach to assess carbon losses, GHG emissions and key processes involved. In the end, we hope to propose a framework for comparing emissions between different practical options.

Monitoring GHG emissions during the clay ripening pilot project

GHG emissions were measured in the first 3 months of the ripening of fine coastal sediments at the clay ripening pilot project Kwelder. Measurements were performed both in the field and in the laboratory. In March 2020, the clay ripening pilot Kwelder was established and filled with fine sediment.

FIGURE 3

Development of the ripening clay week 5 (A), week 13 (B) and week 35 (C).

This sediment originated from Polder Breebaart, a salt marsh area connected to the Eems-Dollard estuary and thus subjected to (dampened) tidal effects, which resulted in a net increase in sediment over the years. The material was removed using a cutter dredger and pumped at a low density (ca 1.05–1.10 kg/m^3) to the mud ripener over ca 10 km, where it was deposited in ten test beds (K1-K10) (see Figure 2).

Sampling sites to gather GHG emissions were carefully selected to contain fine sediments that made up the largest part of the deposit. These sites were far away from the entry location of the sediment, as mainly heavy particles (sand) settled near these locations. In two of these test beds (K1 and K8), GHG measurements were taken. These test beds were not treated by ploughing, desalinisation methods or introduction of plants. In each test bed, three sediment sampling points were selected and respiration flux chambers (see Figure 2) were installed. Measurements were performed in April and June 2020, 5 and 13 weeks respectively after deposition of the material.

To monitor GHG emissions in the field, flux chambers were closed for 4 hours to collect gas samples, which were later analysed in the laboratory. To support field measurements, sediment from both clay ripening pilot projects was incubated under controlled conditions in the laboratory to measure methane (CH_4) production, by monitoring headspace CH_4 concentration. For comparison, fresh salt marsh sediment (starting material in the Kwelder pilot), ripe salt marsh clay from the Delfzijl pilot and freshwater sediment (from a ditch) were incubated in parallel in the laboratory.

To analyse physical and chemical ripening in test bed K1 and K8, sediment samples were collected at three soil depths (10, 50 and 100 cm[1]) below the surface and analysed for electrical conductivity, pH, redox potential, bulk density (BD) and organic matter (OM) content. OM was analysed by loss on ignition with thermogravimetric pyrolysis (using the TGA-701 by Leco.).

Physical and chemical ripening of the clay

Over time, the fine sediments dried and consolidated to form a denser substrate. The shrinking, compaction and formation of cracks is clearly seen in the photos in Figure 3. Over the first 3 months, the moisture content decreased on average from 65% in April (±3% Standard Deviation (SD), over entire profile of 1 m) to lower values in June: 44% (±4% SD) in the top layer, 55% (±1.5% SD) in the intermediate layer and 39% (±2% SD) in the deep layer. Chloride and sulfate concentrations increased in the top layer due to evaporation of water. Electrical conductivity (EC) was used as a proxy for salinity and increased over ten times during the initial 3 months of ripening (April 10 ± 0.8 mS/cm; June 137 ± 69 mS/cm).

Furthermore, the redox potential decreased, reflecting increasingly reduced conditions (average redox potential -62 ± 25 mV vs SHE[2] in April and -162 ± 17 mV in June) and low availability of oxygen. Analysis of sediment along a depth gradient showed that after 13 weeks sediment was similar in terms of pH (range 7.3–7.5), temperature, EC (range of averages 137–199 mS/cm) and redox potential (range of averages 162–192 mV). All average values are based on six measurements per sediment layer.

Change in organic matter and field GHG emissions

There was a significant decrease in organic matter in the top layer of the ripening sediment (Figure 4). The OM content in April was highest in the top 10 cm and declined by 28% in 3 months (mean 12.5% in April and 9% in June).

1. In some analyses in the first period 75 cm.

2. SHE = Standard Hydrogen Electrode

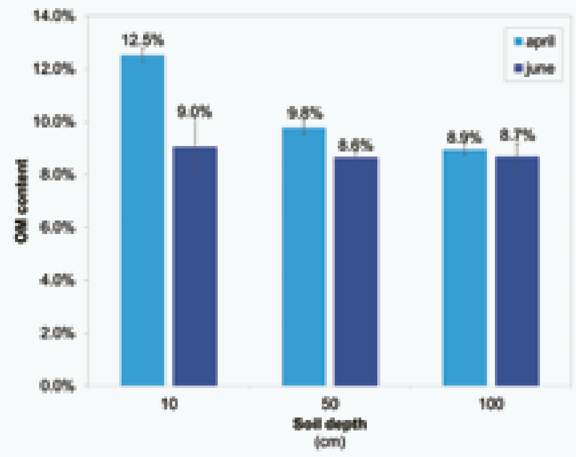


FIGURE 4

Mean (n=6) organic matter (OM) content of the ripening sediment in the Kwelder pilot in April and June for the different soil depths (10, 50 and 100 cm). Error bars represent SEM (Standard Error of the Mean).

Nonetheless, the ripening clay from both pilot project sites was far from the dyke-clay standards' desired 5% of organic matter content as a fraction of dry weight.

No significant emissions of CH_4 and CO_2 were measured in the field (detection limit 0.15% CH_4). This result was confirmed by closed bottle incubations in the laboratory (Figure 5).

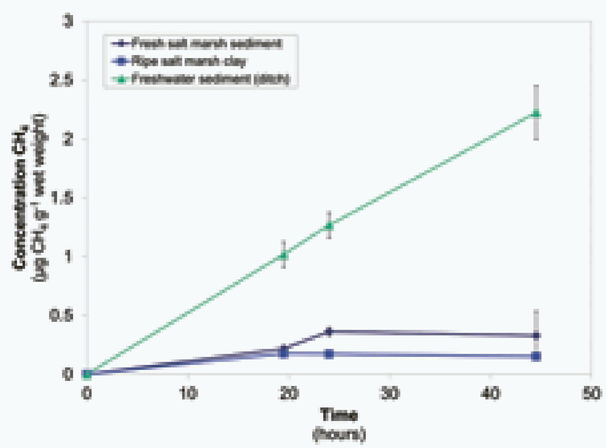


FIGURE 5

CH_4 concentration in the gas headspace of the incubation flasks in time. Bottles contained either freshly collected salt marsh sediment, ripe salt marsh clay or freshwater sediment from a ditch. Error bars indicate standard deviation (SD).

Anoxic conditions create high potential for methane (CH_4) production. The physical and chemical data of the ripening clay showed that oxygen penetration was low and redox potential remained low from April to June in the entire sediment profile. The fact that no considerable CH_4 emissions were observed from the clay ripening might be due to inhibition of CH_4 production by high sulfate concentrations in the estuarine sludge. This results in more favourable conditions for sulfate-reducing microorganisms (that produce sulfide), rather than methane-producing microorganisms. Sulfate reducers are known to outcompete methane-producing microorganisms under anaerobic conditions (Oremland and Taylor, 1975), resulting in limited CH_4 formation. Similar results were found in laboratory measurements of methane emission in 120 ml flask incubations filled with 60 ml of fresh estuarine sediment, estuarine ripe clay and freshwater sediment. Methane emissions from estuarine sediment and clay were negligible, whereas methane emissions from freshwater sediment were significant (ca 1.22 µg methane (g wet weight) $^{-1}$ day^{-1}).

To conclude, for the period of this study we measured relatively limited decline in organic matter content throughout the sediment and low GHG emissions under the given field conditions. Factors that could be the cause for this are:

- our sampling methodology was not suitable for measuring the carbon emissions at the low levels that occurred in the test beds;
- organic matter breakdown by microbial activities is probably limited by limited supply of oxygen (or other electron acceptors); and
- despite favourable redox conditions, methane formation is probably limited because of sulfate reducing conditions.

The degradation of organic matter was studied at this pilot for a limited number of time points over the initial months following deposition and for only one ripening method. To illustrate organic matter degradation over a longer time and for alternative treatment options (e.g. ploughing, stimulated drainage and plants), we compare these to values for the organic matter content for the clay ripening pilot Delfzijl. At the pilot Delfzijl, ripening for 3 years resulted in limited reduction in in organic matter (less than 10%

of the initial amount) (results not shown). This shows that also for the Delfzijl pilot, organic matter degradation remained limited during 2 years of ripening, and alternative methods of ripening did not show significant increase in degradation.

Potential GHG emissions based on changes in sediment carbon stock

Based on the decrease in organic matter concentrations, carbon stocks of sediments and the concomitant GHG emissions of the ripening process can be estimated. This is similar to many studies that have quantified carbon stocks of ecosystems, such as salt marshes and mangroves (Kauffman et al., 2020a; Kauffman et al., 2020b). This is the stock-change approach (SCA) that is also described in the Intergovernmental Panel on Climate Change (IPCC) as an approach to measure carbon stock losses and emissions.

In the current assessment, this SCA approach was performed for two scenarios:

- **Scenario 1:** This scenario represents the results obtained from the field. As described in the results section, transport of oxygen in the sediment and of GHGs out of the sediment was slow, resulting in a thin layer of sediment likely actively emitting GHGs. For this scenario, we assumed the organic carbon degradation values obtained from the clay ripening pilot Kwelder.
- **Scenario 2:** In this scenario, we assumed the clay to reach target values of organic matter content, which were set for the final stage of ripening of this sediment (5% organic matter of dry matter). Starting with 10% of organic matter content in the freshly dredged sediment, this equals a decrease of 5% organic matter loss. In this scenario, this loss of organic matter was assumed for the whole sediment mass. As illustrated with the 2-year data for the Delfzijl pilot, this organic matter degradation was not found in practice, despite efforts to reach the target by aeration through ploughing and the addition of plants. Therefore, this scenario represents a case scenario, not likely to be reached in practice in a short time frame of 2 years. As the Delfzijl pilot showed, even ploughing did not result in this degradation over 2 years.

TABLE 1

Estimated CO_2 emissions per m², per test bed and per tonne of clay for two scenarios.

Scenario	CO_2e emission (kg CO_2e m^{-2})	CO_2e emission (tonne CO_2e test bed^{-1})	CO_2e emission (tonne CO_2e $tonne^{-1}$ clay)
1. Shallow, low OM loss (represents field data)	8	43	0.012
2. Deep, high OM loss (desired quality)	27	149	0.050

Calculation

In order to calculate GHG emissions for the entire test bed for scenario 1, the data collected from specific sampling points and depths were assumed to represent certain depth ranges within the ripening sediment:

- 10 cm sediment samples: representative of the bulk density and soil organic matter at the 0–30 cm[3];
- 50 cm sediment samples: representative of sediments at the 30–60 cm depth; and
- 100 cm sediment samples: representative of sediments at the 60–100 cm depth.

Organic carbon was determined from measured organic matter concentrations from the Kwelder pilot using a relation presented by Fourqurean et al. (2012) and Howard et al. (2014).

$$Y = 0.21 + 0.4X \quad [1]$$

Where Y is organic C (%) and X = organic matter (%), r^2= 0.87.

As is apparent through photos taken at the time of sampling, dramatic changes in soils between the different time periods were observed. In a period of less than 3 months, large cracks had formed in surface layers and a concomitant increase in soil bulk density was observed. Soil bulk density of the surface layers was 0.35 g/cm³ in April compared to 0.67 g/cm³ in the June. Similar responses were found at the middle depths (30–60 cm). Due to differences in the soil bulk density between time periods, comparisons of carbon stocks through examination of the same soil volume would yield incorrect estimations of carbon flux through time.

Therefore, to compare soil carbon stocks adequately, estimates were made using equivalent masses of the mineral soil fraction for April and June (Kauffman et al., 2016; Arifanti et al., 2020). The mineral soil mass is determined through subtraction of the soil organic matter density from the total soil bulk density. Then the total mass of the mineral fraction is determined for the top 100 cm of sediment in April, followed by calculation of the mineral soil mass for the June samples.

We assumed that losses in carbon stock were largely emitted in the form of CO_2 rather than CH_4, based upon our field and lab experiments and given the high salinity contents of sediments. Under this assumption, we report the ecosystem carbon losses as potential CO_2 emissions, or CO_2 equivalents (CO_2e) – obtained by multiplying C values by 3.7, the molecular ratio of CO_2 to C.

Methane emissions from estuarine sediment and clay were negligible, whereas methane emissions from freshwater sediment were significant.

3. The depth range of 0–30 cm for the shallowest layer is probably an overestimation, as visual observations made clear that the oxidised zone extended less deeply, say 10 cm. On the other hand, the formation of cracks might propagate exchange.

Scenario 1: shallow and limited organic matter degradation (representing field data)

Based on the measured organic matter content for the different layers measured in April and June, a mean carbon loss between April and June was calculated of 2 kg C/m^2. This corresponds to a mean potential GHG emission during the April to June clay ripening period of 7.7 kg CO_2e m^{-2} of sediment (Table 1). Extrapolating to an entire single test bed (75 x 75 m or 5625 m^2), we estimate the total emissions from a single clay ripening test bed was 43.1 tonnes CO_2. The CO_2e emissions from the entire ten ripening sites was 431.5 tonnes CO_2e (Table 1). This comes down to 0.012 tonne CO_2 per tonne of clay.

Scenario 2: deep, high (5%) OM degradation (desired quality)

This scenario assumed higher loss of OM (to 5%) across the whole depth transect of the sediment. As can be expected, the estimated CO_2 emission in this scenario was significantly higher (27 kg CO_2e m^{-2}) than in scenario 1. In general, the CO_2 emission will be proportional to the depth to which the organic matter will be degraded and the extent to which organic matter content decreases. There are currently no indications such a scenario is taking place when ripening sediment from the Ems-Dollard estuary[4].

Results

Given the small sample size, short sampling time and indirect measures of organic carbon, data and results must be viewed with caution, as there is a high degree of uncertainty. However, the results do suggest that carbon emissions from the clay-ripening process may be significant. Further investigation using accurate portable infrared gas analysers and intense sampling of sediment carbon pools during the entire clay ripening process is recommended in order to obtain more precise estimates of GHG emissions.

The differences in GHG emissions calculated for the two scenarios demonstrates the influence that environmental conditions, time and sediment management may have on the CO_2 emissions. The depth and degree to which organic matter is degraded strongly determines the CO_2 emission, and is likely strongly dependent on ripening strategy (e.g. ploughing and influencing salinity) as well as the carbon quality of the sediment organic matter. Thus, the different ripening strategies would influence the rate and quality of CO_2 emissions. Furthermore, with the laboratory incubations, we demonstrated a much higher GHG emission from freshwater sediment compared to saltwater sediment. Therefore, the choice between saltwater and freshwater sediment can also strongly influence sediment-related GHG emissions, as the production of CH_4 and consequently the emission of GHG is most likely much higher in freshwater sediments.

To put the numbers calculated here into context, it is useful to compare these to potential alternatives. For building dykes, an alternative source of dyke clay is the import of freshwater sediment from Belgium or other parts of the Netherlands, low in organic matter. An important component of the GHG emission related to this alternative is the emission due to fossil fuel combustion. An estimate can be made of this emission based on known numbers (www.co2emissiefactoren.nl). The GHG emissions of a truck (weighing 10–20 tonnes) is estimated to be 0.256 kg CO_2/tonne kilometre (well-to-wheel). When we assume one-way transport of a loaded truck over 200 km (from Belgium to the pilot locations), this leads to an emission of: 200 km * 0.256 kg CO_2/tonne kilometre = 51.2 kg CO_2/tonne clay or 0.05 tonne CO_2/tonne clay.

This comes down to the same order of magnitude as the GHG emissions from the clay ripening process under the worst-case Scenario 2. Actual emissions from transport will be higher, as we did not take into account other activities, and only included one-way transport. In general, these calculations should be seen as a first estimate to illustrate the methodology; for a complete comparison, emissions from several activities in both scenarios should also be taken into account.

The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions.

Discussion

The urgency of all business sectors to address climate change mitigation through reduction of emissions and the sequestration of GHGs is well recognised. If we are to attain the target of the Paris Agreement, all stakeholders must act. In line with this, the Dutch government aims to reduce the Netherlands' greenhouse gas emissions by 49% by 2030, compared to 1990 levels, and a 95% reduction by 2050. In addition, the Dutch Ministry of Infrastructure and Water Management adopted a target to achieve net-zero emissions by 2030. Companies in the maritime and dredging sector have started to adopt net-zero targets. This has already resulted in serious efforts to minimise emissions from hydraulic engineering, particularly in relation to minimising use of fossil fuels and optimising construction materials. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions, however, many uncertainties remain that deserve further attention. Improved approaches to the sampling of GHG emissions and quantification of the carbon mass within the sediments would facilitate accurate quantification of carbon stocks and GHG emissions from the ripening process.

Direct measurements of GHG emissions are needed to confirm the findings and validate the range of applicability both in the field and in the lab (i.e. Gebert et al., 2019). The use of portable infrared gas analysers would facilitate accurate field measures of trace gas emissions (CO_2, CH_4, N2O). Furthermore, intense sampling of sediment carbon pools

4. Evaluations are taking place to see if clay soil of a higher organic matter and salt levels can nevertheless be safely used in embankments.

during the entire clay ripening process is recommended to obtain more precise estimates of GHG emissions from the clay ripening process. This would entail repeated sampling of carbon concentrations and concentration bulk density at varying depths of the sediment beds over time.

The carbon composition and quality are also unknown. The carbon quality is a measure of the quantity of labile and recalcitrant fractions. This is important as microorganisms can readily decompose labile forms while recalcitrant carbon may indefinitely persist in sediments. Knowledge of carbon quality provides information on the time required and potential to reduce organic matter in dredged sediments. In addition, other components of the sediment, such as clay and salt, may have an impact.

Once salts are washed out of the clay and with greater oxygen penetration (via plant roots, bioturbation or after soil is mixed with sand), the degradation of the organic material will be enhanced. However, this could increase methane emissions, which would increase the global warming potential of the gases arising from this ripening process. The sediment in the two pilot projects described here is both estuarine, salt-water sediment from the same region, which could differ in several more specific parameters such as organic matter quality. For other cases, sediment properties (such as organic matter quality, salinity and clay content) might be different and it is recommended to take this into account.

If the objective of a project involving hydraulic engineering is to minimise GHG emissions or even sequester carbon, then building with nature based solutions can be applied, such as using the soft sediments for salt marsh creation where vegetation could uptake CO_2 and store organic carbon in sediments. Salt marshes not only sequester carbon but also reduce wave heights. When dykes are combined with vegetated foreshores, they can be lower and still provide safety (Temmerman et al., 2013). Lower dykes require less clay and thus involve fewer emissions from clay ripening.

In this pilot study, we only focused on processes during the first stage of the ripening of the sediment and a transition from dredged sediment to clay material. Microbial degradation of organic carbon will result in loss of this organic carbon as CO_2 and/or CH_4. Our pilot study already suggested some parameters that affect the sediment-related GHG emissions during ripening of soft sediments: the concentration of organic carbon in the sediment, the quality of that carbon and the salinity that affects whether emissions will be limited to CO_2 or not. The slow transport in and out of the sediment probably also affects degradation conditions, resulting in low availability of oxygen and slow breakdown of organic matter and slow emission of greenhouse gases.

These and other factors might differ with different dredging methods and ways of deposition during ripening. However, there are many process steps before and after the ripening period in the project where GHG emission estimates are still lacking, therefore more research on this topic is needed. The entire life cycle analysis, including the carbon losses and sediment-related GHG emissions from pre-dredging up to the moment the clay has been implemented in the dykes and the further fate of carbon, should be quantified. Finally, the use of relevant reference scenarios in the life cycle analysis is essential, e.g. of natural ecosystems or alternatives of the sediment use.

Conclusions

Our study aimed to assess GHG emissions from ripening soft sediment to dyke clay and to identify key processes involved. Given the small sample size, short sampling time and indirect measures of carbon loss, our results must be considered as a first exploration. The estimated CO_2 emissions suggest that carbon emissions from the clay ripening process are potentially significant and that these emissions can be affected by the type of sediment and ripening conditions. Emissions from clay ripening ranged between 0.012 tonne CO_2e/tonne of clay for our short-term field experiment up to 0.05 tonne CO_2e/ tonne of clay if the desired clay quality with an organic matter content of 5% would be reached. Alternatively, if a similar amount of clay would have been collected from abroad, GHG emissions from transport alone may equal these emissions.

The results from this study offer an approach to compare GHG emissions from soft sediments to alternatives and give information on control parameters by which GHG emissions from soft sediments can be minimised. Firstly, working with saline sediment it is less likely that organic matter is converted to CO_2 instead of into the more potent greenhouse gas CH_4 than working with freshwater sediment. Secondly, gas exchange between sediment and atmosphere can be limited, minimising GHG emissions directly, and indirectly by maintaining anaerobic conditions. However, for freshwater sediments anaerobic conditions may stimulate emissions of the much stronger GHG CH_4. Minimising gas exchange works against the aim to reduce the organic carbon content in the sediment to 5%. Therefore, studies are performed with ripened to see whether saline clay with a higher than desired OM content (>5% OM) is affecting dyke building strength.

We recommend that sediment-related emissions are addressed in life cycle analysis (LCA) of hydraulic engineering projects, so that different options can be properly compared and well-informed decisions can be made. To achieve this, GHG emissions from and carbon sequestration in sediments need to be integrated into existing tools, such as the ones used by the Dutch government 'DuboCalc' or the 'CO_2 performance ladder'. Meanwhile, hydraulic engineering projects that involve soft sediments should measure and report carbon stocks and fluxes of GHGs to build up the required knowledge base.

Summary

The urgency to address climate change through reduction of emissions and sequestration of GHGs is well recognised. To attain the target of the Paris Agreement, all stakeholders must act now. Companies in the maritime and dredging sector have started to adopt net-zero targets. This has already resulted in serious efforts to minimise emissions from hydraulic engineering, particularly in relation to minimising use of fossil fuels and optimising construction materials.

The carbon footprint or life cycle analysis (LCA) of a hydraulic engineering project focuses mostly on emissions arising from operations and transport (e.g. fossil fuel combustion). However, the carbon stock concealed in ecosystem sediments has the potential to be released as GHGs by dredging, drying, processing and further use. The extent to which GHGs are released upon disturbance is not known. These sediment-related GHG emissions are often not accounted for in the LCA of hydraulic engineering projects.

Using the case study of the clay ripening pilot project ('Kleirijperij') in Groningen, the Netherlands, we studied sediment-related GHG emissions during the ripening of dredged estuarine sediment. The local marine clay ripening pilot seems more favourable in terms of CO_2 and CH_4 emissions than collecting clay from abroad or ripening of freshwater sediment, despite significant emissions from decomposition of organic matter during ripening. For a complete LCA, a thorough analysis of all alternatives should be done and uncertainties should be clarified. There are indications that sediment-related GHG emissions during ripening of clay can be reduced depending on type of dredged material and the ripening conditions.

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REFERENCES

Arifanti V.B., Kauffman J.B., Hadriyanto D., Murdiyarso D. and Diana D. (2019)
Carbon dynamics and land use carbon footprints in mangrove converted aquaculture: The case of the Mahakam Delta, Indonesia. *Forest Ecology and Management*, 432:17–29. https://doi.org/10.1016/j.foreco.2018.08.047

Fiselier J., Vreman B.J., Dekker S. and Thorborg H. (2015)
Ecosystem-based carbon foot printing of marine engineering projects. *Maritime Engineering*, Vol 168: 149–153.

Fourqurean J.W., Kendrick G.A., Collins L.S., Chambers R.M. and Van der Klift M.A. (2012b)
Carbon, nitrogen and phosphorus storage in subtropical seagrass meadows: Examples from Florida Bay and Shark Bay. *Marine and Freshwater Research*, 63:967–983. http://dx.doi.org/10.1071/MF12101

Gebert, J., Knoblauch, C., and Gröngröft, A. (2019)
Gas production from dredged sediment. *Waste Management*, 85, 82–89. https://doi.org/10.1016/j.wasman.2018.12.009

Howard J., Hoyt S., Isensee K., Pidgeon E. and Telszewski M. (eds.) (2014)
Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA.

Kauffman J. B., Adame M.F., Arifanti V. B., Schile-Beers L. M., Bernardino A. F., Bhomia R. K., Donato D. C., Feller I. C., Ferreira T. O., Jesus Garcia M. C., MacKenzie R. A., Megonigal J. P., Murdiyarso D., Simpson L. and Hernandez Trejo H. (2020a)
Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. *Ecological Monographs* 90(2): e01405. https://doi.org/10.1002/ecm.1405

Kauffman J.B., Giovanonni L., Kelly J., Dunstan N., Borde A., Diefenderfer H., Cornu C., Janousek C., Apple J. and Brophy L. (2020b)
Total ecosystem carbon stocks at the marine-terrestrial interface: Blue carbon of the Pacific Coast, USA. *Global Change Biology*, 26(10):5679–5692. https://doi.org/10.1111/gcb.15248

Kauffman J.B., Hernandez Trejo H., Jesus Garcia M.C., Heider C. and Contreras W. (2016)
Carbon stocks of mangroves and losses arising from their conversion to cattle pastures in the Pantanos de Centla, Mexico. *Wetlands Ecology and Management* 24:203-216. https://doi.org/10.1007/s11273-015-9453-z

Macreadie P.I., Anton A. and Raven J.A. et al. (2019)
The future of Blue Carbon science. *Nature Communications*, 10, 3998. https://doi.org/10.1038/s41467-019-11693-w

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., and Zhang, H. (2013)
Anthropogenic and Natural Radiative Forcing. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1021/ie801542g

Oremland R.S. and Taylor B.F. (1975)
Inhibition of methanogenesis in marine sediments by acetylene and ethylene: validity of the acetylene reduction assay for anaerobic microcosms. Applied Microbiology, 30(4):707–9. https://doi.org/10.1128/am.30.4.707-709.1975

Sittoni L., Boer, J., Van der Star, W.R.L., Van den Heuvel, M.J.M., Baptist, M.J., Van Eekelen, E.M.M., Van der Groot, F., Nieboer, H.E. and Doets, I. (2019)
Beneficial and nature-based sediment use – Experiences from Dutch pilots. *Australasian Coasts and Ports 2019*. pp 325–330. Engineers Media, Hobart, Australia. ISBN 9781510895256.

Temmerman S., Meire P., Bouma T.J., Herman P.M.J., Ysebaert T., and De Vriend H.J. (2013)
Ecosystem-based coastal defence in the face of global change. *Nature*, 504(7478):79–83. https://doi.org/10.1038/nature12859

Van Maren D.S., Oos, A.P., Wang Z.B. and Vos P.C. (2016)
The effect of land reclamations and sediment extraction on the suspended sediment concentration in the Ems Estuary. *Marine Geology*, 376:147–157. https://doi.org/10.1016/j.margeo.2016.03.007

FINDING INNOVATIVE SOLUTIONS TO IMPROVE SAFETY

When individual employees, teams and companies view everyday processes and situations through a continuous lens of safety, they can each contribute to making all aspects of operational processes, whether on water or land, safer. For the 2021 Safety Awards, IADC's Safety Committee received 15 submissions. Each one is assessed on five different categories; sustainability; level of impact on the industry; simplicity in use; effectiveness; and level of innovation.

IADC's members are committed to safeguarding their employees, continuously improving to guarantee a safe and healthy work environment.

Affirming the importance of safety

Dredging activities can be risky operations with hidden dangers amongst heavy machinery. In response, the dredging industry proactively maintains a high level of safety standards. A representative of contractors in the dredging industry, IADC encourages its own members, as well as non-members participating in the global dredging industry, to establish common standards and a high level of conduct in their worldwide operations.

IADC's members are committed to safeguarding their employees, continuously improving to guarantee a safe and healthy work environment and reducing the number of industry accidents and incidents to zero.

Recognising advancers of safety

IADC conceived its Safety Award to encourage the development of safety skills on the job and reward individuals and companies demonstrating diligence in safety awareness in the performance of their profession. The award is a recognition of the exceptional safety performance demonstrated by a particular project, product, ship, team or employee(s).

As of this year, two IADC Safety Awards will be granted: one to a dredging contractor (also non-IADC members) and one to a supply chain organisation active in the dredging industry. This concerns subcontractors and suppliers of goods and services. In total, 15 submissions were received. Each one aims to improve routine processes and situations encountered in the dredging industry.

The winners of both awards will be announced during IADC's virtual Annual General Meeting on 16 September 2021.

Dredging contractor safety award submissions

SIMOPS between two TSHD dredgers by Jan De Nul

Jan De Nul's first submission is a tool that visualises and controls the maximum distance between two TSHD dredgers based on the length of a floating pipeline and live position of both ships. This allows for greater control in the challenging operation of pumping dredged material between two vessels. Due to the nature of the works on a project in Germany, JDN's dredgers TSHD Pedro Álvares Cabral (PA) and Tristao da Cunha (TC) had to be connected by means of a floating pipeline. Dredged material was then pumped via the pipeline from the larger TSHD (PC) into the smaller TSHD (TC).

The operation, carried out on the river Elbe, presented several challenges, primarily maintaining the vessels positions with difficult site conditions. Other challenges included the smaller TSHD being pushed out of position due to the current, changing weather conditions and having to maintain a certain length of floating pipeline. Coordination of the relative movements of both TSHD dredgers is crucial in this type of SIMOPS. The position of the TSHD (PA) was transmitted in real time to the TSHD (TC) by means of Rajant wireless network set-up, making it possible to ensure the bow of the TSHD (TC) remained within the predefined circle. The diameter was adjusted when current or weather conditions changed.

By means of this active monitoring system, increased forces at the couplings and in the floating pipeline could be prevented. Additionally, the smaller TSHD (TC) did not have to drop its anchor, resulting in reduced cycle times without compromising on operational control. Crew, having used the tool consistently on the project, found one of its greatest benefits is its use at night when no direct visibility of the pipeline was possible.

Self-moving traffic barrier by Boskalis

The idea of a Self-Moving Traffic Barrier (SMTB) came about during Boskalis' Houtribdijk project when, due to ecological restrictions, it was not possible to move barriers during the night. This meant everything had to be done during the daytime, which not only caused traffic congestion but also, on occasion, unsafe situations.

The Self-Moving Traffic Barrier (SMTB) is a barrier that can easily be moved and creates a safe work environment for all its employees. The design of the barrier is robust making it a safe construction and its use can also prevent having to close a road, in turn avoiding possible inconvenience to road users.

A prototype has since been built for the A9 project, a major motorway in the Netherlands, where its implementation will play a role in the safe continuation of the project activities next to regular traffic. Dredging projects with infrastructure related aspects can also benefit from the SMTB.

Gangway platform by Jan De Nul

The risks involved with marine transfer are numerous. Jan De Nul's design of a gangway platform increases safety and reduces the risk of falling in the water. During marine transfer, the standard pilot ladder remains in place and the removable gangway platform is added, creating a stable and easy way of stepping on board. The platform is easy to deploy and store when not needed. It is already in use and will be equipped on every new vessel build within the JDN fleet.

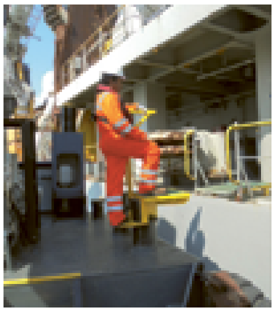
At the start of the COVID-19 pandemic and with the situation uncertain, it appeared impossible to continue with project activities.

CSD mobilisation at the beginning of the COVID-19 pandemic by Dredging International and Van Oord

At the start of the COVID-19 pandemic and with the situation uncertain, it appeared impossible to continue with project activities. Nevertheless, the joint-venture team of Dredging International and Van Oord managed to mobilise a cutter suction dredger (CSD) to the 'Modernisation of the Świnoujście – Szczecin fairway' project site to begin dredging and reclamation activities.

Implementation of increased measures to protect the health of employees at a time when there was not yet a standard practice and no clear information on the actual exposure risks, made the task extremely difficult. Strict follow up of the determined safety measures put in place were maintained throughout the project duration. During a 12-month period, the project managed to continue without any delays due to the COVID-19 pandemic.

Bollard step by Jan De Nul

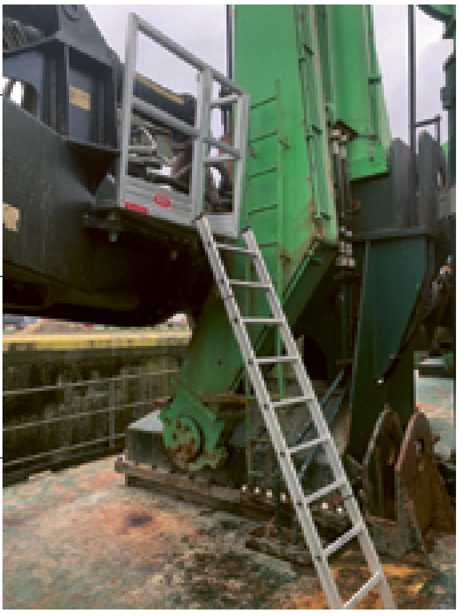


Jan De Nul's bollard step provides a solution that is both easy and quick to use, and is low on maintenance. Designed by crew, the bollard step transforms mooring equipment into a safe and secure step on which to make marine transfers.

The main materials used are steel and anti-skid grating. The latter creates a safe surface from which a safe vessel-to-vessel or ship-to-shore transfer can be made. The fact that the bollard step is quick and easy to use is reflected in the way it is mounted: two people can effortlessly carry the step and put it in place without extra securing measures. Not being a fixed structure also provides an operational advantage: the deck space is not restricted as the bollard step can be dismounted at any time (e.g. when cargo needs to be lifted on deck), nor does it need to interfere with mooring operations.

There are several step designs to cope with different locations and scenarios, all of which can be used on a variety of vessels. The simple and clever design solution is adjustable to different types of bollards, creating a safe and steady platform where there could never be a step-over zone. The innovation will also increase safety of crew transfers on small CTVs. In addition, CTVs that otherwise might not be suitable during a project could be used thanks to the bollard step, resulting in potential savings.

Draghead access platform by DEME



Access to the draghead for maintenance or repair purposes is usually done by climbing a steep ladder with no attachment point for a fall harness. Climbing on the draghead to carry out such works carries many risks when working on heights. Dragheads usually have lots of (jet)pipes, cables and other obstacles that need to be navigated. After investigating and trying several different possibilities, DEME came up with the design of an access platform that provides a safe working space during maintenance and repair works.

DEME's simple and effective custom-made, lightweight platform attaches to the side of the draghead, providing easy access. Made from aluminium for easy manipulation and assembly, the platform is designed with collective protection to improve the work area.

To access the platform, a tailor-made ladder attached to the platform is used instead of a steep ladder. The platform provides a safe area in which to work with increased manoeuvrability and workability of crew. The designed platform is lightweight, easy to manipulate and removable when not in use. Additionally, it is within reach of the on-board crane, which allows storage within one movement of the crane.

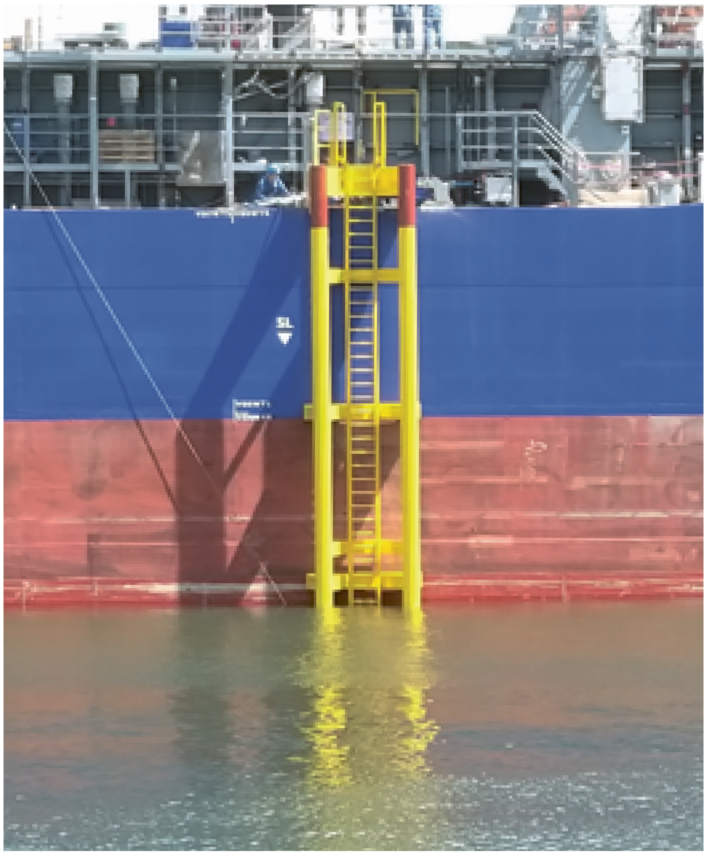
The simple and clever design solution is adjustable to different types of bollards, creating a safe and steady platform where there could never be a step-over zone.

Aerial drone to monitor excavation works by Jan De Nul

An excavation operation is typically monitored by topographical surveyors. Jan De Nul employed the use of aerial drones to monitor the excavation works of soil contaminated with asbestos. By using an aerial drone, possible SIMOPS with heavy equipment is avoided. Additionally, the topographical surveyor does not need to walk or work on contaminated soil.

The use of drones in such activities is part of Jan De Nul's QHSSE values: to provide a safe environment for all persons working for or on behalf of Jan De Nul Group, taking into account physical and mental health.

What makes this innovation unique is that the project team did not rely on standard survey procedures, but utilised a solution that guaranteed the safety and health of the topographical surveyor. Using this technique is relatively easy and can be used after a day's in-house training.



Retractable boat landing by Van Oord

Using a boat landing at sea normally requires manual handling, which is a high-risk operation. Sometimes many vessel-to-vessel transfers are required and the conditions at sea can be challenging. Van Oord therefore came up with a design to provide a safe alternative for vessel-to-vessel transfer.

Its design of a retractable boat landing, which can be deployed without the use of a deck crane, means high-risk operations, such as rigging and hoisting at sea are avoided. The boat landing is deployed by the push of a button, therefore eliminating the manual handling element. The hydraulically driven system is integrated into the vessels' installation and deployment of the landing takes about a minute.

Aside from the safety element, another benefit is that since the boat landing can be stored easily on deck and is deployed in a time efficient manner, it can be used frequently even during short stretches of sailing, reducing drag and thus saving fuel.

A unique piece of equipment to the industry, Van Oord is the first to have the retractable boat landing installed on one of its vessels. Fitted on flexible fall pipe vessel Bravenes, it has been in use for one year. The boat landing has been built according to the standards in place and can be used during the entire operational life of a vessel. The only requirement for fitting is having the necessary deck space required.

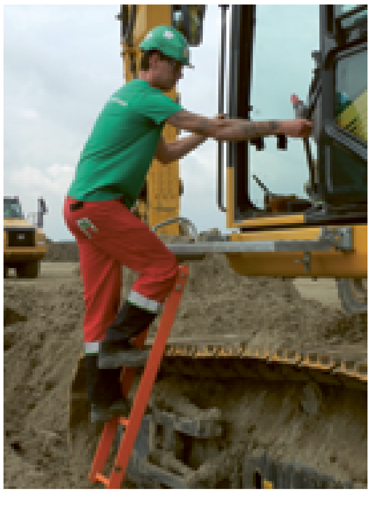
Pipeline walkway by Jan De Nul and DEME

SeReAnt (a joint venture between Jan De Nul and DEME), co-designed and delivered a floating pipeline approx. 200 metres long equipped with a walkway to facilitate the safe transfer of personnel to a CSD during the AMORAS project. The pipeline and walkway are hinged and able to rotate, and serve as a hang-up system for the high-voltage electric cable powering the CSD.

The innovative, multifunctional floating pipeline allows for (1) the pumping of dredged material to shore, (2) the safe and healthy transfer of personnel on and off a CSD and (3) power connection from shore to the CSD.

The walkway provides a unique way to transfer personnel from ship to shore and can be used during any weather conditions where CTVs are limited. The multifunctional floating pipeline both decreases the risk of falling into the water and provides a positive impact on fuel consumption and CO_2 emission compared to traditional methods of marine transfer.

Retractable ladder for track excavators by DEME



Stepping on and of machinery is not without risks. Following an LTI, DEME carried out a thorough investigation and found a lot of operators had scars on their shins caused by contact with the tracks when stepping on and off track excavators.

The existing steps on an excavator are located inside the boundary of the tracks, which is the cause of many injuries and near misses. Bringing the steps outside the tracks is not an option however, since this creates other risks both operational and for transport.

The solution – a retractable ladder that can be folded up just above the upper structure of the crane cabin. The area between the tracks and upper cabin stays completely free so there is no contact with sand or mud sticking on the tracks. Located on a safety area besides the excavator door, this innovative design needs almost no maintenance.

The ladder is made out of one piece of metal and retracts by itself after use. It can be positioned in the location of the original platform and both a bolted or welded connection is possible. The benefit of the design is that you only need one type of ladder. DEME foresee one standard ladder with a maximum length that can be adjusted on smaller type of track excavators.

Wire shield for marine barge winch by Hyundai Engineering and Construction

Marine barges are installed with a winch made of steel wire rope used for barge anchoring and hauling weights during operation. Seawater corrosion and abrasive wear cause the winch wire to degrade over time, thus increasing the likelihood of breakage. Winches are widely used in the marine industry without, however, proper protection or covers.

The marine barge winch stores a tremendous amount of energy under load. In the case of breakage, the wire can violently snap back in a whiplash effect, potentially causing serious injury to those involved in the winching procedure and anyone nearby. Wire breakage related accidents happen often in the marine industry and pose a high safety risk. Hyundai Engineering and Construction therefore took the initiative to introduce a wire shield for the marine barge winch to protect marine crews in the event of a wire breakage.

One of the main factors considered during the design of the innovation was that it had to be strong and easy to use for marine crews. Consideration was also given to the maintenance aspect to ensure maintenance works can easily be carried out without any safety lapses. This is achieved via the modular design of the winch shield.

Hyundai Engineering and Construction is monitoring the effectiveness of the shield during its reclamation project in Singapore. The company has made it mandatory for marine barges to be installed with the winch shield and has also put in place stringent daily pre-operation checks of the winch to ensure its safety and effectiveness.

Tetris challenge campaign Jan De Nul

When the Zurich police published a photo of all the equipment that they carry in a patrol car, you would have thought that this was nothing special. However, they placed the material in such a way that it all fitted perfectly together in the picture frame and so the Tetris Challenge was born.

Refraining from the idea of lining up all its vessels to create the best Tetris challenge picture ever, Jan De Nul wanted to focus on what really counts – the safety of its people.

As the dredging industry is typically characterised as a busy and demanding work environment, very clear and visual communication is a key for success. The existing means of communications, such as safety posters, QHSSE notices and incident bulletins are an effective way to transfer information but with this Tetris challenge, Jan De Nul triggered its employees on another level.

Trends come and go and social media advances at a speed that even the company's design department cannot follow. They quickly jumped aboard with the trend and reached employees with a safety message in a way that they maybe did not expect.

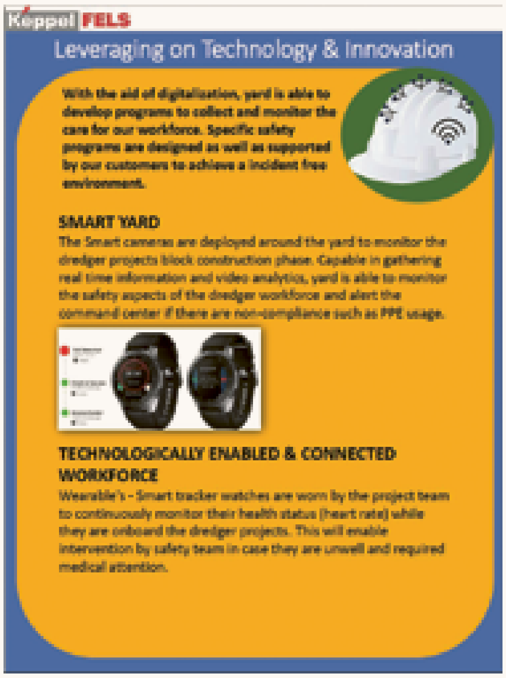
Supply chain organisation safety award submissions

Quick coupling floating pipeline by APT Global Marine Services

APT Global Marine Services' quick coupling system creates a safer, faster and watertight floating pipeline connection. The innovative system for floating pipeline reduces the manual handling to one single operation. Furthermore, the pipelines are floating during the coupling, which results in minimal use of the crane and excludes any (heavy) lifting. All this while the connection is solid and watertight.

By excluding lifting operations, the potential safety threat from working underneath the pipeline is eliminated. In addition, the hands-free connection reduces the risk of hand injuries from the flanges. Furthermore, the connection of two sections of pipeline is established by one single spanner operation in a matter of minutes, which reduces the amount of handling to the bear minimum.

The system is both simple and intuitive for crew to use and operate. The male and female part of the quick coupling attaches to the existing flanges of a pipeline, meaning no additional equipment is necessary.



Safety Plus Programme and National WSH Vision 2028 by Keppel FELS

Anchored in its Safety Plus Programme and Singapore's National WSH Vision 2028, Keppel FELS continues to consistently improve and enhance its existing Health, Safety and Environment (HSE) management systems. Safety is a key priority in its operations and the company is committed to ensuring everyone goes home safe at the end of each workday.

Keppel FELS has robust HSE management systems in place and invests in building HSE competency and capabilities through training, outreach activities and empowering every individual in its workforce to intervene and stop any unsafe acts. The shipyard adopts a set of 10 lifesaving rules and performs an assessment of high impact risk activities (HIRA) prior to the execution of work.

Technology and innovation are ingrained in the culture of Keppel FELS. It is essential in building a strong safety culture and constantly enhancing safety standards for work processes. The company invests in its design, engineering, planning and construction processes by adopting digitalisation and smart asset technology to further value-add to its products by simplifying processes, tracking operations, improving safety considerations and supporting its customers.

Non-nuclear Slurry Density Meter (SDM) by Rhonsonics

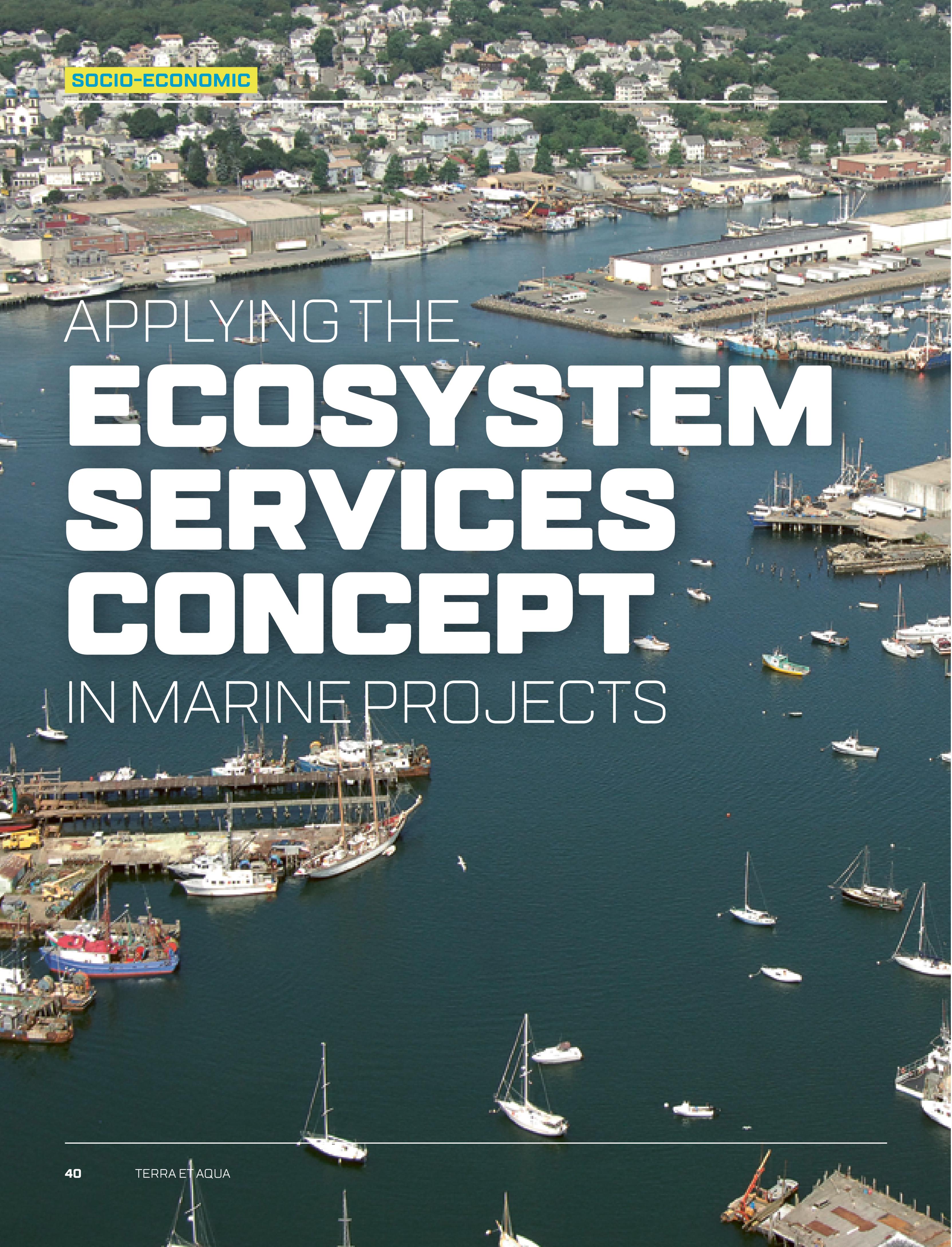
The Rhosonics Slurry Density Meters (SDM) are a new sustainable solution for the mineral processing industry. The ultrasonic-based measuring instrument can determine the slurry density in real time to check the amount of solids in a liquid.

This innovative way of measuring slurry densities is challenging the status quo, i.e. the radiation-based instruments currently used in the industry. The Rhosonics SDM operates in the same accuracy and repeatability ranges as the nuclear density gauges, however the device is safe to use, can easily being calibrated and has a more compact design.

For radiation safety reasons, the nuclear source is located in a capsule surrounded by a source holder (a radiation protection shielding). This shielding is usually made of lead and can weight up to 500 kilos or more to protect the employees working with those instruments. The SDM is always the same weight, which is only 6.8 kilos and the size is very compact as well, since it is an all-in-one design. The transmitter and transducer are connected by

a tri-clamp, therefore no cables are used in between the SDM sensor and analyser.

The SDM is a real game-changer for slurry density measurement applications, especially in the mining and dredging industries, where it is increasingly being used to optimise processes.



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

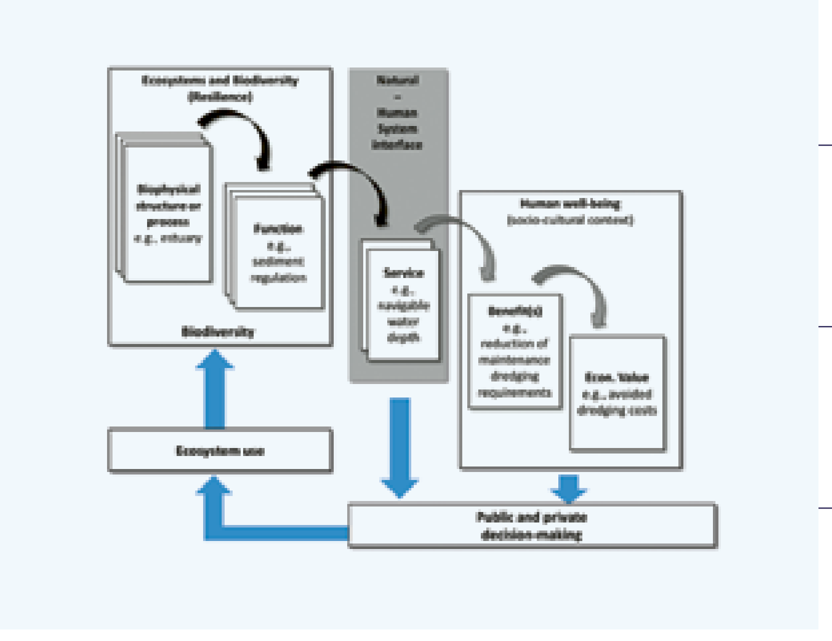


FIGURE 1

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

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.

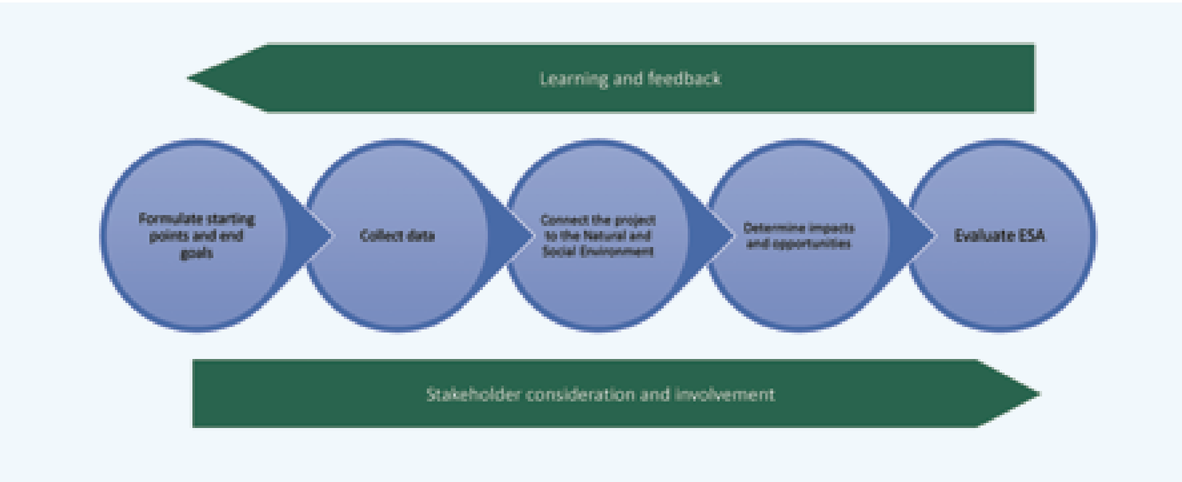


FIGURE 2

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

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.

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.

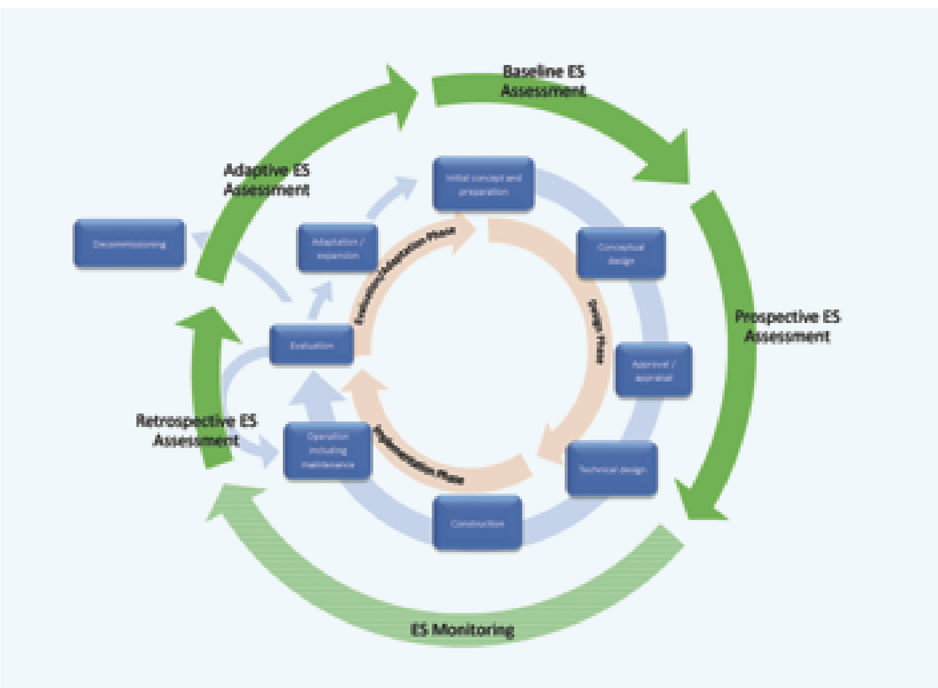


FIGURE 3

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

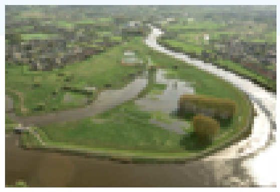
Overview of how case studies illustrate potential applications of the ES concept throughout the entire project cycle. >>

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.

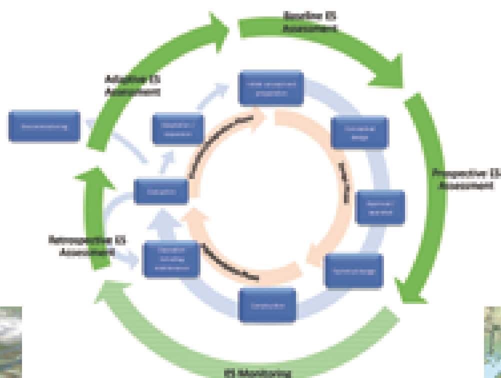


Case 6: Ems estuary

- 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.

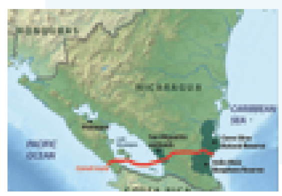
Case 1: Maasvlakte II

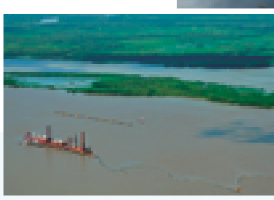
- **Prospective ESA** of design solution trade-offs.
- Legislation-driven inclusion of natural and social values identified opportunities to mitigate or compensate for impacts.
- Early consideration would save time and money; facilitating approval.



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.



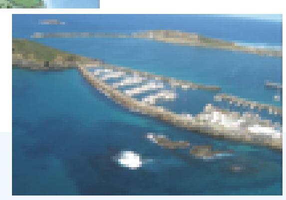


Case 3: Atchafalaya

- **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).

		Case studies							
ES classification	ES sub-category	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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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 2016, she obtained a PhD in Environmental Science at the Ecosystem Management research group at the University of Antwerp in Belgium. Since 2020, she works as an advisor at IMDC, an international engineering and consultancy company in the field of natural waters.

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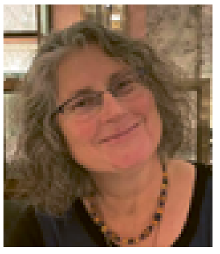
Ine is a marine scientist with 18 years of experience in both the public and private sector. As an environmental engineer at Jan De Nul, she was responsible for the environmental management on offshore, coastal and estuarine projects worldwide, including research and innovation projects on nature-based solutions. Ine currently works as Blue Innovation Officer at the Flemish Marine Institute in Ostend where she targets the validation of marine scientific research and knowledge into innovative business solutions for sustainable coastal management and marine infrastructure projects in general.



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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/SIO, 1991), 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.

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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.

Acknowledgments

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.

REFERENCES

Apitz S.E. (2012)
Conceptualising the role of sediment in sustaining ecosystem services: Sediment-ecosystem regional assessment (SEcoRA), *Science of the Total Environment*, 415: 9–30. DOI:10.1016/j.scitotenv.2011.05.060.

Apitz S.E. (2013)
Ecosystem services and environmental decision making: Seeking order in complexity, *Integrated Environmental Assessment and Management*, 9(2): 414–430. DOI: 10.1002/ieam.1389.

Boerema A., Van der Biest K. and Meire P. (2017a)
Towards sustainable port development, *Terra et Aqua*, 149: 5–17.

Boerema A., Rebelo A. J., Bodi M. B., Esler K. J. and Meire P. (2017b)
Are ecosystem services adequately quantified? *Journal of Applied Ecology*, 54:358–370.

Laboyrie P., van Koningsveld M., Aarninkhof S., van Parys M., Lee M., Jensen A., Csiti A. and Kolman R. (2018)
Dredging for sustainable infrastructure, CEDA and IADC. ISBN: 9789090313184.

MEA (2005)
Ecosystems and human wellbeing: Synthesis, millennium ecosystem assessment. Island Press, Washington, DC, USA. p.160.

Moore D., P Booth A., Aixe S. E., Apitz D. Forrow E., Huber-Sanwald A. and Jayasundara N. (2017)
Application of ecosystem services in natural resource management decision making, *Integrated Environmental Assessment and Management*, 13:74-78.

PIANC (2016)
Opportunities to apply the concept of ecosystems services (ES) to the waterborne transport infrastructure (WTI) sector. Position paper.

TEEB (2010)
The economics of ecosystems and biodiversity: The ecological and economic foundations.

WRI (2013)
Weaving ecosystem services into impact assessment: A step-by-step method. Washington, USA.

BACK TO THE CLASSROOM

Dredging and Reclamation Seminar
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IHE Delft Institute for Water Education
www.iadc-dredging.com

For (future) decision makers and their advisors in governments, port and harbour authorities, off-shore companies and other organisations that execute dredging projects, IADC organises its International Seminar on Dredging and Reclamation for the 60th time. Since 1993, this week-long seminar has been continually updated to reflect the dynamic nature of the industry and is successfully presented in cities all over the world. The five-day course covers a wide range of subjects, from explanations about dredging equipment and methods, rainbowing sand and placing stone to cost estimates and contracts. There is no other dredging seminar that includes workshop exercises covering a complete tender process from start to finish.

Programme
The in-depth lectures are given by dredging experts from IADC member companies, whose practical knowledge and experience add an extra value to the classroom lessons. Subjects covered include topics such as the development of new ports and maintenance of existing ports, and environmental aspects of dredging. Activities outside the classroom are equally as important. An on-site visit to the dredging yard of an IADC member gives participants the opportunity to see dredging equipment in action and to gain a better feeling of the extent of a dredging activity. A mid-week dinner where participants, lecturers and other dredging employees can interact, network and discuss the real, hands-on world of dredging provides another dimension to this stimulating week.

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Each participant receives a set of comprehensive proceedings and a Certificate of Achievement in recognition of the completion of the coursework. Register for the seminar at: http://bit.ly/Delft2021

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Participants will learn how to achieve dredging projects that fulfil primary functional requirements while adding value to the natural and socio-economic systems by acquiring an understanding of these systems in the context of dredging as well as stakeholder engagement throughout a project's development. Experienced lecturers will inform about the latest thinking and approaches, explain methodologies and techniques as well as demonstrate, through numerous practical examples, how to implement this information in practice with challenging workshops and case studies.

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