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Underwater Sound
In Relation To Dredging

The Central Dredging Association is committed to environmentally responsible management of dredging activities and this paper – produced by the CEDA Environment Commission – seeks to inform those parties concerned about sounds produced by dredgers

Dredging is an activity that is carried out for many purposes. The dredging process can simplistically be described as the excavation of sediment from a sea, river or lake bed and the handling and transport of the excavated sediments and soils to a placement site elsewhere. Dredging is commonly applied for:

- Construction and maintenance of ports and waterways, dikes and other infrastructures
- Reclamation of new land
- Flood and storm protection and erosion control by maintaining river flows and by nourishing beaches
- Extraction of mineral resources from underwater deposits, particularly sand and gravel, to provide raw materials for the construction industry, and
- Environmental remediation of contaminated sediments.

Thus dredging provides many benefits to society with the goal of sustainable development while protecting natural resources and quality of life.

Objectives

Like many other activities, dredging produces underwater sound. Recently, the issue of effects of underwater sound on aquatic life has received broader attention within the scientific community, with stakeholders and the general public.

In this paper we will:

1). Summarise the effects of sound on aquatic life to set the scene
2). Describe in detail the underwater sounds generated by various components of the dredging process
3). Summarise what is known about potential effects of dredging sounds
4). Identify options for managing dredging-related sound, and
5). Provide conclusions and an outline of future areas of research.

Effects Of Sound On Aquatic Life

What is sound? – It can be described as a moving wave in which particles of the medium are forced together and then apart. This creates changes in pressure that propagate with the speed of sound.

The speed of sound in water is more than four times faster than in air and attenuation is also much less in water compared to air. Thus, water is an ideal medium for sound propagation.

Sounds can be described in terms of their intensity, which is measured or expressed in decibels (dB), pitch or frequency (in Hertz or kilohertz) and their duration (in seconds or milliseconds).

Sources of underwater sound – Both the natural environment and man can produce underwater sound. Natural sources of sound can be vocalisations of marine life – eg the elaborate songs of humpback whales or the snapping of shrimp. Wind, rain, waves, and subsea volcanic and seismic activity all contribute to ambient sounds in bodies of water.

Human-induced sound comes from construction of marine infrastructure (including dredging) and industrial activities such as drilling or aggregate extraction (including dredging); shipping; military activities using various types of sonar; geophysical exploration using seismic surveys, and a variety of other activities.

Anthropogenic sound sources can be broadly divided into high intensity impulsive sources, such as pile driving, and less intensive but more continuous sources like shipping and dredging. It has to be noted here that the dredging fleet represents 0.5% of the world total shipping fleet.

Human activities in the aquatic environment have intensified since the last century and research has indicated that ambient sound has been increasing in some regions too. While ambient sound levels are the result of both natural and anthropogenic sources, it is the latter we have control over since these can be managed.

Use of sound by aquatic life – As sound transits very well underwater, many marine species use it for a variety of purposes.

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Both fish and marine mammals communicate with underwater sound. Some whales communicate over great distances of many tens of kilometres. Sound is also used for navigation and finding prey. Dolphins, for example, produce short ultrasonic clicks and use the echoes to form an acoustic image that can help them to detect food or obstacles. There is also evidence that naturally occurring sounds are used by fish and marine mammals for orientation.

The effects of sound are strongly dependent on hearing abilities, which differ greatly between marine organisms. In general, marine mammals have a wide hearing range with some toothed whales able to hear ultrasounds (sounds above 20 kHz) that humans cannot detect. Fish hear over a narrower band and generally their sensitivity is better at lower frequencies. Some fish, such as sole or salmon, only detect differences in the movements of the particles moving within the sound wave and have a poor sensitivity. Others, such as herring, are able to detect sound pressure and have strong sensitivity.

Effects of sound on aquatic life – Sounds can have a variety of effects on aquatic life, ranging from subtle to strong behavioural reactions such as startle response or complete avoidance of an area. It is well documented that short and impulsive sounds such as those produced from pile driving strikes, seismic airguns and military sonar can cause behavioural reactions by fishes and cetaceans (whales, dolphins and porpoises; see OSPAR 2009 for example) up to distances of several tens of kilometres from the sound sources.

Certain sounds can also mask biologically important signals such as communication calls between baleen whales or fish. If the level that the animals receive is high enough, sound can affect hearing either temporarily or permanently and extremes can lead to injury or even death. The latter, however, usually occurs only in the case where animals are very close to very high intensity sounds, without having the opportunity to move away.

Research on the effects of underwater sound on aquatic life has increased over the last decade, but there are still many unanswered questions, especially with regards to the significance of sound impacts for conservation objectives. In particular, the translation of individual effects into consequences at the population level involves great uncertainty.

Even when sound alone is not severe enough to affect the well-being of populations of concern, together with factors such as fishery by-catch, pollution and other stressors, sounds may create conditions that contribute to reduced productivity and effects on survival. It is therefore important to assess the effects of sound together with other stressors when undertaking assessments of impacts on ecosystems.

Dredging Sound

Activities producing underwater sound – For the majority of projects, one or more of four basic types of vessel are used: cutter suction dredgers (CSD), trailing suction hopper dredgers (TSHD), grab dredgers (GD) and backhoe dredgers (BHD). Generally speaking during dredging operations, there are three categories of sound sources that are associated with:

- Dredging excavation
- Dredging vessels during transport
- Dredged material placement.

Figure 1 through 4 give an overview of the different types of dredging vessels and the sources of underwater sound for each type of vessel.

If self-propelled, the dredger's power plant and propeller can produce sounds, though not all vessels use propulsion during dredging. CSDs advance using spuds and by swinging between anchors, but for operational assistance many CSDs use workboats or tugs, which also produce underwater sounds (*see Figure 1*).

Internally located engines produce relatively strong and continuous sounds, which are transferred through the ship's hull to the water. These sounds will, in general, be continuous and relatively constant with respect to frequency and intensity depending on the type of engine.

Various configurations of winches, generators, and hydraulic equipment specific to a given dredger's design can also produce sounds. Lack of proper maintenance and lubrication can cause increased sound levels.

Both CSDs and TSHDs (*Figure 1 and 2 respectively*) use a suction pipe to transport entrained material from the seabed to

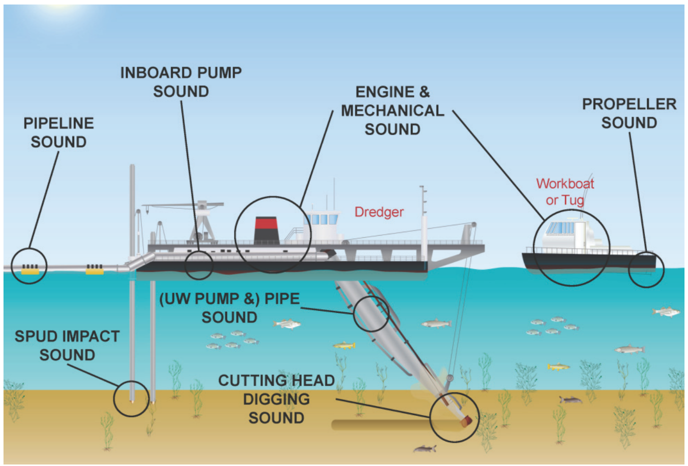

Figure 1 Schematic overview of a cutter suction dredger

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a transport barge, to a pipeline or to a hopper. Depending on the material, a regular rumbling sound will be produced, possibly with irregular peak-pulses when pumping fragmented rock. When working stationary this sound is relatively low in frequency, fairly constant and continuous. For non-stationary equipment this sound production is less continuous (cyclic).

Sounds are also produced by the dredge pumps both above and underwater. Dredge pump sounds are relatively constant and continuous during operation. TSHD operations produce pump sounds intermittently during dredging, trailing and during self-discharge.

TSHD's propellers continuously work during dredging and can produce sounds of high frequencies, particularly during episodes of cavitation. But because TSHDs depart the dredging site for the placement site on a regular cycle, exposures to such sounds would be limited to the period of active excavation.

Sound production during excavation is strongly influenced by soil properties – eg to excavate hard, cohesive and consolidated soils, the dredger must apply greater force to dislodge or entrain the material. Consequently, dredging these types of soils may involve more intense sounds than for excavation of soft, high water content soils. Soil type also influences the selection of dredger type as well the equipment used, including cutterheads, dragheads, grab buckets and backhoes.

Grab and backhoe dredgers (*Figure 3 and 4 respectively*) require the use of transportation barges. Production of underwater sounds by these mechanical dredgers depends on the dredging cycle, including the availability of barges. In general, they produce relatively low frequency sounds.

Sometimes it is necessary to break up the soil using explosives or hammering before dredging is possible. Underwater sounds due to the use of explosives and rock breaking by mechanical action can be considerably stronger than those of routine dredging activities. Likewise, sounds caused by dredging equipment maintenance and repair works, such as rust chipping and hammering, can be passed through the hull to the water and can contribute to underwater sound levels.

Dredging sound measurements – Although dredging sounds can be generally described as in the previous sections, few data and few published characterisations of dredging-induced sound levels exist.

The one investigation carried out on grab dredgers indicates that this activity is relatively quiet and that recorded sound levels were just above the background sound at approximately 1km from the source (Clarke *et al.* 2002).

Both CSDs and TSHDs are louder (see summary in Thomsen *et al.* 2009).

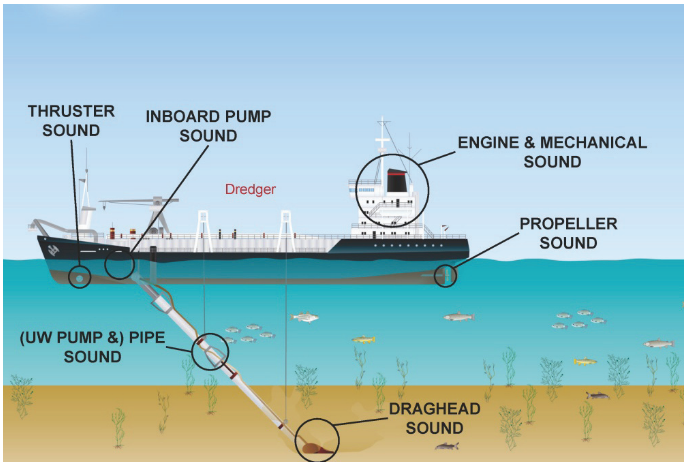

Figure 2 Schematic overview of a trailing suction hopper dredger

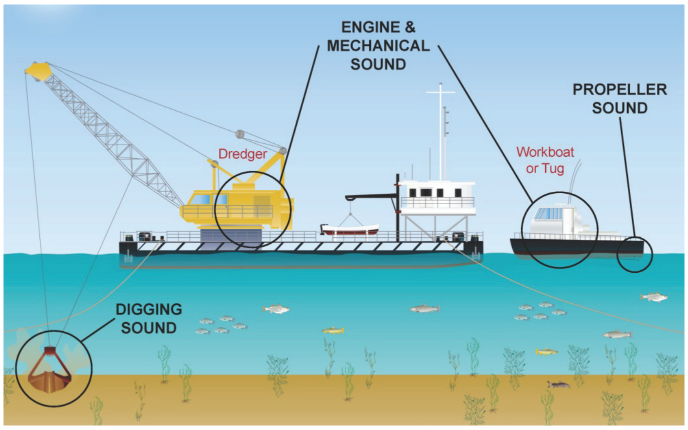

Figure 3 Schematic overview of a grab dredger

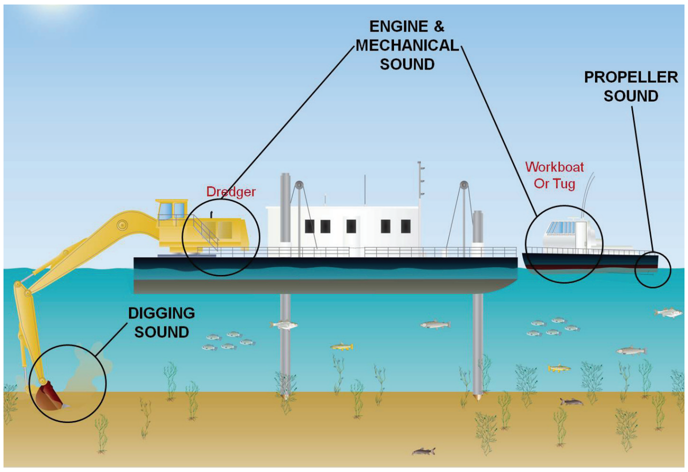

Figure 4 Schematic overview of a backhoe dredger

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A very recent investigation (Robinson *et al.* 2011) found that trailing suction hopper dredgers emit sound levels at frequencies below 500Hz that are generally in line with those expected for a cargo ship travelling at a modest speed – ie between 8kt and 16kt. It was also found that source levels at frequencies above 1kHz show elevated levels of broadband sound generated by the aggregate extraction process; however these sounds attenuate rapidly with distance.

There were strong indications that the presence of aggregate pumped through the pipe is a major source of these elevated levels at higher frequencies. Finally, the sound levels were dependent on the aggregate type being extracted, with coarse gravel generating higher sound levels than sand (Robinson *et al.* 2011).

Appendix 1 gives an overview of the currently available results of these monitoring campaigns and also lists other sources of natural and anthropogenic underwater sounds for comparison.

Potential and documented effects of dredging sound – Based on the information presented in *Appendix 1*, we can see that dredging is at the lower end of the scale with regards to emitted sound pressure levels in aquatic environments. These sounds primarily fall within lower frequency ranges where many toothed whales, such as harbour porpoises, are less sensitive. Although higher frequency sounds are emitted by the transport of sand and gravel through a suction pipeline, such sounds can be expected to attenuate faster than the lower frequency sounds, thereby limiting potential impact ranges.

With respect to underwater sound in general, insufficient knowledge exists to confidently predict at what levels sound can cause injury, such as temporary or permanent hearing threshold shifts.

Two study groups have developed suggestions for marine mammals and fish based on the limited information available (see Popper *et al.* 2006; Southall *et al.* 2007). Based on these recommendations, it is very unlikely that underwater sound from dredging operations can cause injury. Temporary loss of normal hearing capabilities might happen if individuals are in the immediate vicinity of a dredger and are exposed for a long time, which is unlikely.

Behavioural reactions, however, such as startle or avoidance behaviours and masking effects, cannot be ruled out. The ecological significance of these responses will vary among species. Both can have negative consequences for individuals if important behaviours such as mating or foraging are affected.

Very little research has been carried out on the effects of dredging on the behaviour of marine life and results are therefore sparse. Some investigations indicate that gray and bowhead whales avoid areas of dredging activity (reviewed by Richardson *et al.* 1995) and recent research also indicates that harbour porpoises leave areas during sand extraction. The reactions were relatively short term however (Diederichs *et al.* 2010).

No information exists about effects on seals or most species of fish.

Management of dredging related sound – Dredging conductors should have an interest in carrying out their activities in an environmentally friendly manner. In Europe, dredging is in most cases licensed through an *Environmental Impact Assessment* (EIA) that is usually comprised of a careful analysis of the baseline situation, including information on the distribution and abundance of sensitive species within the planning area, for which literature data and own investigation can be used.

Based on these investigations, an impact assessment is then carried out that gives some detail on the expected intensity, duration and range of impacts. The decision to permit a project and to impose reasonable and appropriate restrictions lies with the licensing authority.

Recently, Boyd *et al.* 2008 developed a risk-based approach for assessing the impacts of sound on marine mammals that involves several steps leading to an overall assessment of risks of an activity to the well-being of mammal populations. CEDA acknowledges these new developments and encourages further steps in refining the methodology in relation to underwater sound.

Once risks have been identified, there are a variety of options available to mitigate against adverse impacts. These range from temporal restrictions on dredging activities and spatial buffer zones to technical solutions that reduce the levels of sounds emitted into the sea (overview by OSPAR 2009). These methodologies, however, need careful consideration and clear justification based on clearly identified risks to the aquatic environment. This also guarantees the involvement of responsible developers and stakeholders in the process. Ideally, in a transparent decision making process, policy will effectively balance the risk of impact with social-economic benefits.

Conclusion And Recommendations For Further Studies

Dredging involves a variety of activities that produce underwater sounds. Most of these are relatively low in intensity and frequency, although recent investigations indicated that occasionally higher frequencies are emitted.

Compared to other activities that generate underwater sound,

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dredging is within the lower range of emitted sound level pressures. While it is clear that dredging sound has the potential to affect the behaviour of aquatic life in some cases, injury in most scenarios should not be a concern, or should be preventable. It is very unlikely that dredging-induced sounds will lead to any population level consequences, although harm to individuals should not be overlooked.

To reduce remaining uncertainties, there remains a need to increase our knowledge about the effects of dredging sounds on aquatic life. In the meantime a lack of knowledge should not lead to unjustified restrictions on projects. More information on emitted sounds from all types of activities carried out during dredging are necessary to further identify risks and support informed decisions about the necessity of sound mitigation measures.

CEDA encourages the development of a standardised monitoring protocol for underwater sound, to facilitate evaluations of reasonable and appropriate management practices. It is also recommended that rigorous investigations of the effects of dredging on marine mammals and fish be undertaken either in the field or under more controlled conditions in the lab. CEDA is committed to sustainable management of environmental resources and therefore recommends a balanced approach to the management of effects of underwater sound from dredging. We encourage prudent investment in research related to the environmental impacts of underwater sound so that human activities can be carried out with the lowest possible risk to the well-being of individuals and populations.

Table 1 – an overview of biological and manmade sound sources listed in decreasing order of source levels at 1 m.
Sources: 1). Review by OSPAR 2009; 2). Review by Thomsen et al. 2011; 3). Zimmer 2004; 4). Møhl et al. 2003; 5). Villadsgaard et al. 2007; 6). Review by Thomsen et al. 2009; 7). Review by Robinson et al. 2011; 8). Au & Banks 1998.

Sounds in the aquatic environment

Sound source	Source level at 1m	Bandwidth	Main energy	Duration	Directionality	Source
Explosives	272dB-287dB re 1μPa zero-to-peak	2Hz-~1kHz>	6Hz-21Hz	~1ms	Omni-directional	1)
Seismic air gun arrays	220dB-262dB re 1μPa peak- to-peak	5Hz-100kHz	10Hz-120Hz	10ms-100ms	Downwards	2)
Pile driving	220dB-257dB re 1μPa peak-to-peak	10Hz >-20kHz	100Hz-200Hz	5ms-100ms	Omni-directional	1), 2)
Echosounders	230dB-245dB re 1μPa (rms)	11.5kHz-100kHz	Various	0.01ms-2ms	Downwards	2)
Low-frequency military sonar	240dB re 1μPa peak	0.1kHz-0.5kHz	-	6s-100s	Horizontally focussed	3)
Sperm whale click	236dB re 1μPa rms	5kHz-40kHz	15kHz	100μs	Directional	4)
Mid-frequency military sonar	223dB-235dB re 1μPa peak	2.8kHz-8.2kHz		0.5s-2s	Horizontally focussed	1)
Sparkers, boomers, chirp sonars	204-230 dB re 1μPa (rms)	0.5-12kHz	Various	0.2ms	Downwards	2)
Harbour porpoise click	205dB re 1μPa peak-to-peak	110kHz-160kHz	130kHz-140kHz	100μs	Directional	5)
Shipping (large vessels)	180dB-190dB re 1μPa (rms)	6Hz >-30kHz	<200Hz	Continuous	Omni-directional	1)
TSHD	186dB-188dB re 1μPa rms	30Hz>-20kHz	100Hz-500Hz	Continuous	Omni-directional	6), 7)
Snapping shrimp	183dB-189dB re 1μPa peak-to-peak	<2kHz-200kHz	2kHz-5kHz	Milliseconds	Omni-directional	8)
CSD	172dB-185dB re 1μPa rms	30Hz>-20kHz	100Hz-500Hz	Continuous	Omni-directional	6), 7)
Construction and maintenance ships	150dB-180dB 1μPa rms	20Hz-20kHz	<1kHz	Continuous	Omni-directional	1)
Drilling	115dB-117dB re 1μPa (at 405m and 125m)	10Hz-~1kHz	<30Hz-60Hz	Continuous	Omni-directional	1)

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Acknowledgements

This Position Paper is presented by the Central Dredging Association (CEDA), an independent, international, easy-to-access platform for the exchange of knowledge and experience on all aspects of dredging and marine construction. It has been prepared by the CEDA Working Group on Underwater Sound under the remit of the CEDA Environment Commission, and reviewed by experts on dredging from various professional groups.

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Valuable contribution has been received from CEDA's sister association, the Western Dredging Association (WEDA) through its Environment Commission: Douglas Clark and Kevin Reine, US Army Engineer R & D Center, Environmental Laboratory

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