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SCOPING ACTIVITIES

CG 5: Sand and Gravel Mining in the Marine Environment – New Insights on a Growing Environmental Problem

Submitted by the co-leads of the Correspondence Group

Introduction

1 Sand and gravel represent the highest volume of raw material consumed on earth after water and air (UNEP, 2014). Sand is important to our daily life but an underestimated resource because it is very often cheap, freely accessible, and for the most part only the extraction costs need to be covered. This "high volume - low value" paradox in sand and gravel mining undermines the colossal quantities being used and our increasing dependence on them despite the significant adverse impacts their extraction can have on the environment. Hence, a large discrepancy exists between the magnitude of the problem, public perception and its lack of visibility on the scientific and political agenda.

2 Over the past 25 years, the social and environmental pressures on traditional land-based sources of sand and gravel have been increasing. Indeed, this was one of the major factors for many national marine aggregate industries being established (ICES, 2016). Being more expensive than terrestrial exploitation, offshore dredging is most common in developed economies due to the cost of specialized equipment and special environmental permits required (Pereira, 2012).

Sand – What is it?

Sand is a naturally occurring loose granular substance, typically pale yellowish brown, resulting from the erosion of siliceous and other rocks and forming a major constituent of beaches, river beds, the seabed, and deserts. Sand particles range in diameter from 0.0625 mm to 2 mm. An individual particle in this range size is termed a sand grain. Sand grains are between gravel (2 mm up to 64 mm diameter) and silt (0.004 to 0.0625 mm) in size. The scale used for the grain size of sediments in geology and marine science is that of Wentworth as modified by Krumbein (1934).

The composition of sand varies depending on the local rock sources in adjacent river catchments and the seabed, living resources that may contribute material to sediments e.g. coral and shellfish and on hydrodynamic conditions in the marine environment. The most common constituent in inland continental and non-tropical coastal settings is silica (Silicon dioxide or SiO_2) usually in the form of quartz. Quartz because of its chemical inertness and considerable hardness is the most common mineral due to its resistance to weathering. In marine situations, sand can often also have a significant fraction made of shell fragments. In tropical environments, sand can often be predominantly made of calcium carbonate ($CaCO_3$ – Calcite or Aragonite) formed by various forms of life like coral, and shellfish. Quartz sand that is recently weathered from hard rocks such as granite or gneiss or the waste material from quarrying hard rock is angular and called "sharp sand" in the building trade.

3 Between 1900 and 2010, the global volume of natural resources used in buildings and transport infrastructure increased 23-fold (Krausmann, *et al*., 2017). The international trade of sand value has skyrocketed, increasing almost six-fold in the last 25 years. Sand and gravel are

the largest portion of these primary material inputs (79% or 28.6 gigatons per year in 2010) and are the most extracted group of materials worldwide, exceeding fossil fuels and biomass (Schandl *et al*., 2016). China and developing countries require more sand for urbanization and economic growth (Wang, 2016). While other countries use other types of sand for the glass industry, electronics industry, etc. (Spanne, 2015). A significant new use for sand recently is its use in fracking i.e. the hydraulic fracturing of rocks by injecting sand and water into rock formations to release oil or gas that is otherwise inaccessible. In the US, the rapid increase in this use has led to competition for industrial sand resources (Edwards, 2015).

4 Generally, there is a lack of information and reliable data on aggregate mining. Globally, between 47 and 59 billion tonnes of material is estimated to be mined from the earth every year, of which sand and gravel (also called aggregates) account for both the largest share (from 68-85%) and the fastest increase in the rate of extraction (Chilamkurthy *et al*., 2016; Krausmann *et al*., 2009; Steinberger *et al*., 2010; UNEP, 2014). This makes assessment of its global environmental impact very difficult and has contributed to the lack of awareness on this issue. However, taking all estimates of use in a wide range of sectors into consideration, the world consumption of aggregates exceeds 40 billion tonnes a year (Krausmann *et al*., 2009; USGS, 2013a, 2013b; EDE, 2013) and this is estimated to be equivalent to twice the yearly amount of sediment carried by all of the rivers of the world (Milliman and Syvitski, 1992). Extraction rates were highest in the Asia-Pacific region, followed by Europe and North America. In the United States alone, production and use of construction sand and gravel was valued at US$8.9 billion in 2016, and production has increased by 24 percent in the past five years (Torres *et al*., 2017b).

5 The demand for sand and gravel will continue to grow rapidly around the world particularly in newly developing countries where rapid economic development requires strong growth in the construction industry (e.g. India, China, UAE, etc) and to a lesser extent in developed countries for upgrading dilapidated infrastructure (e.g. USA). However, resource depletion and environmental concerns, among other factors, restrict the possibilities of sand mining e.g. in China (De Leeuw *et al*., 2010) and in densely populated regions such as north-western Europe. Sand and gravel resources were identified by Sutherland *et al*. (2017) as an emerging issue of concern for global conservation and biological diversity.

6 Over-exploitation of global supplies of sand is damaging the environment, endangering communities, causing shortages and promoting violent conflict (Edwards, 2015; Torres *et al*., 2017b). Sand and gravel mining can represent serious threats to marine habitats especially at uncontrolled and rapid rates of exploitation. These include impacts on the physical landscape, biodiversity, water turbidity and water table levels (UNEP, 2014, UNEP, 2019). There can also be indirect impacts e.g. from the dewatering of dredged sediment in stilling ponds which can impact aquifers and groundwater Lachaal and Gana (2016).

7 The need to maintain retreating coasts or shrinking beaches has led to the nourishment of existing beaches and the building of artificial beaches by the replacement of sand lost to erosion. This can severely impact habitats at and adjacent to the nourishment activity. Large-scale reclamation effectively destroys habitats and can also severely impact habitats adjacent to the reclamation activity (Ge and Jun-yan, 2011; Priyandes and Rafaee, 2009).

Scope of the paper

8 At its 43rd annual session in Nairobi, Kenya, GESAMP agreed to set up a Correspondence Group to investigate the topic further, in particular whether GESAMP might provide a useful mechanism for allowing the science community and industry to coordinate their efforts and find solutions to sustainable mining of aggregates with minimal effects on the environment.

9 Objectives of the GESAMP Correspondence Group are:

.1 To provide a brief summary of the current state of knowledge regarding the extraction of sand and gravel from sand dunes just above the high-water mark, the intertidal zone between the high and low water marks and the seabed offshore;

.2 To provide a record of the many organisations and individual researchers who have published or are undertaking initiatives related to this phenomenon;

.3 To assess the potential role of GESAMP in helping to take this work forward, by bringing together the relevant multi-disciplinary expertise and the regional and international bodies with responsibility in this area; and

.4 To provide a revised scoping report with recommendations for consideration by the GESAMP Executive Committee in advance of the 46th Session (9-13 September 2019, New York).

Background to sand and gravel resources and utilization

10 Extraction of sand and gravel (aggregates) from rivers, flood plains, lakes, estuaries, coasts, nearshore and the offshore seabed, represent a global industry with huge socio-economic significance. Land quarries and river beds have been traditional repositories for sand mining in many countries. However, the decline of inland resources due to resource depletion and environmental concerns has resulted in some countries in a shift to coastal and/or offshore aggregates mining, although offshore sources of sand and gravel have been exploited in some countries for many decades e.g. since the 1960’s or earlier in the case of the UK. Currently, river and offshore areas supply a major volume of aggregates used for building and land reclamation globally.

11 Marine aggregates need to be thoroughly washed to remove salt which otherwise would cause corrosion of concrete and eventual collapse of structures after few decades (Delestrac, 2013). Also, onshore dewatering methods are used to prepare aggregates for construction use.

12 Most sands from deserts are not ideal for use in concrete and mortars, as the wind erosion process forms round grains that do not bind well, although in some cases they can be used in concrete (Zhang *et al*., 2006), possibly in mixtures with sand-sized material from crushed rock production (Cisse *et al*., 2012).

13 Use of land that has agricultural or hydrological value is at high competitive disadvantage when it has aggregates resources and this pressure can be overcome through marine extraction. Where aggregate extracted offshore can be landed close to the point of use, an additional benefit is that long-distance overland transport is avoided and the bulk transportation of sand and gravel by vessels at sea or on major rivers has proportionately much lower carbon dioxide emissions than land-based transportation. However, the benefits of using marine sand and gravel must be balanced with the potentially significant environmental impacts, particularly where the activity is not effectively regulated and managed. Some negative effects on the environment are inevitable and these are evident in the scientific and other literature from around the world. The scale of extraction can have a major impact on rivers, deltas, coastal and marine ecosystems due to the loss of land through coastal erosion, lowering of the water table, impacts on habitats and decreases in the amount of sediment supply.

14 Marine aggregates are mostly used in the construction industry for making concrete, beach replenishment/shoreline protection, land reclamation, for fill and other fill-related uses (e.g. drainage and capping material). High-quality marine aggregates are used for mixing with a cementing agent, to produce hard building materials (e.g., concrete, mortar, and plaster), or are coated with bitumen for road surfacing. Lower grade materials can be used in base materials

under foundations, for roads, and railways, or in the construction of embankments. The quality of the material used for beach nourishment may show strong variability, with location and local/regional policies. Nonetheless, the grain size of the nourished material should be similar to (or greater than) that eroded to ensure retention at the placement site and without fresh biogenic material or contaminants.

15 Countries producing large quantities of marine aggregates from offshore (Belgium, Netherlands, Denmark, UK, France, Germany, USA, Japan, Hong Kong, Dubai), extract different types of material, and for distinct purposes (e.g., industrial, concrete, filling, reclamation or beach recharge). In addition, they may import and export material to and from other countries. For example, in 1998, almost 90% of the marine aggregates production in the UK was for concrete (gravel and coarse sand), but a third of this (c. 7 Mt) was exported to other north-western European countries. In Spain, by contrast, the dredging of marine aggregates is authorized only for beach replenishment (Garel, 2009). Data on historic patterns of marine aggregate extraction (Mm^3) for these countries are available from ca. 1974 onward.

16 Singapore was by far the largest importer of sand world-wide (UN Comtrade, 2014; Aquaknow, 2014). The aggregates imported were mainly sourced from neighbouring countries including Indonesia. Export of sand to Singapore was reported to be responsible for the disappearance of some 24 Indonesian Islands and political tensions between the two countries (New York Times, 2010; Guerin, 2003). However, this sand export declined sharply after a ban in February 2002 (Guerin, 2003). The increase in price of imported sand into Singapore from US $3 per tonne between 1995 and 2001 to US $190 per tonne in 2005 caused an alleged escalation in illegal traffic of sand by local mafias (Global Witness, 2010).

Examples of significant large scale uses of marine sand and gravel around the world

17 Examples of large-scale uses/imports of marine aggregates around the world include those of Singapore (city state expansion), Hong Kong (ports and harbour and airport), Dubai (Burj Khalifa tower, World Island projects, etc), Netherlands (Sand Motor, Maasvlakte), USA (various dynamic beach nourishment projects), South Korea, China (South China Sea Islands), India (city building spree), Caribbean Islands, South Africa, Morocco, Japan, Lagos (Atlantic city), and recently the Principality of Monaco (a €2/$2.3 billion 15 acres coastline extension into the Mediterranean). Reclamation activities in Bahrain resulted in adding around 91 km^2 representing an increase of 11% of the total land area (Zainal *et al*., 2012).

18 The scale of these reclamations is illustrated by the islands that were built in Dubai primarily of sand dredged from the bottom of the Gulf, from nearby borrow sites within the UAE. 200 million cubic meters of sand was dredged for fill for the Palm Islands land reclamation and breakwater construction. In addition, the World Islands are built of more than 320 million m^3 of dredged sand (von Mayer and The Writers for Hire, 2017).

Examples of smaller scale impacts of sand and gravel mining on the coastal environment

19 Examples from around the world can be found on a number of websites[1] as well as in the scientific literature. The Coastal Care website says that sand mining occurs in 73 countries on 5 continents, although it is likely that only a proportion of those numbers are in the marine environment. Examples from the scientific literature include from Morocco (Pilkey *et al*., 2009), Ghana (Jonah *et al*., 2016), Tanzania (Masalu, 2002), India (Cousins, 2019), Philippines (Chaussard and Kerosky, 2016), Asia generally (Larson, 2018), the Maldives (Brown *et al*., 1988), Pacific Islands (Babinard *et al*., 2014; Holland *et al*., 2011; McKenzie *et al*., 2006) and Australia (Charlier, 2002).

[1] E.g. http://www.sandstories.org/ and http://coastalcare.org/sections/features/sand-mining/

Extraction methods and technologies

Intertidal Areas and Dunes Immediately Behind the High-Water Mark

20 Sand extraction from beaches and inland dunes is performed mainly through open pit methods. These require only basic equipment – a bulldozer to clear vegetation and build access roads, an excavator/mechanical digger or front-end loader to remove sand deposits and trucks for transportation of the excavated material.

Offshore Dredging

21 Offshore marine aggregate extraction is undertaken by dredging vessels in 3 stages - excavation, transport and offloading – with these stages carried out using different technologies that may be combined in one vessel or done by 3 separate vessels/machinery.

22 The development of the dredging industry over many decades has brought about different types of dredgers for different applications. Excavation of sediment at an offshore excavation site is usually accomplished with hydraulic and/or mechanical dredgers (Aarninkhof *et al*. 2018; Bray *et al*., 1996; Bray, 2008, Manap and Voulvoulis, 2015). These vessels can contain the excavated material in the vessel's hull – called a 'hopper' - although the excavated material can also pumped ashore through a pipeline or be directly offloaded into barges alongside, provided sea conditions permit such an operation. Hydraulic dredging can either be undertaken while the dredger is moving over the seabed, usually by trailer suction hopper dredgers or while the dredger is anchored and stationary, known as static or anchor dredging. Anchor dredgers are generally confined to small areas such as lakes, lagoons and port basins and their use in offshore dredging is now generally less common. Cutter suction dredgers are a type of dredger that excavate material with a combination of a rotating cutter head and suction with the material either being piped to shore or loaded into barges alongside. Mechanical dredgers can be used for smaller scale dredging operations and include the use of e.g. backhoe or grab dredgers (Aarninkhof *et al*. 2018; Bray *et al*., 1996; Bray, 2008, Manap and Voulvoulis, 2015).

23 After a cargo has been loaded, the aggregate is transported to the desired location by hopper dredgers, barges or by pipeline. This would be either to a wharf located in a port for discharge, delivery for construction purposes, to a dewatering site for removal of liquids and fines or placed at a site for land reclamation/beach nourishment, using methods including bottom dumping, side casting or direct pumping ashore (Fig.1).

24 On-board screening of the sediment (generally only on trailer suction hopper dredgers), if desired, can remove particular sizes of dredged material at sea, to obtain a cargo that meets the needs of a particular market or customer. Screening may remove either finer sediments (sand), to provide a predominantly gravel material, or in a reverse process, coarser sediment particles may be removed to provide a cargo of sand (BMAPA/TCE, 2017).

Figure 1: A typical trailer suction hopper dredger supplying sand for beach nourishment.

Effects of sand and gravel extraction on the marine environment

25 It needs to be stressed that effective regulation and management of sand and gravel extraction from the marine environment can minimise and mitigate the effects of sand and gravel extraction to a significant degree.

In Intertidal Areas and Dunes Immediately Behind the High-Water Mark

26 Large-scale extraction and reclamation activities have significant physical and biological impacts on the intertidal area and dunes immediately behind the high-water mark.

Physical Effects

27 Coastal erosion is often a direct result of the mining of aggregates from intertidal areas and dunes immediately behind the high-water mark and can also occur indirectly, as a result of near-shore marine dredging of aggregates, or as a result of sand mining in rivers (De Leeuw, 2013; Kondolf, 1997; Thornton *et al*., 2006). Damming and mining have reduced sediment delivery from rivers to many coastal areas, leading to accelerated beach erosion (Kondolf, 1997).

28 The process of mining and depositing material is likely to increase turbidity and fine sediment suspension in coastal waters. Any fine sediments stirred up during the mining process take longer to settle and thus remain suspended for longer. Consequent decreased light reaching the sea floor may impact on photosynthetic organisms. Land reclamation is also associated with the destruction of coral reefs, the shifting of water currents, and the disruption of wave patterns (Ge and Juh-yan, 2011; von Mayer *et al*., 2017). Infill and dredging for waterfront developments and artificial islands has impacted the natural shores of most western Gulf countries.

29 The creation of artificial islands in the Gulf is an example where material containing a significant fraction of fines was dredged for their construction. Also, the construction of the Saudi-Bahrain Causeway back in the 1980's created massive plumes of fine sediments which eventually settled forming a widespread semi-solid layer on the seabed some 50-60 centimetres deep and mostly anoxic (Vousden, 1985). This remained in this condition for at least 2 years (after which monitoring was sparse).

30 During the past decades Bahrain has gained wide land areas by reclamation and dredging. These operations have caused drastic effects on the coastal marine ecosystems and environments. They have induced siltation, increased turbidity of the sea-water and of the salinity of the island's ground waters.

31 According to Pilkey *et al*. (2009), coastal sand mining in many areas of northern Morocco has resulted in:

- A lunar landscape end result of the mined sites in Morocco;
- No sand reserve for natural beach storm response. Beach mining increases the vulnerability of all coastal infrastructure and ecosystems that were once protected;
- Increased shoreline erosion rates. In addition, neighbouring, unmined shorelines may also see an increase in erosion as the shoreline reaches a new equilibrium; and

- Destruction of archaeological sites.

32 Several hotspots of shoreline erosion have been identified along the African coastline (UNIDO, 2011) from Conakry (Guinea) to Luanda (Angola). While shoreline dynamics are largely natural processes (hydrographic conditions like reinforcement of onshore waves due to wave refraction from adjacent headlands) human activities such as sand and gravel mining and damming of inland rivers contribute to accelerated coastal erosion. Aggregate mining on the continent is largely unregulated and results in several embayment along the shoreline due to localized coastal recession with changes in near shore bathymetric contours and wave refraction pattern.

33 Coastal mining for aggregates on Pacific island coral atolls such as Tarawa (Kiribati), Funafuti (Tuvalu)and Majuro (Marshall Islands), has increased coastal erosion and led to increased flooding in some cases (Babinard *et al*., 2014; Holland *et al*., 2011; McKenzie *et al*., 2006). Alternative sources of aggregates such as dredging from atoll lagoons or importing aggregates from overseas at great cost have been used. However, imported aggregates risks importing invasive species (Holland *et al*., 2011).

Chemical Effects

34 The sands which constitute the bulk of mined aggregates generally show little chemical interaction due to their composition, low fines content and low particle surface area. However, where mined sands have high levels of silts and clays, those materials may have higher levels of organic content and/or contaminants and then any discharges containing these fines could demonstrate greater chemical activity. Any fine sediments can adsorb chemical pollutants, removing them from the water column by binding and stabilising them within the substrate. The disturbance and resuspension of these fines by dredging may reintroduce these pollutants to the water column, re-exposing the biological community to their effects.

Biological Effects

35 The biological effects of the mining of aggregates from intertidal areas and dunes immediately behind the high-water mark are the result of the physical effects, whether direct or indirect. Recent scientific evidence demonstrates the ecological value of intertidal and shallow subtidal ecosystems that are disappearing rapidly in the Gulf. Fisheries are declining due to the loss of nursery and feeding grounds (Jones *et al*., 2007). The massive land-reclamation projects and rapid industrial developments in this region – see section 3.1 above - are posing an unprecedented threat to seagrass habitats in this region (Erftemeijer and Shuail, 2012) and indeed across the world (Erftmeijer *et al*., 2006). The massive dredging (~94 million tonnes) required to build the Palm Islands in Dubai killed a whole square mile of coral (Jennings, 2015). Sand mining in many areas of northern Morocco has resulted in the total destruction and loss of the coastal and nearshore ecosystems, including the beach (impacting nesting shorebirds and sea turtles), the dunes (impacting rare endemic vegetation), and coastal wetlands (impacting migratory waterfowl among other organisms) (Pilkey *et al*., 2009). Mining of sand dunes leads to soil erosion, landslides, loss of vegetation and may promote the growth of alien plant species (Mngeni *et al*., 2016).

Recovery/Restoration

36 Recovery/restoration of intertidal areas and dunes immediately behind the high-water mark that have been subject to significant mining activities is generally very difficult and costly. Consequently, it does not happen very often.

Cumulative Effects

37 Cumulative effects of multiple mining activities in intertidal areas and dunes immediately behind the high-water mark can be very significant and can cause effects further along the coast due to impacts on sediment transport regimes.

Socio-economic effects

Sand mining

38 Sand mining has serious impacts on people's livelihoods. Beaches and wetlands buffer coastal communities against surging seas. Increased erosion resulting from extensive mining makes these communities more vulnerable to floods and storm surges (Pilkey and Cooper, 2014).

39 Sand that is transported into the ocean from rivers is eventually deposited along the shore, forming beaches along the coastline. The denudation of beaches and the erosion of dunes can cause damage to coastal properties and infrastructure and have a significantly impact on the tourism industry (Chevallier, 2014). Sand dunes also form a coastal buffer against storms, a pertinent function given global predictions of climate change and the resultant increase in storms and rise in sea level (Chevallier, 2014).

40 Sand mining activities have impacted, in one way or another, on the economic, social and environmental aspects of man in mining areas, particularly in poorer coastal communities. Many people in least developed or developing countries resort to the trade from sand so as to earn a living. Since sand mining has economic gains, many community and traditional leaders sell community lands within their domains to miners. This is done because people derive their livelihoods from sand mining to ensure their survival from the natural resources available and accessible to them. A study of the effects of sand mining on rural communities on the Wild Coast of South Africa indicated that sand mining serves as a source of income to communities through the generation of jobs for both youths and adults (Mngeni *et al*., 2017). Unfortunately, it also triggers tensions between government officials and members of the community. All of the communities on this coast are experiencing social impacts in terms of conflicts either with government officials or the illegal miners themselves.

41 A recent report from Sri Lanka mentioned that sand mining exacerbated the impacts of the 2004 Indian Ocean tsunami (Torres *et al*., 2017a). In the Mekong Delta, sand mining is reducing sediment supplies, threatening the sustainability of the delta, enhancing saltwater intrusion during the dry season, which threatens local communities' water and food security (Torres *et al*., 2017a).

42 Unregulated sand mining also results in high levels of disturbance caused by haphazard road access construction – often across flood plains. The deep holes left after excavation (often not visible) are lethal hazards to local people, especially children (Chevallier, 2014). Extraction activities create new standing pools of water that can become breeding sites for malaria-carrying mosquitoes. The pools may also play an important role in the spread of emerging diseases such as Buruli ulcer in West Africa, a bacterial skin infection (Torres, *et al*., 2017b).

Land reclamation

43 Land reclamation is a process to create new land from the sea and is increasingly a popular response to the perceived need for more land space, particularly in many western Gulf and Asian countries (Al-Madany *et al*.1991; Ge and Jun-yan, 2011; Van Lavieren *et al*. 2011). In Batam Indonesia, the land reclamation had reduced the function of the mangrove forest to hold the water excess due to the rain and the tide. It reduced the total mangrove area, and this had affected the society nearby when the area flooded during high tide, and the waves are strong (Priyandes and Rafaee, 2009). Vousden (1989) noted that there has been continuous loss of highly productive intertidal flats around the coast of Bahrain as a result of the many reclamation

projects. Furthermore, in Bahrain, sea water intrusion affected the agriculture activity of the community as the salinity of the groundwater increase which indicate that the impacts of reclamation in Bahrain is not limited to the area where dredged and reclamation occurred. The increased salinity of groundwater due to the mixing of seawater with ground water in the dredged area, made the ground unsuitable for domestic or agricultural uses (Al-Madany *et al*., 1991). When domestic and agriculture output was affected, it not only reduced the income of farmers but would also affect the population leading to an increase in food imports, which brings implication to national food security (Al-Madany *et al*., 1991). The destruction of the many coral colonies, mangroves and seagrass beds has had several social and economic impacts on the society and economy of Bahrain (Al-Madany *et al*., 1991).
In Offshore Areas

44 Interest in the environmental impacts of offshore sand and gravel extraction dates back more than 50 years and has grown significantly since the 1960s (Millner *et al*., 1977; de Groot, 1979b). The environmental impacts of offshore dredging for marine aggregates have been well documented, with general reviews of the topic provided by Cooper and Brew (2013), de Groot (1979a, 1979b, 1986), ICES (1992, 2001, 2009, 2016), Newell *et al*. (1998) and, OSPAR (2009). Sand and gravel mining offshore can be a serious threat to habitats and has the potential to cause both environmental and socio-economic impacts if it is not well regulated and managed.

Physical effects

45 Direct effects are related to the removal of seabed sediment; and the release of suspended sediment into the seawater. The principal indirect effects of marine minerals dredging relate to the deposition of suspended sediment on the seabed as it settles out of the water; visual disturbance of sensitive species caused by the presence of the dredging vessel; disturbance from sound emissions by the dredger; and vessel collision risk (BMAPA/TCE, 2017). The physical impact of extraction is site-specific and linked to many factors such as dredging method and intensity, hydrodynamics, sediment grain size, and bottom topography (ICES, 2009; Tillin *et al*., 2011).

Topography

46 Dredging changes both the physical characteristics of the seabed (topography and sediment particle size) and the water depth (bathymetry) (BMAPA/MMO, 2017). The method of dredging determines the nature of these changes. Trailer dredging creates shallow furrows that may extend for several kilometres in length with lowering of the seabed by several metres through repeated dredging of the same area of seabed (typically during a 15-year licence period in the UK) (Tillin *et al*., 2011). Static dredging can create deep (typically 5-10 m) depressions in the seabed, which may join over time to form an irregular seabed. However, static dredging is little used in regions such as north-west Europe now as trailer suction hopper dredgers are more efficient and can have much larger cargo capacities.

Seabed removal

47 Removal of aggregate can change the seabed substrate and leave a new substrate exposed or alter the particle-size distribution.

Bathymetry, hydrodynamics and sediment patterns

48 Dredging will increase water depth and cause a localized drop in current strength which can cause deposition of fine sediments within the dredged depressions from overflow discharges (Krause *et al*., 2010) or from natural sediment transport (Le Bot *et al*., 2010). A study of the seabed surrounding marine aggregate dredge pits off the south coast of the United Kingdom showed that the physical effects of dredging on the seabed was limited to a zone within approximately 300 metres downtide of the dredge pits (Hitchcock and Bell, 2004). While

direct seabed lowering is generally confined to the area actually dredged, significant bathymetric changes have the potential to alter the existing hydrodynamic and sediment patterns within and outside the dredged area. These effects are considered to be indirect and may potentially result in: changes to wave propagation, including height; spacing between waves and direction averaged over a period of time; reduction in the sheltering effect of offshore submerged sandbanks; removal of material from beaches into deeper water ("beach drawdown"); changes in tidal currents; and alteration of other sediment pathways (BMAPA/TCE, 2017). Effects include increases and decreases in bed shear stress that can result in changes to sediment mobility and scour. These effects can potentially lead to coastal erosion if the dredging site is not appropriately located. In England and Wales, risks to coastal erosion are assessed as part of the environment impact assessment process using a well-established process set out in a document produced by the Crown Estate and BMAPA (TCE/BMAPA, 2013).

49 Brampton (2010) reviewed the effects of marine aggregate dredging on the coastline and concluded that in England and Wales changes made in dredging areas are very limited in extent and do not extend as far as any coastline for any aggregate dredging area licensed in the last 20 years or so.

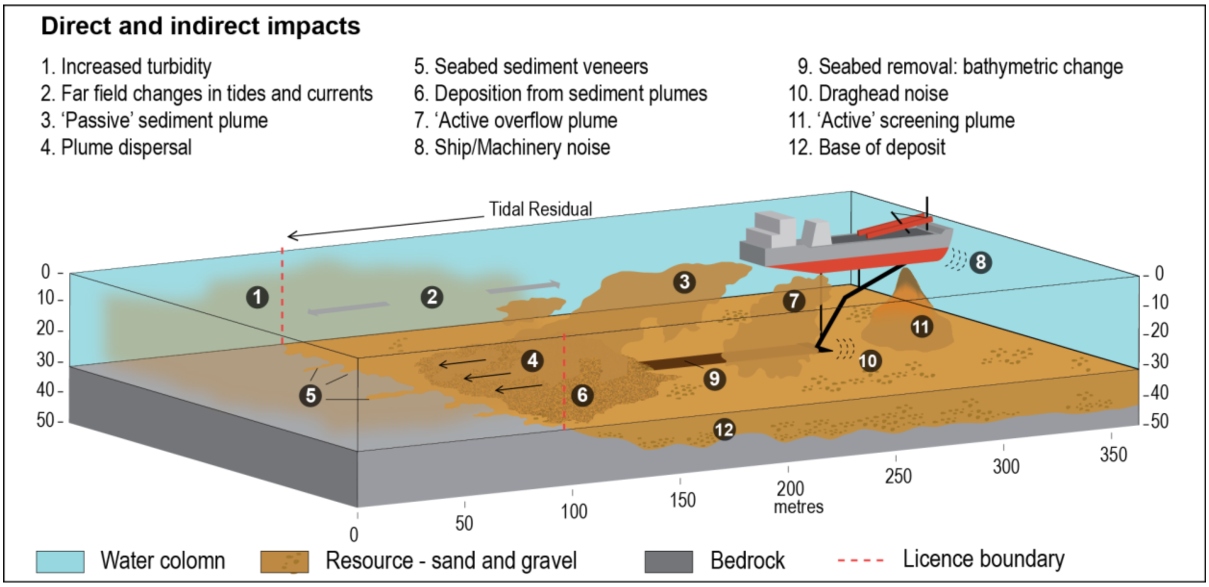

Figure 2: Direct and indirect consequences of aggregates dredging on the marine environment. Figure adapted from Tillin *et al*., 2011.

Sediment plume, turbidity and changes in suspended sediment concentration

50 Dredging marine aggregate results in fine sediment plumes in the water column derived from a) the draghead or cutter head in contact with the seabed; b) water overflow form the cargo hold; c) outflow from onshore dewatering basins. In the context of turbidity and suspended sediments, the impacts from the last two are usually more significant than the first which happens close to the seabed and would normally settle out more quickly'. The plumes disperse under the influence of gravity and tidal currents with the constituent sediment being transported away from the location of dredging or deposited on the seabed within and surrounding the dredging area. Under normal conditions the surface plume will disperse relatively quickly (over a period of 2-3 hours - HR Wallingford, 2011) after which suspended sediment concentrations return to near natural levels.

51 The evidence for the physical effect of direct and indirect impacts of sediment dispersion from marine aggregate dredging have been reviewed and synthesised by Spearman (2015). This evidence included the results of numerical modelling, plume measurements, seabed surveys and sediment measurements based on a number of years of research in this subject.

This synthesis has shown that no impacts of dredging have been identified more than 3 km from dredging whether due to increases in suspended sediment concentration, changes in bed substrate or the creation of bedforms. Footprints of increases in suspended sediment extended typically from a few hundred metres to 3 km from the point of dredging. Footprints of change in substrate generally extend a few hundred metres from the point of dredging unless there is a combination of extensive screening, a strong net transport potential and little background sand transport, when footprints extend up to 2 km, and potentially up to 2.6 km, from the dredging location have been identified. Spearman (2015) suggests that the 3 km limit serves as a useful broad upper limit of potential impact.

Noise and vibration

52 Internationally, there is growing concern about the potential harmful impact of anthropogenic sound (from the operation of vessels and mechanical activity during dredging) on marine life, causing, for example, temporary or permanent hearing loss, disturbance from feeding or spawning grounds, causing a barrier to migration or possible injury or death (ICES, 2016). However, studies have shown that hearing damage is unlikely to be caused by aggregate dredging vessels (Heinis *et al*., 2013). The environmental effects of underwater sound are more dependent on the sensitivity of the local ecosystem. Therefore, potential adverse effects of sound that might last for extended periods in areas of high ecological sensitivity should not be overlooked (Thomsen *et al*., 2009).

53 Dredging can also result in indirect effects due to sound and vibrations emitted into the environment. This noise may cause disturbance to animals that inhabit dredging areas and their immediate surroundings. An increase in underwater sound emissions has the potential to alter the behaviour of some fish and marine mammal species and may cause them to avoid the area of dredging activity. Certain bird species are sensitive to the presence of large structures and vessels on the surface of the sea. A recent study of the potential effects and how to assess these interactions has confirmed that disturbance events from currently operating dredgers in the UK are unlikely to be significant (Reach *et al*., 2013).

Chemical effects

54 The sands and gravels which constitute the bulk of offshore dredged aggregates in NW Europe show little chemical interaction due to their low level of fines and thus low particle surface area, (ICES, 1992). In the UK, most sediments dredged for marine aggregates have low levels of material finer than sand (i.e. silt and clays constitute < 10% and often <<10% of the total sediment) and consequently have low levels of organic material. However, where dredged sediments have higher levels of silts and clays, those materials may have higher levels of organic content and/or contaminants and then the dredger overflow or screened material could demonstrate greater chemical activity. Any fine sediments can adsorb chemical pollutants, removing them from the water column by binding and stabilising them within the substrate. The disturbance and resuspension of these muds by dredging may reintroduce these pollutants to the water column, re-exposing the biological community to their effects.

Biological effects

55 The biological effects of dredging occur in response to the physical effects described above. The faunal communities that exist on the seabed and in the water column are influenced by the changes to the physical environment resulting from aggregate extraction. Dredging operations may potentially interact with a wide range of marine wildlife and ecosystems, both directly and indirectly, affecting seabed habitats and associated benthic organisms; fish and shellfish; seabirds and coastal birds; and marine mammals. It is well known that marine aggregate extraction has a direct impact on the benthic community within the dredging zone (de Groot, 1979a, 1979b; 1986), Gubbay, 2003; ICES, 1992, 2001, 2009, 2016; Newell and Woodcock, 2013; Newell *et al*., 1998 and OSPAR, 2009). Changes in diversity and abundance

and other secondary effects on the community and ecosystem structures may be caused by disruption of food webs, changes in predator-prey relationships, reduced community stability in response to environmental fluctuations, changes in age structure of populations by selective mortality, changes in dynamic behavioural patterns, concentration of toxic fractions through food chain transfers, loss of bottom habitat, migration of population, and introduction of dormant species from bottom to surface waters (Cruickshank and Hess, 1978).

56 A particular issue with borrow pits in some locations is than an increased depth at those sites can often drop the seabed below the level of light penetration necessary for certain species such as seagrasses to thrive (Vousden, 1994). These borrow pits can then take much longer to recolonise and often the communities become completely different due to the increased depth and decreased light availability for photosynthesis. Also, deep borrow pits can potentially become anaerobic due to restricted water movement.

On Benthos:

57 Loss of benthic habitats and species is the most obvious effect of aggregate extraction. Few benthic invertebrates are able to escape the direct extraction process. Lees *et al*. (1993) studied the physical condition of benthic organisms being returned to the sea in the overflow from a trailer suction hopper dredger (TSHD). They found that not all benthic species were affected in the same way and that, while some appear prone to injury or death, others did appear in remarkably good physical condition and may have survived upon return to the sea.

58 Not only is there a direct loss of abundance, species diversity and biomass of the benthic community in the dredged area, but the effects of turbidity and resettlement of suspended material may cause similar (albeit lessened) effects over a wider area (OSPAR, 2009). Research has shown that under the path of the drag head there is a 30-70% reduction in species diversity, a 40-95% reduction in the number of individuals, and a similar reduction in biomass of benthic communities (Newell *et al*., 1998). Direct removal of seabed sediments can also affect important spawning areas and recruitment for certain fish species, although such areas will not normally be licensed for dredging in many countries. For some species, seasonal variations in behaviour or key life stages may result in an increased risk of interactions with dredging activity. In such cases restrictions for dredging at specific times can prevent adverse effects.

59 Surveys have been designed to examine the nature of impacts on the benthos arising from commercial aggregate extraction at different sites and to investigate the effect of different levels of dredging intensity on macrofaunal assemblages (Barrio Froján et al., 2008; Boyd and Rees, 2003; Boyd *et al*., 2004, 2005; Cooper *et al*., 2005). Samples from intensively dredged sediments differed from undredged sites due to significant reductions ($p<0.05$) in numbers of species, biomass, species richness and diversity. Such studies have indicated that increasing the level of dredging intensity increases the proportion of species affected by dredging, thereby potentially delaying the onset of recovery. This suggests that in assessing the environmental impact of dredging operations on the benthic fauna consideration should be given both to the type of dredger employed and the expected level of dredging intensity.

60 Also, although the short-term effects of dredging on the benthos appear to be similar irrespective of the type of dredging, there are important differences in the persistence of physical effects on the seabed as a result of the different dredging techniques. These differences in the persistence of dredge scarring are likely to influence the recovery potential of extraction sites in the longer term and may also have significant implications for interference with other activities such as bottom trawling.

61 Boyd and Rees (2003) found that at the locations they investigated the effects of marine aggregate extraction (both trailer and static dredging), are confined to within 1 km of the centre of intensive dredging. Multivariate methods appear to be more sensitive and show a clear

gradient of change with increasing distance away from extraction activity extending beyond the margins of the extraction sites. This is not unexpected, as it is now widely acknowledged that multivariate statistical techniques offer greater sensitivity than species-independent univariate methods for discriminating subtle changes in benthic community structure. At the sites investigated, no screening was carried out. Overboard losses of fine material are minimal at such sites in comparison to sites where screening operations are undertaken. Therefore, impacts outside of the boundaries of dredged areas may be more obvious adjacent to -sites where screening activity is routinely undertaken. Suspended sediment in the water column may affect some predatory species of fish, seabirds and mammal species that inhabit the area resulting in avoidance behaviour whilst the plume exists (Cook and Burton, 2010). Because sediment settles out of the water within 2-3 hours of cessation of dredging (Duclos *et al*., 2013; HR Wallingford, 2011), mobile species are able to return when suspended sediment has returned to normal background levels. Therefore, the impact is generally short-term and localised.

62 The main indirect impact of dredging is linked to the deposition of sediment from the overflow or screening plume, which can cause smothering/damage to sensitive benthic receptors, damage and blockage to respiratory and feeding organs (Tillin *et al*., 2011). Both the epifauna and infauna can potentially be buried beneath sediment as it settles from the dredging plume. Thick accumulation of sediment may cause the death of some organisms. Also, a change of habitat from coarse sediment to finer sands is likely to alter the composition of the associated seabed communities (Last *et al*., 2011; Cooper, 2013). However, many species associated with habitats at licensed dredging areas are tolerant of some smothering because they are adapted to living in generally turbid waters at the seabed. Differences in impact and subsequent recovery of the structure and function of benthic macrofaunal communities depend on a number of factors, including the nature and intensity of extraction, local hydrodynamics, and sediment characteristics (Tillin *et al*., 2011).

63 Maurer *et al*. (1978 and 1986) studied the effect of simulated dredged material disposal on the vertical migration ability and survival of benthic invertebrates. While this is not exactly the same as burial by sediments from marine aggregate dredging overflows, it has some relevance. They found that mortalities generally increased with increased sediment depth, with increased burial time, and with overlying sediments whose particle size distribution differed from that of the animals' preferred habitat. Many of the species tested showed a surprising ability to vertically migrate and successfully survive in relatively thick deposits of native and exotic sediments. They found that some organisms could vertically migrate through 0.9 m of overburden similar in sediment type to their indigenous sediment.

On fisheries resources:

64 The processes involved in the extraction of marine aggregates impact the ecology of benthic communities and the food webs they support, including fisheries resources.

65 Aggregate extraction can have direct effects on the higher trophic level organisms. For example, changes in or loss of a preferred grain size can disturb mobile species in these areas. A study by Pearce (2008) showed that the alterations to the benthos due to dredging were likely to cause alterations to the diet of demersal fish, which may be unfavourable. Studies have highlighted the importance of spawning grounds, increasing its vulnerability to disturbance if marine aggregate extraction occurs within these areas (de Groot, 1979b; ICES, 2011; ICES, 2016). Crustaceans, particularly edible crab, are the main over-wintering species that require coarse aggregates, and they are less active during winter periods and so also vulnerable to direct up-take. Over time, the potential impact on the over-wintering ground may increase as continued degradation reduces its' quality and area. Besides, fish and shellfish migration routes can be under threat if dredging activity takes place during a migratory period, and at a site which is used during migration.

66 Predicting the disturbance of mobile species, such as fish or marine mammals, is particularly difficult because there are few studies that have directly investigated disturbance in relation to marine aggregate extraction or suggested that significant impacts occur (ICES, 2016). While there is little evidence that can clearly define the impacts to higher trophic levels due to marine aggregate extraction, studies do highlight the complexities in assessing this impact. The ability of species at higher trophic levels to adapt will be influenced by the cumulative effects of dredging, along with other activities that may similarly impact food resource. Mobile species are also likely to be influenced by other impacts or anthropogenic activities outside of a licence area, again making direct predictions between marine aggregate extraction and mobile species difficult to assess (ICES, 2016).

Scale of the operation

67 The scale of the operation has the potential to cause significant disturbance to the breeding / spawning grounds of some crustacea and demersal fish species, by disrupting access to and from the area. A spawning ground may also lose the key sedimentary and topographical characteristics that make it an important site for spawning adults especially for species laying eggs on the seabed (e.g. herring and black sea bream); cause significant disturbance to nursery grounds by restricting access to the onshore recruitment of juvenile fish at key times of the year and disrupt the sedimentary characteristics of the nursery ground and thereby adversely affect the food supply of juveniles.

Method of aggregate extraction

68 Spawning grounds may be sensitive to the method that is used to extract aggregate (including noise disturbance and screening impacts). Potential impacts may be mitigated by the scale of the operation and will be especially important when the topography of the seabed is important. However, ICES (2017) reported that extraction of marine aggregates can potentially be a serious threat to commercial fish species when functional impacts can affect sensible and threatened species (e.g. through loss of spawning areas). Anchor dredging will tend to have a more localised impact than trailer dredging, but elevated noise levels may also have an impact on spawning grounds.

69 The method of extraction has the potential to impact over-wintering grounds. Crustaceans, the main over-wintering species in coarse aggregates are potentially sensitive to long-term topographical and sedimentary change. The physical impacts and noise disturbance caused by the method of extraction has some potential to impact fish and shellfish migratory routes which are only under threat if dredging activity takes place during a migratory period.

Plume effects

70 A direct consequence of increased turbidity from aggregate extraction is the reduction of light penetration into the water column, which can negatively affect phytoplankton growth (Cloern, 1987) as well as that of plants growing on the seabed in shallow water e.g. seagrasses. A decreased availability of phytoplankton can affect higher trophic levels. In addition to a reduced phytoplankton abundance in the water column, elevated silt concentrations may impede the intake of phytoplankton by shellfish, and potentially cause additional stress (i.e. higher energetic costs) to these organisms as they need to excrete silt in the form of pseudo-faeces (Michel *et al*., 2013). It may also disrupt the feeding and respiration of zooplankton and affect filter feeders (e.g. clogging). Turbidity may also cause avoidance behaviour in visual predatory fish affect migration/movements of fish, affect the buoyancy of pelagic eggs or the development/survival of eggs and larvae, or hamper sight predators (Birklund and Wijsman, 2005; Kjelland *et al*., 2015 Westerberg *et al*., 1996). However, see section 5.2.1 where it is indicated sediment plumes tend to be fairly short-term (2-3 hours) and thus the impact is generally short-term and localised.

71 Persistent turbidity plumes can disrupt the feeding and respiration of zooplankton; cause avoidance behaviour in visual predatory fish, such as mackerel and turbot; and impair vision for foraging in a number of species of seabirds (Cook and Burton, 2010) ; as well as damaging the gills of some fish and invertebrates. Todd *et al*. (2014) conclude that sediment plumes are generally localized, and marine mammals reside often in turbid waters, so significant impacts from turbidity are less critical. However, entrainment, habitat degradation, noise, suspended sediments, and sedimentation can affect benthic, epibenthic, and infauna communities, which may impact marine mammals indirectly through changes to prey.

72 There is potential for extensive sediment plumes to alter the surface sediment structure of the seabed and thereby change both its' physical and biological characteristics. Such direct impacts may adversely affect the quality of breeding / spawning grounds in nearby areas. Increased levels of sedimentation may also adversely affect juvenile and larval populations of fish (such as bass or bream) which occupy mid-water or swim near the seabed. Some juvenile flatfish occur in relatively turbid, fine sediment environments, and their nursery grounds are less likely to be impacted by moderate sedimentation from plumes. However, Spearman (2015) indicated that no impacts of dredging have been identified more than 3 km from dredging due to increases in suspended sediment concentration – see section 5.2.1 above.

73 In addition, increased turbidity at the seabed and increases in sedimentation could adversely affect the ventilation within coarse aggregate substrates used by immobile crustacea for over-wintering. This impact provides a potentially serious threat to over-wintering populations since the ability, of especially diadromous fish species, to locate topographical features when migrating may be impaired by increased levels of sedimentation as a result of plume effects.

Cumulative effects

74 Increased stress on fish populations caused by a higher density of dredging licences in a region may have more significant impacts on reproductive potential than more localised impacts. The extent of the spawning grounds is an important consideration as well as impact on nursery grounds, through the indirect effect on the physical structure of the seabed and the resulting changes in fauna that this may produce. The increased geographic extent of dredging activity has some potential to impact fish and shellfish migratory routes if dredging activity takes place during a migratory period. Local fishing grounds may become impoverished due to long-term changes in the habitats used by commercial species, and potential behavioural changes due to long-term environmental degradation. This may result in decreased income and profitability for some coastal fishing fleets.

Impacts of marine aggregate extraction on fishing activity

75 It has been estimated that 30% of the total fisheries yield is derived from benthic resources (Newell *et al*., 1998). Knowing how much of a particular resource coincides with aggregate licences is the first step towards evaluating whether dredging will adversely affect the resource. Such evaluations rely entirely on good quality data describing the distribution of fish spawning grounds, or the seasonal distribution of fisheries. Overall, it appears possible to map the area of potential impact of marine aggregate extraction in relation to the distribution of local fishing grounds. Kim *et al*. (2008) illustrated a methodology for estimating the damages to commercial fisheries due to marine sand mining.

76 There is often a perception by fishermen that they are excluded from their traditional fishing grounds where these coincide with aggregate extraction activities, either because of the disturbance caused during dredging, or perhaps by secondary effects on the habitat. Where a number of licences occur in the same region, the combined effects of this 'exclusion' can cause considerable local concern. Although of importance in offshore waters, this effect can be more marked in local inshore waters where fleets are comprised of small day boats with limited range.

A further issue highlighted by Cooper *et al*. (2005) concerns the safety of vessels in relation to increased distances offshore that relatively small vessels (<14m) are working and this was attributed by the fishermen, to be a direct consequence of displacement from extraction areas. Some areas are considered by fishermen as unsuitable for trawling activity as a result of the physical presence of dredgers, changes to the topography of the seabed, and alterations in sediment composition as a consequence of aggregate extraction. The physical presence of trailer suction hopper dredgers was particularly problematic as their movements are more difficult to predict in comparison with static suction hopper dredgers which tend to have more restricted movements whilst dredging.

77 The scale of the operation also has the potential to adversely affect the financial yield of the fishery, by affecting the distribution and abundance of the target species and the quality of the environment and their food resource. Fishing vessels could be displaced away from their traditional fishing grounds because they are denied access, but often most applications include strict zoning proposals to reduce or eliminate this possibility. Strict adherence to predetermined zones, of limited spatial extent, should ensure that physical displacement of vessels is minimised.

On biodiversity

78 The marine sediments targeted by the extraction industry, correspond to sand and gravel bottoms which represent only a fraction of the high diversity of habitats and marine life (variety of bottom types, habitats of common interest, rare and endangered species). In general, the biodiversity of the seabed tends to increase with the size and heterogeneity of the sediment (microhabitats) and with the stability of the substrate. Sublittoral sand and gravels support a diversity of marine life including molluscs, polychaete worms, starfish, crustaceans and fish such as plaice and sand eel. However, mobile banks of coarse sand targeted for extraction in a number of countries e.g. Belgium, are typically poor in species and biomass.

79 Gravelly bottoms are the most diversified among the marine habitats, the larger size of gravel allowing settling and providing shelter for many sessile and mobile organisms. This knowledge resulted in many studies related to the commercial extraction of marine aggregates (Seiderer and Newell, 1999; Desprez, 2000; Cooper *et al*., 2007a). The deep gravel habitats are more diverse than those closer to the coast, with a diverse and abundant epifauna with sponges, tunicates, bryozoans, hydroids and polychaetes. Biogenic reefs under threat and of high heritage value are associated with these gravels.

80 Gubbay (2003) reviewed the information, issues and gaps in understanding the effects of marine aggregate extraction on biodiversity in UK waters. She concluded that there is a good understanding of the likely impacts of aggregate extraction at a general level and some information from particular locations that have provided a more in-depth appreciation of the changes that take place during and after aggregate extraction. She also concluded that the issues and gaps identified in her report are concerned with the more complex areas such as assessing cumulative impacts, identifying ecosystem effects, questions about recovery and the broader significance of any impact on marine biodiversity. Addressing these points should be seen as a necessary, continuous, and evolving task in order to improve our understanding of the impacts of aggregate extraction on marine biodiversity and to help safeguard the marine biodiversity interest in UK waters. However, there has been much research done since that review so there is probably a significantly better understanding of the issues today.

81 A loss of 60 % for the number of benthic species is generally observed within dredging sites (Boyd *et al*., 2002; Boyd and Rees, 2003; Desprez, 2000; Desprez *et al*., 2014; ICES, 2009, 2016; Krause *et al*., 2010; Newell *et al*., 1998, 2004). This loss of structural biodiversity is local and its duration varies according to extraction strategy. It is local and important in coarse bottoms where intensive extraction takes place (cumulative effects). Cusson *et al*. (2014) observed that changes within community assemblages in terms of structure are generally

independent of biodiversity. ICES (2017) reported that extraction of marine aggregates can potentially be a serious threat to biodiversity when exploitation projects affect gravelly areas either of small size or under-represented in the geographical area (loss of habitat).

82 The ICES Guidelines for the Management of Marine Sediment Extraction (ICES, 2003), as adopted by OSPAR (OSPAR, 2003) , provide for the adoption of appropriate extraction site locations, with the aim to prevent any harmful effect on habitats of prime importance. The species composition and the variety of biotopes that are associated with licenced aggregate extraction areas are reasonably well understood although in inshore areas, where aggregate extraction is most prevalent, relatively little is known of the faunal characteristics within a wider context. Faunal communities were found to respond to the underlying substrata but, importantly, differences in faunal communities only clearly occurred when the superficial depth of substrata was less than 2m.

83 In the UK, marine aggregate producers have long been at the forefront of efforts to achieve better understanding of marine biodiversity. The knowledge of the species and habitats in the seas around England has increased significantly in the last few years, in no small part due to evidence provided by the sector. This has allowed designation of marine protected areas (MPAs) to proceed in partnership with development of aggregate extraction activity. As such, marine aggregate producers are leading the way in demonstrating marine environmental stewardship.

Recovery

84 While the impact of dredging on physical and biological resources is well understood less is known about how these resources recover after dredging stops.

Physical

85 Physical recovery from aggregate dredging is considered complete when dredge tracks and scours are no longer detectable and where sediment composition is “similar” to either pre-dredge conditions or local reference sites (Foden *et al*., 2009; ICES, 2009).

86 The period of time required for seabed topography to recover is highly variable, ranging from months to decades and recovery is often site-specific and dependent on the unique combination of local conditions (Boyd *et al*, 2004; Cooper *et al*., 2011; Foden *et al*. 2009; Hill *et al*., 2011; Le Bot *et al*., 2010; Newell *et al*., 1998; Wan Hussin, *et al*., 2012). From those studies there are several environmental factors and dredge practices known to affect recovery times, particularly intensity of dredging, local hydrodynamics and sediment composition which all play a large part in determining the character and stability of surficial sediments (Kubicki *et al*., 2007; Eggleton *et al*., 2011). Also, the effects of screening may significantly alter the seabed (de Groot, 1996), extending the period for recovery.

87 Monitoring studies have also found that the dredge furrows caused by trailer aggregate dredging are typically, substantially degraded over a period of 3 to 7 years (Cooper *et al*., 2005) whereas deeper depressions resulting from static dredging may take significantly longer to degrade, particularly in gravelly sediments ICES, 2009). Additionally, where dredging of sediments occurs in less dynamic environments where the sediments are often coarser-grained, the dredge furrows may be longer lasting (Cooper *et al*., 2007a). The latter extraction areas are located in coarse sediments with moderate hydrodynamics where the average duration of physical restoration of seabeds is estimated to be 20 years (Foden *et al*., 2009).

Biological

88 Biological recovery following a disturbance, is normally considered to have occurred when there is the establishment of a faunal assemblage that is similar in species composition, population density and biomass to the original pre-dredge assemblage or local reference sites (Boyd *et al*. 2004; Cooper *et al*. 2005; ICES, 2016).

89 Where sediment characteristics, topography and the natural hydrodynamic regime do not differ before and after dredging, re-establishment of a similar biological assemblage is probable (van Dalfsen *et al*., 2000; Boyd *et al*., 2004; Cooper *et al*., 2008; Robinson *et al*., 2005,). In such situations, recovery can be rapid: 24 to 30 months in the North Adriatic, for example (Simonini *et al*. 2007). As expected, the least sensitive habitats, occur in estuaries, highly mobile sands in shallow waters and conditions of strong tidal stress (Millner *et al*. 1977, Bax and Williams 2001). The most rapid recovery occurs in habitats subject to high levels of natural disturbance. For example, dredge furrows on sand banks, which are naturally subject to high levels of sediment mobility, may disappear within a few tidal cycles. Similarly, dredge tracks at an area of the North Sea exposed to high levels of wave action disappeared in less than a year. Whereas, biological recovery takes the longest period of time at dredge sites characterised by coarse sediments and low tidal energy that have been intensively dredged. Nevertheless, in many habitats where aggregate dredging has occurred, a return to a pre-dredge physical or biological conditions often takes years or decades if it occurs at all. In many cases a return to a similar pre-dredge condition may never be possible. Overall impacts range from temporary reversion to an earlier stage in succession to permanent changes in the environment.

90 Recolonization of a dredged area may start to take place relatively rapidly, with restoration of biomass to pre-dredge levels anticipated to occur within two to four years if the activity is short-term (Kenny and Rees, 1994, 1996;). Faunal recovery after high intensity, repetitive dredging can require up to 10 years or more for recovery after cessation (Boyd *et al*. 2004; Waye-Barker *et al*., 2015). The timescale depends on the seabed sediments and the hydrodynamic regime (mainly tidal currents) present in the area, which play a large part in determining the character and stability of surficial sediments as well as broad-scale community patterns (Kubicki *et al*., 2007; Eggleton *et al*., 2011).

Cumulative effects of multiple activities

91 Extraction activity tends to be focused in discrete geographical locations dictated by the spatial extent of the distribution of marine sand and gravel resources. While a single dredging operation may result in an acceptable level of environmental impact, multiple dredging activities operating in close proximity to one another can increase significantly the potential for unacceptable impacts (Cooper *et al*., 2007b). Such cumulative impacts may also occur when aggregate extraction occurs close to another seabed activity, for example an offshore wind farm, or a dredged material disposal site. The cumulative effect of aggregate extraction at a single site over time may also exacerbate the impact of individual extraction operations, such as the depression formed on the Kwintebank- Belgium. The new hydrodynamics around this depression have led to a different and unstable sediment type and a differing benthic community (Van Lancker *et al*., 2010).

92 It is clear therefore, that there is a need for integrated management of the exploitation of marine resources that goes beyond the single protection of species and habitats within an individual aggregate site. Thus, in addition to the findings of regional and site-specific EIAs, assessment of environmental impact for marine aggregate dredging projects should also include a cumulative and in-combination impact assessment. This aspect of EIA considers the combined effect of a proposal and all similar dredging activity, and the effect of the proposal combined with the impacts from all other human activities that may have an impact on the environment, other users of the sea and the seabed. This is now a commonly adopted practice and is employed for all marine aggregate EIA activities in the UK. While cumulative assessments are becoming increasingly important, there is still a continuing need for work to resolve the cumulative effects of multiple licence areas on wider aspects of ecosystem function,

including a greater emphasis on potential effects on species and communities of conservation and economic significance at a regional scale (Tillin *et al*., 2011).

Socio-economic effects

93 Socio-economic impacts are the impacts on the economy and society of an action (e.g. policy, programme or project) and include market effects such as value generated by and jobs created in each affected sector and multiplier effects in the wider economy. For example, the financial benefits associated with a proposed new aggregates extraction area and the costs of exclusion to local fishermen and so on (Dickie *et al*. 2011, 2013). Activities of other users of the marine environment that may be affected by dredging include shipping and recreational sailing, commercial and recreational fishing, diving and also activities that require the emplacement of infrastructure on the seabed such as offshore renewable energy projects, cable and pipeline installation, and oil and gas infrastructure.

94 The main interactions are through: the presence of the dredger; the physical effects of dredge gear on seabed installations; the displacement from licensed dredging areas; the creation of turbid plumes of sediment; and the historic environment and heritage assets. Such effects may include damage to wrecks or protected sites and loss or removal of artefacts / assets from their historic context. A range of protocols and procedures have been developed by the marine aggregate dredging industry in England in collaboration with statutory advisors Historic England and The Crown Estate (UK), aimed at mitigating and managing the potential impacts of dredging on the marine historic environment.

Mitigation of the effects of dredging activities

In Intertidal Areas and Dunes Immediately Behind the High-Water Mark

95 Once mining has occurred, mitigation of the effects of mining aggregates from intertidal areas and dunes immediately behind the high-water mark is generally difficult and likely to be costly. Beach replenishment could be used to re-establish beaches but that requires dredging of sand from somewhere else that will have its own impacts on the environment.

In Offshore Areas

96 A number of commonly accepted and proven practices are available to operators for the mitigation of specific effects associated with offshore extraction operations – see BMAPA/TCE (2017). In general terms, mitigation requires certain operating practices that reduce the potential for deleterious/detrimental effects on the environment or other users of the sea and seabed. Where necessary, specific licence conditions may be imposed to direct mitigation measures and management practices to limit potential impacts of aggregate dredging operations on the environment and other seabed users. For example, the following mitigation options are commonly used to manage the effects of marine aggregate dredging in the UK:

.1 Screening restrictions – for example where there are species or habitats that are particularly sensitive to the effects of fine sediment plumes in the water column, or smothering by fine sediment sinking to the seabed;

.2 Seasonal restrictions – to prevent dredging at certain times of the year to mitigate negative effects on sensitive species, their key life stages, and/or habitats associated with the species, or the activities of fishing fleets;

.3 Exclusion zones – used to mitigate the potential impacts of dredging on archaeological resources, maritime heritage resources including shipwrecks, wrecks identified as War Graves, the existence of sensitive or protected habitats or species, and the proximity to activities of other seabed users e.g. pipelines and cables;

.4 Similar seabed sediment and capping/covering layers (0.5m) – to allow natural recolonization by marine life after dredging ceases, and to develop a faunal community similar to that before dredging commenced;

.5 Minimising the area of seabed licensed - using analysis of Electronic Monitoring System (EMS) data, licensed areas are now required to correspond closely to the extent of commercially viable seabed resource that is being targeted;

.6 Active dredging zones and extraction management plans - dredging activity is spatially restricted by use of active dredge areas limiting the spatial extent of potential impacts on the natural environment and of interactions with other users of the sea and seabed with set production zones or lanes to ensure that the commercially viable resource is extracted as efficiently as possible; and

.7 Liaison with fishermen - The latest version of the Marine Aggregate Fisheries Liaison Code of Practice that aims to minimise operational conflicts between aggregate dredging vessels and fishing vessels/activity; particularly the loss or damage of fishing gear was developed in 2015 (BMAPA/MMO/TCE, 2015). The code defines best practices for communication between marine aggregate operators and fisheries interests before and during dredging operations, and also includes the liaison requirements required when undertaking survey works associated with marine aggregate operations.

97 In England in order to demonstrate point d above, BMAPA and The Crown Estate (TCE) analyse the Electronic Monitoring System (EMS – see section 7.2 below) data and produce an annual report showing the total areas licensed, the total active dredge areas and the total area actually dredged - broken down by areas around the coast. The report for 2017 (BMAPA/TCE, 2018a) showed that the total area of seabed licensed was 1057 km^2 but the area actually dredged (for total of 19 Mt aggregate) was just 94 km^2, 8.6% of the licensed area. This is less than 1% of the area trawled for fish (Foden *et al*. 2009). Also, the area of seabed dredged for more than 1.25 hours (high intensity) was 7.42 km^2 and 90% of dredging took place from an area of 38.30 Km^2, a tiny fraction of the UK Continental shelf area of ~860,000 km^2. Also, every five years BMAPA/TCE produce an overview of aggregate dredging activity and licensed area since 1998 with the latest being the 20-year review for 1998-2017 (BMAPA/TCE, 2018b).

Assessment and Monitoring

In Intertidal Areas and Dunes Immediately Behind the High-Water Mark

98 The mining of aggregates from intertidal areas and dunes immediately behind the high-water mark was largely discontinued some time ago in most developed countries. The lack of information about the mining of aggregates from intertidal areas and dunes immediately behind the high-water mark in many developing countries indicates that these countries do not have systems in place to monitor such activities and consequently they can have only a rough idea about the scale of the activity, the volumes extracted, its value to the economy and its impact on the environment. However, the use of satellite imagery does provide a reasonably cost-effective means to monitor the scale of the mining of aggregates from intertidal areas and dunes immediately behind the high-water mark.

In Offshore Areas

99 The main aspects of good practice employed by the aggregate industry in the UK to ensure that development of any marine aggregate extraction project should consider the requirements of sustainable development are embodied in a range of planning and regulatory mechanisms. These include Regional Environmental Assessment/Marine Aggregate Regional

Environmental Assessments (MAREAs), Site Specific Environmental Impact Assessments, Coastal Impact Studies, Cumulative and In-combination Impact Assessments, Environmental Characterisation Surveys, and any other Surveys and Monitoring required to ensure compliance with licence conditions. An essential requirement for the effective control of marine aggregate extraction is the monitoring of dredging activities to ensure conformity with the authorization requirements.

100 This has been achieved in several ways, e.g., an Electronic Monitoring System (EMS) or Black Box. The information provided allows the regulatory authority to monitor the activities of aggregate dredging vessels to ensure compliance with particular conditions in the authorization. Since 1993, EMS has been installed on every dredging vessel working licensed areas in English waters and increasingly with widespread use in Belgium, Denmark and The Netherlands. It provides secure data with detailed information on the spatial and temporal extent of extraction activities which can be reviewed to ensure that dredging operations strictly comply with the regulator's conditions. These provisions are sufficiently robust to ensure that any dredging project should be managed to avoid unacceptable adverse impacts on the environment or other users and interests in the relevant area.

101 Each potential impact of a dredging operation (grouped into three categories: method and scale of the operation; plume effects; cumulative effects) must be evaluated in terms of the potential impact that they each may have on fish resources and commercial fishing activity. However, the actual site-specific response of a resource to an impact may be completely different, and this could be illustrated by each individual EIA (Carlin and Rogers, 2002).

102 There are examples of international guidance for assessing aggregate dredging e.g. ICES (2001) for north-western Europe, Vousden (1994) for Belize and based on previous studies and guidelines developed for documents from the Gulf region and for Asia by James *et al*. (2001). Some of these also deal with guidance for onshore management of 'landed' aggregates, especially in relation to dewatering and holding/stilling basins.

Policy, legislative frameworks and resource management

103 Despite the colossal quantities of sand and gravel being used worldwide and our increasing dependence on them and the reported deleterious impacts that their extraction has on the environment, this emerging issue has not attracted widespread political attention for any political action. However, it has attracted significant attention from the public and politicians in some local/regional locations e.g. in South Wales, UK where marine sand is the dominant source due to lack of resources on land. However, in that case research did not show any links between offshore marine aggregate dredging and changes in beach erosion (Phillips, 2008).

104 In some parts of the world the mining of aggregates has reached a level significantly threatening the environment and ecosystems and also reaching a level of scarcity that threatens the economy e.g. in India – see the Indian Sustainable Sand Mining Management Guidelines (Ministry of Environment, Forest and Climate Change, 2016). Marine sand is still abundant (marine gravel is not so abundant) and relatively little tapped globally. Lack of monitoring systems, regulatory policies and in some cases environmental impact assessments have led to indiscriminate mining triggering severe damage to the environment and related ecosystem services in some parts of the world, particularly in inter-tidal areas and dunes immediately behind the high-water mark (UNEP, 2014). However, in the USA, north-western Europe and some other parts of the world regulation efforts are robust and embraced by a well-informed industry with leading roles in ensuring compliance.

105 The UNEP (2019) report suggests a hierarchy of three major strategies that could lay new foundations for improved governance of sand resources in 2019 and thereafter:

.1 Avoiding unnecessary natural sand consumption in construction;

.2 Using alternative materials to replace natural sand in construction; and

.3 Reducing sand extraction impacts with existing standards and best practices.

106 The UNEP (2019) report states that “At current infrastructure production rates, avoidance is a challenge and alternatives cannot yet substitute a significant share of the 2.7 billion tonnes of aggregates demand in Europe, let alone the 20 billion tonnes in China. The emphasis must be on reducing natural sand extraction and its impacts in the near term”. Most, but not all, of the suggested solutions in the 2nd and 3rd strategies suggested by UNEP (2019) are relevant to this Scoping Paper, and they were very largely already incorporated in the draft version of this paper. Note that despite what UNEP (2019) said about avoiding unnecessary sand consumption, the first 2 bullet points in section 8.1 below address this issue.

Policies and actions to reduce the demand for marine sand and gravel

107 There are a number of approaches that can assist with reducing the demand for marine sand and gravel including:

.1 More efficient use of concrete in buildings and infrastructure – For example, before 1995 aggregates consumption and construction output in the UK was closely correlated but this changed with the introduction of the Landfill Tax in 1996. It appears that absolute decoupling was achieved with an overall increase in construction output and an overall decrease in aggregates consumption over the period between 1995 and 2010[2].

,2 Waste minimisation in construction – e.g. the Material Logistics Plan Good Practice Guidance from the Waste and Resources Action Plan in the UK[3].

.3 Greater use of timber in construction would reduce the demand for concrete and hence the demand for sand and gravel. There is evidence of a resurgence of construction of timber buildings in many countries[4].

.4 Recycling of material from the demolition of buildings and infrastructure – e.g. In the United Kingdom the use of recycled and secondary aggregates increased from 30 Mt in 1990 to 225 Mt in 2015 with their share of the aggregates market rising from 10 to 28 % over that period[5]. The 28% market share is 3 times the European average.

.5 Use of secondary aggregates i.e. by-products of other industrial processes – e.g. pulverised fuel ash, metallurgical slags, waste foundry sand and quarrying wastes.

.6 Accessing unused resources – e.g. the sand and gravel accumulated behind dams and other impoundments (Gomby, 2019) and desert sand (Zhang et al., 2006; Cisse et al., 2012).

.7 Pricing and tax – In the United Kingdom, the UK Landfill Tax, introduced in 1996 and the UK Aggregates Levy from 2002 has encouraged both the more efficient

[2] https://pub.iges.or.jp/pub_file/reductionsfactsheetsaggrigatespdf/download
[3] http://www.wrap.org.uk/sites/files/wrap/MLP%20Guidance%20Document.pdf
[4] http://www.structuraltimbermagazine.co.uk/news/multi-storey-timber-buildings-a-renaissance-in-timber-construction/ and e.g. See Table 7.4 in https://bze.org.au/wp-content/uploads/rethinking-cement-bze-report-2017.pdf
[5] https://mineralproducts.org/prod_agg_recy01.htm
https://mineralproducts.org/documents/Information_Sheet_Recycled_Aggregates_WRAP_QP.pdf

use of aggregates in construction and the increased use of recycled and secondary aggregates (see footnote 1).

In intertidal areas and dunes immediately behind the high-water mark

108 It appears that in a significant number of developing countries there is either no legislation to control the mining of aggregates from intertidal areas and dunes immediately behind the high-water mark or if there is legislation, it is not enforced so that illegal mining takes place (Chevallier, 2014; Pearce, 2019; Pilkey *et al*., 2009; Torres *et al*., 2017b). Illegal or unregulated mining activities have been reported from many areas around the world, including in Africa, Asia and South America (UNEP, 2019). Until countries have policies, legislative frameworks and resource management systems in place that they then enforce, it is almost impossible to manage these activities effectively – including their monitoring, assessment and mitigation. However, sand mining serves as a source of income for impoverished communities and can lead to tensions with governmental bodies that try to enforce legislation e.g. Mngeni *et al*. (2017). In Pacific Islands it has been found that controlling beach mining by communities is difficult and trying to regulate the practice in the absence of alternative sources of income is almost impossible (Babinard *et al*., 2014). Also, in a number of areas sand mining is carried out by criminal gangs that can use violence to obtain the sand (Torres *et al*. 2017;). A holistic approach to these problems is needed.

In offshore areas

109 The current guidance for offshore marine aggregate dredging in England is the 'Good Practice Guidance: Extraction by Dredging of Aggregates from England's Seabed (BMAPA/MMO, 2017) and provides a thorough coverage of the issues that need to be considered when dealing with offshore marine aggregate dredging. The OSPAR Convention has adopted ICES guidance on environmental impact assessment of aggregate extraction (OSPAR, 2003). It promotes the management of marine aggregate operations in such way that the footprint and potential resource conflict with other marine users is minimised. de Jong *et al*. (2016) developed ecosystem-based design rules for offshore marine sand extraction sites to simultaneously maximise sand yields and decrease the surface area of direct impact. There is, however, a lack of global standards in governance, often several layers of regulations between national and international conventions; and a need for appropriate national policies to regulate the extraction, use and trade of sand and gravel in developing countries.

Knowledge gaps

110 The absence of global data makes assessment of the global environmental impact of this activity very difficult and contributes to a lack of political action. The implementation of a monitoring mechanism, coordinated by an international body such as UNEP, could provide better data on the nature and scale of the sand and gravel mining in the marine environment in coastal states and would help identify knowledge gaps that need to be filled. The most significant knowledge gaps for these activities seem likely to be in the issues around mitigating their effects and recovery/restoration of impacted areas.

111 However, a substantial body of knowledge exists about the impacts of the extraction of sand and gravel from sand dunes just above the high-water mark, the intertidal zone between the high and low water marks and the seabed offshore. With the appropriate legislation and regulatory instruments in place and enforced, the existing knowledge is sufficient to enable effective management of these activities in almost all circumstances. This would avoid the most damaging effects of these activities.

Recommendations for GESAMP's consideration

112 A number of recommendations are suggested below and no attempt has been made to prioritise them. These recommendations are consistent with the key messages in UNEP (2019) and should incorporate, as appropriate, the policies and actions referred to in section 8 above.

In intertidal areas and dunes immediately behind the high-water mark

113 In principle, mining of aggregates from intertidal areas and dunes immediately behind the high-water mark should be discouraged and preferably phased out. However, local circumstances are likely to make this impractical in some locations e.g. small islands. Three options are suggested below:

- We could prepare a good practice guide for managing the extraction of aggregates aimed at small islands or other locations with similar limitations who are not in a position to phase out the extraction of aggregates from their intertidal areas. This would require a working group.

- We could prepare a synthesis document summarising the available information on the recovery/restoration of intertidal areas and dunes immediately behind the high-water mark that have been damaged by aggregate extraction. This would also require a working group and be a more substantial task than that in 10.1.1.

- As a simple alternative to 10.1.2, we could prepare an annotated bibliography covering all the issues that would have been covered in the synthesis document referred to above. This would still require a range of experts in a working group to prepare such a document but could probably be done by correspondence.

In offshore areas

114 Three options are suggested below. Only one of the two options in 10.2.2 and 10.2.3 would be needed.

Good practice guidance

115 We could prepare an international Good Practice Guidance document based on the 'Good Practice Guidance: Extraction by Dredging of Aggregates from England's Seabed' (BMAPA/TCE, 2017). This document has been uploaded to Basecamp. Some generic guidance about regulation/legislation would need to be added. This would require a working group and would be a significant piece of work. Regionally based guidance could also be prepared where needed e.g. see James *et al*. (2001).

116 A synthesis document covering the impacts, assessment, monitoring, mitigation and management of offshore dredging for marine aggregates.

117 There is a large amount of information in existence about the impacts, assessment, monitoring, mitigation and management of offshore dredging for marine aggregates. However, this information has not been synthesised in a single document and may not be readily accessible for all those countries and institutions who might benefit from it. We could consider preparing a document to synthesise all this information but it would take a substantial effort and we would need to involve a range of experts in a working group to prepare such a document. It would be primarily of use to those countries already involved with offshore marine aggregate

dredging that do not have well developed regulatory and management systems for offshore marine aggregates or those who may be considering moving into such activities.

118 If it is considered to be useful to develop such a document, it is suggested that GESAMP could consider partnering with PIANC[6] (The World Association for Waterborne Transport Infrastructure - https://www.pianc.org/) and WODA (World Organisation of Dredging Associations - http://woda.org/) to develop such a document. Other international organisations might also be interested in being involved e.g. the World Bank, UNEP Regional Seas Program. This would also require a working group and be a substantial piece of work.

An annotated bibliography

119 GESAMP could simply prepare an annotated or detailed bibliography covering all the issues that would have been covered in the synthesis document referred to above. This would still require a range of experts in a working group to prepare such a document but could probably be done by correspondence.

Action requested of GESAMP

120 GESAMP is invited to consider the information provided and take action as appropriate.

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[6] Note that PIANC in cooperation with UNEP prepared a report on dredging and port construction around coral reefs in 2010 - https://www.pianc.org/publications/envicom/dredging-and-port-construction-around-coral-reefs.

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