INDEX COPERNICUS INTERNATIONAL

ORIGINAL ARTICLE

Bulletin of the Maritime Institute in Gdańsk

Environmental aspects of dredging technology

Technologia prac pogłębiarskich – aspekty środowiskowe

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Article history: Received: 15.06.2017 Accepted: 06.11.2017 Published: 20.12.2017

Abstract: This work is an attempt to answer the question of what types of dredgers applied in dredging works at sea are most advantageous in the context of the rule of the most limited possible intervention into the marine environment. Elaborated reviews and depictions of the most popular types of dredgers are presented. An analysis with respect to the impact of the phenomenon of releasing pollutants accumulated in bottom sediments at all stages of the dredging process is also conducted. Its results indicate that application of mechanical or hydraulic suction dredgers is the most advantageous technique in terms of environment protection.

Keywords: dredgers, dredged material, contaminants, coastline zone of the sea

Streszczenie: W pracy próbowano znaleźć odpowiedź, jakie pogłębiarki stosowane w pracach pogłębiarskich na morzu są najkorzystniejsze w kontekście zachowania jak najmniejszej ingerencji w środowisko morskie. Dokonano przeglądu i charakterystyki najbardziej popularnych typów pogłębiarek. Przeprowadzona analiza w kontekście wpływu wszystkich etapów procesu pogłębiania na zjawisko uwalniania zanieczyszczeń zawartych w osadach dennych wykazała, że najkorzystniejsze jest stosowanie pogłębiarek ssących z mechanicznym lub hydraulicznym odspajaniem urobku.

Słowa kluczowe: pogłębiarki, urobek czerpalny, zanieczyszczenia, strefa brzegowa morza

INTRODUCTION

One of the major problems in operation of the Polish seaports is maintenance of the existent access infrastructure in a good condition and appropriate navigable depth of waterways, roadsteads and port basins, which is associated with the implementation of dredging works, as well as removal of dredged material and its management. Dredging works include a range of activities associated with both the preparatory phase and dredging itself: extraction of sediments, their transport and deposition (at sea or on land), assessment of their 'purity,' treatment or/and practical application of sediments for other purposes [23-25]. This publication focuses on the first stage of these works, i.e. sediment extraction. Dredging works result in extraction of large amounts of dredged material often in a short time. Not only these works do affect seabed sediments but they also exert a direct and indirect impact on all the elements of the marine environment. As a result, living conditions of benthic organisms as well as fish, birds, mammals and people may worsen [23]. All necessary efforts should be made to ensure that this negative impact is minimized when performing works of this kind. Therefore, this process must be conducted in an effective manner and with application of the most beneficial pro-ecological and economical solutions. To ensure such requirements, the works should be conducted at the right time (in the right season of the year) as well as with the use of appropriate equipment that is provided with a modern software, positioning system and dredging equipment supervision system which enables real-time control over the dredging processes and their impact on the environment [8].

This paper is an attempt to answer the question of what types of dredgers are the most advantageous in the context of the rule of the most limited intervention into the marine environment.

DEPICTION OF BASIC TYPES OF DREDGERS

The operation of all types of dredgers consists of the following works: loosening or digging of the substratum (dredged material) from the bottom, extraction of the loosened mate-

Fig. 1. Trailing suction hopper dredgers -TSHDs [14]

rial from the bottom to the water surface and transport of excavated floor material from the dredger onto the place of its deposition. Three basic types of dredgers may be pointed out with respect to methods of loosening the material and raising it from the seabed [1, 8, 9, 26]:

1. hydraulic dredgers, which loosen and raise material using energy of water motion, and which are not equipped with any mechanical devices for loosening of material. Their work consists in fluidizing the material with the use of water jets and rising of such loosened material with a suction device. A mixture of loosened material is sucked with a centrifugal pump and next, it is pumped via a pipeline directly to a reclamation area or aboard transport vessels (Fig. 1);

2. dredgers that loosen material mechanically but raise it from the seabed with the use of a hydraulic system with the so-called cutter head usually in the form of a rotating cutter; these are mostly suction or suction-cutter dredgers. Cutter blades cut material into chips, which are next taken into the suction mouth, raised and transported hydraulically. Such dredgers are called cutter suction dredgers (CSDs) (Fig. 2);

3. mechanical dredgers, which loosen and raise material mechanically - bucket ladder dredgers (raising material with use of a ladder supporting an endless chain of buckets) (Fig. 3) and dipper dredgers (which raise material with use of a grab or bucket) (Fig. 4, 5).

With respect to methods of rising and transporting the dredged material, the following types of dredgers may be differentiated [1, 9, 26]:

1. dredgers requiring transport of material on hopper barges or dredgers which transport dredged material into their own holds. Such machines are applied when the material is to be deposited at a disposal site (DMDS) at sea. In the first case, material extracted from the seabed is raised above the water table to an appropriate height and next loaded into holds of special auxiliary vessels called hopper barges, which transport the material with the help of a towing boat

Fig. 2. Cutter suction dredger, trailing [13]

Fig. 3. Bucket ladder dredger – photo by Piotr Tatarczuk for the PRCiP [14]

Fig. 4. Grab/clamshell dredger [14]

or without it (self-propelled barges) to the point of reclamation or relocation. Transportation of dredged material is applied in case of both suction dredgers and dredgers that loosen and raise the material mechanically. In the second case, the extracted and raised material is transported into a hopper within the hull of the dredger. Following transportation, the dredged material is discharged by means of opening the bottom doors or conical valves (offloading). These are self-propelled hopper dredgers;

2. dredgers which transport material directly to shore for reclamation and beach nourishment purposes or dredgers using transport of dredged material via conveyor belts. They are usually applied in the case of works conducted close to the shore, when dredging is combined with beach nourishment.

Potential environmental problems encountered with the application of various technologies of sediment extraction and deposition

Dredging works include a wide range of activities introducing changes to the sea basin's seabed aimed at adjusting them to the purposes of human activity and/or protection against the destructive power of water. The basic dredging works include [21]:

1. creation of new usable water areas (aquatories) to be used in marine and inland transport. Aquatories can be divided into open (canals giving access to ports and marinas, farwaters meeting the required depth parameters) and closed ones (port basins, inland canals, river regulations). They may be either new investments, consisting in transformation of natural environmental elements into regulated aquatories, or modernisation works, that is changing of the already existent aquatories, e.g. broadening, lengthening, deepening, reinforcing waterways, port basins etc. Simultaneous construction of a deep water basin and a new jetty by a TSHD dredger is presented in Fig 6. The material dredged from the seabed provides material for construction of the artificial embankment.

2. Works aimed at maintaining the technical parameters in the already created aquatories. These works involve a recurrent restoration of the required depth parameters in a given sea basin by means of removing shoals. What makes such works necessary is the force of nature i.e. accumulation of sand brought by rivers, sea currents, storms, etc. The frequency of repeating the works depends on the natural conditions prevailing in a given sea basin. A CSD dredger performing dredging works aimed at maintenance of the Panama Canal is presented in Fig.7. The size of the dredger is the same as that of the PANA-MAX ship, which makes it able to operate along the entire length of the route [21].

3. The underwater dredging works for construction of installations or hydro-engineering facilities. The purpose of such works is to provide the profile (shape) of the seabed adequate for construction of a jetty, embankments, breakwater, bridges, etc. Such works constitute a separate category as their performance involves usage of technical equipment designed for precise and specialist works.

Fig. 5. Backhoe dredger (excavator) [14]

Fig. 6. TSDH dredger forming new land[13]

Fig. 7. CDD dredger in the Panama Canal [15]

Fig. 8. A pipeline a short moment before submergence; photo by Piotr Tatarczuk for the PRCiP

Tab. I. Compilation of basic parameters of typical dredgers [3,4]

DREDGER	TYPE	ACCURACY* [CM]	MAXIMUM TURBULENCE* [MG DM-3]	MAXIMUM LOSS* [M]	EFFICIENCY* [M3 H-1]	DEPTH* [M]
Bucket ladder dredger	Mechanical	<10	<50	<0.05	150	8–19
Dipper dredger	Mechanical	<10	<50	<0.05	60	2–22
Suction dredger with adjustable head	Hydraulic	<10	<50	<0.1	2000	3–28
Suction dredger with non-adjustable head	Hydraulic	<5	<30	<0.01	1000	2–14

accuracy – the maximum error in positioning of the dredger workpiece,
maximum turbulence – the maximum amount of sediment subjected to resuspension in direct vicinity of the dredger workpiece,
maximum loss – the maximum amount of sediment lost in the course of a single cycle (thickness of layer formed as a result of its resedimentation),
efficiency – volume of extracted material per unit of time,
depth – the maximum depth from which sediment may be extracted.

Fig. 9. The Gdynia-Orłowo beach during silting works; photo by Piotr Tatarczuk for the PRCiP

They include also: construction of underwater gas, water, and fuel pipelines, watercourse outlet collectors, purified water collectors, construction of culverts on the seabed, underwater cable laying and embedding. Fig. 8 presents a pipeline ready to be submerged and buried inside a trench prepared beforehand using a dredger. It will serve as a collector and then as a diffusor of water purified in the Dębogórze water treatment plant (in Gdynia).

4. Filling-up works – expanding the land areas using material obtained from the seabed, i.e. reconstruction of beaches flooded by the sea, providing space for port, technical or agricultural infrastructure. Reconstruction of the beach with parameters ensuring the required level of safety for the hinterland in the area of Gdynia Orłowo with the use of the material obtained from a waterway is presented in Fig.9. Application of material dredged from waterways and of parameters similar to those of the material forming the beach originally allows for sustainable management of the natural resources and limits human interference into the seabed to the necessary minimum.

5. Excavation of aggregates of minerals for the purposes of the construction industry. Deep-water excavation of particularly rare types of minerals used in electronics and medicine is a special type of such dredging works. It is a prospective direc-

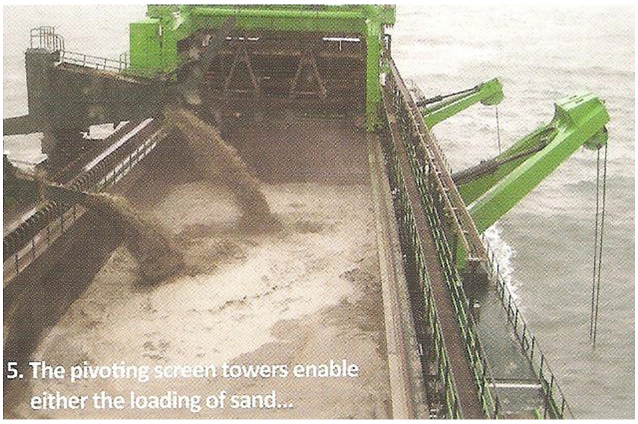

Fig. 10. a) Aggregate dredger,

Fig. 10. b) Deepwater dredging vehicle [16]

Tab. II. Characteristics of basic types of dredgers in the context of the phenomenon of fluidization (release) of pollutants contained in seabed sediments [1, 4, 8, 9]

DREDGER TYPE	LOOSENING OF MATERIAL	RAISING OF LOOSENED MATERIAL	RESEDIMENTATION OF SUSPENSION CLOUD – STATE OF THE SEABED AFTER FINISHED WORKS
Grab dredger, dipper dredger	The least invasive technique – the process of mechanical loosening consisting in unconstrained lowering of the grabber onto the seabed followed by gradual closing of its jaws accompanied ad raising it simultaneously. Changes of mechanical parameters of the floor occur only in the areas of grabber operation. Also, size of turbulence caused in the course of loosening is relatively small.	Material is raised mechanically by means of transporting of the container, during which there occurs gradual loss of dredged material from the very bottom to the surface of the water column. Amount of lost material depends on the construction of the grabber or bucket (open or closed) and on the speed of its elevation. A suspension cloud formed this way remains suspended for a long time and it is very susceptible to spreading due to the impact of water currents.	After the works are finished, the bottom of the sea area consists of a thin layer of sediment with a disturbed structure as a result of loosening of the floor covered with a layer of sediments characterised by a low level of consolidation and resedimentation of sediments lost in the course of raising of the material. The area of sediment resedimentation and resuspension will be significant as sediments are being lost over the entire water column of the sea area and they are very susceptible to transportation by water currents, wave motion, prop washes, etc.
Bucket ladder dredger	The process of mechanical loosening occurs more violently as there is not one freely lowered grabber but an entire continuous chain of grabs (buckets) motioned by an engine and causing a much greater impact (than a grab dredger) on sediment layers. Also, turbulence caused by works of this kind of dredger is more intensive.		
Water injection jet suction dredger Cutter suction dredger	The work of a suction pipe pushed vertically into the deposit combined with the impact of water jets causes that, not only in the place of actual loosening of sediment (which is next pulled into the suction mouth) but also in a certain area around the place where the device operates, sediment structures are disturbed which results in significant changes in mechanical parameters, and thus also in the formation of an area favouring phenomenon of pollution fluidization. Also, turbulence occurring in the direct vicinity of the place of the raising head's operation is much more intensive than in the previous cases.	The most advantageous technology – the smallest amount of sediment is lost; dredged material is raised with the use of a suction pipe in the form of a pipeline section running from the raising head aboard the dredger, which ensures that both amounts of lost material and caused turbulence are practically negligible.	Limited area of resedimentation and resuspension applies basically to the site where works are conducted. After the works are finished, the bottom of the sea area consists of a thin layer of sediments with a disturbed structure resulting from loosening of the floor and resedimentation of deposits only in the direct vicinity of the raising head. Note that the degree of consolidation of these sediments will be much higher than in the case of bucket dredgers. Resuspension of sediments occurs only directly by the seabed; thus, the formed sediment cloud is not so susceptible to transportation processes and it undergoes faster resedimentation.

tion of the dredging industry development. Fig. 10 shows a dredger sourcing aggregates from the seabed at a depth of approx. 20 m, while Fig. 10b presents a submarine vehicle moving on the seabed at a depth of about 100 m and harvesting the valuable material via its suction head.

In the context of a pro-environmental approach, the most important criterion for the selection of an appropriate dredger is minimizing the phenomenon of sediment fluidization and release of toxic pollutants from sediment into the water depth, which is associated with spreading of the suspension cloud and disturbed structures of sediment layers [2, 23]. Dredging, impact of prop washes, increased intensity of water currents affecting the seabed, and wave motion disturb sediment structures as a result leading to, first of all, changes in mechanical properties of sediments associated with the degree to which they are consolidated, their density and critical levels of shear stress etc. Such changes affect physico-chemical balance on the border of two media, i.e. seabed sediment and overlaying water, thus initiating desorption of contaminants such as metals and polycyclic aromatic hydrocarbons (PAHs) from the surface of sediment grains into the water [6, 17].

The total amount of pollutants that can be released during the processes of fluidization depends to a large extent on the following three factors [4, 19]:

- difference in physico-chemical parameters between sediment and overlaying water, influencing the intensity and kinetics of occurring chemical reactions;
- time period during which the seabed sediment remains in the state of limited consolidation (suspension, mechanical fluidization) which favours the process of pollution release;
- hydrodynamic conditions prevailing in the vicinity of the generated active layer of the seabed affecting the dynamics of the occurring processes and the extent to which the released contaminants disseminate in the sea basin.

It may be stated that while the first of the above-mentioned factors is practically independent from the selected method of dredging, two other parameters are considerably influenced by the choice of technique to be applied. In result, minimization of the degree of pollutants released from seabed sediments in the course of dredging works is associated with the selection of such s method of dredging which ensures minimization of the [4, 23]:

Tab. III. Impact of the soil type on the choice of technical solutions and dredging fleet [26]

SOIL TYPES AND THEIR VARIATIONS	TECHNICAL SOLUTIONS AND DREDGING FLEET		COMMENTS
	EXTRACTION	TRANSPORT	
Solid rocks, conglomerates Cohesive clay, hard loam	Chisels for crumbling rocks, explosives, bucket dredgers, grab dredgers, bucket ladder dredgers	Dump barges – dump trucks, dump barges with bevelled bottom holds, deck pontoons, all vessels secured with a wooden board platform	Very thick boulders are blown up with explosives beforehand. It is possible to use dredgers with steel cutting teeth.
Stony soils in heaps, rubble, cobbles	Dipper dredgers, bucket ladder dredgers, or polyp-grabs in the case of single boulders	Dump barges with with bevelled bottoms or hold walls secured with wooden boards	Bucket ladder dredgers can be used only exceptionally.
Soil with large boulders and rocks	Bucket dredgers, grab dredgers with polyp-grab, bucket ladder dredgers	Dump barges – dump trucks, dump barges with bevelled bottom or hold walls secured with wooden boards, conveyor belts	
Slates, sandstone, clays, medium-hard loams	Chisels for crumbling rocks, explosives, dipper dredgers, bucket ladder dredgers	Dump barges – dump trucks, dump barges with bevelled bottom, dump barges with vertical hold walls secured with wooden boards, pontoons with bottoms secured with wooden boards.	Adhesive, clammy soils, loams, clays, etc.. deposit on equipment affecting its performance.
Cohesive and adhesive soils	Bucket dredgers, grab dredgers, trailing suction dredgers with a scarifier, bucket ladder dredgers with spray pipes for emptying the buckets	Dump barges with bevelled bottom, dump barges with vertical hold walls with spray pipes for emptying buckets, conveyor belts, hydraulic unloaders	Silty sands are difficult to be sucked and transported on dump barges. Their deposition is much limited; they slip through the bottom flaps.
Loams, clayey soils, sandy clays, silty sands, heavy clays	Bucket ladder dredgers, hydraulic suction dredgers with a scarifier, bucket dredgers, grab dredgers	Dump barges with bevelled bottom, conveyor belts, hydraulic unloaders, bucket ladder dredger with a long launcher	Sandy and silty clays may be quarried using dredgers of all sorts.
Coarse gravel, fine gravel, coarse sands	Bucket ladder dredgers, hydraulic suction dredgers with a scarifier, bucket dredgers, dredgers with a long launcher, grab dredgers, bucket ladder dredgers	Bottom dumping barges, bottom dumping hopper barges, conveyor belts, long launchers with spray pipes, hydraulic unloaders	Presence of seashells increases friction between the soil and the launcher. In the case of very tight soil it is necessary to use a scarifier. High resistance to refulation.
Medium- and fine-grained sands	Trailing dredgers, hydraulic suction dredgers, bucket ladder dredgers, bucket dredgers, grab dredgers	Hydraulic unloaders, long launchers, bottom dumping hopper barges with a water extraction system, conveyor belts	Very fine, coherent sands which are difficult to be sucked by hydraulic suction dredgers.
Fluid loams, silts, sludge, quick grounds	Trailing dredgers, hopper dredgers, Hydraulic suction dredgers Bucket ladder dredgers	Hydraulic unloaders, Long launchers, bottom dumping barges, bottom dumping hopper barges	Usage of hydraulic suction dredgers requires a lot of water.
Peats, decomposed plant soils, turfs, etc.	Bucket dredgers, Grab dredgers, Bucket ladder dredgers, Cutter suction dredger with a scarifier	Dump barges, hydraulic unloaders, conveyor belts	If impurities in the form of wooden splint, roots, boulders occur, the pipeline may get blocked; such material should not be quarried using hydraulic suction dredgers. In the case of tight deposition of cobblestones, a scarifier is necessary. Soil should be sucked from below the contaminated layer.
Soils fouled with roots, grass, stumps	Bucket dredgers, Grab dredgers, Bucket ladder dredgers	Dump barges with vertical hold walls, conveyor belts	

- time period during which seabed sediment remains in the state of limited consolidation, in consequence of which sediments raised from the seabed disseminate together with accumulated contaminants;
- disturbance of sediments (their turbulence) in the vicinity of the dredging site;
- loss of dredged material in the process of its extraction.

According to the available data the most advantageous option in this context is to conduct dredging works with the use of a suction dredger with an adjustable head raising the material hydraulically (Table I). However, this type of dredger may fail while operating at great depths. Hence, criteria for choice of dredger are sometimes dependent on assumptions and requirements of individual dredging projects. In case of some projects, efficiency of the dredging process is the main criterion, while other projects may require accuracy or application of dredgers operating at great depths, etc.

The impact of typical dredgiers on the aquatic environment

The depiction of basic types of dredgers with respect to the impact exerted at all stages of dredging processes (loosening, raising of the material and resedimentation of suspension cloud) on the phenomenon of fluidization (releasing) of pollutants accumulated in seabed sediments, which is included in Table II, indicates that application of mechanical dredgers or hydraulic suction dredgers is most advantageous. However, at the stage of floor loosening, mechanical techniques of floor loosening

Tab. IV. Examples of dredgers which may run on liquefied natural gas (LNG) [11]

NAME/COUNTRY	PROPULSION	CHARACTERISATION
Minerva (Belgium)	The first dredger powered with *dual-fuel* (diesel fuel or liquefied natural gas LNG); it can also be run solely on gas fuel	Type of vessel: *Trailing Suction Hopper Dredger* (TSDH); manager: DEME, Belgium; shipyard: Royal IHC; total length: 83.5 m, width: 18 m, side height: 6.8 m, moulded draft: 5.0 m, hopper volume: 3500 m³, maximum dredging depth 30 m, operational speed: 12 knots, seating configuration for 14 crew members.
Ecodelta (Netherlands)	Fuelled with liquefied natural gas (LNG)	Type of vessel: Trailing Suction Hopper Dredger (TSHD); total length: 134.1 m, width: 21.4 m, draft: 8.35 m, hopper volume 5500 m³, maximum dredging depth 37 m. Under construction (to be delivered to its owner Van de Kamp in 2018)
Scheldt River (Belgium) *(January 2017)*	Equipped with a dual-fuel engine: 12-cylinder and 9-cylinder 34DF engine, storage system and system of operating in LNG mode	Type of vessel: TSHD, manager: DEME – Dredging Environmental and Marine Engineering N.V. length (OA): 115.8 m, width: 25 m, depth: 9 m draft (loaded): 6.5 m, speed: 14 knots, total power: 10860 kW, hopper volume: 7950 m³, maximum dredging depth: 60 m operating from January 2017

prove themselves to be superior, but at the stage of raising the material, hydraulic methods of rising applied in suction dredgers gain a major edge. Additionally, there are special pro-ecological dredging techniques developed for these types of dredgers, which may be achieved with the use of e.g. special cutting discs that prevent the dredged material from entering the surroundings and suction of too much water at the same time.

Such general guidelines sometimes require verification depending on, e.g. physical and mechanical properties of the soil in the place of dredging. Soils can be divided into the following categories with regard to their workability levels: great workability, i.e. liquid loam and stratified peat; standard workability, that is ductible loam and cohesive peat; medium workability: solid loam, loose sand; poor workability, which include cohesive coarse-grained sand, clayey sands, cohesive dusty sands; no workability, e.g. deeply deposited sand, cohesive loam, cobbles, agglomerates and conglomerates. The soil type is often the decisive factor for the choice of the dredging equipment (Table III).

The introduced criteria for selection of dredgers are certainly not exhaustive, as they do not take into account numerous important practical factors such as economic aspects, availability of equipment, etc. In practice, it may turn out that it is impossible to satisfy all the criteria, and so a compromise needs to be reached (such as limiting the costs in exchange of decreasing accuracy). Sometimes, in very specific situations, customised dredgers are applied for small-scale work such as narrow canals, industrial lagoons, and reservoirs. Certain types were developed specifically to handle contaminated sediments with minimum disturbance. They are not typically employed on a large scale. For example, amphibious dredgers stand out for their ability to work afloat or elevated on legs clear of the water surface. Pneumatic dredgers work on the 'evacuator' principle. The unit is generally suspended from a crane standing on land or from a small pontoon or barge [10].

In case of water basins with small depths, where the bottom consists of silts with large amounts of organic matter, it is necessary to apply special solutions in the form of turbidity curtains and barriers in order to limit negative impact of dredging works on environment. This method consists in separating the place of sediment cloud formation (the dredging site) from the remaining part of the water area with the use of floating curtains. Protective curtains take the form of floating screens fastened to carrying elements on one side (floats – at the level of the water table) and tied or clipped together with stiffening ropes or chains at the other end (at the bottom). Depending on hydrodynamic conditions prevailing in the basin, there may be distinguished many types of protective curtains which differ from one to another in reliability of their construction, resistance to wave motion, currents, and winds. Thanks to the application of such mechanical screens, a sediment cloud formed at the dredging site does not spread outside the borders delineated by the installed curtains [5, 22].

A solution that may be environmentally sound, especially in water areas characterized by smaller depths may be the ecological system of deposition tested within the framework of the Spanish project ECODRAGA. The main features of the ECODRAGA system are that it channels the excess water gathered in the hull over the collected dredged material back to the place of the suction head's operation, as well as usage of geotextile, which is next deposited on the seabed. It allows for a considerable reduction of the negative effects on the ecosystem. When the hull is full, the material is dumped in the disposal site together with geotextile, which is next covered together with deposited sediment with a new layer of sand in order to enable growth of new marine biota. Some dredging systems allow emptying the hold via a pipe instead of duping the load. For this purpose, the Ecodraga uses monobuoys (offshore floating platforms anchored at the sea in the place of dredged material deposition and equipped with pipelines combined with disposal sites on land) thus connecting pipe with both platform and seabed [7, 27].

Another pro-ecological solution is the application of dredgers powered with gas fuel. It allows to reduce the emission of nitrogen and sulphur oxides (requirements of i.a. the MARPOL Convention MARPOL 73/78 [20]) and to limit costs. Usage of an alternative fuel such as LNG turns out to be cheaper, especially in the long run. Due to a higher calorific value of LNG (49 200 kJ kg^{-1}) in comparison to heavy fuel oils (IFO 180 – 41 800 kJ kg^{-1}) or distilled fuels (MGO – 42 800 kJ kg^{-1}), application of gas is associated with lower consumption of this fuel. Additionally, the price of LNG is currently lower than that of traditional fuels. Minerva and Ecodelta are examples of dredgers incorporating solutions allowing them to run solely on gas fuel [11] (Table IV).

The new approach to optimum strategy of conducting dredging works, especially aimed at economic interests is modelling strategy of these works in ports. It takes into account i.a. types of dredgers and their number, frequency and place of work performance in order to limit hindrances to normal functioning of port, reduce fuel consumption (as a result, the reduction of pollutant emissions into the air) and working time of dredgers. The optimum schedule of dredging works that is coordinated with, among others, the rigid schedule or a random structure of ship calls, allows both for the effective performance of planned works and reduction of financial losses of vessel managers and port terminals by 20–50 % [18].

The employment of dredgers, dump barges, pumps, etc. also generates other threats to environment. Usage of this equipment should be subject to additional guidelines in order to minimize negative impacts [1, 23], e.g.:

- usage of only top-quality machines and devices that are fully technically efficient and operated by authorised persons;
- maintaining the air quality standards in the area of planned works and reduction of noise emission, especially in case of works conducted in close proximity of residential areas;
- proper selection of date of work performance, i.e. the period of time allowing avoidance of a significant impact on the environment and marine biota. The season that favours morphodynamic, hydrodynamic and hydrological processes is fall/winter. The spring season of demersal fish reproduction is the least favourable for biological processes; in the summer season, intensification in vessel traffic and works conducted at sea is expected, which may additionally increase the likelihood of oil derivative substances getting spilled as a result of collision of two vessels. The threat of oil derivatives spillage shall be small, yet its occurrence cannot be excluded. In the port and aboard vessels, there should be oil separators and mats for securing such a site. It is assumed that dredging works should be conducted only in weather conditions specified in certificates of individual vessels, which limits the risk of polluting the environment.

Summary

It may be concluded that the choice of a suitable dredger is the first stage of dredging works, the objective of which is to minimize the negative impact of these works on the environment (including the influence of contaminants that can be dispersed into the water column during dredging operations).

The depiction of basic types of dredgers with respect to the impact exerted at each stage of the dredging process (loosening, raising of the material and resedimentation of the suspension cloud) on releasing pollutants accumulated in dredged sediments indicates that the application of mechanical or hydraulic suction dredgers is most advantageous. The important features of the new generation of dredgers are not only the modern positioning systems and systems for monitoring of water quality parameters, but also reduction of CO_2, NOx and SOx emissions, which assures high standards of air quality in the area where dredging works are conducted.

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Word count: 3500 Page count: 8 Tables: 4 Figures: 7 References: 27

Scientific Disciplines: Other

DOI: 10.5604/01.3001.0010.6973

Full-text PDF: https://bullmaritimeinstitute.com/resources/html/articlesList?issueId=9519

Cite this article as: Boniecka H., Staniszewska M., Cylkowska H.: Environmental aspects of dredging technology.: BMI, 2017; 32(1): 106-114

Competing interests: The authors declare that they have no competing interests.

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Ministerstwo Nauki i Szkolnictwa Wyższego The goals are financed according to the agreement 591/P-DUN/2017 from the funds of the Ministry of Science and Higher Education for science promotion.