Ecological Effects of Sand Extraction in the North Sea.

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1. INTRODUCTION

In the Netherlands, various Ministries are involved in policy making and licensing for activities in the Dutch continental shelf. With a large array of stakeholders both direct and indirect, everyone has their own vested interest and priorities in harnessing the resources from the sea. Currently, policies are developed with a key sector and/or activity in mind; an all-encompassing policy does not exist yet. The impact of cumulative effect of these activities is also overlooked, as the “big picture” or total impact is not taken into consideration. The communication between different Ministries and/or users is not always optimal, especially when interests and goals are different. An example of this is when the Ministry of Transport, Public Works and Water Management is looking into the possibilities of sand and gravel extraction on the Cleaver bank while on the other hand the Ministry of Agriculture, Nature and Food Quality is working towards developing marine protected areas and looking at the Cleaver Bank as a candidate.

As both Ministries have their own management goals, it is important to be aware of the actual and potential ecological impact of marine aggregate extraction to avoid underestimation of the ecological values of the North Sea. In order to evaluate the costs and benefits of marine aggregate extraction, a collation of current literature and case studies is beneficial in developing mitigation measures that the stakeholders such as dredgers (aggregate extractors) can adopt.

1.1. Project description

As the demand for extracted sand in the Netherlands increases (for beach nourishment, land reclamation and construction), there is greater cause for concern that the ecological values of the North Sea will be overlooked in the policy making process. North Sea Foundation started a project to investigate the ecological impact of marine sand extraction. This project also aimed to outline laws, policies and regulations concerning marine sand extraction and the way environmental values are being taken into account in the regulatory process. The objectives of the project are:

1) To develop an ecological impact study based on literature review and interviews with experts. This review will include actual and potential impacts of dredging, with focus on regular, deep and large-scale dredging;
2) To conduct a legal study, which will determine current laws and policies applicable to marine sand extraction, taking into account the ecological and natural values of the North Sea. The study will also determine (if necessary) what possibilities exist in order to adjust legislation or policies to ensure an ecological consideration is done when sand is extracted;
3) To define measures to mitigate ecological negative effects in co-operation with dredgers, policy-makers, scientists and NGO’s in a workshop.

The project resulted in 3 reports, one for every objective mentioned above. This report is the result of the ecological impact study (1). The other reports are only available in Dutch and can be downloaded at www.noordzee.nl.

1.2. The report

This report gives an overview of marine sand extraction in the Netherlands (chapter 2), a summary of the legal framework and Dutch laws and regulations (chapter 2.4) and a short description of different dredging techniques and strategies (2.3) Chapter 3 of this report aims to outline the various ecological effects (including potential effects) of sand extraction on the Dutch continental shelf. Chapter 4 of this report deals with the recovery process and mitigation measures. The final chapter deals with discussions and conclusions from this study.

2. Aggregate extraction in the Netherlands

The Netherlands is Western Europe's largest marine sand extractor. In late 1990s the Dutch extracted an average of about 23 Mm^3 of sand per year. In the year 2000, 7.6 Mm^3 of the sand was used for beach nourishment and 17.8 Mm^3 was used for land filling, construction and concrete production. Compared to other countries, the Netherlands have the largest quantities of material taken from the sea for coastal defence measures: in 2002 16.28 Mm^3 (ICES WGEXT 2003).

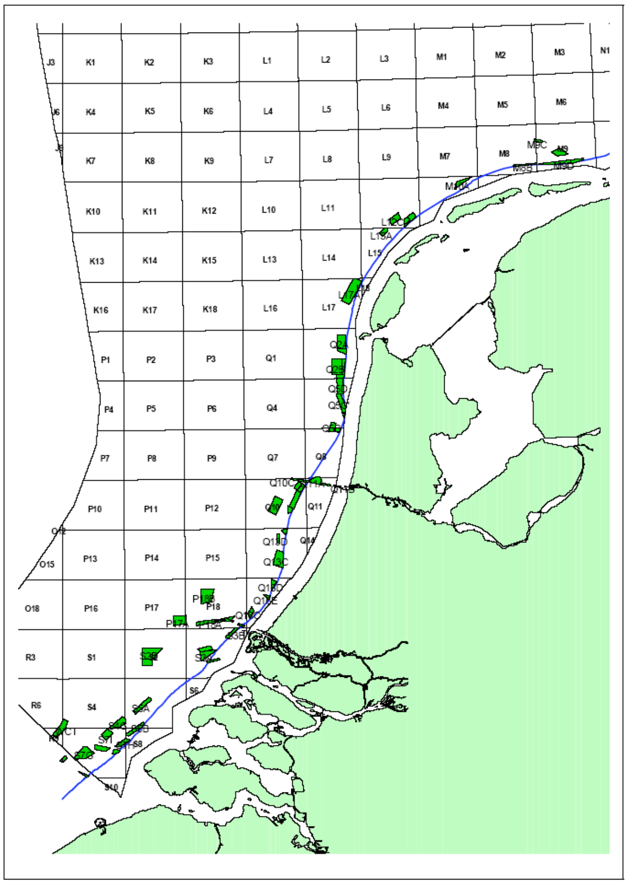


Figure 2.1 Dredging locations in the Netherlands (indicated by dark green areas)

Aggregates in this study are defined as materials such as sand and gravel, which are extracted from the seabed for their economic value or as a part of maintenance works. The extracted materials can be used for a variety of uses, but the dredging activity or extraction itself is done for:

- Maintenance dredging – to preserve navigational channels and berths;
- Capital dredging - in order to improve channels, create new channels or deeper channels;
- Aggregate or minerals dredging – where raw materials such as sand and gravel are extracted from the seabed for the construction industry or coastal defence.

In this report we focus on extraction or dredging of sand from the North Sea; aggregate extraction can be read as 'sand extraction' or sand 'dredging'.

2.1. Sand extraction demand and trends

Figure 2.2 illustrates the increase of sand dredging from the 1970's onwards. Although a large portion of the sand dredged is done for harbour maintenance, dredging in the Dutch continental shelf has increased significantly since the 1990s (ICES WGEXT, 2001).

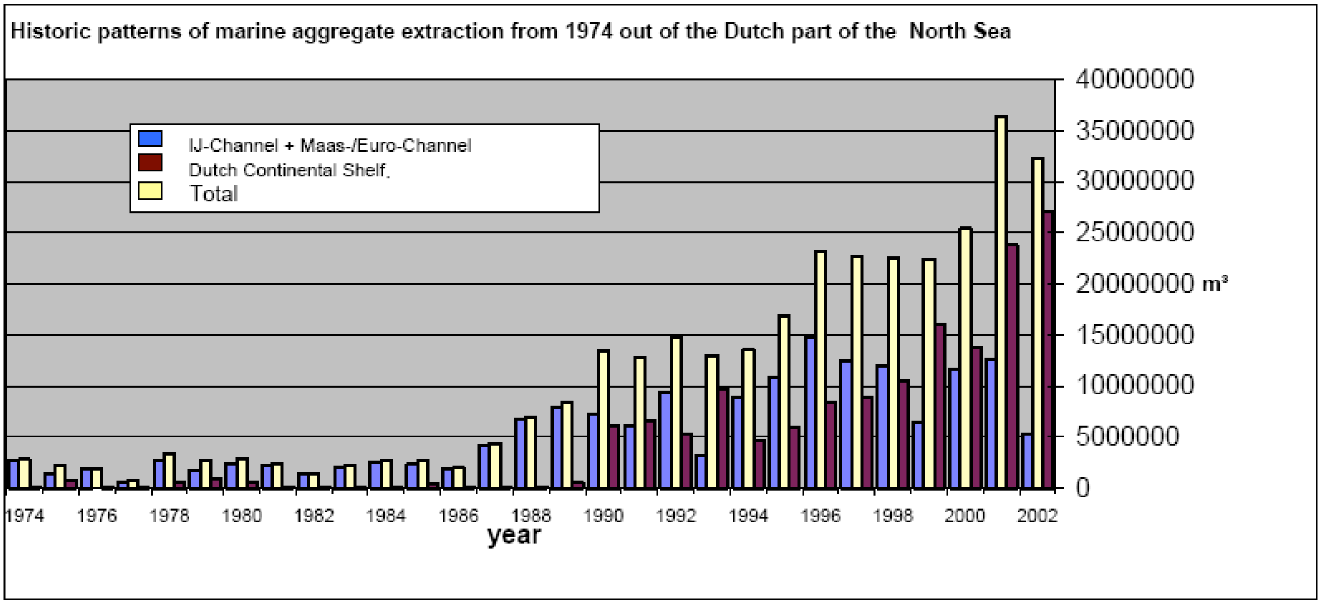


Figure 2.2 Historic pattern of marine aggregate extraction (ICES-WGEXT)

In the coming decades, it has been estimated that annually an extra 6-7-million m^3 sand will be required for beach nourishment to compensate for sand loss in areas susceptible to erosion in the Dutch coast. If we take into consideration sea level rise of 20 cm per century, than an extra annual 5 million m^3 of sand may be necessary (van Dalfsen & Essink, 1997).

RON2 (*Regionale Ontgrondingenplan Noordzee* 2), or Regional Extraction Plan for the North Sea, (2003) provided different scenarios and volumes for future need of sand for beach nourishment. Depending on the scenario used, an average of 9.8-14 million m^3 a year is estimated. Harte et al. (2003) believes the future need will be 12 million m^3 a year. For construction sand (excluding large infrastructural projects and beach nourishment) RON2 expects a demand of 9.3-29 million m^3 a year. Moreover, in the near future, there are two projects land reclamation projects that could increase aggregate extraction in the Netherlands tenfold. These two projects are:

- Enlargement of the Rotterdam harbour estimate up to 300 Mm^3 of sand to be extracted;
- *Westerschelde* (Western Scheldt) Container Terminal (WCT) will require 20 Mm^3.

The Rotterdam harbour extension project will require up to 300 Mm^3 of sand. From this amount, around 50 Mm^3 will come from maintenance dredging the Euro Maas *geul* or shipping lane and from maintenance dredging at the current port. The other 250 Mm^3 will be extracted from the North Sea from at a location situated off the coast of the provinces *Zuid-Holland* and *Zeeland*, outside –20 m depth zone (average line) plus 2 km. There is an overlap with the area selected for this project and the area where research has been done on the availability of concrete and construction sand.

In case of the WCT project approximately 20 Mm^3 of sand is needed. The WCT developers have included dredge depth of more 2m in their Environmental Impact Assessment (EIA) to reduce the surface area required to produce the 20 Mm^3 (DHV, 2003).

2.2. Concrete and Construction quality sand

The extraction of concrete and construction quality sand is not covered in detail in this report as the Ministry of Transport, Public Works and Water Management have recently completed a study in 2004, exploring the possibility for concrete and construction sand extraction in the North Sea. The conclusions of the study were that the extraction of gravel in the Dutch Continental Shelf is not economically viable in the short term and the desired sand lies under large volumes of top sand. Moreover, only about 1/3 of the volume of the layer in which the concrete and construction sand is present can actually be used. The fine sand by-production will be 5 to 6 times the volume of the desired grain size sand extracted.

The Cleaver Bank contains the largest gravel deposit in the Dutch part of the North Sea, which is an estimated 34 million tons. There is also concrete and construction sand present at the surface layer (estimated 30 million tons), so potentially easy to extract. The Cleaver Bank is the only gravel bank in the Dutch part of the North Sea. The sediment in the area consists of a mixture of gravel, sand and larger rocks. It is a dynamic area where the bottom conditions are strongly influenced by waves and currents. Altogether this makes it an area with a unique biodiversity. However, extraction of sand and gravel will be allowed if ecological recovery is secured.

The Ministry of Transport, Public Works and Water Management started an EIA in 2002 to investigate whether 10 million tons of concrete and construction sand could be extracted from the Cleaver Bank. Since the sector is not interested in extraction on the Cleaver Bank and the Ministry of Transport, Public Works and Water Management has changed their policies concerning marine sand and gravel extraction, and the procedure has been halted. If a party in future is interested in extraction on the Cleaver Bank, a new procedure has to be started.

2.3. Dredging

In the Netherlands, the most commonly used vessel for sand extraction is the trailer suction hopper. Trailer suction hoppers have varying carrying capacities, ranging from less than 1000 m^3 to more than 7000 m^3.

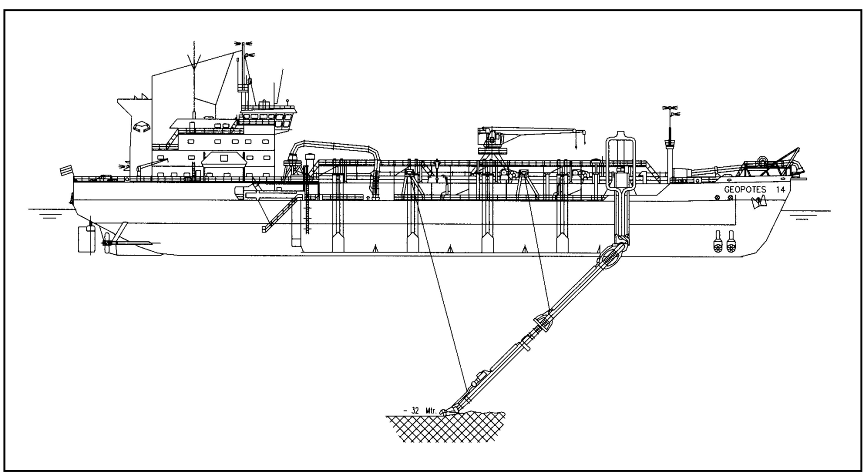


Figure 2.3: An example of trailer suction hopper. The suction pipes are on both sides of the vessel (PIA S.Z., 2004).

The vessel lifts material from the seabed via suction pipes (either 1 or 2) directed backwards, into the hopper while the vessel is in motion. The top layer of the sediment is removed, tracks sized 1-2 m broad and 20-50 cm deep is left on the seabed (Wijsman & Anderson, 2004). Sediment and water will be lifted on board. The water and some (fine) sand will overflow during filling. Once the material is on board, most vessels can screen on board for the desired composition of grain size and aggregates. Unwanted sediment fractions will be rejected from the vessel. Often large plumes of increased turbidity in the vicinity of the vessel are created, when the hoppers overflow or when screening is being carried out.

With static suction hoppers, a suction pipe facing forward lifts material on board while the vessel is static. The extraction leaves conical shaped pits, which range between 20 to 75 metres wide. This method of extraction is commonly used when the aggregates targeted are deep and/or spatially limited, or when the targeted aggregate is located under or is embedded with unsuitable material (for e.g. fine sediment, organic matter). The maximum dredging depth for both dredgers is usually around 30 metres (Wijsman & Anderson, 2004).

During the extraction process, plumes of suspended material are created. Due to the mechanical disturbance at the seabed, materials arise. Plumes created by the drag head are referred to as bottom plumes. However, bottom plumes are often not as widespread as the plumes created from the outwash of material from spillways on the vessel hopper, also referred to as surface plumes. Another source of surface plumes is on board screening of the incoming material, where unwanted sediment fractions are rejected (Boyd & Rees, 2003).

Depending on national regulations and local circumstances different strategies in dredging can be applied. Variations can be made in the dimensions of the extraction area, as well as in the number of dredging pits. Moreover, different methods for dredging can be applied. Each strategy will have its own effects.

In the Netherlands the regular extraction of marine sediments has a maximum extraction depth of 2 meters below the seabed surface. This is referred to as 'regular' or 'shallow' dredging. However, in future deep dredging (over 2 meters and possibly up to over 20 meters) will be allowed.

2.3.1. Shallow Dredging

With shallow dredging, a maximum of 2 meters below the seabed will be extracted. In general, suction will be 0.2-0.5 meters deep, so a suction hopper can cover an area 4 to 10 times. Because of the limited extraction depth, the surface area of an extraction will be relatively large and directly related to the volume of sand extracted: the larger the volume, the larger the area affected. In most cases, sediment composition at a depth of 2 meters below the seafloor will be more or less the same as the sediment at the seafloor. Different strategies can be applied, for example an area can be extracted completely or extraction can take place in 'lanes', leaving undisturbed lanes in between the affected areas.

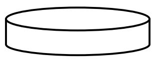
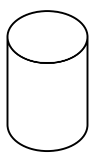
2.3.2. Deep Dredging

Deep dredging is defined by Dutch policy as dredging over 2 meters below the surface. However, in this report deep dredging is defined as dredging over 10 m of depth. Deep dredging can change local water depth significantly (as the Dutch part of the North Sea is quite shallow, often not deeper than 30 m); it also influences the hydrodynamics of the extraction site. Depending on the dimensions of the dredging area this can lead to (temporary) increased scouring, but also increased stratification in the pit is possible. The surface area affected by the deep dredging is smaller compared to shallow dredging for the same volume of sediment.

With extraction depth the chances of exposing sediment layers with different sediment composition than the previous seafloor increases. Depending on the depth, location and dimension of the deep pit oxygen depletion at the bottom of the pit is possible.

Table 2.4 summarizes the main effects and potential effects from the two projects, PUTMOR and RIACON, which both extracted at shallow and deep ranges. Both project areas were located in highly dynamic situations.

Table 2.4 Dredging depth and effects

Dredge depth	Simplified pit visualisation	Example/ Case Study	Effects	Potential effects
Shallow dredging (+/-2m)		Terschelling, The Netherlands (RIACON Project) ▪ 14-20m deep water ▪ vol. extracted 2.1 mil.m^3 ▪ 1.5 m thick layer of sand highly dynamic system (van Dalfsen & Essink, 1997))	After 1 year, extraction favoured bivalve recruitment; ▪ *Spisula sp.,* ▪ *Tellina fabula,* ▪ *Tellina tenuis*. These species however, failed to establish lasting populations. After 2 years, long lived macro fauna species abundance recovered (minor changes in sediment structure). Conditions after dredging mainly favoured opportunistic species (polychaetes). Local population of *Donax vittatus,* was seriously affected by sand extraction-disappearance of adult specimens.	- Reduction in benthic species, is a reduction of food supply for demersal fish. - There were no serious effects for the common scoter as the duck is able to dive up to 30m to collect molluscs. Dredging extensively within the 20m depth contour could have serious repercussions for this species.
Deep dredging (+/-20m)		The Netherlands-off Hook of Holland. (PUTMOR project) ▪ Extraction pit of 10 m deep (1300 m long, 500 m wide) ▪ 22 m water depth ▪ pit left open from 1/10/99-1/4/00. after that filled with harbour mud	O_2 concentration within the sandpit was slightly lower than concentrations outside the sandpit.	The pit was refilled with harbour mud which encouraged the recovery process. As deep pits may have an entirely different sediment layer the pit bottom, this could encourage an entirely different composition of species to populate the pit area. Hence, the species composition will not resemble the pre-dredging state.
		The Netherlands, (beach nourishment near Heemskerk/Wijk aan Zee) PUNAISE project ▪ pit depth 7m, then refilled with sand ▪ highly dynamic environment	After 15 months, benthic fauna had largely recovered but there were still differences between the former borrow pit & surrounding area in terms of ▪ community structure; ▪ density; and ▪ biomass. After 4 years, the borrow pit could not be distinguished from the surrounding area. The benthic community recovered completely.	The benthic community structure is severely disrupted and recovery to resemble similar age composition and community structure could take more than 2 years.

2.4. Legal framework regarding sand extraction

There is ever growing resistance in society against sand and gravel extraction in the land situation, because of damage to the natural environment and the pressures on the landscape. The governmental policy is therefore aimed at strengthening the position of the North Sea as supplier of sand. This chapter will give a brief overview of the obligations resting on the Netherlands in order to regulate sand and gravel extraction stemming from international conventions, European law and how those obligations are implemented in Dutch laws and regulations. The full report on legal framework, regulations and policy is available (only in Dutch) on www.noordzee.nl.

2.4.1. The United Nations Convention on Law of the Sea

In line with the United Nations Convention on Law of the Sea ("LOSC")[1] the starting point for measuring the different maritime zones is the baseline, which may be drawn straight in order to include a fringe of islands or a delta. Therefore, both the *Westerschelde* and the Wadden Sea are included in the internal waters over which the Netherlands has sovereignty and all Dutch laws are applicable. From the baseline

[1] Montego Bay, 10 December 1982; Entry into Force 16 November 1994; Entry into force for the Netherlands 28th of July 1996

on the territorial sea stretches 12 nautical miles into the sea. Here, all Dutch law is applicable as well, with that exception that all ships enjoy the right of innocent passage. Since 2000 the Netherlands has claimed an Exclusive Economic Zone (EEZ)[2] with which the Netherlands has obtained the sovereign right to explore and exploit the natural resources, whether living or non-living, of the waters superjacent to the sea-bed and of the sea-bed and its subsoil; and jurisdiction over artificial structures, marine scientific research and the protection of the marine environment. This regime encompasses the Continental Shelf regime, and the delimitation of the EEZ is the same as that of the Dutch Continental Shelf, which has been laid down in a number of treaties. [3]

According to LOSC the Netherlands is under the obligation to protect the marine environment (art. 192) and take all measures to prevent pollution (art. 194), which is understood to include the degradation of the seafloor through extraction of sand. These measures shall include those designed to minimize to the fullest possible extent: "pollution from installations and devices used in exploration or exploitation of the natural resources of the sea-bed and subsoil, (..) and regulating the design, construction, equipment, operation and manning of such installations or devices." Special consideration has to be given to rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species, states article 194, 5. Such examples might be found in the North sea, in the Coastal Zone, the Frisian Front, the Central Oyster grounds, the Cleaver bank and the Dogger bank which are identified as areas with high ecological values. The Netherlands is therefore under the obligation to research whether potential harmful effects of sand extraction will occur, and whether they can be mitigated.[4] Not only does the Netherlands have to have laws and regulations in place to this effect, it also has to reinforce those rules.[5]

2.4.2. The OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention")[6] sets a legal framework for regional agreements, with the objective of taking all possible steps to prevent and eliminate pollution and of taking measures necessary to protect the maritime area against the adverse effects of human activities. The issue of sand extraction has explicitly been recognized as potentially harmful, under Appendix 3 of Annex V, which aims at the conservation of marine ecosystems and, when practicable, restoration of marine areas. An agreement[7] has been adopted, obliging the Netherlands among other things to apply the *Guidelines for the management of marine sediment extraction* drafted by the International Council for Exploration of the Sea (ICES) when issuing permits. The Netherlands has implemented these and other obligations through the Extraction Law.

2.4.3. European law

Since the Netherlands has so far not made the Nature Protection Act suitable for application in the territorial sea, the framework for assessing the potential negative effects of sand extraction in or near a Special Area for Conservation under the Bird[8] or Habitat Directive[9] is contained in the Habitat Directive

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[2] Rijkswet van 27 mei 1999, tot instelling van een exclusieve economische zone van het Koninkrijk (*Stb*. 1999, 281). Deze wet trad in werking bij besluit van 13 maart 2000 (Stb. 2000, 167).
[3] Treaty between the Kingdom of the Netherlands and the Kingdom of Belgium concerning the delimination of the Continental Shelf of 18 December 1996 (*Trb*. 1997, 15), entry into force 1 January 1999 (*Trb*. 1998, 264); Treaty between the Kingdom of the Netherlands and Bundesrepublik Deutschland concering the delimination of the Continental Shelf of the North Sea of 28 January 1971 (*Trb*. 1971, 53), entry into force on 7 December 1972 (*Trb*. 1972, 137); Agreement between the Kingdom of the Netherlands and the United Kingdom concerning the delimination of the between those countries lying Continental Shelf under the North Sea of 6 October 1965 (*Trb*. 1965, 191), entry into force (*Trb*. 1966, 299) and additional Protocol of 25 November 1971 (*Trb*. 1971, 212), entry into force 7 December 1972 (*Trb*. 1972, 140).
[4] Article 206 and 204
[5] Article 214
[6] The Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention") was opened for signature at the Ministerial Meeting of the Oslo and Paris Commissions in Paris on 22 September 1992 and entered into force on 25 March 1998.
[7] OSPAR 03/17/1, paragraph 4.17. Agreement on Sand and Gravel Extraction
[8] Council Directive of 2 April 1979 on the conservation of wild birds (79/409/EEC)

article 6 itself. Several sites along the coast of the Netherlands have been appointed as SAC's. The extraction of sand therefore has to be assessed, in order to estimate its implications in view of the site's conservation objectives. Only if this appropriate assessment shows that extraction will not adversely affect the integrity of the Area, a permit can be issued. If negative effects are to be expected, only imperative reasons of overriding public interest, including those of a social or economic nature, can justify permission, given that compensatory measures are in place.

Of importance are also the European Environmental Impact Assessment (EIA) Directive[10], which determines in Annex II, sub 2c) Extraction of minerals (..) such as (…) sand will be subject to an EIA where Member States consider that their characteristics so require, for example, if it exceeds a certain threshold, which is implemented in the Dutch EIA Decision.[11] Also, the Directive on Strategic Environmental Assessment (SEA)[12] will become important in the future, as it requires a systematic environmental assessment for all plans and programmes which set a framework for future development consent of projects listed in either the EIA Directive, and all plans and programmes which have been determined to require assessment pursuant to the Habitat Directive. An important improvement to the SEA directive is the obligation to investigate the cumulative effects.

2.4.4. Implementation in Dutch laws and regulations

The several obligations and rights stemming from the conventions set out above, have mostly been implemented through sectoral legislation, governing the extraction of sand and other materials from the soil, the Extraction Act from 1971, which is applicable on the Dutch Continental Shelf since 1996. Under this act a license is required to extract material from the soil or subsoil (art 3,1) from the Minister of Transport and Public Works*, Rijkswaterstaat*, North Sea Directorate. A license will be issued after evaluation of all interests at stake, including the possible damage to the natural habitat.[13] In the territorial sea the Dutch State is owner of the seafloor, based on two laws. However, those are not applicable on the Dutch Continental Shelf, en therefore the Netherlands has implemented the ownership of the materials in and immediately under the seafloor in article 4b of the Extraction law.[14] Therefore, apart from the license, a private contract has to be concluded with the State as the owner of the materials, at a set price per tonnes. At one stage it was about a third of the price of sand mined on land. For license applications to mine an area over 100 hectares in the territorial sea an Environmental Impact Assessment has to be made, on the Continental Shelf the threshold is an area of 500 hectares.[15] Also, if the areas to be mined are within close range, and might affect each other, they might have to be considered as covering a bigger area together and thus cross the threshold. [16] In the future an additional threshold of 10 million tonnes sand mined will be included. [17]

On land an extensive procedure[18] is followed to give out a license, giving stakeholders ample time to bring forward their points of view. However, for sand extraction in the North Sea a shorter route can be taken, when none or hardly any other interests are at stake.[19] To this end a plan has been drafted, the Regional

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[9] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
[10] Council Directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment. 85/337/EEC
[11] Decision, dated the 4th of July 1994, containing rules in order to execute chapter Environmental Impact Assesment of the Environmental Law
[12] Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment of 21 june 2001
[13] Step-by-step plan Legal Protection Exclusive Economic Zone; Parliament 2002-2003, 28 600 XII, nr. 89, p.10
[14] Extraction Law
[15] Decision, dated the 4th of July 1994, containing rules in order to execute chapter Environmental Impact Assesment of the Environmental Law; Category C 16.1 and 16.2
[16] As set out in the Staatsblad nr. 224, 1999, p. 67
[17] Report of the Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem, ICES CM 2003/E:07, p.8
[18] Based on article 10, Extraction Law
[19] According to article 6 of the *Rijksregelement Ontgrondingen*

Extraction plan for the North Sea (RON)[20] accompanied by an Environmental Impact Assessment (EIA). Based on the EIA, small-scale, shallow extractions are deemed the ones at which none, or hardly any other interests are at stake. Those are defined to be less than 2 meters below the seafloor and covering an area less than 500 hectares. As extra precaution mining has to take place beyond the 20 meters depth contour, in order to protect the fundament of the coast (*kustfundament*). Mining licenses, which aim to go deeper than two meters, but stay under the area surface threshold, will have to comply with a similar environmental assessment, based on the ICES guidelines, mentioned above.

The license can be given out with a set of conditions to mitigate damage, which is mostly done by stipulating that archaeological finds have to be reported and to facilitate control by ordering the supply of tracking data. The license can be subject to review, when conflict of interest is found. Exempted from the licensing requirements are normal maintenance of seaways and harbour entrances. The Regional Plan is up for review, the second edition (RON2) is about to be presented to Parliament. It opens the door for deeper extractions, beyond 2 meter deep in the seafloor. For deeper dredging, an EIA will be compulsory. RON2 will probably also allow the use of pits in order store sand temporarily just outside the 7 meters depth contour.

[20] RON, abbreviated after the Dutch Name "*Regionaal Ontgrondingenplan Noordzee*", offered to Dutch Parliament on the 20th of April 1993 for their information

3. Ecological effects

In this chapter an overview of potential ecological effects of sand dredging is presented. This report focuses on the ecological effects of aggregate dredging. As marine biodiversity is strongly linked to the physical environment it occurs on, the impact of aggregate dredging on the physical environment is therefore of major importance in determining effects of dredging on the marine ecosystem. These effects may be apparent on the seabed and in the water column (Gubbay, 2003). Figure 4.0 illustrates in general some the effects sand extraction.

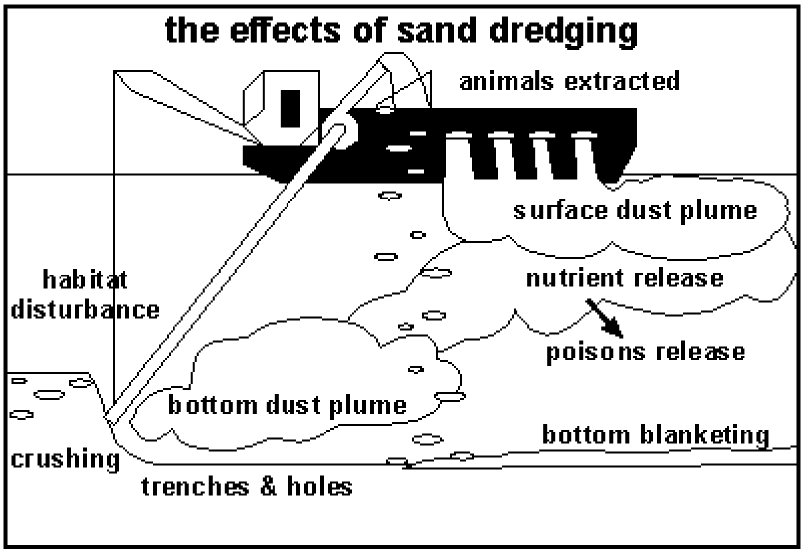

Figure 3.1: Effects of marine aggregate extraction

3.1. Effects of removing marine aggregates

One of the more obvious effects of aggregate extraction is removal of sediment. The vessel hopper leaves extraction tracks on the sediment. Depending on the strategy of dredging it can result in a relatively deep and narrow pit or a larger area dredged up to 2 m deep. Gubbay (2003) notes that it can take up to several years for the dredge tracks to erode or recover after dredging has ceased, dependent on the dynamicity of the environment. When the local habitat is destroyed, and changes occur in the bottom surface and sediment composition, depending on the function of the dredged area, effects can range between being a minor effect to a significant effect (e.g. in case of a herring spawning ground).

Regardless the dredging technique, the benthic life will be destroyed on the dredge location, through either removal, smothering or destruction caused by the dredge head. The significance of the impact depends on among others the value of the local community (e.g. presence of threatened or declining species or staple food for other species), the dimensions of the area and the recovery rate of the benthic community (see chapter 4.1). The loss of the local benthic fauna can have effects further down food chains. However, links and effects at higher trophic levels are not well known (Gubbay, 2003).

The extraction activity may also inadvertently create an abundance of food in the form of damaged animals like bivalves or crustaceans (Posford Duvivier Environment and Hill, 2001). This can temporarily enhance numbers of fish and marine mammals present in the area.

Depending on the dredging strategy and the scale of the dredging activity, several effects have been predicted for fisheries. Removing large areas of top sand (through dredging); which are rich in benthic species, have been signalled to cause an effect on plaice, both on the population and conditions that are suitable for plaice to successfully spawn (Rozenmeijer, 1999).

With the removal and/or disturbance of these ecologically significant areas (habitats, spawning grounds) species that are closely related to these areas are also potentially at threat. The North Sea plaice

(*Pleuronectes platessa*) spawns mostly in the southern part of the North Sea and off the German Bight. Previous studies conducted on the spawning areas off the Dutch and Belgian coasts, have shown that plaice spawn at depths between 20 and 40 metres below sea level between the months of January and June (Muus & Dahlström, 1978).

Previous studies have shown that changing conditions that are desirable for spawning discourages fish from spawning, and some persistent species such as herring, might still attempt to lay their eggs on different substrates, where in the case of the *Afsluitdijk* in the Netherlands, it resulted in the unsuccessful spawning for herring (de Groot, 1979).

Deep and shallow dredging will have different effects. When shallow dredging is applied as is the case, in the Netherlands to a maximum of 2 meters, the volume of material extracted will be directly related to the surface area that is affected. The ecological effects of shallow dredging will be relative large as most of the marine benthic life occur on the seabed surface or reside in the top 30 cm of the sediment. Shallow dredging will therefore effectively remove most of the benthic life in the dredged area (Heinis & van Dalfsen, 2001).

Deep dredging will affect less of the seabed surface area, resulting in localized effects on the benthic community. The total amount of benthic life disturbed during the dredging process will be reduced. As benthic species are influenced by hydrodynamic conditions and sediment composition, deep dredging will probably have effect on the benthic species composition at the bottom of the pit, which will result in a different ecosystem. If oxygen depletion in the deep pit occurs, this will create an inhabitable condition for benthos and other animals to exist.

3.2. Effects of sedimentation on the seabed

Particles that are suspended in the water column (surface and bottom plumes) will have varying effects on the biota depending on which stage the particles are in, which is divided in two stages: (Dankers, 2002);

- The water stage (where the particles are suspended in the water column/ surface & bottom plumes) (see 4.2); and
- The settlement stage (where the suspended particles have settled on the seabed/ bottom blanketing) (this paragraph).

During actual dredging, most of the sediment found in the overflow will settle rapidly to the bottom due to its density, and the current below and close to the stern of the vessel. Larger material will descend to the seabed more rapidly than finer grained material. Hitchcock and Drucker (1996: in Gubbay, 2003) note that very fine sand dispersed by dredging may be carried up to 11 km from the dredging site, fine sand up to 5 km, medium sand up to 1 km and coarse sand 50 m.

The ecological effects of the sediment settling on the seabed are dependent on several factors, namely the rate of sedimentation, the sediment type and the ability of the benthic species to overcome the rapid build-up of sediment (Wijsman & Anderson, 2004). Not all benthic species react to sediment deposition at the same level of sensitivity. Mobile benthic species such as polycheates, some species of bivalves, gastropods and crustaceans are able to migrate, between 2-26 cm in a period of 8 days after burial under 32 cm of sand. However, not all are able to adapt to burial under layers of sediment, for example the bivalve *Macoma balthica*, was unaffected by sedimentation rates of 7 cm/month, but at 10.2 cm/per month 20% of the specimens did not survive. Other species such as *Corophium volutator*, a crustacean, showed even more sensitivity with survival rates of 56% for sedimentation rate of 2.3 cm/month, 18% for 7 cm/month and 0.4% 10.2 cm/month (Turk and Risk, 1981).

In the RIACON project ecological effects of beach nourishment and sand extraction have been investigated (van Dalfsen & Essink, 1997) (see appendix 1 for more information). Sedimentation rates during the operation ranged from 1.5 m per 120 hours to 1.5 m per 30 hours. When sedimentation was occurring at a lower rate, certain species were able to crawl out; therefore some species were able to survive. This contributed to the recovery process, as the survivors and other migrants probably contributed to the recovery process starting immediately (van Dalfsen & Essink, 1997). Right after nourishment, densities of deposit feeders such as *Urothoe poseidonis* and *Enchinocardium cordatum*, and filter feeders such as *Macoma balthica* decreased at the nourishment site and not at the reference site.

In the longer term, species that disappeared but reappeared in almost a year were *Spio filicornis* and *Spisula cordatum*. The total abundance and biomass of macrofauna in the nourished site 2 years since the nourishment operation began showed signs of recovery towards the pre-nourishment state.

It is important to realise that ecological effects because of the settling sediment also can occur in a larger area than the extraction and during an extended period. Moreover, the effect of smothering or burial of benthic species does not only occur due to the settling plumes. It also occurs during shoreface nourishment (beach nourishment by bringing sand close to shore into the water column to wash ashore) or when sand is temporarily dumped at a location before is carried away for further use.

3.3. Effects in the water column

As mentioned before, particles that are suspended in the water column (surface and bottom plumes) will have varying effects on the biota, both if the particles are settling and if they are in the water stage. Figure 3.2 outlines biological effects of dredging. The effects in the water column are integrated in the figure.

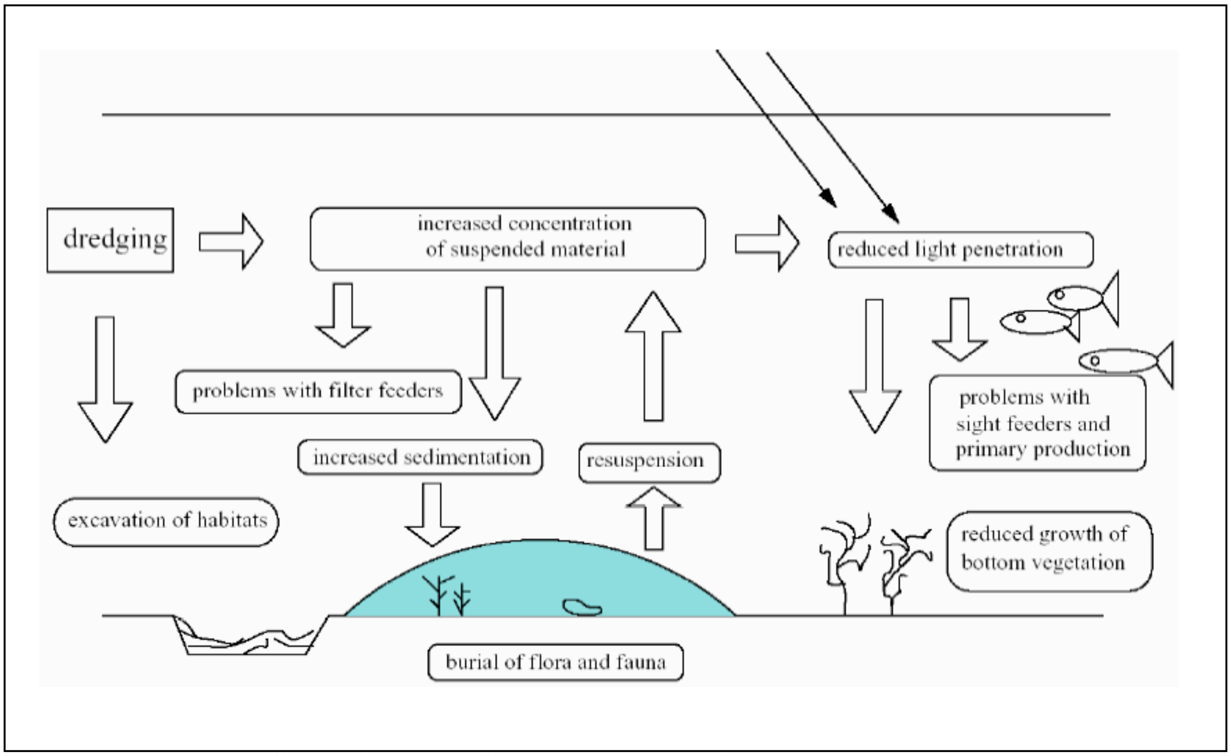

Figure 3.2 Ecological effects of dredging (from Dankers, 2002).

When particles that absorb light and cause backscattering are found in the water column, it is referred to as turbidity (CEDA, 2000). High turbidity is caused by high content of fine sediments and/or organic particles. High turbidity levels (or high levels of sediment suspension) can be harmful to the benthic vegetation and fauna due to shading (blocking of sunlight) and the burial by the suspended sediment released by dredging (Dankers, 2002). This effect only occurs when the turbidity level is significantly higher that the natural variations in turbidity and sedimentation in the area (CEDA, 2002). Ecological effects of dredging in the water stage are dependent on a number of factors, which include: the method of extraction, the sediment type (including the content of fines in the extraction site), rate and amount of sediment spill and the local hydrodynamics (Wijsman & Anderson, 2004).

3.3.1. Plankton

Reduction of light penetration and changes in light spectra caused by high turbidity levels can affect primary production. Increased turbidity can give way to a shorter or shifted bloom period for algae, or shifts in the composition of phytoplankton communities or the introduction of deep-sea microbes to the surface zone (Dankers, 2002). Ecological models developed for the construction of an airport island in the North Sea did show in a worst case scenario with continues large scale dredging and maximum release of fines in the water column, a delay in algal blooms by several weeks. Changes in primary production will have a carry on effect on other species in the food chain, as primary producers form its basis. An increase in suspended matter concentrations may affect foraging efficiency of zooplankton as the amount of food particles captures per time period will be reduced as a result of increased concentrations of non-digestible material and clogging of feeding appendages may occur.

3.3.2. Benthos

During the water stage, when high concentrations of particulate matter remain suspended, benthic filter feeders are at risk due to the clogging of their filtering organ or the dilution of the organic material due to suspension of inorganic particles. However, filter-feeding bivalves such the mussels (*Mytilus edulis*) are able to select food particles in mixed suspension of algae and sediment. Some literature suggest that the “grinding” of sediment by raft mussels (*Mytilus galloprovincialis*) have been noted to improve the ingestions of organic particulate matter, which enhances the growth in this species (Navarro *et al*., 1996).

3.3.3. Fish & other sight feeders

In the water stage, increase in suspended matter concentrations could lead to suboptimal functioning of the gills for fishes, due to clogging of silt in their gills. Such clogging could lead to infections and even death for fish. Some fish and mobile invertebrates have been observed to move away from plumes (Dankers, 2002).

Atlantic cod (*Gadus morhua*) and herring (*Clupea harengus*) have been recorded to display avoidance behaviour when encountering a large flume with sediment plumes of equally sized particles of clay or lime concentrations of between 2 mg/l and 8-9 mg/l, where the background concentration of suspended matter was less than 0.4 mg/l. When Cod was exposed in the night to the plume, the response was noted, which meant that there was a non-visual component in the response, and avoidance was not based on seeing the plume but by an excursion through in it (Westerberger *et al.,* 1996).

Visual feeders as fish, birds and marine mammals are mostly likely to be negatively affected by increased turbidity levels. The reduced visibility through the water column may affect localisation and capturing of prey. Changes in the spectral composition and in polarisation patterns of light can also contribute to a decrease in the success rate of catching prey (Essink, 1999).

Localised effects of increased turbidity on fishes and birds are expected. A prey species such as the mollusc *Donax vittatus*, was seriously affected by sand extraction and disappearance of adult specimens were noted in the RIACON study (van Dalfsen & Essink, 1997).

3.4. Nutrient & chemical release

The marine sediment contains organic matter and nutrients. During extraction, organic matter and nutrients can be released both at the surface as dust plumes and or at the bottom as bottom plumes. This causes an increase of nutrients in the water, which could enhance the primary production. Gubbay (2003) mentions in a study in Australia, wherever fine sediments were dredged; enhancement in benthic biota was noted. Seys (2003) concluded that due to extraction which probably enriched the waters through the release of organic material a strong increase of biomass was found at a study area 100 km east of Hull.

Another potential less positive effect of dredging is the decrease of oxygen levels caused by disturbance of anaerobic sediment layers (Gubbay, 2003). According to Wijsman and Anderson (2004), the release of nutrients and other oxygen consuming compounds from the interstitial water during aggregate extraction will be insignificant, as the content of organic matter and nutrients are very low in oxygenated sand and gravel dynamic areas. Another effect is the release of contaminants like heavy metals from the sediment. It is expected that only the upper layer of the sediment contain contaminants.

3.5. Other effects

3.5.1. Noise

Hopper vessels produce noise when dredging and when moving. It is expected that airborne noise is not a problem at sea, but underwater noise can have an effect on the ecosystem, especially on marine mammals and possibly fishes. Limited information was found on underwater noise caused by dredging. However, there is some research that shows that underwater noise from other human activities can disturb marine mammals. Depending on frequency and source levels, marine mammals can avoid an area or even get hearing damage. Underwater sound is transported over large distances (depending on frequency and amplitude); the area in which effects could occur can be much larger than the extraction area. Studies done on bowhead whales that were exposed to dredger noise, recordings at broadband received levels of 122-131 dB, were displaced from the area. The whales stopped feeding and moved until they were 2km away from the sound source. Changes in behaviour of the bowhead whales were also spotted, as the whale vocalisations decreased and changes were also noted in their surfacing, respiration and diving patterns (Richardson *et al.* 1985a, 1985b).

Although bowhead whales are not found in the North Sea, other cetaceans especially small cetaceans such as harbour porpoises (*Phocoena phocoena)* and the white-beaked dolphin (*Lagenorhynchus albirostris)* have all been spotted regularly. Therefore, it is important to conduct research on the effects of dredging noise on small cetaceans.

3.5.2. Safety

If there is an increase in the number of hopper vessels during the extraction activities, it is only logical to assume there will be also be increased risk of collisions, unless precautionary measures are taken. The extracted material has to then be transported to shore: which will also increase shipping movements. The risk of collisions will further increased especially in intensively used areas, e.g. for fishing grounds and/or shipping lanes. Effects of a collision vary from minor to disastrous, depending on the kind of vessels involved and their cargo. No information on this subject has been found. Probably the risk is minor, because there is a lot of experience of dredging in shipping lanes, and the amounts of vessels are very small compared to the regular shipping traffic. In 2 Dutch EIA's on sand extraction from DHV (2003) and Haskoning (2003), the risk on safety is expected to be minor.

3.6. Cumulative effects

Most studies and reports describe the effects of a single extraction. However, it is very important to consider potential cumulative effects as well, especially since the marine sand demands is expected to increase in the coming years. Gubbay (2003) notes that the pace of recovery may be affected by the presence disturbance in adjacent areas subjected to other or similar activities. She also notes there is a threshold level for disturbance, above which significant changes to the ecosystem functioning in the area can occur. Cumulative effects could also occur as a result of different activities. Gubbay (2003) states that the most likely activity will be fisheries, but other activities that cause the disturbance of the seafloor are also cause for concern.

3.7. Determining the ecological effects of sand extraction

It is possible to make a general overview of what effects can occur. However, each location has its own physical and biological characteristics, with varies according to habitat type and ecological function (e.g. spawning ground, nursing ground, feeding ground). The description of ecological effects in this chapter is general and does not qualify the seriousness of an effect. If sand is extracted in an which is abundant in shellfish that seabirds depend on for food, the effects of aggregate extraction on such a site is far reaching that just the removal of shellfish.

In order to determine the severity or the significance on marine aggregate extraction on a certain area, the natural values and the various uses and effects that the area is subjected to (e.g. offshore wind farms, fishing) needs to determined and studied. Which leads us to ask, then what level of effects is considered "acceptable"? In order determine the actual effects of marine aggregate extraction on the natural marine environment one needs to consider:

- Spatial scale of the effect: is it highly localised or large-scale occurrence?
- Temporal scale: is effect occurring over a short period or a longer period (defining temporary and ongoing/long term).
- Are there cumulative effects?
- Is the effect reversible, or is recovery be possible, and over what time period?
- What are the location specific natural values?

4. Recovery and mitigation

In the previous chapter we have outlined the various effects that marine aggregate extraction might have on the ecosystem. By anticipating the types of effects that can occur, it is possible to take (mitigating) measures before damage is done. It is also important to monitor changes before, during and after an extraction activity has taken place in order to assess the effects of extraction activities in the longer term. The next chapter will focus on recovery and possible mitigation measures.

4.1. Recovery

The debate over the recovery process after dredging is an ongoing one. There are contradicting views regarding the establishment of benthic community once dredging has ceased. Boyd *et al*. (2003) have stated that re-establishment of a community similar to that which existed prior to dredging can only be attained if the topography and original sediment composition are restored. Seiderer and Newell (1999) on the other hand, highlight the occurrences of natural fluctuations in the benthic community composition. Rather than expecting a total recovery to the area dredged to a situation prior to dredging, they suggest that recovery could be interpreted as the 'establishment of sufficient species diversity following cessation of dredging to allow the biological resources to progress towards the diverse "equilibrium" communities which characterise stable deposits of coastal waters'. The definition of "recovery" directly influences the level of acceptance in the disturbance or distortion caused by the dredging activity. Other studies done by van Dalfsen *et al*. (2000) noted that there is a direct relationship between the duration and type of the impact of sand extraction on the seabed and the "recovery" time.

According to Boyd et al. (2003), commonly encountered scenarios in the aftermath of marine aggregate extraction are:

A) Sites where substratum has changed (for instance from a sandy gravel to a gravely sand); and
B) Sites where the substratum has remained merely unchanged.

In the second scenario (B), where the composition remains the same after dredging, there will at first be a replacement of dominant taxa, which later decreases over time. Macrobenthic community response to the dredging can be divided into three main phases (ICES, 2000):

1. Stage 1 comprises an initial recolonisation by dominant taxa present before dredging. These species are usually opportunistic (in behaviour), mainly r-type species, and highly contribute to an overall increase in general abundance and number of species following the early months after dredging has ceased.
2. Stage 2 is characterised by a low community biomass, which can persist for several years. This is due to the increase of sediments in transport.
3. In the last stage the sand or sediment has reached its pre-dredged state. This recovery phase is also characterised by a significant increase in the community biomass.

This situation was encountered in the RIACON project. Changes in sediment structure were only minor and long-lived macro fauna species abundance recovered within a short period (2 years). However, recovery in population structure took 4 years. Studies to a limited extraction depth have shown that most dredge sites recover within a few years, in terms of biodiversity and biomass (van Dalfsen & Essink, 1997; Boyd et al, 2003). However, the community structure of long living species such as *Enchinocardium cordatum* and some mollusc species require up to 6 years to recover to a community age structure that was comparable to the situation prior to dredging (van Dalfsen & Essink, 1997, van Dalfsen, 1999).

In the first scenario (A), the abundance of gravely or sandy fauna is dependent on the length of perturbation or dredging. If the sediment composition of the surface layer changes, the fauna composition that is closely related to the sediment structure, will also change. This will probably happen at deep dredging. In situations were changes have occurred in the sediment composition, the recovery process took much longer than 2-4 years (van Dalfsen *et al.*, 2000).

Besides time and sediment structure change, another factor that strongly influences recolonisation of dredged sites is larval settlement and adult pool of potential colonisers (Desprez, 2000). Faunal recovery in dredged sites is less influenced by the transport of new recruits from the slumping sediment, but rather larval settlements have been noted to be a more important source of new recruits than the migration of adults from nearby (Boyd & Rees, 2003).

4.2. Mitigation

Although effects of marine aggregate extraction are dependent on several factors (as discussed in earlier chapters), there are measures that can be taken to reduce either the effect of extraction process itself or the results of extraction process. Possible mitigation measures are:

- Restriction of overflow and onboard screening, to limit surface plume and effects of sedimentation in the water column, by either mechanical means or regulatory restrictions;
- Development and application of dredging strategies in order to speed up the recovery process. For e.g. extraction in lanes or shallow dredging which will make recolonisation from the unaffected areas possible;
- Temporal restrictions: to take into account seasonal fluctuations and sensitivity;
- Spatial restrictions: not in sensitive areas or areas with a special natural value or ecological function.

One should take into account location specific values to evaluate the effectiveness of mitigation measures. For instance: it’s of no use to restrict overflow in an area where there is already a lot of turbidity. Moreover, it’s questionable if extraction in lanes will be a useful mitigation measure, since recolonisation in the North Sea mostly depends on the settlement of larvae and eggs, which are transported in the water.

5. Conclusions and recommendations

The literature review conducted in this study has provided scientific arguments to support the idea that marine aggregate extraction has an effect on the ecosystem. Studies have shown that the actual dredging and screening processes have varying effects on the marine environment, over varying time scales. The extraction processes affect the benthic species directly through removal, smothering, and damage caused by the dredge head. These direct effects are mostly limited to the dredged are or the area immediately around it, but surface and bottom plumes, changes in plankton bloom seasons, release of nutrients and chemicals and noise, affect an area beyond the dredge area and the immediate area around it. These effects are not only limited to the seabed and benthos, but also on different trophic levels in the marine ecosystem. Both direct effects (e.g. killing of benthos by extraction) and indirect effects (e.g. change of primary production in larger area because of turbidity plume) need to be addressed in evaluating the effects of marine aggregate extraction. The level of disturbance and acceptability of the level of disturbance is different, as site specific values and dynamics need to be considered.

An important question in identifying how significant these effects are, is how detrimental and extensive are these afore mentioned effects? The North Sea Foundation concludes from this study, that the effects of a regular sand extraction (not too large) in general within the Dutch continental shelf (excluding areas of ecological significance) will be limited. Most of these extractions will be local and temporal and recovery will be the case within a relatively short period, as the Dutch part of the North Sea is rather dynamic. If we limit the discussion to locally occurring effects, it is very important to look specifically at the characteristics of the location in order to predict what the effects will be. Sensitivity maps which could indicate site-specific effects could assist in the decision making process, in weighing the true costs and benefits of an extraction activity.

It is also crucial to keep in mind the “big picture”. One should be aware of cumulative effects of several (small) extractions, which combined can possibly have a greater effect. Moreover, not only aggregate extractions have to be considered, as the North Sea is a heavily used area. Therefore, the cumulative impact of different activities should be considered when answering the question if an effect is significant or not, but such a study has yet to be carried out. More importantly, very little is known about the effects of deep dredging, and it is difficult to determine effects of this type of dredging and whether the effects will be significant. The North Sea Foundation recommends further research be carried out on deep dredging before it is considered a potential dredging strategy within the Dutch Continental Shelf.

As a result of this study, the North Sea Foundation recommends in considering marine aggregate extraction in the North Sea, that several issues and points are covered. Assessments on effects should be location specific to take into consideration the various variables (e.g. biota, sediments composition, dynamicity). In determining or outlining areas for marine aggregate extraction that areas that are sensitive to marine aggregate extraction and of ecological significance should be excluded from potential extraction area lists. Areas that are of ecological significance with in the Dutch Continental Shelf are the Cleaver Bank, Dogger Bank, Frisian Front, Coastal zone, Oyster Grounds, and areas of special ecological functions (like banks of shellfish, nursery grounds).

The North Sea Foundation also recommends that mitigation measures should be implemented as much as possible, for example previous initiatives to reduce overflow by funnelling overflow before the water surface should be further tested and studied to determine applicability. Besides mitigation measures the Foundation would also like to stress the importance of monitoring and evaluating the effects of deep dredging and compare this with effects of shallow dredging. Experiments and pilots studies are needed to further our understanding in this field.

Through this study the North Sea Foundation also found that there was lack of strategic environmental impact assessments for the North Sea, in which cumulative effects of different activities (e.g. fishing, aggregate extraction, and wind farms) are taken into account when determining effects of one activity on the marine environment and biota. The Foundation believes such strategic EIA are crucial in determining the “true” effects of various activities in the North Sea. We hope that policy makers, dredgers, and other stakeholders of the North Sea awaken to the importance of holistic management strategies and policies.

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