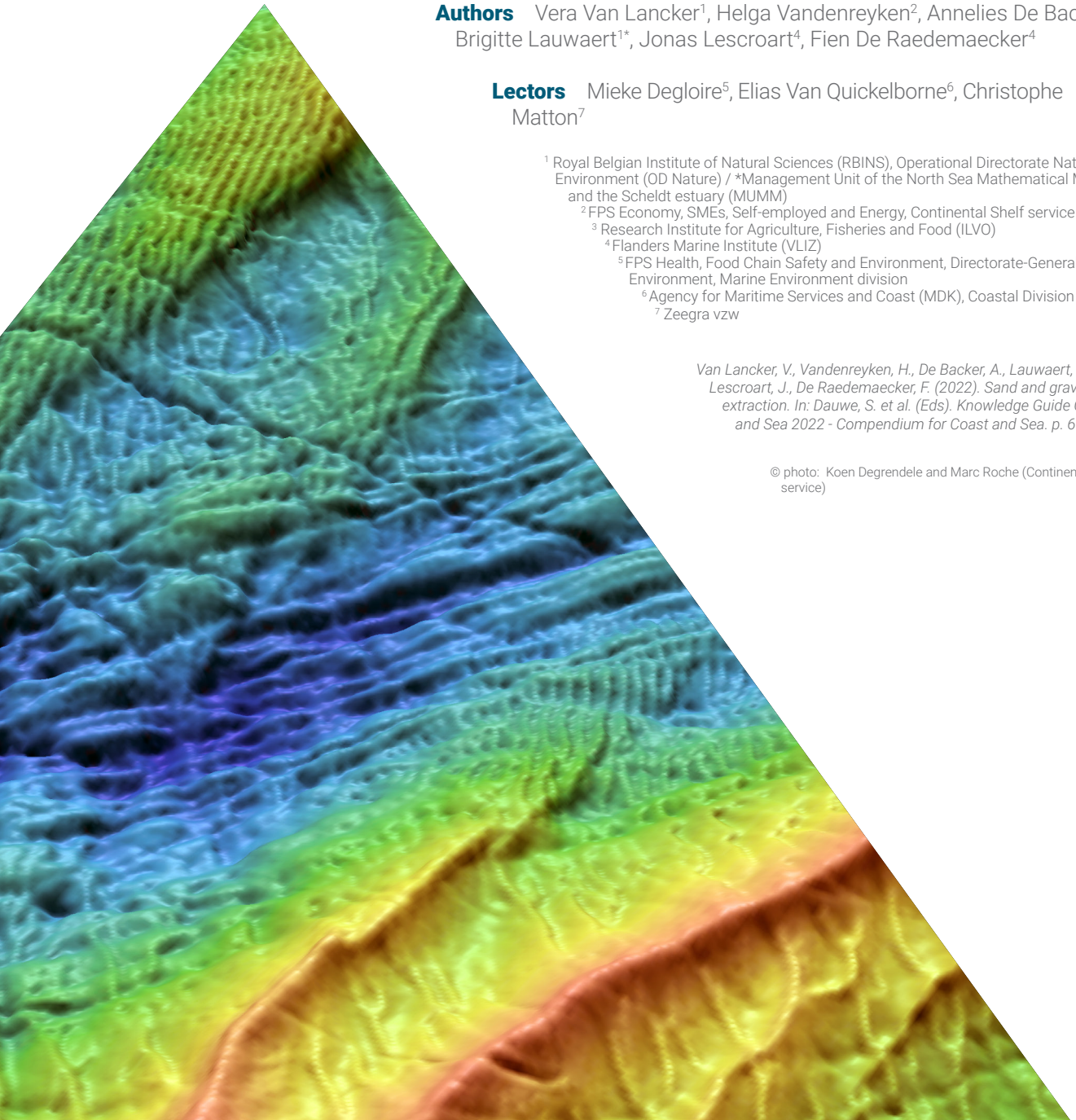
4 Sand and gravel extraction



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Van Lancker, V., Vandenreyken, H., De Backer, A., Lauwaert, B., Lescroart, J., De Raedemaecker, F. (2022). Sand and gravel extraction. In: Dauwe, S. et al. (Eds). Knowledge Guide Coast and Sea 2022 - Compendium for Coast and Sea. p. 67-78.

Between 40 and 82 million m³ of marine sediment has been extracted annually in the OSPAR region (North-East Atlantic and North Sea) between 2015-2018 (ICES 2019). This mainly concerns the extraction of sand and gravel for the construction industry and coastal protection. Furthermore, marl was extracted for use in agricultural land improvement and water filtering (OSPAR 2010).

Most of the marine sediment in the OSPAR region is extracted by countries such as the Netherlands (24.6 million m³ in 2018), the United Kingdom (9.4 million m³ in 2018), Denmark (5.7 million m³ in 2018) and France (3.7 million m³ in 2018) (ICES 2019). In the Belgian part of the North Sea (BNS), sand is the most extracted type of sediment in recent decades, with an annual volume that fluctuated between 2 and 4 million m³ over the past ten years. In 2014, this volume was considerably higher at almost 6 million m³, 60% of which was used for beach nourishments (FPS Economy, S.M.Es, Self-employed and Energy 2020). In 2018, approximately 3.8 million m³ was extracted, of which 26% was used for coastal protection (ICES 2019). Gravel is generally not extracted in the BNS due to the extremely limited presence, the small grain size and the heterogeneity of the material in the permitted areas (FPS Economy, S.M.Es, Self-employed and Energy 2020).

4.1 Policy context

The sand and gravel extraction in the BNS is a federal competence that belongs to the FPS Economy, SMEs, Self-employed and Energy and is regulated by the Law of 13 June 1969 (see also General Direction Quality and Safety 2020). Coordination with and alignment between the public administrations involved in the management of the exploration and exploitation on the continental shelf (CS) and in the territorial sea is done within an Advisory Committee (RD of 12 August 2000).

4.2 Spatial use

The zones for sand and gravel extraction are legally demarcated in the marine spatial plan (MSP 2020-2026, as stipulated in the RD of 22 May 2019, see also Verhalle and Van de Velde 2020). Prior to a previous demarcation in 2004, a study on the possible control zones[1] for sand extraction was conducted (Schotte 1999). A total of three control zones were demarcated in 2004 and divided into sectors for which concessions can be obtained. A fourth control zone was demarcated in 2010, in which four new sectors were defined on the basis of new exploration data. Given the expectation that the demand for sand will further increase (e.g. in function of the needs for coastal protection and the demand for construction sand on land), a new exploration zone[2] was designated in the MSP (2020-2026) (RD of 22 May 2019) in the northern part of the BNS and a fifth control zone is provided on the Blighbank, consisting of a single sector (see also Belgian State 2018). In addition, some minor changes have been made compared to the previous MSP (2014-2020) (RD of 20 March 2014) regarding the delineation of the sectors: Thortonbank, Sierra Ventana (b) and Oosthinder-Zuid.

In addition, a reference zone for monitoring[3] was also demarcated, similar to the sand extraction areas in terms of sediment and habitat composition. In this reference zone, sand and gravel extraction is prohibited in order to monitor the impact on the environment. This closed zone is located on the Thornton Bank (THBREF zone in figure 1, MSP 2020-2026) and also serves as a reference area for wind turbine activities in the BNS (see also thematic chapter **Energy (including cables and pipes)**). To assess the impact of sand extraction more accurately, several monitoring areas[4] were defined, which are mapped (at least twice) annually (FPS Economy, S.M.Es, Self-employed and Energy 2020).

If a negative seabed evolution occurs due to extraction, parts of the sectors may be closed (figure 1 and table 1). In the period prior to 2021, a maximum of 5 m of sediment was allowed to be removed below a predefined bathymetric reference model (Degrendele et al. 2014). As a result, a number of areas on the Kwintebank (BBMA and KBMB) and on the Buiten Ratel (BRMC) have been closed for exploitation (Degrendele and Vandenreyken 2017). Since 2021, the Continental Shelf service has applied new criteria for closing subareas based on the new

[1] A control zone is an area stipulated by law where sand extraction is permitted (delimitation stipulated in the MSP 2020-2026, RD of 22 May 2019).
[2] An exploration zone is an area stipulated by law where qualitative sand and gravel can be searched for (delimitation stipulated in the MSP 2020-2026, RD of 22 May 2019). If the results of the exploration research are positive, the minister of Economy, after advice from the minister responsible for maritime mobility, can define new sectors for exploitation within this zone.
[3] A reference area for monitoring the impact of sand extraction and wind farms on the environment is located in control zone 1 on the Thorntonbank. Sand and gravel extraction have been prohibited in this area since 1 October 2010. Provided that the advice of the Advisory Commission is favourable, extraction can resume from 1 May 2023 (General Direction Quality and Safety 2020).
[4] A monitoring area is an area that is assessed on a regular basis in order to accurately follow the evolution and evaluate the impact of sand extraction on the sea bed. Such a monitoring area can be located both inside and outside a control zone. In this way, the evolution of the seabed in a reclamation area can be compared to the natural evolution of the seabed (FPS Economy, S.M.Es, Self-employed and Energy 2020).

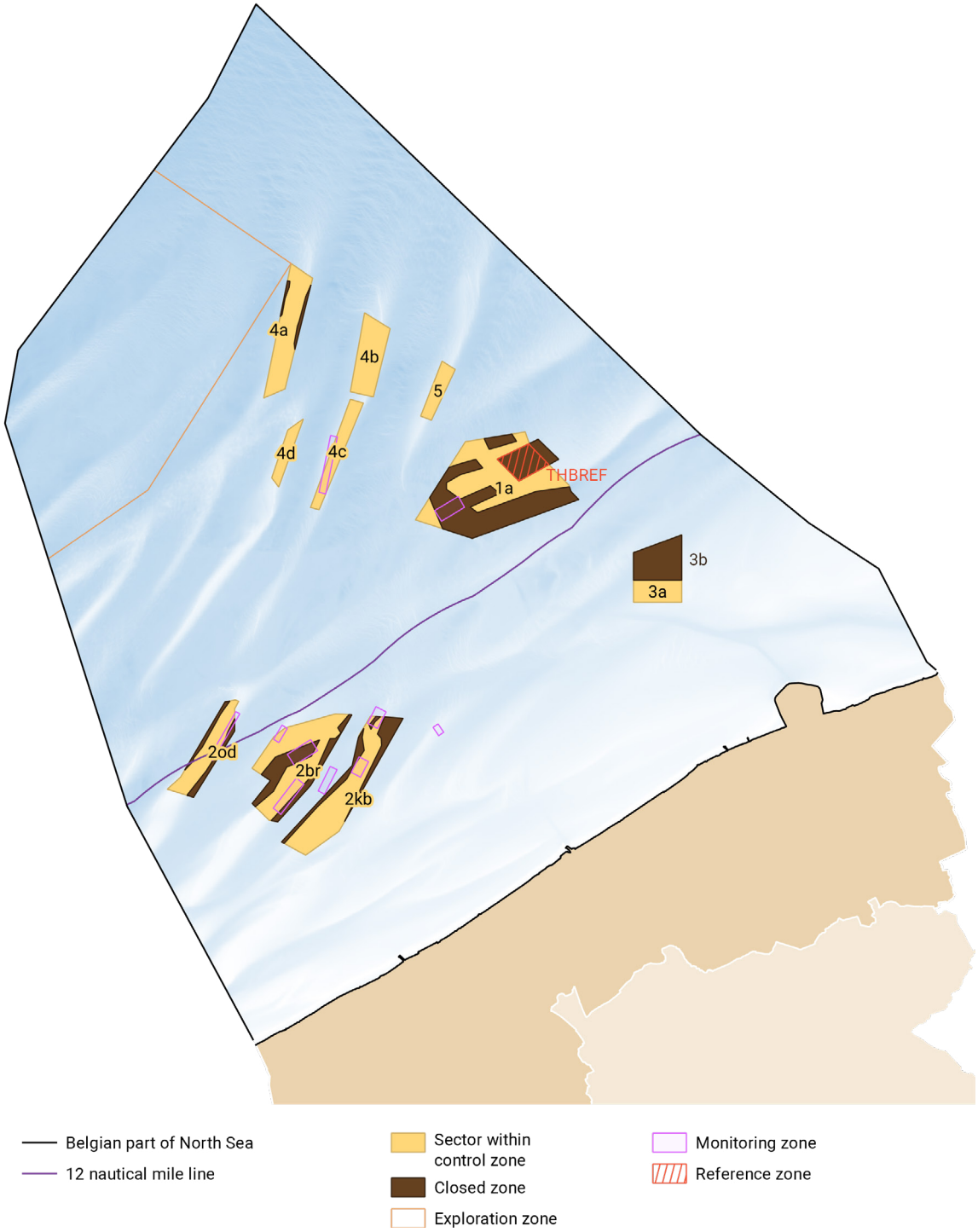

Figure 1. The demarcation of the sectors within the control zones for sand extraction in the BNS with the location of the closed sub-zones in 2022, the exploration zone, the monitoring zone and the reference zone (Sources: BNS, 12 nautical mile line: Flemish Hydrography, sector within control zone, exploration zone, reference zone (based on RD of 22 May 2019): MarineAtlas.be, Closed zone, monitoring area: FPS Economy, Coastal Portal).

reference surface and the available volume of sand within the various sectors (FPS Economy). Exploitation will no longer be allowed if the limit is reached within a certain area. The new reference surface was defined based on scientific and legal criteria (De Mol et al. 2014, Degrendele 2016, Degrendele et al. 2017, Degrendele et al. 2021) and aims to limit the impact of extraction in the most sensitive areas and to increase economic sustainability taking into account the availability of quality sand. In 2021, this resulted in the closure of 11 subareas, spread over control zones 1, 2 and 4, which cover 24% of the total area, but contain only 2% of the stock of sand. The demarcation of these closed zones is re-evaluated annually and adjusted if necessary.

Table 1. An overview of the different control zones for sand extraction in the BNS by location and accessibility.

Control zone	Sector	Location	Accessibility
Zone 1	1a	Thorntonbank	Open, except for the area THBREF
Zone 2	2kb	Kwintebank	Open
	2br	Buiten Ratel	Open
	2od	Oostdyck	Open
Zone 3	3a	Sierra Ventana	Open*
	3b	Sierra Ventana	Closed
Zone 4	4a	Noordhinder	Open**
	4b	Oosthinder-Noord	Open
	4c	Oosthinder-Zuid	Open
	4d	Westhinder	Open
Zone 5	5	Blighbank	Open

* Sectors 3a and 3b are alternately open for extraction. Currently, sector 3b is being used as a disposal site for dredged materials (see also General Direction Quality and Safety 2020).
** Sector 4a overlaps with a zone dedicated to the production and transmission of electricity from renewable sources. This sector remains open, as long as sand and gravel extraction are reconcilable with it.

The offshore extraction of sand and gravel requires a concession permit (figure 2). In order to obtain a permit, an application form has to be submitted to the director of the General Direction Quality and Safety of the FPS Economy, according to the procedure stipulated in the RD of 1 September 2004 concerning the granting procedure. Furthermore, the RD of 21 October 2018 about the environmental impact assessment (EIA) defines that an EIA-report has to be submitted to the Management Unit of the Mathematical Model of the North Sea of the Royal Belgian Institute of Natural Sciences (RBINS-MUMM). MUMM's assessment of the Environmental Impact Report (EIR) is subsequently transferred to the minister/secretary of state competent for the Marine Environment, who in turn formulates a binding recommendation to the federal minister competent for economy (Belgian State 2018, General Direction Quality and Safety 2020).

The concessions that have been granted for the exploration and exploitation of the mineral and other non-living resources in the BNS can be found in the ministerial decrees in the Belgian official journal (table 2). Each concessionaire pays a fee in line with the volume he has extracted, with an annual minimum of 18,592.02 euro (FPS Economy, S.M.Es, Self-employed and Energy 2020). The amounts of the fees are adjusted annually and vary according to the type of material. In 2022, sand from control zones 1, 2 and 4 will be worth 0.70 euro/m³; sand from control zone 3 (lower quality) 0.46 euro/m³ and gravel 1.49 euro/m³. A new concessionaire will be granted a minimum volume of 100,000 m³/year for the first year per concession. Every year, an Advisory Committee advises the minister competent for economy on the quantities that each concessionaire can extract in the following year (FPS Economy, S.M.Es, Self-employed and Energy 2020). For Belgium, the effective surface with actual extraction was about 32% of the legal concession zone in 2015, only 12% in 2016, and 33% in 2017 (ICES 2016, ICES 2017, ICES 2019). Between 2015 and 2019, more than 48% of the total volume extracted occurred in control area 1, 21% in control area 2, 13% in control area 3 and 18% in control area 4 (FPS Economy, S.M.Es, Self-employed and Energy 2020).

4.3 Societal interest

The extraction of sand in the BNS has strongly increased since the first reporting year, i.e. 1976 (figure 3). At that time, a sediment volume of approximately 29,000 m³ was extracted and this further increased to 3.8 million m³ in 2020, with a peak of almost 6 million m³ in 2014 (Source: FPS Economy, Continental Shelf service). Between 1976 and 2018, a total of 73 million m³ of sea sand was extracted. Since 2003, three phases can be distinguished in the evolution of sand extraction on the BNS (Roche et al. 2017). Between 2003 and 2010, more than 75% of the sediment was extracted in control zone 2, especially on the Kwintebank (sector 2kb). After the closure of two regions on the Kwintebank (2kb), a shift took place since 2007 to zone 2br (Buiten Ratel). A section of this zone was also closed for extraction in 2015. From 2014 onwards, extraction shifted to three sectors: Thorntonbank (1a), Sierra Ventana (3a) and the Oosthinder (4c). Currently, a maximum of 15 million m³ of sediment can be extracted from the control zones over a period of five years (not considering exceptional projects such as coastal protection).

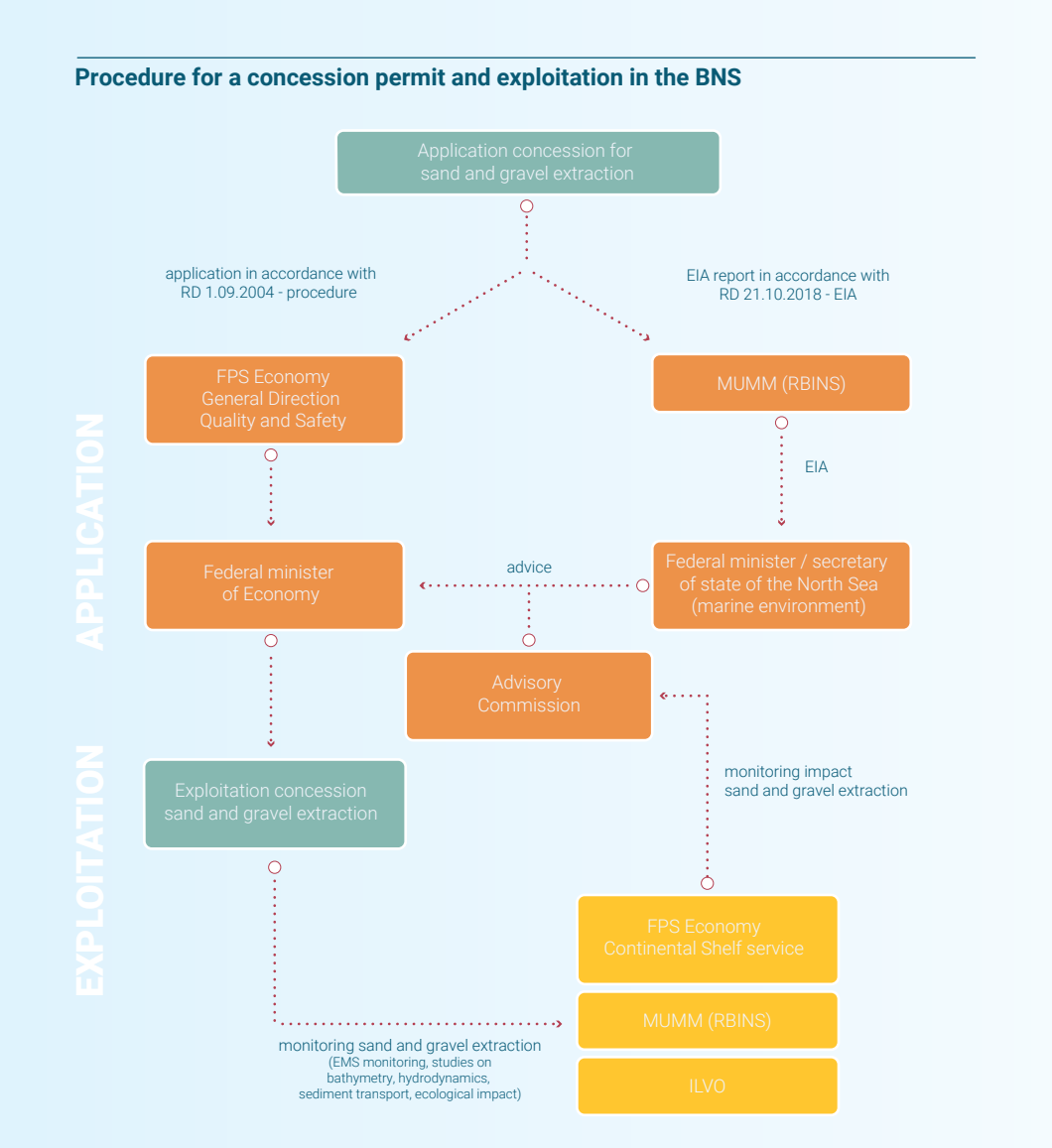

Figure 2. Flowchart of the procedure for a concession permit and the exploitation of sand and gravel extraction in the BNS (Law of 13 June 1969 and Implementation Decrees).

In 2019, about 55% of this sediment was landed in Flanders, 15% was used for beach nourishments and 30% was unloaded in Dutch, French and UK ports (FPS Economy, S.M.Es, Self-employed and Energy 2020). The share of exported sand to the Netherlands that is landed in Vlissingen, is ultimately destined for the Belgian market (ICES 2019). The Long-Term Vision North Sea 2050 estimates that 8.75 million m³ of sand will be needed annually in 2050, calculated on a steady annual increase of 6% (De Backer 2017).

In cooperation with Zeegra vzw, the professional association of importers and producers of sea aggregates, the Continental Shelf service has attempted to assess the direct economic impact of the sea aggregates sector (see below). Naturally, there is also a major indirect impact, such as the economic growth of port activities, the Belgian construction industry, road transport, suppliers, etc. Some relevant figures are listed below:

- 12 private companies with a concession permit employ 90 people in Belgium and 175 people in the rest of Europe. These employees are mainly active in the extraction of marine sand;
- The annual turnover from the sale of sea sand and gravel in Belgium amounted to more than 70 million euro in 2020;
- The concession holders do not only mine sand on the BNS, but also extract or buy sand in our neighbouring countries (table 3). The sand extracted in Belgium amounted to more than 3 million m³ in 2020. In the Netherlands, over 2.5 million m³ of sand was extracted or purchased that year. In the United Kingdom and

Table 2. An overview of the concession holders for sand extraction in the BNS with the maximum extraction volume granted for 2021 (Source: FPS Economy, Continental Shelf service).

Concessionaire	Maximum extraction volume allocated for 2022
Charles Kesteleyn nv	119,000 m³
Dranaco nv	33,000 m³
SATIC nv	152,000 m³
TV Zeezand Exploitatie	97,000 m³
Alzagri nv	86,000 m³
Belmagri nv	30,000 m³
CBR - Sagrex	307,000 m³
De Hoop Bouwgrondstoffen bv c.o. SATIC nv	144,000 m³
DEME Building Materials nv	772,000 m³
Government of Flanders – MDK – Coastal Division *	700,000 m³
Government of Flanders – MDK – Coastal Division **	700,000 m³
Government of Flanders – Maritime Access division ***	200,000 m³
DC Industrial nv	567,000 m³
NHM nv	523,000 m³
Betoncentrale Van den Braembussche nv	168,000 m³
Total	**4,598,000 m³**

** The concession of the Coastal Division for sand extraction in zone 3 ends on 31 July 2022.*
*** The Coastal Division is allowed to extract 7 million m³ in zones 4 and 5 for ten years. On average this is 700,000 m³ per year.*
**** The Maritime Access division can extract 3.5 million m³ in zone 3 over a period of ten years. On average this is 350,000 m³ per year. The concession of the Maritime Access division for sand extraction in zone 3 ends on 31 July 2022.*

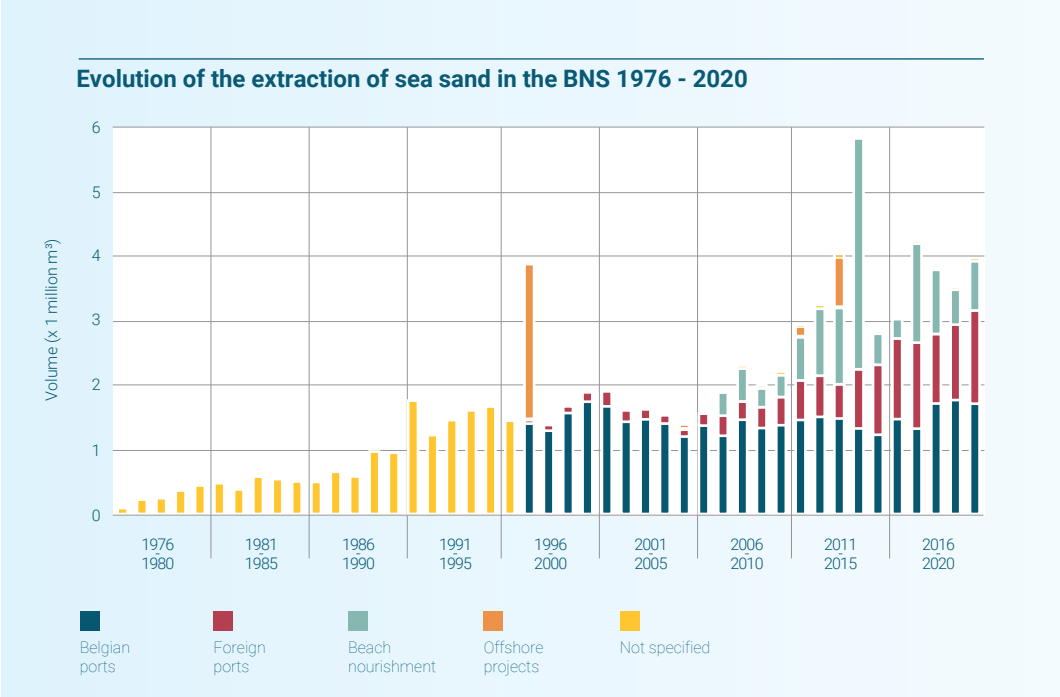

Figure 3. The evolution of the extraction of marine sand in the BNS between 1976 and 2020. Note on a number of outliers in this evolution: construction of submarine gas pipelines in 1991 and 1997 and coinciding nourishments following the *Sinterklaas* storm in 2014 (Source: FPS Economy, S.M.Es, Self-employed and Energy 2020).

Germany, more than 1 million m³ and about 20,000 m³ of sand were extracted or purchased respectively. In the United Kingdom, in addition to sand, gravel is also extracted;

- Sea sand has many applications (figure 4). Most of the extracted sea sand is medium-grade sand for use in: ready-mixed concrete (67%), precast concrete (11%) and other concrete products (12%). In addition, sea sand is also used for the production of asphalt, as sand filling used for e.g. drainage, foundation and embankment sand and for beach works;
- In addition to the use of sea sand in the construction sector, sea sand is also used for coastal protection (see thematic chapter **Safety against flooding**). The implementation of beach nourishment is currently the most important coastal protection measure in Belgium. Beach nourishment ensures that the beaches are sufficiently wide and high to protect the coast against flooding in the event of very heavy storm surges. For beach nourishment, sand with a median grain size of 250-350 µm[5] is used, while this is ± 200 µm for forshore nourishment. The required quantities of sediment have been provided for within the framework of the Master Plan Coastal Safety (2011) since 2011. In addition, the Coastal Vision project will determine the most desirable societal measures needed to protect the coast against a sea level rise of up to 3 m, which may lead to an increased need for sand;
- The indirect economic impact of the sand extraction sector is difficult to quantify. In addition to the purchase of marine granulates, nearly 29 million euro was spent in the private sector in Belgium in 2020 on the required infrastructure and 46 million euro in the rest of Europe. Investments were also made in the public sector, such as ports and pilotage, with almost 3.5 million euro in Belgium and over 7.5 million euro in the rest of Europe;
- It can be said that the extraction of marine aggregates is not only of strategic importance, but also comprises an important economic activity with high added value that contributes greatly to the growth and prosperity of Belgian construction companies (Source: FPS Economy, Continental Shelf service).

Table 3. Volumes (m³) of sand extracted or purchased, by concession holders for sand extraction in the BNS, in Belgium and neighbouring countries in 2020 (Source: FPS Economy, SMEs, Self-employed and Energy, Continental Shelf service).

Country	Extracted or acquired volumes in 2020
Belgium	3,172,963 m³
The Netherlands	2,579,396 m³
United Kingdom	1,223,712 m³
Germany	19,432 m³

Good quality sand is a finite resource and in Belgium, its use in the construction sector is twice as high compared to the production (Vrijders 2021). Therefore, the concept of a circular economy is gaining increasing attention in this sector in order to sustain the future of this economic activity for generations to come (Demoulin 2021, Hammöhner and Fincke 2021, Janssens 2021, Pirard and Courard 2021).

4.4 Impact

The most commonly used method for sand extraction is the trailing suction hopper dredger which draws grooves in the seabed that are typically 1-3 m wide and 0.2-0.5 m deep (Degrendele et al. 2010, Newell and Woodcock 2013). The RD of 21 October 2018 regarding the environmental impact assessment (EIA), stipulates the various effects of sand extraction on the marine environment that need to be considered in the EIA (Environmental impact report for the extraction of marine aggregates at the BNS in 2006, 2010, 2016 and 2020). Tables 4 and 5 list studies related to the impact of sand and gravel extraction in the BNS, supplemented by publications that are widely applicable or provide a general overview (e.g. ICES reports). Sediment extraction is also included in the 'Ecosystem vision for the Flemish Coast' (Van der Biest et al. 2017) as one of the processes that can have a major impact on the health of the ecosystem components and on other ecosystem services.

The monitoring approach as described in **4.5 Sustainable use** aims to prevent any irreversible or long-term negative effects as a result of sand extraction.

[5] Micrometer

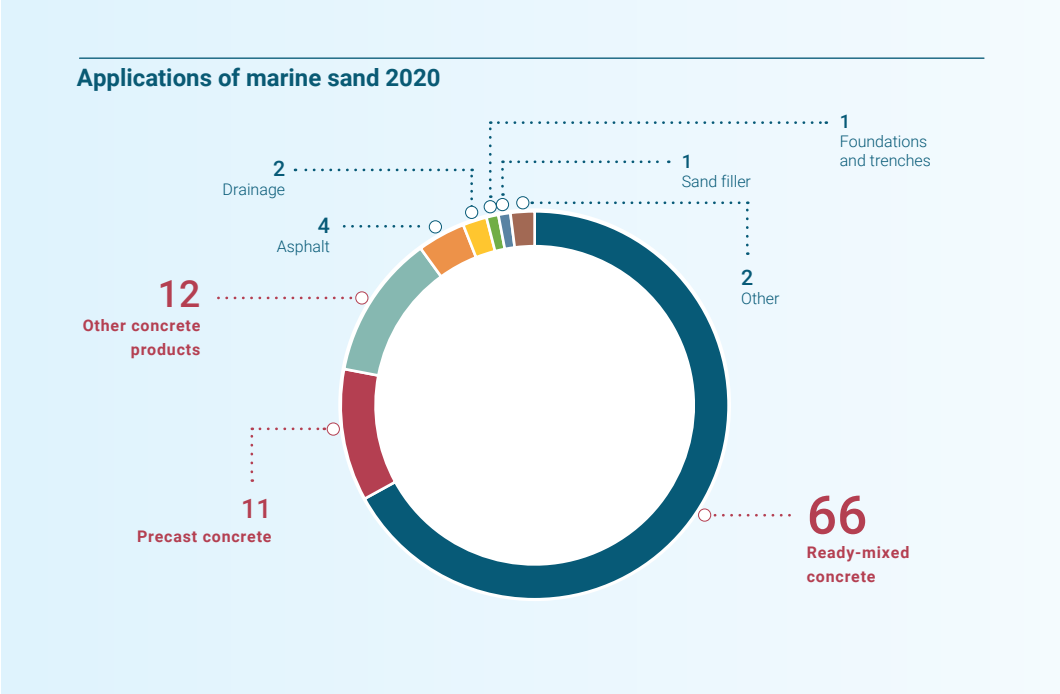

Figure 4. The different applications (with their % share) of sea sand in 2020 (private sector) (Source: FPS Economy, S.M.Es, Self-employed and Energy 2020).

Table 4. A literature overview of the impact of sand extraction on the environment where extraction takes place, considering near- and far-field effects.

Environmental impact	Literature
Seabed and water (changes in the bathymetry, sedimentology, sediment plumes, turbidity, hydrodynamic regime, etc.)	Van Lancker et al. 2007, Vanaverbeke et al. 2007, Van Lancker et al. 2009, Van Lancker et al. 2010, Bellec et al. 2010, Degrendele et al. 2010, Van den Eynde et al. 2010, Garel 2010, Roche et al. 2011, De Sutter and Mathys 2011, Van Lancker et al. 2014a, Degrendele et al. 2014, Van Lancker et al. 2014b, Francken et al. 2014, Van Lancker et al. 2015, Van Lancker and Baeye 2015, Van Lancker et al. 2016a, Walker et al. 2016, Van den Eynde et al. 2017, Van Lancker et al. 2017a, Baeye et al. 2017, Van Lancker et al. 2017b, Van Lancker et al. 2017c, Montereale-Gavazzi et al. 2018, Hademenos et al. 2019, Van den Eynde et al. 2019a, Van den Eynde et al. 2019b, Van Lancker et al. 2020a, Rommens and Hauquier 2020, Van Lancker et al. 2020b, Vandenreyken 2020, Van den Eynde et al. 2021, Van Lancker et al. 2021, Wyns et al. 2021
Fauna, flora and biodiversity	Vanaverbeke et al. 2007, Van Lancker et al. 2010, Bonne 2010, De Backer et al. 2011, De Sutter and Mathys 2011, De Backer et al. 2014a, De Backer et al. 2014b, De Backer and Hostens 2014, Van Lancker et al. 2014a, Van Lancker et al. 2014b, Van Lancker et al. 2015, Van Lancker et al. 2016a, Walker et al. 2016, De Backer et al. 2017, Van Lancker 2017, Rommens and Hauquier 2020, Van Lancker et al. 2020b, Vandenreyken 2020, Wyns et al. 2021, Derycke et al. 2021
Air quality and climate	De Sutter and Mathys 2011, Walker et al. 2016, Francken et al. 2017, Rommens and Hauquier 2020
Sound and vibrations	De Sutter and Mathys 2011, Heinis et al. 2013, Walker et al. 2016, Jones and Marten 2016, Durinck and Casteleyn 2017, Rommens and Hauquier 2020

4.5 Sustainable use

4.5.1 Nature and environmental guidelines for the sustainable extraction of sand

Within the OSPAR region, all countries that extract sand and gravel on a large scale have a legislation that complies with the European Directive 85/337/EEC concerning the environmental impact assessment of specific public and private projects, as well as with the European Habitats Directive (Directive 92/43/EEC). With regard to the management of marine sediment extraction, the OSPAR countries have agreed to apply the directives as proposed by the International Council for the Exploration of the Sea (ICES) (see annex 10 of the ICES 2003). These directives

Table 5. An overview of the impact of sand extraction on other users.

Impact on users	Literature
Risk and safety (shipping, oil pollution, coastal safety, etc.)	Verwaest 2008, De Sutter and Mathys 2011, Liste Muñoz et al. 2011, Walker et al. 2016, Van den Eynde et al. 2017, Rommens and Hauquier 2020
Seascape and cultural heritage	De Sutter and Mathys 2011, Van Haelst and Pieters 2014, Walker et al. 2016, Missiaen et al. 2016, Rommens and Hauquier 2020
Interaction with other human activities (including coastal protection)	Verwaest and Verelst 2006, Verwaest 2008, De Sutter and Mathys 2011, Vandenborre 2014, Walker et al. 2016, Van Lancker et al. 2016a, Van den Eynde 2017, Van den Eynde et al. 2019a, Rommens and Hauquier 2020, Van Lancker et al. 2020b
Cumulative effects (e.g. in combination with the activities in the offshore wind parks)	Van Lancker et al. 2010, De Sutter and Mathys 2011, Van Lancker et al. 2015, Walker et al. 2016, Van Lancker et al. 2016a, Van Lancker et al. 2017a, Rommens and Hauquier 2020, Van Lancker et al. 2020b

also discuss nature conservation and spatial conflicts among users. Belgium, Denmark, Germany, France, the Netherlands and the United Kingdom demand the use of a so-called EMS system (Electronic Monitoring System), which allows the monitoring of the extraction in space and time. The effects of the sand and gravel extraction on the marine environment are examined by the ICES working group WGEXT, in which Belgium is represented by RBINS-MUMM and Flanders Research Institute for Agriculture, Fisheries and Food (ILVO).

The Marine Strategy Framework Directive (Directive 2008/56/EC) (MSFD; see also RD of 23 June 2010) and the Habitat Directive (Directive 92/43/EEC) (see thematic chapter **Nature and environment**) provide an important framework for the sustainable sand exploitation in the BNS.

- In the MSFD, several descriptors for a good environmental status (GES) are identified (Belgian State 2012, for Belgian waters), some of which are relevant for the extraction of marine sediments (Degraer and Vanden Berghe 2014). In this respect, descriptor 6 on the seafloor integrity is of course important (more information: Rice et al. 2010, ICES 2019b) but also the direct and indirect effects of sand extraction on the conservation of biodiversity (descriptor 1, more information: Cochrane et al. 2010), and marine food webs (descriptor 4, more information: Rogers et al. 2010) should be considered. Also relevant to sand extraction are descriptor 7 on the hydrographical conditions (Walker et al. 2016, ICES 2016, ICES 2017, Fettweis et al. 2020) and descriptor 11 on the introduction of energy, including underwater noise (more information: Tasker et al. 2010). For each descriptor, a number of environmental targets are set (Decision (EU) 2017/848) and trends and changes are evaluated every six years. A first assessment was conducted in 2018 (MSFD cycle 2012-2018) and the results are included in the update of the initial assessment for the Belgian marine waters (Belgian State 2018). The selective extraction of living and non-living resources on the seabed and subsoil was included in the list of pressures. At the request of the European Commission, the quantification of physical loss and disturbance was further elaborated in ICES working groups leading to an ICES advice on the assessment of human pressures on the seabed (ICES 2019b). This is part of a revision of the guidelines for the MSFD assessments in the second cycle (EU Commission Technical Group TG Seabed with experts from ILVO and RBINS). Belgium is also committed to innovative methodological developments for the monitoring of descriptors 6 and 7 (Montereale Gavazzi 2019, Montereale-Gavazzi et al. 2019, Fettweis et al. 2020, Derycke et al. 2021).
- Furthermore, the European Habitats Directive (Directive 92/43/EEC) deals with the protection of a number of habitats including the gravel beds (Degrendele et al. 2008, Houziaux et al. 2008, Degraer et al. 2009, Raeymaekers 2011, De Mesel et al. 2017). The most ecologically valuable natural gravel beds are located just south of the extraction areas of the Hinder banks. Therefore, these were also incorporated into the monitoring programme linked to the extraction on the Hinder banks (Van Lancker et al. 2014a, Van Lancker et al. 2014b, Van Lancker et al. 2015, Van Lancker et al. 2016a, Van Lancker et al. 2017b, Montereale-Gavazzi et al. 2018, Van den Eynde et al. 2019b, Van Lancker et al. 2020a, Van Lancker et al. 2020b). In order to determine reference conditions, gravel areas with different pressures on the seabed are also studied (Belgian State 2018, Montereale-Gavazzi et al. 2021). From a management perspective, the MSP 2020-2026 (RD of 22 May 2019, see also Verhalle and Van de Velde 2020) demarcates a reference zone for monitoring the impact on the environment and sand and gravel extraction activities within the Habitats Directive area of the Flemish Banks are strongly restricted (control zone 2). The maximum extraction volume in this zone amounts 1,578,000 m³ per year in the period 2020-2025 and gravel extraction is prohibited.

4.5.2 Monitoring of the environmental impact

The sand and gravel extraction in the BNS is monitored by the Continental Shelf service (FPS Economy), MUMM and ILVO. This research is ongoing and is financed by the fees paid by the operators, which are based on the extracted volume (see **4.2 Spatial use**) (Degrendele 2008, FPS Economy, SMEs, Self-employed and Energy 2020). The results of this monitoring are presented at a three-yearly conference organised by the Continental Shelf service (e.g. website FPS Economy, Degrendele and Vandenreyken 2017, Vandenreyken 2020, Vandenreyken 2021).

Over the years, the European guidelines have helped to determine the monitoring approach (Van Lancker 2011). An important part of the monitoring programme of sand extraction in the BNS is the monitoring of the extraction operations. This is done both by checking the registers kept on board of the dredging vessels, and by a black-box system (Electronic Monitoring System, EMS) on board of those vessels (Van den Branden et al. 2017, FOD Economie, K.M.O., Middenstand en Energie 2020, General Direction Quality and Safety 2020). This system was introduced in 1996 and subsequently modernised in 2014 and is managed by MUMM as commissioned by the Continental Shelf service (Degrendele et al. 2014, Roche et al. 2017). An additional monitoring system for sand extraction based on Automatic Identification System (AIS) data was developed. Since the implementation of the new reference level for sand extraction in 2021, this monitoring approach has proven to be efficient in verifying that sand extraction activities are in compliance with the regulation on the new closed sub-zones (Barette et al. 2021).

In addition, the physical impact of extraction on the seabed is closely monitored by the Continental Shelf service (FPS Economy), ILVO and MUMM. The sediment volumes in the control areas are monitored using the research vessels RV Belgica and RV Simon Stevin. MUMM is also responsible for monitoring the hydrodynamics and the sediment transport in the BNS by means of models and measurements (Van Lancker et al. 2014a, Van Lancker et al. 2014b, Francken et al. 2014, Francken et al. 2017, Van Lancker et al. 2017a, Van den Eynde et al. 2017, Van den Eynde et al. 2019a, Van den Eynde et al. 2019b, Van Lancker et al. 2020a, Van Lancker et al. 2020b, Van den Eynde et al. 2021, Van Lancker et al. 2021). ILVO examines the ecological impact of the extraction activities as well as the biological evolution after cessation of the activities (De Backer et al. 2014, De Backer and Hostens 2014, De Backer et al. 2017, Wyns et al. 2020, Wyns et al. 2021). In exploitation zone 4, demarcated in the Hinder banks in 2010, a comprehensive 'baseline study' has been executed to better assess the impact of the current extraction activities (Mathys et al. 2011, Van Lancker et al. 2014a, Van Lancker et al. 2015, Van Lancker et al. 2016a, Van Lancker et al. 2017a, Van den Eynde et al. 2019b, Van Lancker et al. 2020a, Van Lancker et al. 2020b, Van Lancker et al. 2021).

4.5.3 Research in Belgium

Many studies and research projects have already been carried out that contribute to a better understanding of the impact and sustainable management of sand and gravel extraction: e.g. the BUDGET project (1999-2001, BELSPO) (Lanckneus et al. 2001), the SPEEK project (2003-2006, BELSPO) (Vanaverbeke et al. 2007), the MAREBASSE project (2002-2006, BELSPO) (Van Lancker et al. 2007), the EUMARSAND project (2002-2006, EU-FP6 project) Van Lancker et al. 2010), the RESOURCE-3D project (2006-2007, BELSPO) (Van Lancker et al. 2009), the QUEST4D project (2006-2010, BELSPO) (Van Lancker et al. 2009) and the TILES project (2012-2017, BELSPO) (Van Lancker et al. 2014c, Van Lancker et al. 2017c, Van Lancker et al. 2019, figure 5) contribute to a better understanding of the impact and sustainable management of sand and gravel extraction. A project such as CREST (2015-2019, IWT-VLAIO) provides more insight in the broader framework. Furthermore, other studies and projects focus on the ecological effects of beach nourishments such as Speybroeck et al. 2006, the 4SHORE project (2013-2016, ILVO) and the GEANS project (2019-2022, Interreg) (Derycke et al. 2021). Through the Seabed4U project (2019-2021, BELSPO), aimed at communicating the sustainability of sand extraction in a changing world, a web portal (release December 2021) will explain seabed-related data and information, as well as initiatives that place resource availability in a broader international framework (e.g. UNEP 2019).

In the TILES project, a harmonised geological knowledge-base was developed to support resource management in the Belgian and Dutch part of the North Sea in the long term. The approach is explained in figure 5. First, available drillings (Kint et al. 2016, RBINS SediLITHO database, TILES Dataportal) and seismic data were combined into 3D geological models that map the quality and quantity of the exploitable geological layers (the raw material or resource) (Hademenos et al. 2019, Van Lancker et al. 2019). After linking the resource models with numerical impact models, parameters were calculated that can support a more sustainable exploitation strategy (Terseleer et al. 2016, Terseleer et al. 2017, Van Lancker et al. 2018). The final 'reserve' that can be extracted is mainly determined by all types of restrictions that do not permit extraction, such as the use of space by other activities. The generated knowledge and information is offered in a multi-criteria decision support system (TILES

Consortium 2019) in which data quality is taken into account (De Tré et al. 2018, Kint et al. 2021). The information obtained from such a system contributes to a better support of the evaluation of sand extraction in the BNS. Specifically, the determination of the thickness of the (homogeneous) quaternary sand layer has contributed to the definition of the new reference surface (Degrendele et al. 2017). The research into the granulometry of the sediments present in the available layers in the concession zones is used for drawing up forecasts about the evolution of the sand stocks. RBINS manages the subsurface models developed in TILES, and is committed to further valorisation including data addition.

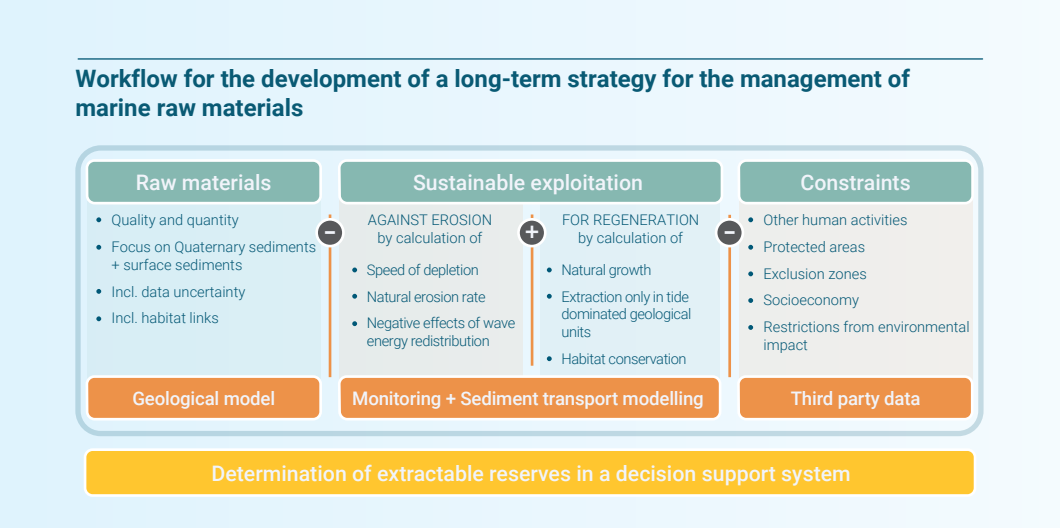

Figure 5. Conceptual workflow for the development of a long-term strategy for the management of marine raw materials at the BNS (Van Lancker et al. 2017c, Van Lancker et al. 2019).

Legislation reference list

Overview of the relevant legislation on European, federal and Flemish level. For the consolidated European policy context see Eurlex. The national legislation can be consulted on the Belgian official journal and the Justel-database, the Flemish legislation is available on the Flemish Codex.

European legislation and policy context			
Document number	**Title**	**Year**	**Number**
Directives			
Directive 92/43/EEC	Directive on the conservation of natural habitats and of wild fauna and flora (Habitats Directive)	1992	43
Directive 2000/60/EC	Directive establishing a framework for Community action in the field of water policy (Water Framework Directive)	2000	60
Directive 2008/56/EC	Directive establishing a framework for Community action in the field of marine environmental policy (Marine Strategy Framework Directive)	2008	56
Directive 2011/92/EU	Directive on the assessment of the effects of certain public and private projects on the environment	2011	92

Belgian and Flemish legislation		
Dates	**Title**	**File number**
Royal Decrees		
RD of 12 August 2000	Koninklijk besluit tot instelling van de raadgevende commissie belast met de coördinatie tussen de administraties die betrokken zijn bij het beheer van de exploratie en de exploitatie van het continentaal plat en van de territoriale zee en tot vaststelling van de werkingsmodaliteiten en -kosten ervan	2000-08-12/83
RD of 1 September 2004	Koninklijk besluit betreffende de voorwaarden, de geografische begrenzing en de toekenningsprocedure van concessies voor de exploratie en de exploitatie van de minerale en andere niet-levende rijkdommen in de territoriale zee en op het continentaal plat	2004-09-01/51
RD of 23 June 2010	Koninklijk besluit betreffende de mariene strategie voor de Belgische zeegebieden	2010-06-23/05
RD of 19 April 2014	Koninklijk besluit tot wijziging van verscheidene koninklijke besluiten betreffende de exploratie en de exploitatie van de minerale en andere niet-levende rijkdommen in de territoriale zee en op het continentaal plat	2014-04-19/49
RD of 27 October 2016	Koninklijk besluit betreffende de procedure tot aanduiding en beheer van de mariene beschermde gebieden	2016-10-27/11
RD of 21 October 2018	Koninklijk besluit houdende de regels betreffende de milieueffectenbeoordeling in toepassing van de wet van 13 juni 1969 inzake de exploratie en exploitatie van niet-levende rijkdommen van de territoriale zee en het continentaal plat	2018-10-21/03
RD of 22 May 2019	Koninklijk besluit tot vaststelling van het marien ruimtelijk plan voor de periode van 2020 tot 2026 in de Belgische zeegebieden	2019-05-22/23
Laws		
Law of 13 June 1969	Wet inzake de exploratie en exploitatie van niet-levende rijkdommen van de territoriale zee en het continentaal plat	1969-06-13/30