On 5 September 2023, IADC published a paper by the same name in response to a 2022 United Nations Environmental Program (UNEP) report “Sand and sustainability: 10 strategic recommendations to avert a crisis”. In this report, UNEP calls for actions to set the global sand agenda in addressing environmental needs alongside justice, equity, technical, economic and political considerations. IADC’s paper highlights the dredging industry’s best practices for optimal use of scarce sand resources. This article is a condensed version of that paper.

“Sand, gravel, crushed stone and aggregates (hereinafter sand resources) are the second most exploited natural resource in the world after water, and their use has tripled in the last two decades to reach an estimated 40-50 billion metric tonnes per year, driven by factors such as urbanisation, population growth, economic growth, and climate change.

Sand is the key raw material in concrete, asphalt and glass that built our infrastructure. It is also used for land reclamation as well as flood protection in coastal areas, part of the efforts to protect eroding coasts and address climate change impacts such as sea-level rise and increasingly severe storms. Satisfying a growing sand demand without transgressing planetary boundaries represents an important and insufficiently recognised sustainability frontier.” (UNEP, 2022)

Global sand consumption
For hundreds of years, dredging activities have shaped the interface between land and water to support a variety of human activities including navigation, coastal...
protection, flood risk management, as well as residential, tourist, commercial, agricultural and industrial activities. The use of dredging to achieve these purposes has always been guided by an understanding of the costs and benefits (CEDA/IADC, 2018).

The increasing tension between human development and planetary resilience urges us to rethink the way we work and live. The dredging sector is no exception. It uses sand as a building block to create infrastructure projects for social and economic development. At the same time, the increasing quantities extracted and its impacts on environment and society raise concerns.

The dredging industry has an important part to play in addressing these concerns. Operating globally, dredging contractors are working within a wide variety of physical, environmental, social, and legal conditions. Their first-hand experience can serve as a guide to formulate recommendations for responsible use of sand resources.

The dredging industry has measures at its disposal on both project and operational levels. On a project level, impacts can be reduced before the construction starts, with nature-inclusive designs, alternative materials and by using sand in such a way that it contributes to a more sustainable world. Other impacts can be reduced during the implementation of the project – on an operational level – by adapting working procedures and technology and applying mitigation measures.

Nonetheless, global sand consumption is the sum of the activities of many local parties, each having their own motives and drivers. There are no dominant players (Holms, 2023). The dredging industry is keen to turn this issue around but cannot do it in isolation. It is the shared responsibility of suppliers, contractors, project designers, project owners and authorities.

**Societal concerns about sand consumption**

Dredging projects are usually part of larger-scale socio-economic development schemes that impact a significant portion of society. It is therefore not surprising that societal concerns about sand consumption have been raised in several recent publications and that the issue has been thoroughly studied by international institutions such as the United Nations Environmental Programme Finance Initiative (UNEP FI) and working groups, such as the joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) and the International Council for Exploration of the Sea (ICES). In the following paragraphs these concerns are thematically summarised.

**Environmental concerns**

When sand is extracted from active riverine and marine ecosystems, the activities can disturb both local and regional systemic functions and underlying chemical, biological, ecological, hydrological, hydrodynamic and morphological processes.

Local effects include the removal of habitats and marine organisms, and the introduction of abnormal stress levels. Suspended sediments may result in smothering benthic species and disturbing fish that rely on visual cues for predation.

Regional effects include changes in current and wave patterns, sediment transport and soil permeability that can lead to coastal and river erosion, salinisation of coastal aquifers and groundwater reserves, shrinking deltas, threats to freshwater, fish stocks, biodiversity, land-use changes and air pollution.

The impact of the activities and therefore the concerns about them vary depending on location, affected ecosystems and stakeholders. Finding consensus about the conditions under which sand extraction can be allowed and about the measures to accompany the activities is always a delicate balance that requires thorough understanding of natural processes and the ecosystem services provided by both the project and environment. These are the prerequisites of an effective Environmental and Social Impact Assessment (ESIA).

**Socio-political concerns**

The degree to which sand mining is regulated exhibits a huge range across the globe. Many countries have strict regulations for sand extraction, and this creates a fair and level economic playing field.

At the other end of the spectrum, reports indicate that sand extraction is undertaken illegally in both riverine and coastal areas in some 70 countries (Peduzzi, 2014). Such illegal markets are often controlled through coercion and violence, with disregard for property rights, liveable wages, safe working conditions and health risks (Brown, 2019).

Bringing practices in line with regulations will contribute to more environmentally sustainable supply chains but can also disturb the local social balances. Interference in existing informal markets without accompanying social measures may lead to loss of income, disruption
Socio-economic concerns

The increasing demand for sand is driven by the growth of the global population, welfare and the associated need for housing, transport infrastructure and climate adaptation measures. In areas where sand is scarce and extraction is unregulated, inequalities and shortcomings in decent work standards may be exacerbated by this growth trajectory. Stark levels of inequality can be found when looking at the distribution of benefits (e.g. jobs, revenues) and environmental, social, and economic impacts resulting from these developments (Lamb, 2019). Large discrepancies along the value chain may occur, leaving those dependent on the industry and natural resources impoverished, without improved social and economic advantages (WWF, 2021; John, 2021).

Environmental effects, such as changing hydrodynamic conditions, may affect a variety of other ecosystem services and thus negatively impact livelihoods that people in affected communities depend upon, such as fishermen, sea farers and farmers (WWF, 2021; Aliu, 2022). These aspects are all part of an effective Environmental and Social Impact Assessment (ESIA).

Project level approaches to responsible dredging

To make optimal use of scarce sand resources, interventions are required before the operational phase. It is during project preparation that the required quantities and qualities of sand are determined and the ecosystem functions are incorporated into the project scope. Decreasing negative impacts and increasing positive contributions can be done with different strategies in every stage of the project.

Quantity of sand extracted

Sand deposits that are accessible and eligible for extraction are considered to be finite, non-renewable resources. Even though sand is formed continuously by weathering and erosion processes of rock and accumulation of inorganic remains of marine organisms, only a fraction is readily accessible (Padmadal, 2014).

The issue of depleting sand resources is not visible to the same extent in every region. For developed countries that have a large infrastructure budget but limited sand deposits such as Singapore, Florida and Israel, the issue is pressing. It is even more pressing for developing countries where the lack of sand deposits lead to uncontrolled excavation and destruction of crucial ecosystems. This, for example, is the case at Cabo Verde’s beaches (Vieira, 2021). These countries are faced with rising aggregate prices, which push them towards illegal and environmentally detrimental practices. Transitioning towards reduced sand consumption by promoting alternative materials, construction techniques and infrastructure concepts is a very challenging task.

Other countries, such as the Netherlands, Germany and India have seemingly infinite quantities of sand available for centuries to come, despite the large quantities consumed.

For developed countries that can afford the significant costs, international transport from countries with abundant resources can be a solution, but it is not an option for many developing countries. Moreover, countries that are geologically blessed with large sand deposits are more and more inclined to keep this strategic resource for their own future generations.

While the focus of this paper is on the impact of sand extraction, infrastructure projects require other primary materials such as gravel, rock and cement. It is important to note that the availability, sourcing and/or impact of using these materials deserve equal attention. In some cases, a design that uses more sand and less concrete or rock may therefore be a more sustainable option.

The quantity of sand extracted from marine resources can be reduced by using alternative sources, such as sediments extracted during capital and maintenance dredging works (CEDA, 2019). Prerequisite is that the quality of the material — that can be mud, clay, silt sand, or rock — fits its potential use, that a suitable recipient is nearby and that the time schedule of the two projects fit (USEPA/ USACE, 2007; PIANC, 2009).
In an ideal scenario, there are recharge plans in place (with required consent) for vulnerable and suitable sites so that sediments of all types can be used effectively and quickly when they are available [ABPmer 2016]. Although other alternative materials are available, such as crushed rock, quarry dust, fly-ash and metal slag, they do not play a significant role as a sand alternative.

Example
Between 1990 and 2023, dredged sediments were placed onto intertidal habitat to achieve both habitat restoration and coastal protection objectives at Horsey Island on the eastern coast of England. Sand and silt from capital and maintenance dredging at the nearby ports of Harwich and Felixstowe were used to create a mix of habitats including mudflats, marsh and a shingle spit to be used by nesting birds. The project has demonstrated that the environmental benefits can persist over decades [USEPA/USACE, 2007]. Case studies such as this one were collected by the CEDA Working Group on the Beneficial Use of Sediments (CEDA, 2023).

Local effects of sand extraction
When sand is extracted from marine deposits, sediment layers are removed that have different ecosystem functions, such as hosting nutrients and benthic fauna and flora in the top layer. Exposing older geological strata with different composition alters living conditions. The most poignant manifestations of habitat destruction are found in countries lacking sand resources. This deficiency combined with a high demand for aggregates often leads to destruction of vulnerable ecosystems and illegal economies.

Dredging in or near sensitive sites with high natural or cultural value is only feasible with extensive monitoring, adherence to strict limits and adequate supervision. These sites can be protected by defining marine conservation areas, setting up a marine spatial plan and enforcing compliance. This is applicable to areas with living coral reefs, coastal wetlands and other habitats with high biodiversity or endangered species and similarly to sites with historical or cultural importance, including indigenous values.

Habitat and biodiversity losses are best tackled in the conception and design phase of a project. In this early project phase, abundance and biodiversity can be inventoried. With this knowledge, the sand extraction zone with the lowest impact can be selected and mitigation, compensation and restoration measures can be included in the project scope. Loss of substrate or alteration of seabed composition can be transformed into the creation of a habitat that is regionally in decline, rare or specifically targeted for valuable or endangered species.

When an area is approved for sand extraction, authorities monitor dredging activities in order to ensure that extraction remains within the boundaries of the licenced area. In many countries, the representative on board of the dredger has been replaced by a black box computer system that is installed before the vessel arrives on site. The system transmits the drag head’s location and production data in real-time without the interference of the crew or computer systems on board.

Due care has to be taken that vessels do not inadvertently carry species that are considered invasive exotics at its destination. For this reason, international and local regulations may require cleaning of hull, water intakes and ballast tanks before the start of a voyage. Such regulations also apply to dredging vessels.

Example
For the extension Maasvlakte 2 of the Port of Rotterdam, 220 million m³ of sand were extracted between 2009 and 2013. The maximum extraction depth was 20 m below seabed, which is tenfold the traditional limit. This method reduced the directly impacted surface area from 110 km² to 11 km². Two sandbars mimicking natural sand waves were left behind after extraction to increase habitat heterogeneity [De Jongh, 2016]. This is one of the optimisations researched in OR ELSE (recommendations for Ecosystem-based large-scale sand extraction) a consortium of 21 partners funded by the Dutch Research Council (NWO) programme.

Regional effects of sand extraction
Extraction of sediments results in a local depression of the seabed. This changes local bottom friction and may have an impact on local hydrodynamics. Currents and waves may be less attenuated on their way to the coast when the seabed is deepened. Waves encountering a depression in the seabed at specific angles may refract or reflect in a different direction and hit previously sheltered coastlines.

In rivers and deltas, the tidal flow is in dynamic equilibrium with bottom level, shape and roughness. When sand is extracted from these systems, the equilibrium is disturbed and this may lead to increased tidal amplitude (flood risk) and increased flow (change of habitat conditions). When impermeable layers are removed, salt water may infiltrate into nearby coastal areas.

All these issues can be identified through modelling during the planning and permitting...
phase of a project. Modelling of coastal zones outside the dredging area is however not a standard requirement for a dredging permit. A marine special plan may define exclusion zones for dredging in highly dynamic zones such as reefs, sandbanks, river beds, beaches and beach foreshores.

Example
Since 2021, the extraction depth limit of 5 metres in the Belgian Continental Shelf was replaced by a limit based on scientific principles. The limit ensures the preservation of the surface sediment characteristics, the structure of the sandbanks, a maximum use of sand from mobile structures and limited impact on hydrodynamic conditions. The implementation of this new reference level led to a reduction of less than 2% of available quantity, while the extraction area was reduced by 25%, excluding the ecologically most valuable areas (Degrendele, 2021).

Regulations and due diligence
Restricting sand extraction to responsible practices inevitably comes down to regulation and enforcement, which can be carried out in several ways. Next to local, national and regional legislation, financial institutions can be held accountable for the impact of the projects they are funding (e.g., by the IFC performance standards (IFC, 2012)). Project owners can reward contractors for their efforts with a competitive advantage. Prequalification criteria can include company-level compliance with requisite minimum environmental and labour standards.

The management of sand resources is necessarily a task of the competent authority. Income from sand concessions can be used for monitoring, assessing the quantity and quality of the resource and drafting a responsible sand resource strategy and marine spatial plan.

Still, the contribution of the dredging industry to a safe and healthy work environment for its employees and its supply chain is essential. Responsible companies promote a safety culture in company-wide programs, organise mandatory courses for their employees, which enable them to recognise signs of modern slavery and conduct due diligence on subcontractors and suppliers. These initiatives are recorded in a register that can be consulted by clients during their due diligence.

Example
The Safety Culture Ladder (SCL) is a certified assessment method for measuring safety awareness and conscious safe and healthy acting in companies, with an emphasis on safety culture. The higher the safety awareness, the higher the assigned ladder step. Steps range from ignorance about safety to full integration of safety in the business processes. Since 2022, the SCL is mandatory for project owners that have undersigned the Dutch construction governance code (Van de Minkelis, 2022).

Stakeholder engagement
Stakeholders can be defined as “any” group or individual who can actively affect or be affected by the project development (Freeman, 1984). As such, stakeholders can be anything from individuals affected by a project through to large-scale NGOs whose organisational goals are related to aspects of the project.

Connecting with all relevant stakeholders and partners as part of any project planning and design is key to unlocking positive potentials.
Through systematic and equitable involvement across partners and stakeholders, a comprehensive system perspective can be derived, and local voices equitably heard.

Infrastructure projects operate across the boundaries of physical, ecological, and socio-economic domains. A multitude of interests and backgrounds are involved in the successful development of such projects. Thoughtful management of these interests – as well as combining them in a specific design – contributes to project success (Biernaux, 2021). Effective incorporation of interests can only be achieved by careful engagement of stakeholders. Key for the organiser is to be attentive to the incitement of the public by project opponents with misinformation and covered funding.

There are several ways to engage stakeholders in a project:

- Public consultation as part of an ESIA process helps to identify societal concerns and impacts on local communities.
- Citizen participation in project capital incorporates the stakeholder’s agenda into the project objectives.
- Design process based on co-creation where working group sessions of stakeholders decide on focus and phasing of the project within the physical and economic boundaries set by the project team.
- Real-time access to a monitoring platform related to the dredger’s activity and environmental parameters.
- Periodic newsletters and grievance procedures.

**Example**
Port Philip channel deepening project, Melbourne, Australia, that involved the removal of 23 million m$^3$ of sediment of which 3 million m$^3$ was contaminated, was met with strong and continued opposition. The client and contractor formed an alliance contract to share responsibilities and risks, as well as communication efforts. Stakeholder acceptance of the project was a result of the accurate and transparent public communications, which included public consultations, public hearings, a dedicated website, a 24-hour toll-free telephone number, weekly press conferences, media releases, mailing lists, signage around the bay and notices to mariners. A vessel tracking system and online video data was used to prove that the operations proceeded in accordance with the environmental management plan. These joint efforts led to successful completion of the project (Biernaux, 2021).

**Nature-inspired design**
An infrastructure project is part of a system. It affects and is affected by the processes operating within that system. The concept of ecosystem services supports this very notion. Ecosystem services are benefits that humans derive from nature. Ecosystems generate human welfare because they produce goods and services that humans can use directly or indirectly (through the use of other goods or services). Examples of indirect forms of use are “nutrient recycling” and “fish nurseries”, which result in “clean water” and “fish production”, respectively (Reed, 2005; TEEB, 2010).

The more ecosystem processes are taken into account over the full life-cycle of a project and the more natural processes and materials are incorporated into the project, the more sustainable a project can be. These practices are commonly referred to as Nature-inspired Design (NID) or Nature-based Solutions (NbS). In practical terms, the sustainability of an infrastructure project is increased by:

1. Increasing the overall value of the project by increasing the range of services it provides;
2. Reducing costs associated with the project, where costs include all monetary and non-monetary (e.g., environmental impacts) costs and resources consumed by the activity; and
3. Balancing the distribution of the value and costs among the social, environmental, and economic domains over time.

For more than a decade the dredging industry has invested in nature-based solutions and has developed multiple initiatives such as

**FIGURE 6**
Encouraging headlines indicate the success of the extensive communication efforts.

Example
In the Atafalaya River (Louisiana, USA), dredged sediment was placed in the middle of the river, just upstream of a natural shoal, and contributed to the formation of an island. In 10 years’ time, a 35 hectare island was created that hosts a rich wildlife habitat with access for recreation and a better aligned navigation channel (Suedal, 2015).

Adaptive management
Alternative building methods and concepts add risks and uncertainties on top of difficult-to-predict natural processes, climate change and the effects on environmental and socio-economic receptors. Adaptive management addresses these uncertainties by incorporating flexibility and robustness, and allowing decision-making based on continuous data/information that is acquired during the project.

In the early stages of the project, project goals on environmental, social and economic levels are defined. The preferred strategy is then selected and implemented based on an inventory of alternatives.

As the project proceeds, goals are translated into warning indicators that are monitored and evaluated continuously. These indicators are the basis of adjustments in design, construction, maintenance and monitoring.

Example
During the dredging works at Teluk Rubiah in Lumut, Malaysia, continuous water quality monitoring was combined with hindcast plume modelling to safeguard the nearby sensitive receptors. Based on the forecast, the dredging schedule was adapted, resulting in a zero exceedance of trigger levels and ahead-of-schedule completion of the project. The setup also allowed the contractor to avoid the necessity of 14 km silt screen (Savioli, 2013).

Early Contractor Involvement
The involvement of contractors and specialist suppliers is from time to time solicited by project owners prior to setting construction phase contracts. Contractors have expertise on construction methods, the availability of equipment and alternative materials, the implications of design for the ease and safety of construction, the resilience and sustainability of the constructed works.
and the cost and time required to provide the designed works (PIANC, 2022). Early Contractor Involvement (ECI) is a tool to introduce sustainable project approaches such as the beneficial use of sediments.

While ECI has many benefits, prior knowledge and equal treatment of tenderers is a concern that needs to be addressed.

Procurement process
The procurement process is decisive for prioritizing within different objectives and risks associated with infrastructure projects and natural processes (CEDA, 2019b). It can therefore contribute to more sustainable practices.

A wide variety of procurement principles are used:
• Prequalification: a first selection of candidates based on setting minimum standards for safety, financial stability, experience and competences.
• Competitive dialogue during tender: meetings are organised between the client and tenderers where concepts and strategies can be checked and adjusted.
• Design and build: the contractors, using their experience and capabilities, can optimise the project design reconciling the project objectives.
• Risk allocation: stakeholder communication, complaint handling and nuisance mitigation can be allocated to the contractor scope.
• Qualitative, non-monetary award criteria: these criteria value proposals that benefit nature and society, and mitigate risks and impacts.

These requirements are demanding and sometimes at odds with the competitive character of the tender process. Strict requirements can lead to exclusion of a number of smaller, local contractors that cannot comply, which can result in the disturbance of the local market. Additional requirements should therefore be accompanied by incentives for local contractors to upgrade their equipment and working methods.

Example
Most Economically Advantageous Tender (MEAT) (Alhola, 2012) and Best Value Procurement (BVP) (Storteboom, 2017) are two tender systems where price is only part of a valuation system that also includes safety initiatives, risk management, stakeholder engagement, innovation, emissions, etc.

Socio-economic contribution
Environmental impacts can have consequences that affect other marine users. The livelihood of local fishing communities may be affected by decreased fish stocks caused by prolonged turbidity or deterioration of their fishing grounds. Coastal communities may be deprived of inhabitable land, cultural sites and natural wealth as a result of erosion or salinization. Addressing these impacts is a requirement for project permits in many countries. This is usually done under “Areas of Operations” in an ESIA.

However, prohibiting sand extraction in vulnerable habitats also has an inevitable impact on the livelihood of local communities. Even if some of these activities may be illegal, they provide the means of survival for many communities. Any change in regulations to protect the environment should therefore be accompanied by measures to provide alternative local employment.

These stakeholder impacts can be identified and mitigated with appropriate regulations and ESIA procedures in place. Although in most projects, these regulations and procedures are beyond the contractor’s scope and responsibility, contractors can exercise due diligence and apply leverage and assist project owners with that responsibility.

A dredging project is short-lived and requires large deployment of human resources and equipment, often in little-developed areas. Yet it has the potential to contribute significantly to the local economy in the form of:
• salaries for the local workforce;
• local expenses (office, housing, transport, catering);
• local purchases and subcontracts (fuel, civil construction, fabrication, equipment rental), and
• tax revenues (import duties, royalties, withholding tax, corporate tax, personal income tax on salaries).

The local content in the project budget can be improved by different incentives:
• Onboarding and awareness training of local workforce with a focus on health and safety, environmental care, diversity, equality and respect.
• Training of local workforce when gaps are identified between required and available skills.
• Selection and training of local suppliers based on labour and human rights, biodiversity, emissions, waste management and business ethics.
• Advertisement of supply opportunities in local media.
• Unbundling of contracts into units that are tailored to the local market.
• Engagement in local community projects.

Innovation and contribution
Knowledge and best practices to increase sustainability in dredging projects are not written in stone. They develop with changing conditions, with learning by doing, with scientific knowledge and with public focus. Knowledge and best practices require a strategy to develop and to disseminate them to the stakeholders.

Development strategy
Many countries and regions have research and innovation funds to encourage scientific institutions and industry to develop new goods and services with the aim to increase competitive advantage and employment. Research and innovation funds can be a tool for authorities to:
• stimulate co-operation between local players in order to create sector-specific communities and local supply chains;
• stimulate the inclusion of small and medium-sized enterprises as they seldom have the means to innovate on their own;
• create programmes where industry, scientific institutions and authorities work
Knowledge and best practices to increase sustainability in dredging projects are not written in stone. They develop with changing conditions, with learning by doing, with scientific knowledge and with public focus.
Jan Fordeyn

Jan studied naval architecture and started working at Jan De Nul in 1994. Since 2007, he has helped develop projects around the world that fall outside the classic canon of marine construction and whose result relies on the symbiosis of different disciplines. For that purpose, he maintains close relations with experts, consultants, universities and manages innovation projects.

Tom Janssens

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